

Model 6220 DC Current Source Model 6221 AC and DC Current Source

Reference Manual

622X-901-01 Rev. B / June 2005

KEITHLEY

A G R E A T E R M E A S U R E O F C O N F I D E N C E

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A G R E A T E R M E A S U R E O F C O N F I D E N C E

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Manual Print History

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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  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 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
Capabilities and features	1-2
Organization of manual sections	1-2
General information	1-3
Warranty information	1-3
Contact information	1-3
Safety symbols and terms	1-3
Unpacking and inspection	1-4
Options and accessories	1-5
User's manual	1-7
Reference manual	1-7
Additional references	1-7
Front and rear panel familiarization	1-7
Front panel summaries	1-7
Rear panel summaries	1-7
Heat sink and cooling vents	1-12
Power-up	1-14
Line power connection	1-14
Power-up sequence	1-15
Beeper and keyclick	1-16
Source preset	1-17
Disabling the front panel	1-17
Menus	1-18
CONFIG menus	1-18
Direct access menus	1-19
Editing controls	1-20
Source and compliance editing	1-20
Menu navigation	1-20
Password	1-22
Interface selection	1-22
GPIB and language	1-23
RS-232	1-23
Ethernet (Model 6221 only)	1-23
Error and status messages	1-24
Default settings	1-24
Front panel setups	1-24
Remote operation setups	1-25
SCPI programming	1-29
Optional command words	1-29
Query commands	1-29

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	2-7
Triax output low	2-7
Guards	2-8
Guard overview	2-8
Triax Cable Guard	2-9
Banana Jack Guard	2-12
Floating the current source	2-13
Connections to DUT	2-15
Supplied triax cable	2-15
Basic connections	2-15
Shields and guarding	2-16
Banana Jack Guard connections	2-19
Floating current source connections	2-19
Using a test fixture	2-20
Custom-built test fixture	2-20

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	3-9
Source and compliance editing	3-9
Autorange	3-12
Source preset	3-12
Sourcing current	3-13
Remote programming – source output commands	3-15

4

Sweeps

Overview	4-2
Section overview	4-2
Sweep overview	4-2

Sweep characteristics	4-4
Linear staircase sweeps	4-4
Logarithmic staircase sweeps	4-5
Custom sweeps	4-6
Setting sweep parameters	4-8
Front panel sweep operation	4-10
Using the sweep configuration menu	4-10
Performing a linear staircase sweep	4-11
Performing a log staircase sweep	4-12
Performing a custom sweep	4-13
Remote sweep operation	4-14
Running a linear staircase sweep	4-15
Running a log staircase sweep	4-16
Running a custom sweep	4-17
SCPI commands — sweeps	4-18
Coupled sweep commands	4-22
Sweep status model events	4-23

5 Delta, Pulse Delta, and Differential Conductance

Part 1	5-2
Overview	5-2
Section overview	5-2
Operation overview	5-2
Test systems	5-4
Keithley instrumentation requirements	5-4
System configurations	5-4
System connections	5-6
DUT test connections	5-8
Configuring communications	5-10
Arming process	5-11
Interlock	5-13
Data flow and read commands	5-13
Data flow	5-13
Read commands	5-15
Measurement units	5-16
Volts, ohms, power or conductance	5-16
Setting measurement units	5-17
Display readings	5-17
Error and status messages	5-18
Part 2	5-20

Delta	5-20
Basic measurement process	5-20
Model 622x measurement process	5-21
Configuration settings	5-24
Arming process	5-24
Triggering sequence	5-25
Operation	5-27
Setup commands	5-30
Pulse Delta	5-32
Model 6221 measurement process	5-32
Pulse Delta outputs	5-35
Configuration settings	5-39
Arming process	5-42
Triggering sequence	5-43
Operation	5-44
Setup commands	5-49
Differential Conductance	5-51
Basic measurement process	5-51
Model 622x measurement process	5-51
Configuration settings	5-55
Arming process	5-56
Triggering sequence	5-58
Operation	5-59
Setup commands	5-64

6

Averaging Filter, Math, and Buffer

Averaging filter	6-2
Averaging filter characteristics	6-2
Filter setup and control	6-8
Remote programming – Averaging filter	6-8
Math	6-9
mX+b and m/X+b (reciprocal)	6-9
Configuring and controlling mX+b and m/X+b	6-9
Remote programming – Math	6-10
Buffer	6-11
Buffer characteristics	6-12
Storing readings	6-14
Recall	6-14
Remote programming – Buffer	6-15

Overview	7-2
Section overview	7-2
Wave function overview	7-2
Wave function characteristics	7-3
Setting waveform parameters	7-4
Amplitude	7-5
Ranging	7-5
Frequency	7-6
Offset	7-6
Duty cycle	7-7
Amplitude units	7-7
Phase marker	7-9
Duration	7-10
Arbitrary waveforms	7-10
Using the external low jitter trigger mode	7-10
Front panel wave function operation	7-14
Using the wave function menu	7-14
Generating a sine wave	7-16
Generating a square wave	7-17
Generating a ramp waveform	7-18
Generating an arbitrary waveform	7-19
Using the external trigger mode	7-20
Remote wave function operation	7-21
Programming sine waves	7-22
Programming square waves	7-23
Programming ramp waveforms	7-24
Programming arbitrary waveforms	7-25
Programming an externally triggered waveform	7-26
SCPI commands — wave functions	7-27

Trigger models	8-2
Front panel trigger model	8-2
Remote trigger model	8-3
Trigger model operation	8-4
Front panel trigger operation	8-7
Using the trigger configuration menu	8-7
Configuring triggering	8-8
Remote trigger operation	8-9
Programming triggering	8-9
SCPI commands — triggering	8-10
External triggering	8-13
External trigger connector	8-13

Input trigger requirements	8-13
Output trigger specifications	8-14
External trigger example	8-15

9 Limit Test and Digital I/O

Limit test	9-2
Overview	9-2
Programming limit testing	9-2
SCPI commands — limit testing	9-3
Digital I/O port	9-5
Digital I/O connector	9-5
+5V output	9-5
SOT line	9-6
Simplified schematic	9-6
Sink mode — controlling external devices	9-6
Source mode — logic control	9-8
Setting digital output lines	9-8
SCPI commands — force digital I/O pattern	9-9

10 Remote Operations

Selecting and configuring an interface	10-2
Interfaces	10-2
Languages	10-3
Interface selection and configuration	10-3
Programming syntax	10-12
Command words	10-12
Program messages	10-15
Response messages	10-17
GPIB interface reference	10-19
GPIB bus standards	10-19
GPIB bus connections	10-19
Primary address	10-21
General IEEE-488 bus commands	10-22
Front panel GPIB operation	10-24
RS-232 interface reference	10-25
Sending and receiving data	10-25
RS-232 settings	10-25
RS-232 connections	10-27
Ethernet interface reference	10-29
Ethernet standards	10-29
Typical Ethernet systems	10-29
Ethernet connections	10-31
Ethernet settings	10-33
Using the example software	10-35

11	Status Structure	
Overview	11-2	
Clearing registers and queues	11-4	
Programming and reading registers	11-5	
Programming enable registers	11-5	
Reading registers	11-6	
Status byte and service request (SRQ)	11-7	
Status byte register	11-7	
Service request enable register	11-8	
Serial polling and SRQ	11-9	
Status byte and service request commands	11-9	
Status register sets	11-10	
Register bit descriptions	11-10	
Queues	11-20	
Output queue	11-20	
Error queue	11-20	
12	Common Commands	
Common commands	12-2	
13	DISPlay, FORMat, and SYSTem Key-Press Codes	
DISPlay subsystem	13-2	
FORMat subsystem	13-4	
FORMat <type>[,<length>]	13-4	
FORMat:ELEMents <item list>	13-7	
FORMat:BORDer <name>	13-8	
SYSTem key-press codes	13-9	
SYSTem:KEY <NRf>	13-9	
14	SCPI Reference Tables	
General notes	14-2	
15	KI-220 Language	
Introduction	15-2	
Notes:	15-3	
16	Performance Verification	
Introduction	16-2	
Test requirements	16-3	
Environmental conditions	16-3	
Warm-up period	16-3	
Line power	16-3	

Recommended test equipment	16-4
Test equipment connections	16-4
Calculating test limits	16-4
Example limit calculation	16-4
Restoring factory defaults	16-5
Test summary and considerations	16-5
Test summary	16-5
Test considerations	16-5
Verification procedures	16-6
DC current output accuracy	16-6
Compliance accuracy	16-8
Waveform function accuracy	16-9

17

Calibration

Introduction	17-2
Calibration requirements	17-3
Environmental conditions	17-3
Warm-up period	17-3
Line power	17-3
Recommended calibration equipment	17-4
Calibration equipment connections	17-4
Restoring factory defaults	17-4
Calibration summary and considerations	17-5
Calibration summary	17-5
Calibration considerations	17-5
Calibration procedures	17-5
Front panel calibration	17-5
Remote calibration	17-14
SCPI commands — calibration	17-20
Calibration dates, count, and password	17-24
Viewing calibration dates and count	17-24
Changing the calibration password	17-24

A

Specifications

B

Error and Status Messages

Introduction	B-2
--------------------	-----

C IEEE-488 Bus Overview

Introduction	C-2
Bus description	C-3
Bus lines	C-4
Data lines	C-5
Bus management lines	C-5
Handshake lines	C-5
Bus commands	C-6
Uniline commands	C-9
Universal multiline commands	C-9
Addressed multiline commands	C-10
Address commands	C-10
Unaddress commands	C-11
Common commands	C-11
SCPI commands	C-11
Command codes	C-12
Typical command sequences	C-12
IEEE command groups	C-14
Interface function codes	C-15

D IEEE-488 and SCPI Conformance Information

Introduction	D-2
--------------------	-----

E Applications

Calibration source	E-2
Resistivity measurements	E-3
Diode characterization	E-4
Transistor characterization	E-5
External user-supplied filter	E-7
Typical filter circuits	E-8
Filter circuit considerations	E-9
Suggested filter circuit components	E-10
Compliance overshoot prevention	E-11
Calculating overshoot	E-11
Effect of compliance setpoint on settling times	E-12
Preventing compliance overshoot	E-12

List of Illustrations

1	Getting Started	
Figure 1-1	Models 6220 and 6621 front panels	1-8
Figure 1-2	Model 622x rear panel	1-11
Figure 1-3	Menu editing keys	1-21
2	Output Connections	
Figure 2-1	Triax connector and ground point	2-2
Figure 2-2	LO and GUARD banana jacks	2-3
Figure 2-3	INTERLOCK	2-4
Figure 2-4	Output configurations – triax inner shield connected to Output Low	2-6
Figure 2-5	Output configurations – triax inner shield connected to Cable Guard	2-6
Figure 2-6	Unguarded triax cable – inner shield connected to Output Low (see Figure 2-4)	2-10
Figure 2-7	Guarded triax cable – inner shield connected to Cable Guard (see Figure 2-5A)	2-11
Figure 2-8	DUT mounting plate (unguarded and guarded)	2-12
Figure 2-9	Using banana jack Guard to measure voltage	2-13
Figure 2-10	Floating the Model 622x current source	2-14
Figure 2-11	Basic connections to DUT	2-16
Figure 2-12	Noise shield	2-17
Figure 2-13	Safety shield	2-17
Figure 2-14	Cable Guard connections – triax inner shield connected to Cable Guard	2-18
Figure 2-15	Connections for noise shield, safety shield, and guarding	2-18
Figure 2-16	Banana Jack Guard connections	2-19
Figure 2-17	Floating current source connections	2-20
Figure 2-18	Custom-built test fixture	2-21
3	DC Current Source Operation	
Figure 3-1	Output boundaries (source and sink)	3-5
Figure 3-2	Source and compliance editing – Model 6220	3-10
Figure 3-3	Source and compliance editing – Model 6221	3-12
4	Sweeps	
Figure 4-1	Comparison of sweep types	4-3
Figure 4-2	Linear staircase sweep	4-4
Figure 4-3	Logarithmic staircase sweep (example 5-point sweep from 1mA to 10mA)	4-5
Figure 4-4	Custom sweep example (1mA to 10mA, arbitrary steps)	4-7

5

Delta, Pulse Delta, and Differential Conductance

Figure 5-1	Delta, Pulse Delta, and Differential Conductance measurements	5-3
Figure 5-2	System configurations for Delta, Pulse Delta, and Differential Conductance ...	5-5
Figure 5-3	System connections – stand-alone operation	5-7
Figure 5-4	System connections – PC control of Model 622x	5-8
Figure 5-5	Guarded test connections	5-10
Figure 5-6	Data flow and read commands	5-14
Figure 5-7	Delta measurement technique	5-22
Figure 5-8	Delta triggering sequence	5-26
Figure 5-9	Pulse Delta 3-point measurement technique	5-32
Figure 5-10	Pulse timing	5-36
Figure 5-11	Pulse sweep output examples	5-38
Figure 5-12	Pulse Delta triggering sequence (two lows measured)	5-44
Figure 5-13	Basic differential measurements	5-51
Figure 5-14	Differential Conductance measurement process	5-52
Figure 5-15	Differential Conductance triggering sequence	5-59

6

Averaging Filter, Math, and Buffer

Figure 6-1	Digital filter types: moving and repeating	6-5
Figure 6-2	Filter window	6-7
Figure 6-3	Buffer recall	6-15

7

Wave Functions (6221 Only)

Figure 7-1	Offset example	7-7
Figure 7-2	Duty cycle	7-8
Figure 7-3	Phase marker	7-9
Figure 7-4	Waveform triggering	7-11
Figure 7-5	Waveform retrigerring	7-13

8

Triggering

Figure 8-1	Trigger model for front panel operation	8-2
Figure 8-2	Trigger model for remote operation	8-3
Figure 8-3	Device action block of trigger model	8-6
Figure 8-4	Trigger link connection operation	8-13
Figure 8-5	Trigger link input pulse specifications	8-14
Figure 8-6	Trigger link output pulse specifications	8-14
Figure 8-7	DUT test system	8-15
Figure 8-8	Trigger link connections	8-15
Figure 8-9	Operation model for triggering example	8-16

9	Limit Test and Digital I/O	
Figure 9-1	Limit 1 test (compliance)	9-2
Figure 9-2	Digital I/O port	9-5
Figure 9-3	Digital I/O port simplified schematic	9-6
Figure 9-4	Controlling externally powered relays	9-7
Figure 9-5	NAND gate control	9-8
10	Remote Operations	
Figure 10-1	IEEE-488 connector	10-19
Figure 10-2	Multi-unit connections	10-20
Figure 10-3	IEEE-488, Ethernet (6221 only), and RS-232 connector locations	10-21
Figure 10-4	RS-232 interface connector	10-27
Figure 10-5	Direct 6221 connection to PC	10-29
Figure 10-6	Small LAN system using a hub	10-30
Figure 10-7	Isolated LAN system using two NICs (Network Interface Cards)	10-30
Figure 10-8	Enterprise-wide or internet network system	10-31
Figure 10-9	RJ-45 Ethernet cable (male/male)	10-31
Figure 10-10	Model 6221 Ethernet connector	10-32
Figure 10-11	Example software typical main screen	10-36
Figure 10-12	Typical instrument connection setup wizard	10-37
Figure 10-13	Typical virtual front panel	10-38
11	Status Structure	
Figure 11-1	Model 622x status mode structure	11-3
Figure 11-2	16-bit status register	11-5
Figure 11-3	Status byte and service request	11-7
Figure 11-4	Standard event status	11-12
Figure 11-5	Operation event status	11-14
Figure 11-6	Measurement event status	11-16
Figure 11-7	Questionable event status	11-17
13	DISPlay, FORMat, and SYSTem Key-Press Codes	
Figure 13-1	ASCII data format	13-5
Figure 13-2	IEEE-754 data formats	13-6
Figure 13-3	Model 6220 key-press codes	13-10
Figure 13-4	Model 6221 key-press codes	13-11
16	Performance Verification	
Figure 16-1	Connections for DC current output accuracy (200nA to 100mA ranges)	16-6
Figure 16-2	Connections for DC current output accuracy (2nA and 20nA ranges)	16-7
Figure 16-3	Connections for compliance accuracy	16-8
Figure 16-4	Connections for waveform function amplitude flatness	16-9
Figure 16-5	Connections for waveform function frequency accuracy	16-10

17

Calibration

Figure 17-1	Connections for current source calibration (200nA to 100mA ranges)	17-8
Figure 17-2	Connections for current source calibration (2nA and 20nA ranges)	17-9
Figure 17-3	Connections for compliance calibration	17-11
Figure 17-4	Connections for guard calibration	17-12

C

IEEE-488 Bus Overview

Figure C-1	IEEE-488 bus configuration	C-4
Figure C-2	IEEE-488 handshake sequence	C-6

E

Applications

Figure E-1	Resistivity measurement test system	E-3
Figure E-2	Diode characterization test system	E-4
Figure E-3	Diode curves	E-5
Figure E-4	BJT characterization test system	E-6
Figure E-5	BJT collector family curves	E-6
Figure E-6	Example filter box	E-7
Figure E-7	Filter circuit examples	E-8

List of Tables

1	Getting Started	
Table 1-1	Front panel default settings	1-26
3	DC Current Source Operation	
Table 3-1	Source ranges and maximum outputs	3-2
Table 3-2	DC output commands	3-16
4	Sweeps	
Table 4-1	Logarithmic sweep points	4-6
Table 4-2	Sweep configuration menu	4-10
Table 4-3	Sweep example parameters	4-14
Table 4-4	Staircase sweep commands (linear and logarithmic)	4-18
Table 4-5	Custom (list) sweep commands	4-21
Table 4-6	Sweep status model bits	4-23
5	Delta, Pulse Delta, and Differential Conductance	
Table 5-1	Measurement unit commands	5-17
Table 5-2	Error/status codes and messages	5-18
Table 5-3	Delta commands	5-31
Table 5-4	Pulse Delta commands	5-49
Table 5-5	Differential Conductance commands	5-64
6	Averaging Filter, Math, and Buffer	
Table 6-1	Average filter types	6-2
Table 6-2	Averaging filter commands	6-8
Table 6-3	Math commands	6-10
Table 6-4	Buffer commands	6-16
7	Wave Functions (6221 Only)	
Table 7-1	Wave function characteristics	7-3
Table 7-2	Wave function configuration menu	7-15
Table 7-3	Waveform example parameters	7-21
Table 7-4	Waveform function commands	7-27
8	Triggering	
Table 8-1	Trigger configuration menu	8-7
Table 8-2	Trigger commands	8-10

9	Limit Test and Digital I/O	
Table 9-1	Limit test commands	9-3
Table 9-2	Limit test fail pattern values	9-4
Table 9-3	Digital I/O commands	9-9
Table 9-4	Digital I/O port values	9-10
10	Remote Operations	
Table 10-1	Communications menu	10-4
Table 10-2	Remote interface configuration commands	10-7
Table 10-3	Unprotected commands and queries	10-11
Table 10-4	General bus commands	10-22
Table 10-5	RS-232 connector pinout	10-27
Table 10-6	PC serial port pinout	10-28
Table 10-7	Network classes	10-34
11	Status Structure	
Table 11-1	Common and SCPI commands — reset registers and clear queues	11-4
Table 11-2	SCPI command — data formats for reading status registers	11-6
Table 11-3	Common commands — status byte and service request enable registers	11-10
Table 11-4	Common and SCPI commands — condition registers	11-17
Table 11-5	Common and SCPI commands — event registers	11-18
Table 11-6	Common and SCPI commands — event enable registers	11-19
Table 11-7	SCPI commands — error queue	11-21
12	Common Commands	
Table 12-1	IEEE-488.2 common commands and queries	12-2
13	DISPlay, FORMat, and SYStem Key-Press Codes	
Table 13-1	Display commands	13-2
Table 13-2	Format commands	13-4
14	SCPI Reference Tables	
Table 14-1	Calculate command summary	14-3
Table 14-2	Display command summary	14-5
Table 14-3	Format command summary	14-6
Table 14-4	Output command summary	14-6
Table 14-5	Sense command summary	14-7
Table 14-6	Source command summary	14-8
Table 14-7	Status command summary	14-13
Table 14-8	System command summary	14-14
Table 14-9	Trace command summary	14-16
Table 14-10	Trigger command summary	14-17
Table 14-11	Units command summary	14-18

15	KI-220 Language	
Table 15-1	DDC emulation commands	15-2
16	Performance Verification	
Table 16-1	Recommended test equipment	16-4
Table 16-2	DC current output limits	16-7
17	Calibration	
Table 17-1	Recommended calibration equipment	17-4
Table 17-2	Calibration menu	17-6
Table 17-3	Front panel current calibration summary	17-8
Table 17-4	Remote current calibration summary	17-16
Table 17-5	Calibration commands	17-20
Table 17-6	CAL:PROT:SENS command parameter ranges	17-22
Table 17-7	CAL:PROT:SOUR command parameter ranges	17-22
Table 17-8	Calibration errors	17-23
Table 17-9	CAL:PROT:GUAR command parameter ranges	17-23
B	Error and Status Messages	
Table B-1	Status and error messages	B-2
C	IEEE-488 Bus Overview	
Table C-1	IEEE-488 bus command summary	C-7
Table C-2	Command codes	C-8
Table C-3	Hexadecimal and decimal command codes	C-12
Table C-4	Typical bus sequence	C-13
Table C-5	Typical addressed command sequence	C-13
Table C-6	IEEE command groups	C-14
Table C-7	Model 622x interface function codes	C-15
D	IEEE-488 and SCPI Conformance Information	
Table D-1	IEEE-488 documentation requirements	D-2
Table D-2	Coupled commands	D-3

Getting Started

Section 1 topics

Introduction, page 1-2

Capabilities and features, page 1-2
Organization of manual sections, 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 1-5
User's manual, page 1-4
Reference manual, page 1-7
Additional references, page 1-7

Front and rear panel familiarization, page 1-7

Front panel summaries, page 1-7
Rear panel summaries, page 1-7

Heat sink and cooling vents, page 1-12

Power-up, page 1-14

Line power connection, page 1-14
Power-up sequence, page 1-15
Beeper and keyclick, page 1-16
Source preset, page 1-17
Disabling the front panel, page 1-17

Menus, page 1-18

CONFIG menus, page 1-18
Direct access menus, page 1-19

Editing controls, page 1-20

Source and compliance editing, page 1-20
Menu navigation, page 1-20

Password, page 1-22

Interface selection, page 1-22

GPIB and language, page 1-23
RS-232, page 1-23
Ethernet (Model 6221 only), page 1-23

Error and status messages, page 1-22

Default settings, page 1-22

Front panel setups, page 1-24
Remote operation setups, page 1-25

SCPI programming, page 1-22

Optional command words, page 1-29
Query commands, page 1-29

Introduction

Capabilities and features

- Source \pm 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 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.

Organization of manual sections

While viewing the PDF version of this manual, the manual sections can be viewed by clicking the “Bookmarks” tab on the left side of this window. This tab also provides direct links to the various sections and section topics.

The manual sections are also listed in the Table of Contents located at the beginning of this manual.

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 the instrument shows that high voltage may be present on the terminal(s). 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 crossover 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 622X User's and Reference Manuals

Options and accessories

Input cables, connectors, and adapters

237-TRX-BAR Barrel Adapter – This is a barrel adapter that allows you to connect two triax cables together. Both ends of the adapter are terminated with 3-lug female triax connectors.

Model 237-ALG-2 Triax Cable – This 2m (6.6 ft) low-noise triax cable terminated with three slot male triax connector on one end and 3 alligator clips on the other. This cable is also a supplied item with the Model 622x.

Model 237-TRX-T Adapter – This is a 3-slot male to dual 3-lug female triax tee adapter for use with 7078-TRX triax cables.

Model 237-TRX-TBC Connector – This is a 3-lug female triax bulkhead connector with cap for installation on test fixtures and boxes.

Model 2187-4 Input Cable – Low-thermal input cable for the Model 2182/2182A. Terminated with a LEMO connector on one end and four banana plugs on the other. The banana plugs allow connection to the Model 622x for banana jack Guard voltage measurements.

Models 7078-TRX-3, 7078-TRX-10, and 7078-TRX-20 Triax Cables – These are low noise triax cables terminated at both ends with 3-slot male triax connectors. The -3 model is 3 ft. (0.9m) in length, the -10 model is 10 ft. (3m) in length, and the -20 model is 20 ft. (6m) in length.

Model 7078-TRX-TBC Connector – This is a 3-lug female triax bulkhead connector with cap for installation on test fixtures and boxes.

Model 7078-TRX-GND – This is a 3-slot male triax to BNC adapter.

GPIB cables and adapter (connects Model 622x to the GPIB bus):

Model 7006-1 and Model 7006-2 – Single-shielded GPIB cables. Terminated with one straight connector (non-stacking) and one feed-through style connector. Model 7006-1 is 1m long; Model 7006-2 is 2m long.

A Model 7006 cable is recommended when using the Model 622x with the Model 2182/2182A for delta testing (Delta, Pulse Delta, or Differential Conductance). Connecting the straight connector of the cable to the Model 622x makes it easier to also connect the required null-modem serial cable to the RS-232 connector. The null-modem serial cable is a supplied item.

Models 7007-05, 7007-1, 7007-2, and 7007-4 – Double-shielded premium GPIB cables. Each end is terminated with a feed through metal housing for longest life and best performance. Model 7007-05 is 0.5m long; 7007-1 is 1m long; Model 7007-2 is 2m long; Model 7007-4 is 4m long.

Models 7008-3, 7008-6 and 7008-13 – Single-shielded standard GPIB cables. Each end is terminated with a feed through molded plastic housing. Model 7008-3 is 0.9m long; 7008-6 is 1.8m long; Model 7008-13 is 4m long.

Model 7010 – Shielded IEEE-to-IEEE Adapter. Provides additional clearance between the rear panel and GPIB cable connector. Allows easier access to cables and other connectors.

RS-232 cable (connects Model 622x to the RS-232):

Model 7009-5 shielded RS-232 cable – This straight-through cable connects the RS-232 of the Model 622x to the RS-232 interface of the PC. This cable is 5ft. long and uses shielded cable and connectors to reduce electromagnetic interference (EMI).

For Delta, Pulse Delta, or Differential Conductance, DO NOT use the Model 7009-5 cable for serial connections between the Model 622x and Model 2182/2182A. A null-modem serial cable is required and is a supplied item.

Trigger link cables and adapter:

Models 8501-1 and 8501-2 trigger link cables – Connects the Model 62xx to other instruments with Trigger Link connectors (e.g., Model 2182/2182A). Model 8501-1 is 1m long; Model 8501-2 is 2m long.

Model 8502 trigger link adapter – Lets you connect any of the six trigger link lines of the Model 622x to instruments that use standard BNC trigger connectors.

Model 8503 DIN to BNC trigger cable – Lets you connect trigger link lines one (input) and two (output) of the Model 622x to instruments that use BNC trigger connectors. Model 8503 is 1m long.

Rack mount kits

Model 4288-1 single fixed rack mount kit – Mounts a single Model 622x in a standard 19-inch rack.

Model 4288-2 side-by-side rack mount kit – Mounts two instruments (Models 182, 428, 486, 487, 2000, 2001, 2002, 2010, 2182, 2182A, 2400, 2410, 2420, 2430, 6220, 6221, 6430, 6485, 6487, 6517A, 7001) side-by-side in a standard 19-inch rack.

Model 4288-4 side-by-side rack mount kit – Mounts Model 622x and a 5.25-inch instrument (Models 195A, 196, 220, 224, 230, 263, 595, 614, 617, 705, 740, 775A, 6512) side-by-side in a standard 19-inch rack.

Carrying case

Model 1050 padded carrying case – A carrying case for Model 622x. Includes handles and shoulder strap.

User's manual

A printed copy of the User's Manual is a supplied item for the Model 622x. It is also provided on the product information CD-ROM as a PDF. This manual provides the fundamental operating information for the instrument.

Reference manual

This Reference Manual is provided on the Product Information CD-ROM as a PDF. This manual provides additional information on the topics covered in the User's Manual. It also includes advanced operation topics and maintenance information.

Additional references

Low Level Measurements handbook — Keithley's guide for effective low current, low voltage, and high impedance measurements. Refer to www.keithley.com for more details.

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](#).

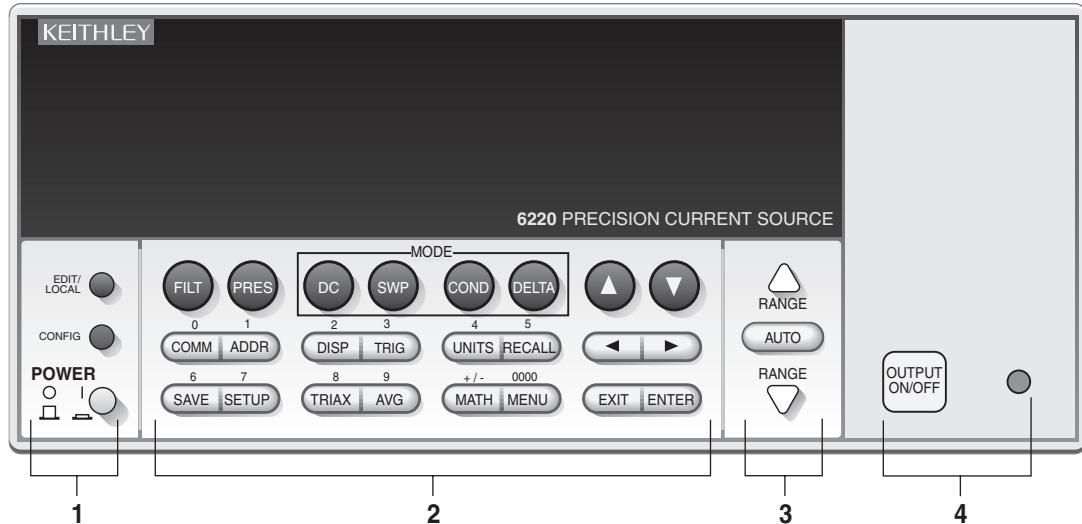
NOTE Many of the keys that are used to select a function or operation are also used for configuration by first pressing the CONFIG key. For example, to configure a sweep, press CONFIG and then SWP.

Rear panel summaries

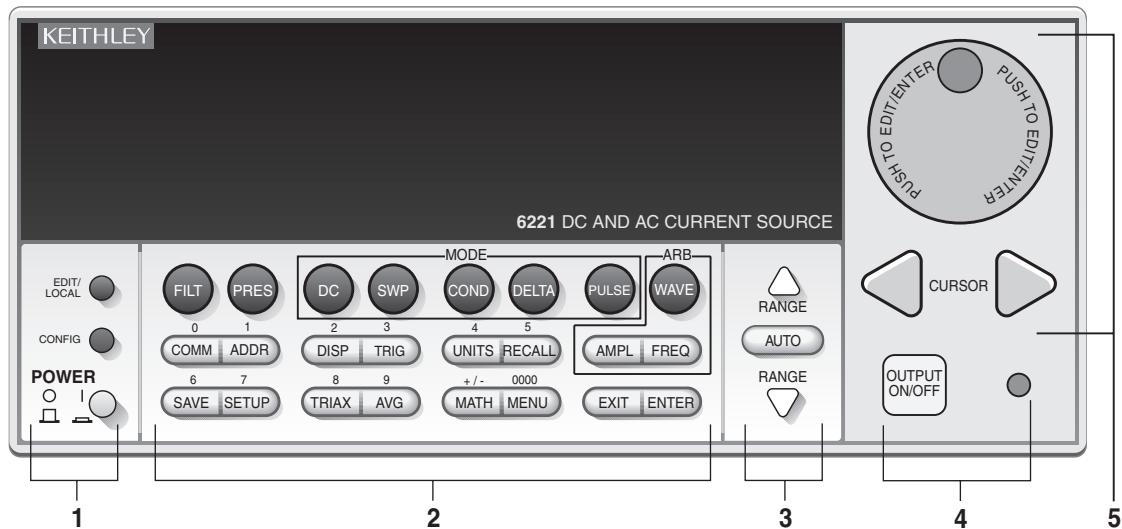
The rear panel of the Models 622x is shown in [Figure 1-2](#). The Model 6221 rear panel is shown, but the Model 6220 is identical except it does not have the Ethernet connector. The descriptions of the rear panel components follow [Figure 1-2](#).

Figure 1-1
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.

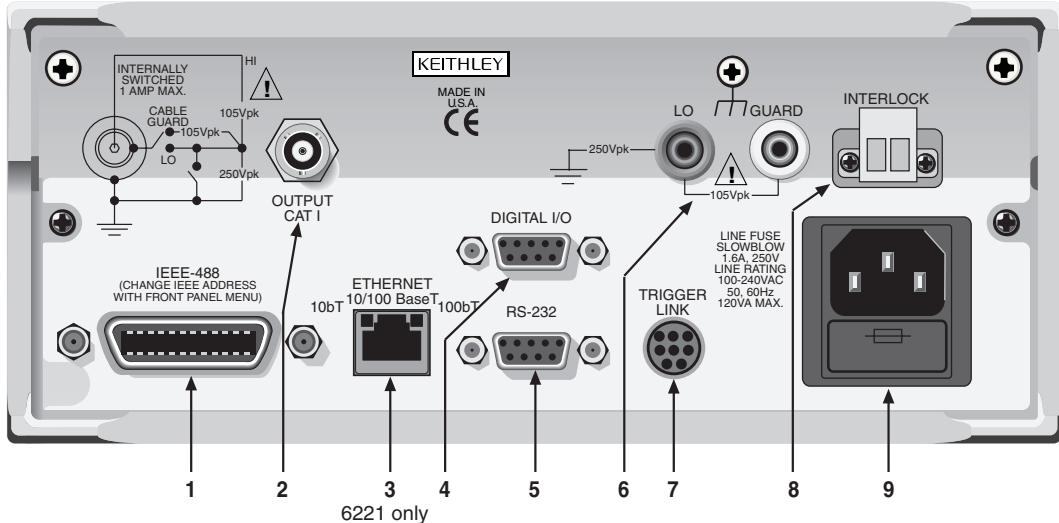
When in a menu, use the CURSOR keys or rotary knob for menu item cursor control. When displaying a menu value, use the CURSOR keys for cursor control and rotate the knob to change the value. Pressing the knob opens a menu item, or selects a menu option or value.

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.

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 7006, 7007, or 7008.

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 (6221 only)

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](#) 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

CAUTION 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.

Line frequency

The Model 622x will operate at line frequencies from 45Hz to 66Hz. There are no user-settings for line frequency. It is automatically sensed at power-up. The following command can be used to read the line frequency:

SYSTem:LFREquency? ' Query power line frequency.

The response for the above query command will be 50 or 60.

Fuse replacement

A rear panel fuse drawer is located below the AC receptacle (see [Figure 1-2](#)). This fuse protects the power line input of the instrument. If the line voltage fuse needs to be replaced, perform the following steps.

WARNING **Make sure the instrument is disconnected from the AC line and other equipment before changing the line voltage setting or replacing the line fuse.**

1. At the top of the fuse holder is a small tab. At this location, use a small bladed screwdriver to pry the fuse drawer open.
2. Slide the fuse drawer out to gain access to the fuse. Note that the fuse drawer does not pull all the way out of the power module.
3. Snap the old fuse out of the drawer and replace it with the same type: 1.6A, 250V, 5 x 20mm (Keithley P/N: FU-106-1.6).
4. Push the fuse drawer back into the power module.

CAUTION **For continued protection against fire or instrument damage, only replace fuse with the type and rating listed. If the instrument repeatedly blows fuses, locate and correct the cause of the problem before replacing the fuse.**

Power-up sequence

On power-up, the Model 622x performs self-tests on its EPROM and RAM and momentarily lights all segments and annunciators. If a failure is detected, the instrument momentarily displays an error message and the ERR annunciator turns on. (Error messages are listed in [Appendix B](#)).

NOTE **If a problem develops while the instrument is under warranty, return it to Keithley Instruments, Inc., for repair.**

Assuming no errors occur, the Model 622x will power-up as follows:

- The message “INITIALIZING...” is displayed for ~3 seconds.
- The message “LOADING DIGITAL FPGA” is displayed briefly.
- The message “LOADING ANALOG FPGA” is displayed briefly.
- The message “LOADING MAIN” is displayed briefly.
- All display digit segments and annunciators are briefly turned on.

- The instrument model number, firmware revision levels, and the GPIB address are displayed briefly as follows:

MODEL 622x

Rev: xxx yyyy

SCPI: 24

where: xxx is the main board ROM revision.

yyyy is the display board ROM revision.

- For the Model 6221, the messages “LOADING WAVEFORM...” and then “WAVEFORM LOAD DONE” are displayed briefly.

NOTE There are two internal LEDs that turn on and blink for a few seconds during the power-up sequence. One LED is visible through the top cover air vents, and the other LED is visible through the air vents on the right side of the case. After the short period of blinking, these LEDs will remain off while the instrument is on.

System identification

Serial numbers and revisions (for the mainframe, analog board, digital board, and SCPI) can be displayed by selecting the SERIAL# item of the main menu (press **MAIN > Select SERIAL#**).

For remote programming, use the following commands to read serial numbers (SN) and revisions.

*IDN?	' Returns serial number revision level of the mainframe.
SYSTem:ABOard:SNumber?	' Returns SN for the analog board.
SYSTem:ABOard:REVision?	' Returns revision of the analog board.
SYSTem:DBOard:SNumber?	' Returns SN for the digital board.
SYSTem:DBOard:REVision?	' Returns revision of the digital board.
SYSTem:VERSION?	' Returns version of SCPI standard (e.g., 1999.0).

Beeper and keyclick

Beeper

With the beeper enabled, a beep will be issued to acknowledge the following actions:

- A short beep is issued when a front panel key is pressed.
- For the Model 6221, a short beep is also issued when the rotary knob is turned or pressed.
- When an error occurs, a slightly longer beep is issued.
- A longer beep is issued when a setup is saved from the front panel.

Perform the following steps to control the beeper:

1. Press **MENU** to display the MAIN MENU.
2. Using the “[Menu navigation](#)” keys (see [page 1-20](#)), place the cursor on **BEEPER** and press **ENTER**.
3. Place the cursor on **DISABLE** or **ENABLE** and press **ENTER**. Beeper enabled is the default setting.
4. Use the **EXIT** key to back out of the menu structure.

Remote programming – The following command controls the beeper:

SYSTem:BEEPer:STATE ‘ Enable or disable the beeper.
‘ = ON or OFF.
‘ Default setting is beeper ON.

Keypress

With keyclick enabled, a “click” sound will be issued when a front panel key is pressed. For the Model 6221, a “click” will also be issued when the rotary knob is turned or pressed. Keypress can only be controlled using remote operation:

SYSTem:KCLick ‘ Enable or disable keyclick.
‘ = ON or OFF.
‘ Default setting is keyclick ON.

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 3-13](#) for details on setting the preset value.

Disabling the front panel

The front panel can be disabled. While disabled, display characters and annunciators are turned off. Also, all front panel controls (except LOCAL and DISP) are locked out.

NOTE A single decimal point will be left on at the bottom right to indicate that the unit is powered on.

Disabling the front panel provides the following benefits:

- Allows testing on light sensitive devices.
- Eliminates step-to-step timing jitter for Sweeps, Delta, and Differential Conductance. Details on “[Step-to-step timing jitter](#)” is provided on [page 1-18](#).
- Increases system speed. Processing time is shortened since readings are not formatted and displayed.

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 ** ‘ Enable or disable the front panel.
‘ = 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 as previously explained.

If the display is disabled while a Sweep, Delta, or Differential Conductance test 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. The front panel keys to arm and start the test are disabled while the front panel is disabled.

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

CONFIG > 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).
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 1-22](#)).
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 1-25](#)).
SETUP opens RESTORE SETUP menu ([page 1-25](#)).
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.

Calibration (CAL) is covered in [Section 17](#). The mainframe serial number and revision levels are provided by “[System identification](#),” [on page 1-16](#). Details on the “[Beeper](#)” are provided on [page 1-16](#).

The **TEST** main menu item is explained as follows:

After pressing the **MAIN** key, select **TEST** from the menu. The menu items are explained as follows:

DISPLAY TESTS – The display tests include the following:

- **KEYS** – Use to test front panel key operation. When a key is pressed, its label name will be displayed. To exit, press the **EXIT** key twice.
- **DISPLAY PATTERNS** – There are five parts to the display test. Each time **ENTER** is pressed, the next part of the test sequence is selected. The five parts of the test sequence are as follows:
 - All digit segments and annunciators are displayed.
 - All digit segments are displayed.
 - For the first digit, a segment line is scrolled up and down.
 - For the first digit, a segment line is scrolled left to right.
 - All digits are sequentially displayed left to right.
 - The segments of each digit are sequentially displayed.

When finished, abort the display test by pressing **EXIT**.

- **CHAR SET** – Use this menu item to show the display symbols used by the Model 622x.

Editing controls

Source and compliance editing

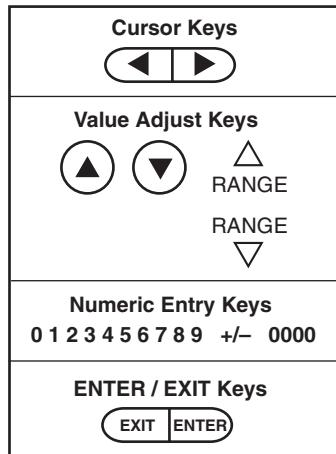
When the Model 622x is in the edit mode (EDIT annunciator on), the editing controls are used to set source and compliance values. The typical way to enter the edit mode is to press the **EDIT** key. Details on “[Source and compliance editing](#)” are provided on [page 3-9](#).

Menu navigation

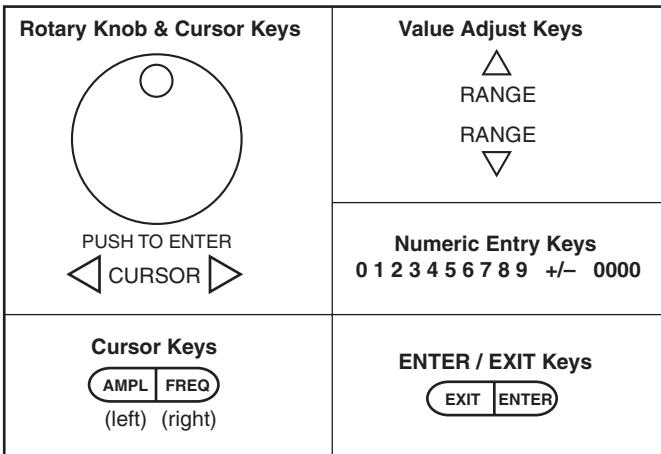
When the Model 622x is not in the edit mode (EDIT annunciator off), the editing controls (see [Figure 1-3](#)) are used to navigate menus to make selections and/or set values.

Figure 1-3
Menu editing keys

6220 Editing Keys:



6221 Editing Keys:



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 past "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](#) for details on password.

Interface selection

The following summarizes interface selection for the Model 6221. Details on the interfaces are provided in [Section 10](#). The KI-220 Language emulation mode (DDC commands) are only valid for GPIB communications.

Use the editing controls for “[Menu navigation](#)” ([page 1-20](#)) to select a different interface and/or language.

GPIB and language

1. Press **COMM** to open the COMMUNICATIONS SETUP menu.
2. Select the **GPIB** interface.

NOTE If a different interface was being used, the Model 622x will reboot when GPIB is selected. If a reboot occurs, repeat steps 1 and 2, and then proceed to step 3.

3. Set the GPIB address (**0 to 30**) and press **ENTER**.
4. Select the desired language (**SCPI** or **KI-220**). The SCPI language uses SCPI commands to control the instrument. The KI-220 language uses Model 220 emulation commands.

NOTE While in the normal display state, the **ADDR** key can also be used to set the GPIB address.

RS-232

1. Press **COMM** to open the COMMUNICATIONS SETUP menu.
2. Select the **RS-232** interface.

NOTE If a different interface was being used, the Model 622x will reboot when RS-232 is selected. If a reboot occurs, repeat steps 1 and 2, and then proceed to step 3.

3. Configure the RS-232 as follows:
 - Set the **BAUD** rate: 300, 600, 1200, 2400, 4800, 9600, 19.2K, 38.4K, 57.6K, or 115.2K.
 - Set the **TERMINATOR**: <CR>, <CR+LF>, <LF>, or <LF+CR>.
 - Set the **FLOW-CTRL**: NONE or XON-XOFF.

Ethernet (Model 6221 only)

1. Press **COMM** to open the COMMUNICATIONS SETUP menu.
2. Select the **ETHERNET** interface.

NOTE If a different interface was being used, the Model 622x will reboot when ETHERNET is selected. If a reboot occurs, repeat steps 1 and 2, and then proceed to step 3.

3. For the ETHERNET, set the **MAC** address, **IP**, **GATEWAY**, and **SUBNET**. Also enable (ON) or disable (OFF) **DHCP** control.

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 of status or error variety, as listed in [Appendix B](#).

Messages, both status and error, are held in queues. For information on retrieving messages from queues, see [Section 11](#).

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.

Default settings for front panel operation are listed in [Table 1-1](#). For front panel operation, PRESET and *RST defaults are the same. For remote operations, the defaults are included in the SCPI table (see [Section 14](#)).

The instrument will power up to the default setup that was saved as the power-on setup.

<p>NOTE At the factory, the PRESET default setup is saved into the five user-saved setups.</p>

Front panel setups

<p>NOTE User setups cannot be saved or recalled while Wave, Sweep, Delta, Pulse Delta, or Differential Conductance is armed or running. Attempting to do so will generate error +413 Not allowed with mode armed. A custom sweep cannot be saved as a user setup. Attempting to do so will generate error +528 Cannot save CUSTOM sweep setup. Source preset values are not saved as part of a user setup.</p>

To save a user setup

1. Configure the Model 622x for the desired sourcing application.
2. Press the **SAVE** key to open the SAVED SETUP MENU.
3. Select the **SAVE** menu item.
4. Enter the desired memory location (0 through 4) and press **ENTER**.

To restore any setup

1. Press **SETUP** to open the RESTORE SETUP menu:
2. Select **USER**, **PRESET**, or ***RST**:
 - **USER** – Enter the desired value (0 to 4) and press **ENTER**.
 - **PRESET** – Press **ENTER** to return to the PRESET defaults.
 - ***RST** – Press **ENTER** to return to *RST defaults.

To select power-on setup

1. Press the **SAVE** key to open the SAVED SETUP MENU.
2. Select the **POWER ON** menu item.
3. Select **BENCH**, **GPIB**, or **USER SETUP NUMBER**:
 - **PRESET** – Press **ENTER** to select the PRESET defaults.
 - ***RST** – Press **ENTER** to select the *RST defaults.
 - **USER SETUP NUMBER** – Key in the desired user setup number and then press **ENTER**.

Remote operation setups

Saving and restoring user setups

The *SAV and *RCL commands are used to save and recall user setups:

- | | |
|------------|--|
| *SAV <NRf> | ‘ Save present setup in memory. |
| *RCL <NRf> | ‘ Recall saved user setup from memory. |
| | ‘ <NRf> = 0, 1, 2, 3, or 4 |

NOTE User setups cannot be saved or recalled while Wave, Sweep, Delta, Pulse Delta or Differential Conductance is armed or running. The *SAV and *RCL commands will generate error +413 (Not allowed with mode armed).

A custom (list) sweep cannot be saved as a user setup. Attempting to do so will generate error +528 Cannot save CUSTOM sweep setup.

Source preset values are not saved as part of a user setup.

Restoring PRESet or *RST default setups

The SYSTem:PRESet command returns Model 622x to the PRESET defaults and the *RST command returns it to the *RST defaults.

- | | |
|---------------|---------------------------------|
| SYSTem:PRESet | ‘ Restore PRESET default setup. |
| *RST | ‘ Restore *RST default setup. |

Selecting power-on setup

The SYSTem:POSetup command is used to select which setup to return to on power-up.

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

Table 1-1
Front panel default settings

Setting	PRESET and *RST Default
Address (ADDR)	No effect (12 at factory)
Amplitude (AMPL)	1.0mA
Averaging Filter (AVG): Type Count	Disabled Moving 10
Beeper	Enabled
Communications (COMM): See Section 10 for details.	No effect (GPIB and address 12 set at factory).
DELTA: I-High I-Low Delay Count Compliance Abort	Unarmed +1mA -1mA 0.002s Infinite No
Differential Conductance (COND): Start Stop Step Delta Delay Cmpl Abort	Unarmed -10µA +10µA 1µA 1µA 0.002s No
Display (DISP)	Enabled
FILTER	Disabled
Frequency (FREQ)	1000 Hz
MATH MX+B and M/X+B: "M" Value "B" Value	MX+B, disabled +1.0 0.0

Table 1-1 (cont.)
Front panel default settings

Setting	PRESET and *RST Default
OUTPUT Response (6221)	Off Fast
Preset (PRES):	0.0mA, disabled
Pulse Delta (PULSE): I-Hi I-Low Width Count Ranging Src Del Interval Sweep Low Meas	Unarmed +1mA 0mA 0.110ms Infinite Best 0.016ms 5 PLC No 2 lows per pulse
RANGE	100mA range, fixed
Sweep (SWP): Type Start Stop Step Delay Sweep Count Source Ranging Compliance Abort	Unarmed Stair 0mA +100mA 10mA 1s Finite, 1 Best No
TRIAX: Inner Shield Output Low	Output Low (220 Style) Floating

Table 1-1 (cont.)
Front panel default settings

Setting	PRESET and *RST Default
Trigger (TRIG) Arm Layer: Arm-In event Arm-Out menu: Line Events: Trig Layer Exit TL Enter Trig Layer: Trigger In Trigger Out: Line Events: Source Delay	Immediate #2 Off Off Immediate #2 Off Off
UNITS	Volts
WAVE: Type Offset Phase Marker Duration Ranging External triggering Mode Trigger link line Ignore mode Inactive value	Unarmed Sine 0mA Off Infinite Best Fixed Off 0 Off (Restart) 0.0

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](#), 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.

Output Connections

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 2-7

Triax output low, page 2-7

Guards, page 2-8

Guard overview, page 2-8

Triax Cable Guard, page 2-9

Banana Jack Guard, page 2-12

Floating the current source, page 2-13

Connections to DUT, page 2-15

Supplied triax cable, page 2-15

Basic connections, page 2-15

Shields and guarding, page 2-16

Banana Jack Guard connections, page 2-19

Floating current source connections, page 2-19

Using a test fixture, page 2-20

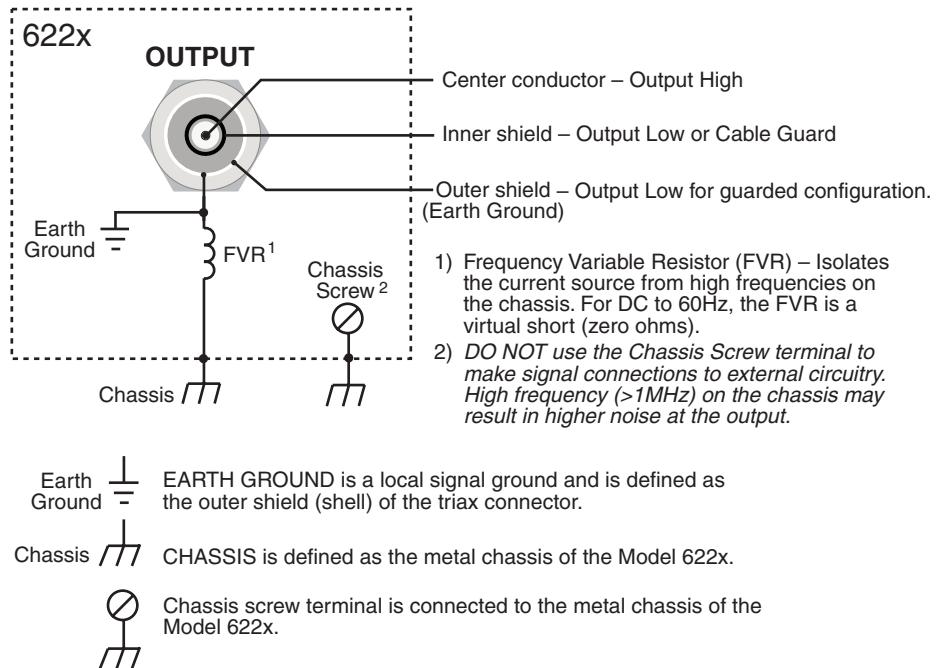
Custom-built test fixture, page 2-20

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 supplied for the Model 622x (see “[Supplied triax cable](#),” on page 2-15). The triax connector is shown in Figure 2-1.

Figure 2-1
Triax connector and ground point



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 2-7 for details on the inner

shield connection setting. See “[Triax Cable Guard](#),” on page 2-9 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.

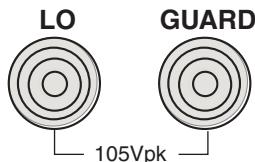
Keep in mind that the **Chassis** should never be used as a ground point for signal connections. High frequencies present on the chassis of the Model 622x may result in higher noise on the output.

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 and GUARD banana jacks



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 details on these two guards.

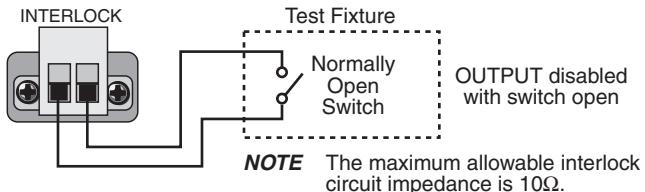
INTERLOCK

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 to be 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](#),” on page [2-20](#) 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

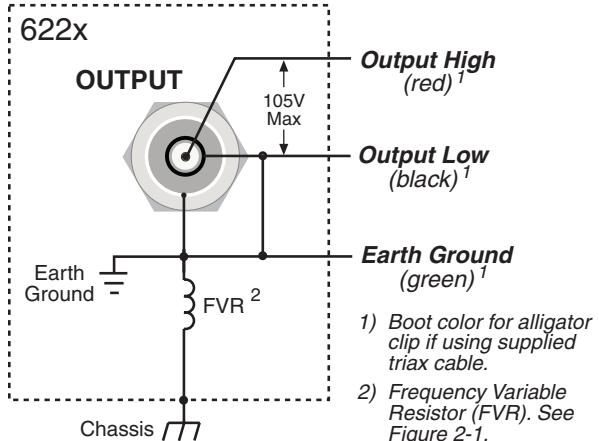
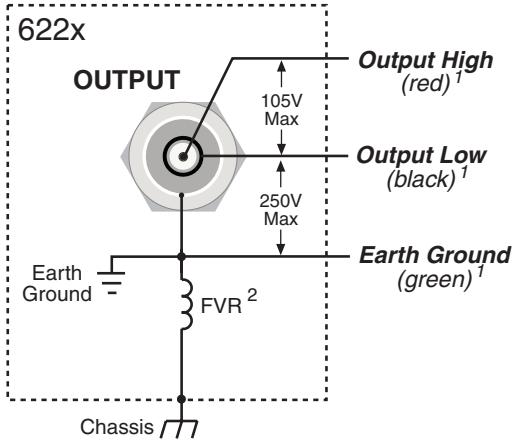
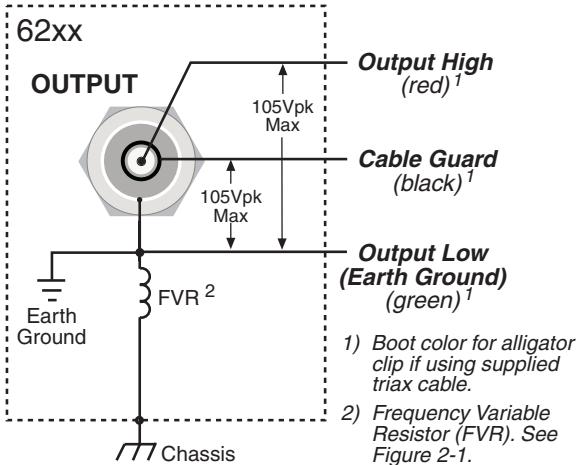
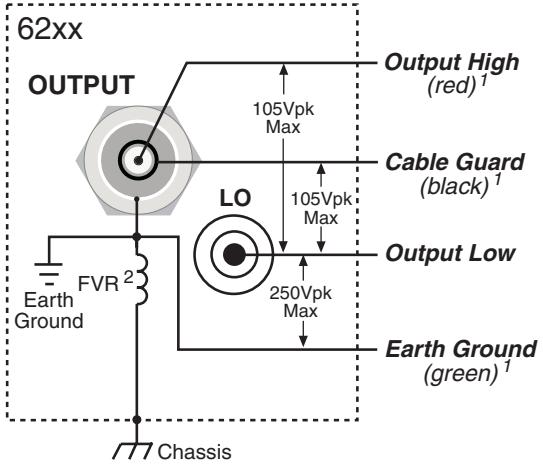
Output configurations – triax inner shield connected to Output Low**A) Triax Output Low setting: Earth Ground****B) Triax Output Low setting: Floating**

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 Model 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 	' Enable or disable triax output low connection to Earth ' Ground. ' = ON (Earth Ground) = OFF (Floating)

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

OUTPut :LTEarth OFF

Guards

Guard overview

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 Devide Under Test (DUT). For details on “[Triax Cable Guard](#)” refer to [page 2-9](#).

Banana Jack Guard – This guard is similar to cable guard in 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. This guard serves as a x1 buffer amplifier to eliminate loading errors that may occur as the impedance of the DUT approaches the voltmeter input impedance. For details, see “[Banana Jack Guard](#),” on [page 2-12](#).

The differences between the two guards are summarized as follows:

Triax Cable Guard	Banana Jack Guard
10mV Accuracy (typical)	1mV Accuracy (typical)
Use for cable and DUT guarding	Use to measure voltage

When to use Cable Guard

When to use Cable Guard is a judgement call that must be made by the user. The information on “[Triax Cable Guard](#)” will provide a basic understanding on the principles of guarding.

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).

Triax Cable Guard

A triax cable has insulation resistance and capacitance between its conductors. A typical triax cable could typically have $1\text{ T}\Omega/\text{ft}$. of insulation resistance and $100\text{ pF}/\text{ft}$. of cable capacitance.

Unguarded triax cable example – inner shield connected to Output Low

The example in [Figure 2-6](#) shows the effects of using an unguarded output configuration (as shown in [Figure 2-4](#)) to source 100nA to a $1\text{ G}\Omega$ DUT (R_{DUT}). As shown, a $100\text{ G}\Omega$ insulator resistance (R_{L1}) and a 100 pF (C_{L1}) cable capacitance exist between output high and output low.

Cable capacitance – Cable capacitance 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 C_{L1} . 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 (5τ) for the capacitor to charge and allow the settled current to flow through the DUT.

As calculated in [Figure 2-6](#), one RC time constant (τ) is 99ms. Therefore, a settling time of 495ms (5τ) is required to allow sufficient settling for the source. The higher the capacitance and impedance of the DUT, the longer the current rise time at the DUT.

Leakage current – After capacitor C_{L1} charges, it is effectively removed from the test circuit (assuming the source level remains constant). What is left is the $100\text{G}\Omega$ insulator resistance (R_{L1}) in parallel with the $1\text{G}\Omega$ DUT (R_{DUT}), effectively making a current divider. As a result, 99nA is sourced to the DUT (1% error). The higher the impedance of the DUT, the higher the source error.

Guarded triax cable example – inner shield connected to Cable Guard

For high impedance DUT, guarding the triax cable greatly reduces leakage current and the effects of cable capacitance.

The example in [Figure 2-7](#) illustrates the principle of triax cable guarding. Output high and guard are at nearly the same potential (in this case 100V). This potential is applied to both sides of resistor R_{L1} and capacitor C_{L1} . This makes the voltage drop across the capacitor 0V . Therefore, the capacitor does not charge and is effectively removed from the test circuit. The response at the DUT is much faster and is determined by the output response settings of the Model 622x (see “[Output response](#),” on page [3-5](#) for details).

The voltage drop across resistor R_{L1} is also 0V . Therefore, no current flows through the resistor R_{L1} . With resistor R_{L1} effectively removed from the test circuit, virtually all the current (100nA) flows through the DUT. Notice that a leakage current will flow from guard to output low (via resistor R_{L2} and capacitor C_{L2}), but it will not affect the current sourced to the DUT.

Figure 2-6

Unguarded triax cable – inner shield connected to Output Low (see [Figure 2-4](#))

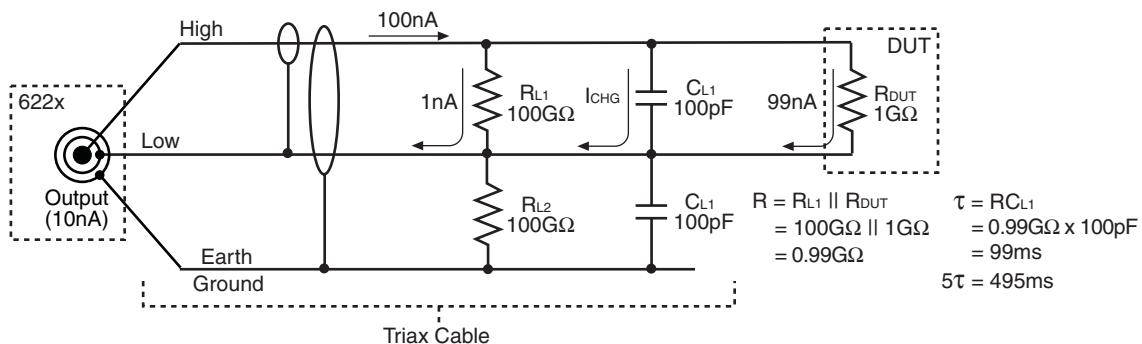
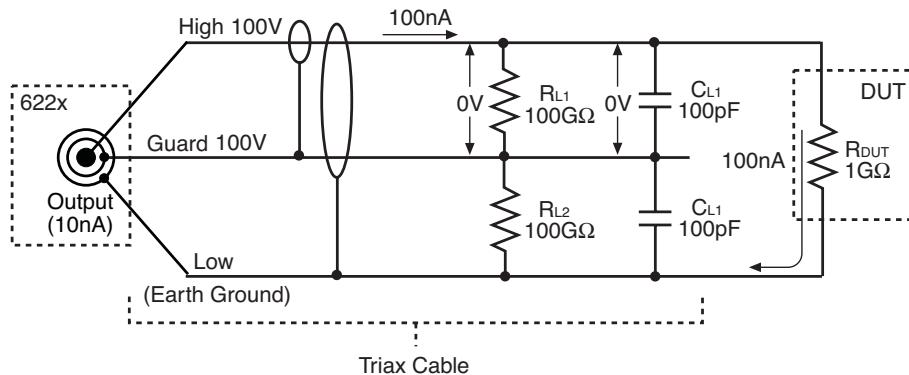


Figure 2-7

Guarded triax cable – inner shield connected to Cable Guard (see Figure 2-5A)



Guarded DUT mounting plate

There may be significant leakage and capacitance in the test fixture. A DUT is typically mounted on a metal plate using insulated terminal posts. In an unguarded configuration, current leakage may occur from output high to output low through the insulators of the terminal posts. Also, capacitance may exist across the DUT.

[Figure 2-8](#) shows how a DUT mounted on a metal plate can be connected to the Model 622x. The unguarded configuration is shown in [Figure 2-8A](#). Resistors R_{L1} and R_{L2} represent the leakage resistance across the DUT, and the capacitors C_1 and C_2 represent the shunt capacitance across the DUT.

The test fixture shunt capacitance across the DUT acts the same as capacitance in an unguarded triax cable and slows down response (increases settling time).

For a high impedance DUT ($>10M\Omega$), significant leakage current may occur through the terminal post insulators. The current through the DUT will be the output current (I_S) from the Model 622x minus the leakage current (I_L).

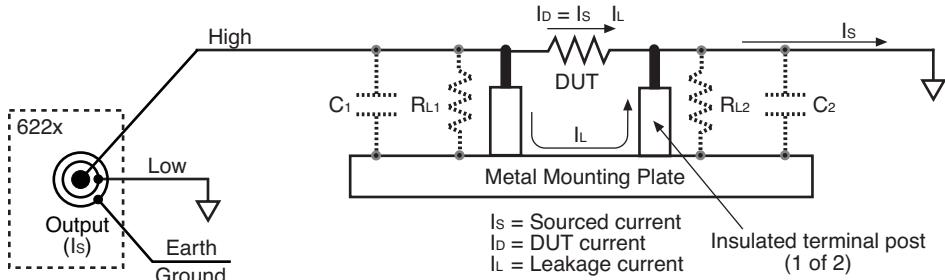
[Figure 2-8B](#) shows how to use guarding to eliminate leakage current at the DUT. The driven guard is connected to the metal mounting plate (now called “Metal Guard Plate”). Since output high and guard are at nearly the same potential, the voltage drop across resistor R_{L1} and capacitor C_1 will be almost 0V.

With such a minimal voltage drop, leakage current through R_{L1} is greatly reduced, and the charging current through C_1 is minimized.

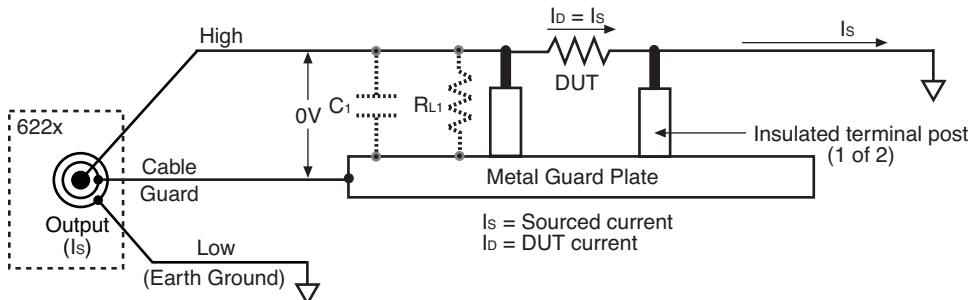
Resistor R_{L2} and capacitor C_2 are effectively removed from the test circuit. Virtually all the current flows through the DUT.

Figure 2-8
DUT mounting plate (unguarded and guarded)

A) Unguarded circuit—inner shield connected to Output Low



B) Guarded circuit—inner shield connected to Cable Guard



Banana Jack Guard

A typical test for the Model 622x is to source a current to a DUT and then use a voltmeter to measure the voltage across the DUT. When using a voltmeter that has low input impedance, a more accurate voltage reading may be obtained by taking the voltage measurement at the banana jack Guard terminal.

Figure 2-9A shows how the conventional voltage measurement method can result in loading error when using a low-impedance voltmeter. As shown, a $10\text{M}\Omega$ impedance voltmeter results in 50% loading error when trying to measure a $10\text{M}\Omega$ DUT. Half the sourced current ($5\mu\text{A}$) flows through the DUT, and the other half flows through the voltmeter. The result is a voltage reading of 50V (instead of the expected 100V). A higher impedance DUT results in even more error, while a lower impedance DUT results in less error.

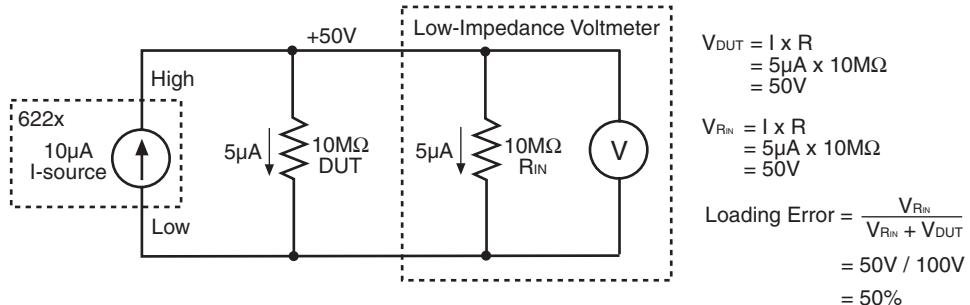
A technique to eliminate the loading factor is to make the measurement at the banana jack Guard terminal. As shown in Figure 2-9B, there is no loading on the DUT. All of the sourced current ($10\mu\text{A}$) is applied to the DUT. The 100V across the DUT is also seen at the Guard terminal. Accuracy for Guard is typically $\pm 1\text{mV}$.

Cable Guard (which has less noise than banana jack Guard) can also be used to measure voltage as previously described. For best accuracy, it is recommended that banana jack Guard be used.

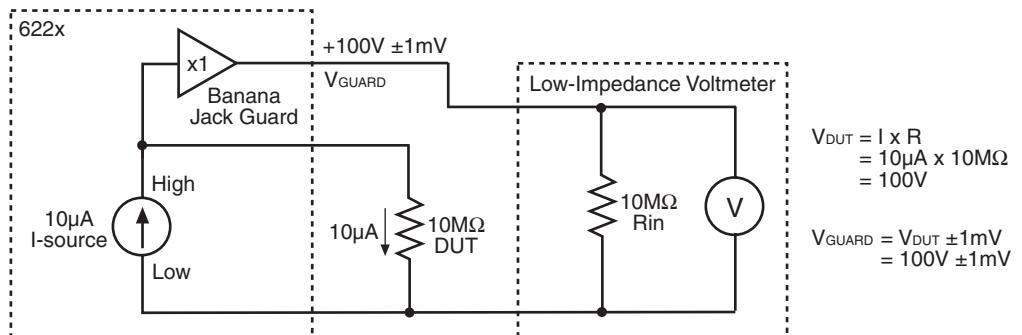
NOTE For the Keithley Model 2182/2182A Nanovoltmeter, the input impedance for the 100V range is 10MΩ. Therefore, for higher impedance DUT, voltage should be measured at banana jack Guard or Cable Guard.

Figure 2-9
Using banana jack Guard to measure voltage

A) 50% measure error due to voltmeter loading



B) Using banana jack Guard to measure voltage



Floating the current source

Using an external source in the test system may require that the Model 622x current source float off Earth Ground. An example of such a test system is shown in [Figure 2-10](#), which includes an external voltage source. Notice that Output Low of the voltage source is connected to earth ground.

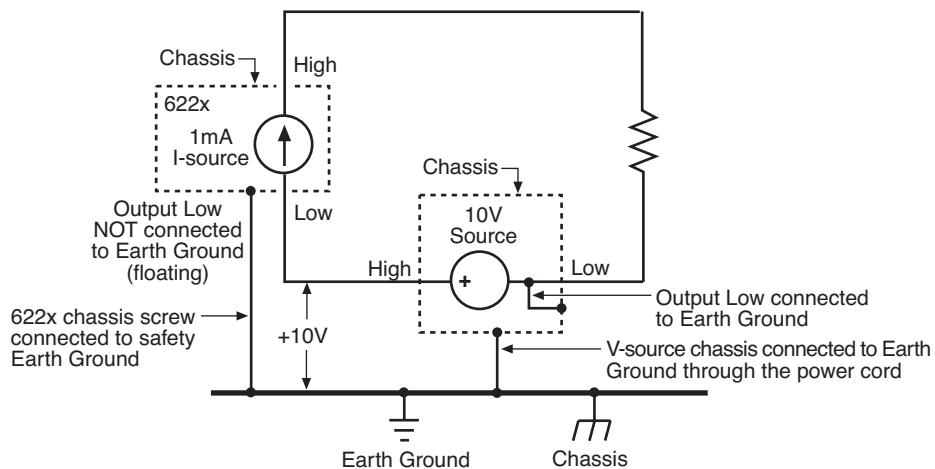
For the test circuit shown in [Figure 2-10](#), the Model 622x current source must be configured to float off Earth Ground. As shown, Output Low of the Model 622x is floating +10V above Earth Ground. If Output Low of the Model 622x was instead connected to Earth Ground, the voltage source would be shorted through Earth Ground.

In order to float the current source, Output Low must be disconnected from Earth Ground. The floating configurations are shown in [Figure 2-4B](#) and [Figure 2-5B](#). See “[Triax output low](#),” on page [2-7](#) for details on selecting the floating configuration.

WARNING When floating the Model 622x, an electric shock hazard may exist between Output Low of the Model 622x and Chassis:

- The chassis of the Model 622x must be connected to Earth Ground. Use the chassis ground screw on the rear panel for connection to a known safety Earth Ground.
- The test circuit must be surrounded by a safety shield that is connected to a safety Earth Ground (see “[Safety shield connections](#),” on page [2-16](#)).

Figure 2-10
Floating the Model 622x current source



NOTE Earth Ground and Chassis are essentially at the same ground potential. The difference between these two ground points is shown in Figure 2-1.

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 instruments and external 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](#)).

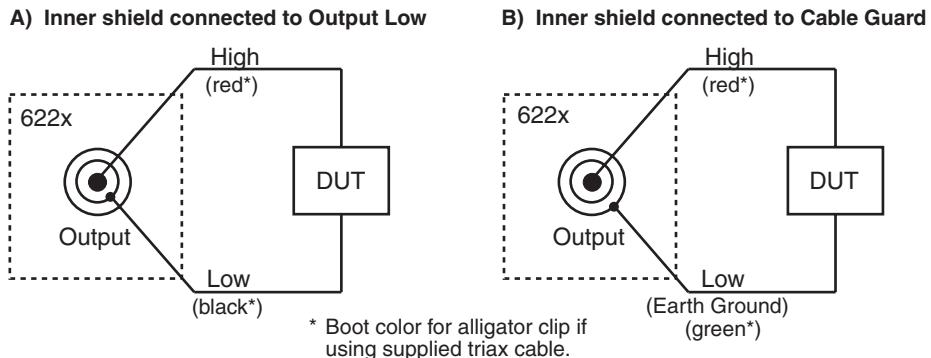
WARNING The Model 237-ALG-2 triax cable can allow exposed voltages when used in certain applications.

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, 42V peak) testing where guarding and/or noise shielding are not required. Basic connections to a DUT are shown in [Figure 2-11](#). Use the connections shown in [Figure 2-11A](#) if the inner shield of the triax connector is connected to Output Low. Use the connections shown in [Figure 2-11B](#) if the inner shield is connected to Cable Guard.

Figure 2-11
Basic connections to DUT



Shields and guarding

Noise shield connections

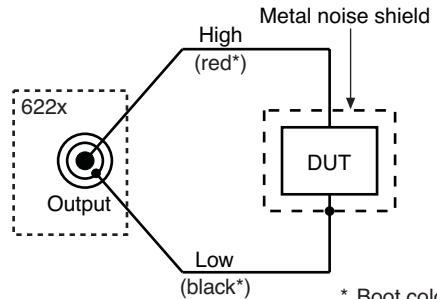
Figure 2-12 shows typical noise shielding for the two triax connector configurations. A noise shield is used to prevent unwanted signals from being induced into the test circuit. A test current below $1\mu\text{A}$ may benefit from effective shielding. Typically, the metal noise shield surrounds the DUT and is connected to Output Low.

Safety shield connections

A safety shield must be used whenever hazardous voltages ($>30\text{Vrms}, 42\text{Vpeak}$) 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 2-13). Use #18AWG wire or larger for connection to safety Earth Ground and Chassis.

Figure 2-12
Noise shield

A) Inner shield connected to Output Low



B) Inner shield connected to Cable Guard, Output Low connected to Earth Ground

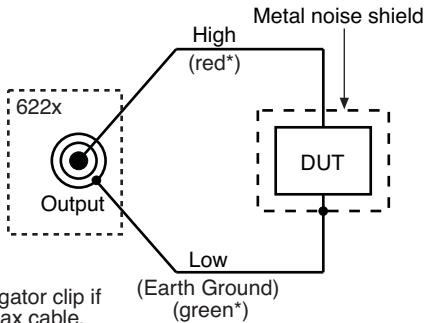
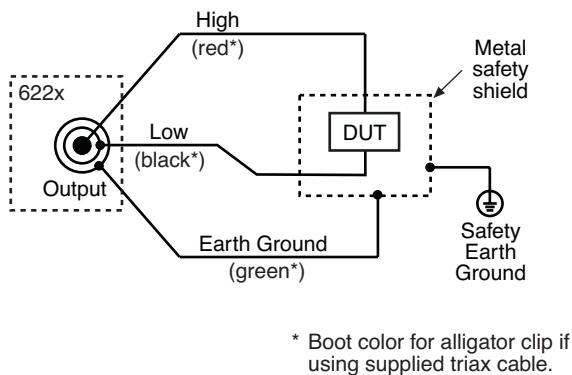
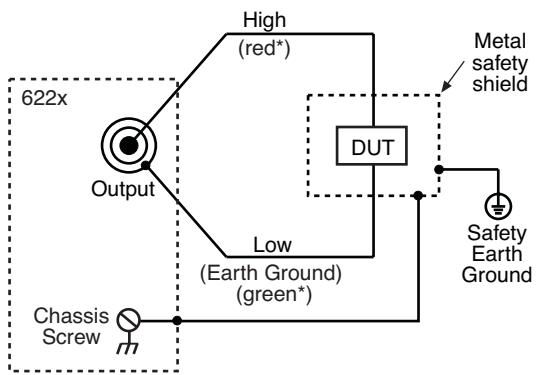


Figure 2-13
Safety shield

A) Inner shield connected to Output Low



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

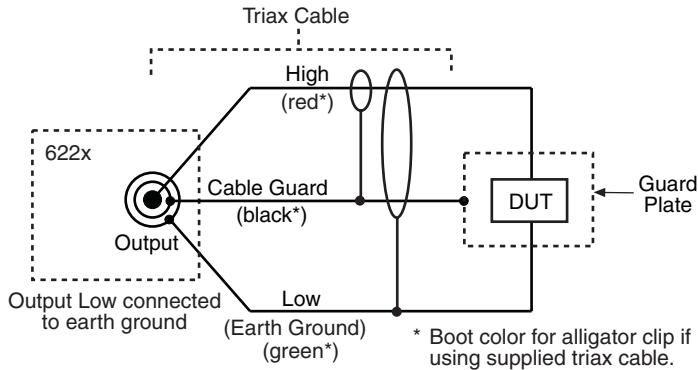


Cable Guard connections

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 2-14](#).

A safety shield must be used whenever hazardous voltages ($>30\text{Vrms}$, 42Vpeak) will be present in the test circuit. [Figure 2-15](#) shows how to make guarded connections with the use of a safety shield.

Figure 2-14
Cable Guard connections – triax inner shield connected to Cable Guard

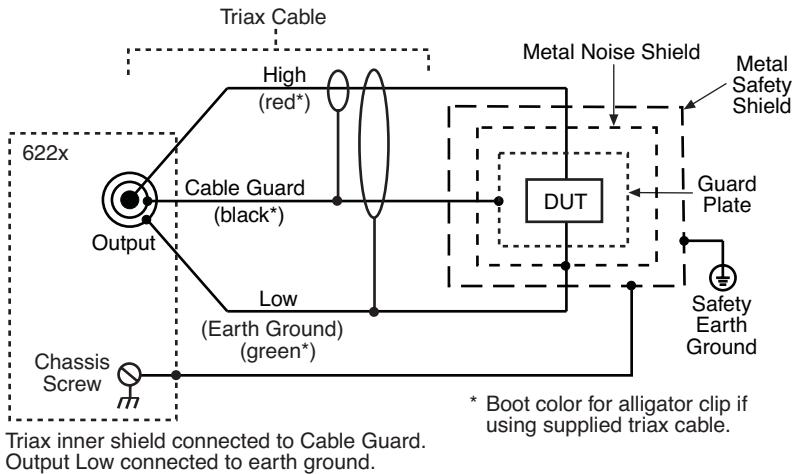


Using shielding and guarding together

Figure 2-15 shows connections for a test system that uses a noise shield, a safety shield, and guarding.

Figure 2-15

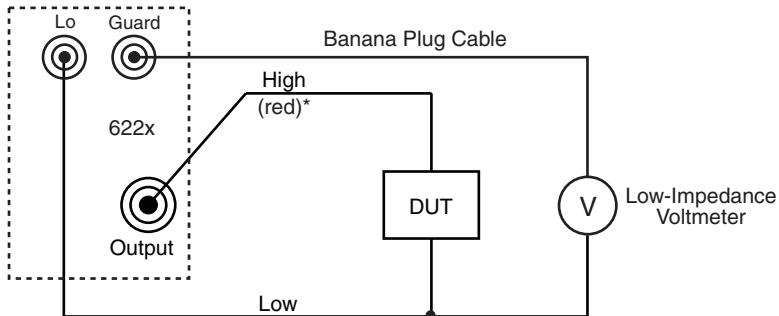
Connections for noise shield, safety shield, and guarding



Banana Jack Guard connections

When using a low-impedance voltmeter to measure voltage, it may be necessary to make the measurement at banana jack Guard (see [Figure 2-16](#)). Keep in mind that banana jack Guard should only be used if voltmeter measurements at the DUT will result in significant loading errors. Details on “[Banana Jack Guard](#)” are provided on [page 2-12](#).

Figure 2-16
Banana Jack Guard connections



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

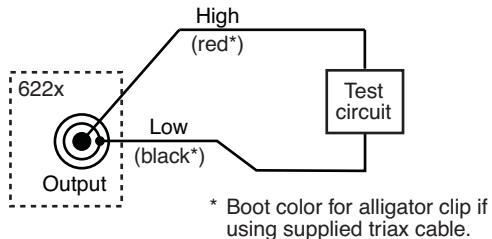
Floating current source connections

When using an external source in the test circuit, it may be necessary to float the Model 622x off Earth Ground (see [Figure 2-17](#)). Details on “[Floating the current source](#)” are provided on [page 2-13](#).

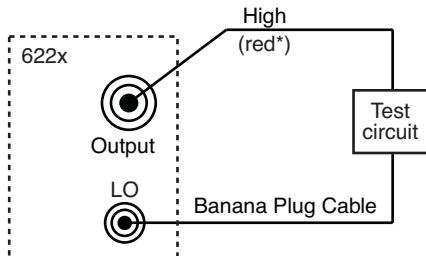
WARNING To prevent electric shock and/or damage to the Model 622x, DO NOT exceed 250Vpk between Output Low and Earth Ground. Above 42Vpk (30Vrms), a shock hazard exists between Output Low and Chassis. A safety shield must surround the test circuit and be connected to a safety Earth Ground (For details, see “[Safety shield connections](#),” on [page 2-16](#)).

Figure 2-17
Floating current source connections

A) Inner shield connected to Output Low



B) Inner shield connected to Cable Guard



NOTE Triax Output low must be disconnected from Earth Ground by using the following key-press sequence:

Press **TRIAX**, select **OUPUT LOW**, select **FLOATING**.

The following command will also disconnect Output Low from Earth Ground:

OUTPut:LTEarth OFF

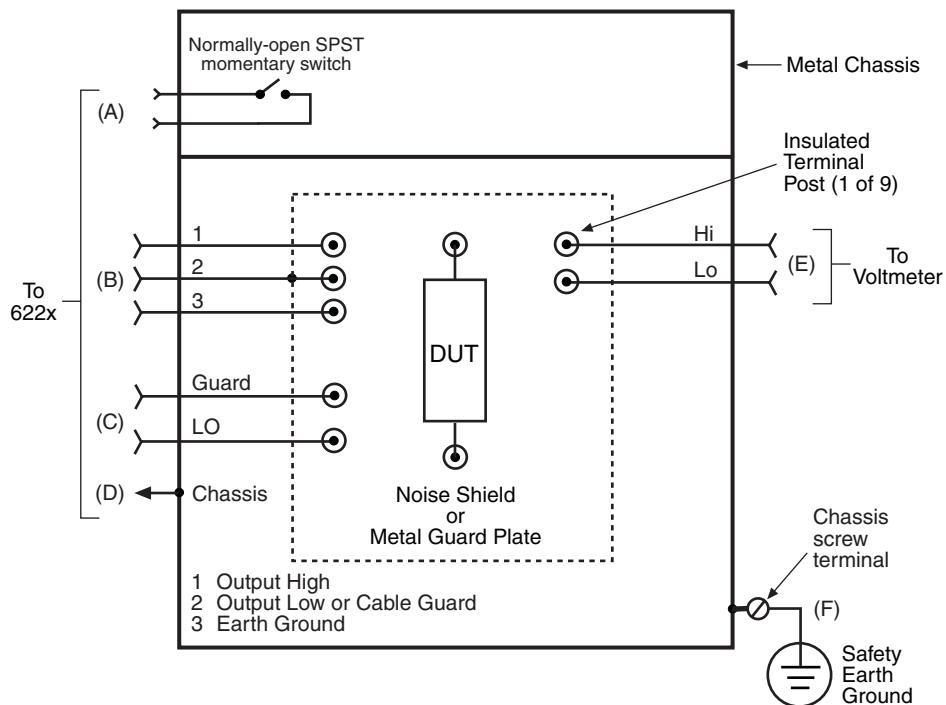
Using a test fixture

Custom-built test fixture

A custom-built test fixture needs to accommodate a variety of connection requirements, including connections to an external voltmeter (such as the Keithley Model 2182/2182A Nanovoltmeter).

[Figure 2-18](#) shows a test fixture that can be custom-built. The included connectors and terminals will accommodate any connection scheme covered in this section. The internal wiring to the DUT will, of course, depend on the connection scheme used.

Figure 2-18
Custom-built test fixture



Test fixture connections

The following describes recommended connections for the test fixture shown in [Figure 2-18](#). Note that the connectors for (B), (C), and (E) must be insulated from the metal chassis of the test fixture.

To minimize thermal EMFs, which could corrupt low level measurements, use copper connectors for the DUT test circuit.

- (A) **Two 5-way binding posts** – wire the binding posts to a normally-open interlock switch as shown in [Figure 2-18](#).

The interlock switch must be installed such that when the lid of the test fixture is opened the switch will open, and when the lid is closed the switch will close. When the test fixture lid is opened, the output of the Model 622x will turn off. The test fixture lid must be closed in order to turn on the output.

Use suitable insulated wires to connect the test fixture interlock to the **INTERLOCK** quick-disconnect block on the rear panel of the Model 622x.

- (B) **Three 5-way binding posts, or one 3-lug female triax connector –**
- If using the supplied triax cable (terminated with alligator clips), mount three 5-way binding points to the test fixture.
 - If using a triax cable that is terminated with 3-slot male triax connectors on both ends (e.g., Model 7078-TRX-3), mount a 3-lug female triax bulkhead connector to the test fixture.
- Connect the triax cable to the Model 622x **OUTPUT**.
- (C) **Banana jacks** – Output Low and/or banana jack Guard can be accessed at the **LO** and **GUARD** banana jacks on the Model 622x. Use banana plug cables to make these connections.
- (D) **Chassis ground** – the chassis of the test fixture must be connected to chassis ground of the Model 622x. For the Guard triax configuration, the chassis of the test fixture can be connected to the chassis ground screw on the rear panel of the Model 622x. This connection to the test fixture could be a direct soldered connection, a banana plug connection, or a screw terminal connection.
- (E) **Binding posts** – 5-way copper binding posts will accommodate cables terminated with banana plugs or spade lugs. The cable supplied with the Model 2182/2182A is terminated with copper spade lugs. A clean copper-to-copper connection minimizes thermal EMFs.
- (F) **Safety earth ground** – the test fixture must have a screw terminal that is used exclusively for connection to safety earth ground. See the “[Test fixture chassis](#)” **WARNING** before for more information on this connection.

Test fixture chassis

- The chassis of the test fixture must be metal so it can function as a safety shield.
- The test box must have a lid that closes to prevent contact with live circuitry. Make sure to install an interlock as previously described.
- The test fixture must have a screw terminal that is used exclusively for connection to safety earth ground.

WARNING **To provide protection from shock hazards, the test fixture chassis must be properly connected to safety earth ground. A grounding wire (#18 AWG or larger) must be attached securely to the test fixture at a screw terminal designed for safety grounding. The other end of the ground wire must be attached to a known safety Earth Ground.**

Noise Shield or Guard plate

A metal plate will provide noise shielding or guarding for the DUT or test circuit. It will also serve as a mounting panel for DUT or test circuits. The guard plate must be insulated with appropriate spacing from the chassis of the test fixture.

When the triax inner shield is connected to Output Low, the metal plate serves as a noise shield. When triax inner shield is connected to Cable Guard, the metal plate servers a guard plate.

Terminals and internal wiring

DUT and test circuits are to be mounted on the guard plate using insulated terminals. To minimize leakage, select terminals that use Teflon insulators.

Inside the test fixture, use insulated wires for connections to DUT. Use silver solder for all connections. Silver solder minimizes thermal EMFs.

Handling and cleaning test fixtures

Dust, body oil, solder flux, and other contaminants on connector and terminal insulators can significantly decrease the insulation resistance resulting in excessive leakage currents. Contaminants on DUT and test circuit components can create a leakage path. The leakage currents may be large enough to corrupt low-level measurements.

Handling tips:

- Do not touch the bodies of DUT or test circuit components. If you cannot handle them by their leads, use clean cotton gloves to install them in the test fixture.
- Do not touch any connector or terminal insulator.
- If installing a test circuit that is on a PC board, handle the board by the edges. Do not touch any board traces or components.

Cleaning tips:

- Use dry nitrogen gas to clean dust off connector and terminal insulators, DUT, and other test circuit components.
- If you have just built the test fixture, remove any solder flux using methanol along with clean foam-tipped swabs or a clean soft brush. Clean the areas as explained in the next tip.
- To clean contaminated areas, use methanol and clean foam-tipped swabs. After cleaning a large area, you may want to flush the area with methanol. Blow dry with dry nitrogen gas.
- After cleaning, the test fixture (and any other cleaned devices or test circuits) should be allowed to dry in a 122° F (50° C) low-humidity environment for several hours.

3

DC Current Source Operation

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 3-9

Source and compliance editing, page 3-9

Sourcing current, page 3-14

Remote programming – source output commands, page 3-16

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](#),” on [page 10-35](#).

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** Δ 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. The Model 622x will automatically select the best (lowest) source range for the source value.

NOTE More information on “[Autorange](#)” is provided on [page 3-13](#). The commands for manual ranging and autorange are listed in [Table 3-2](#).

Table 3-1
Source ranges and maximum outputs

Source Range	Max Output	Source Range	Max Output	Source Range	Max Output
2nA	$\pm 2.1\text{nA}$	2 μA	$\pm 2.1\mu\text{A}$	2mA	$\pm 2.1\text{mA}$
20nA	$\pm 21\text{nA}$	20 μA	$\pm 21.\mu\text{A}$	20mA	$\pm 21\text{mA}$
200nA	$\pm 210\text{nA}$	200 μA	$\pm 210\mu\text{A}$	100mA	$\pm 105\text{mA}$

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 ($10\text{mA} \times 1\text{k}\Omega = 10\text{V}$). 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 ($9\text{V}/1\text{k}\Omega = 9\text{mA}$).

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 Device Under Test (DUT).

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 [“Compliance overshoot prevention”](#) are provided on [page E-11](#).

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.

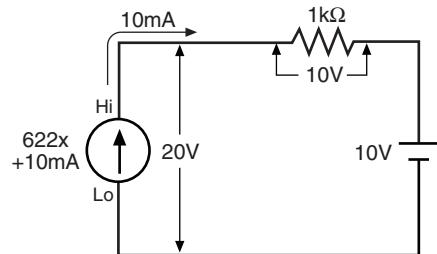
When operating as a source, current is delivered to a test circuit. The polarity of the current and the voltage seen at the output are the same (both positive or both negative).

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.

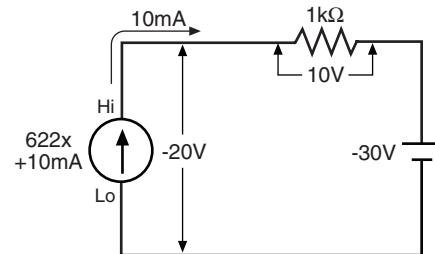
Figure 3-1 shows examples of the Model 622x connected to an external source where it can operate as a source or sink. For both examples, the Model 622x is programmed to output +10mA. When connected to the 1k Ω resistor and 10V source as shown in Figure 3-1A, the Model 622x operates as a 200mW source 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 ($10\text{mA} \times -20\text{V} = -200\text{mW}$).

Figure 3-1
Source and sink examples

A) Source operation



B) Sink operation

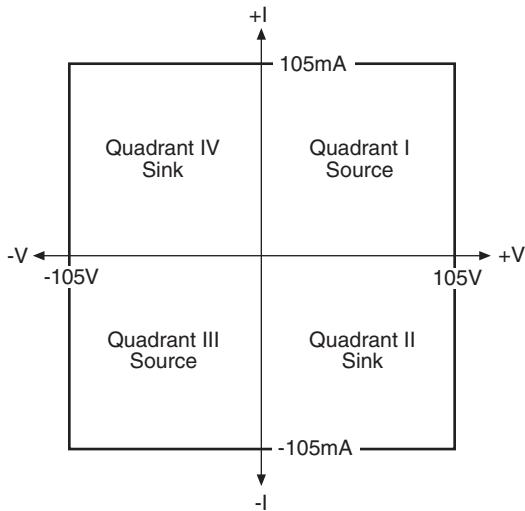


Operating boundaries

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).

Figure 3-2
Output boundaries (source and sink)



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 100 μ s (typical). For the Model 6221, output response can be as fast as 2 μ s (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 100 μ s).

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 2 μ s (typical). Also

assume the load impedance is $1\text{k}\Omega$. With the analog filter enabled, the additional settling time (five time constants) is calculated as follows:

$$\begin{aligned}\text{Additional settling time} &= 5\text{RC} \\ &= 5 \times 1\text{k}\Omega \times 33\text{pF} \\ &= 0.165\mu\text{s}\end{aligned}$$

Enabling the analog filter adds $0.165\mu\text{s}$ settling time, which is not a significant increase in comparison to $2\mu\text{s}$.

Now assume the load is $1\text{M}\Omega$. The additional settling time with the analog filter enabled is $165\mu\text{s}$ ($5 \times 1\text{M}\Omega \times 33\text{pF}$). The analog filter greatly increased the settling time from $2\mu\text{s}$ to approximately $167\mu\text{s}$.

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 $<10\text{k}\Omega$, the analog filter has little effect on the output response. At the $10\text{k}\Omega$ 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 $1\text{M}\Omega$, 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 $<10\text{pF}$. 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](#),” on page E-7.

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 10 μ Hz (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:

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

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

$$\text{Max Load Resistance} = 2V / 20mA = 100\Omega$$

The settling times for other load conditions are calculated as explained in the following paragraphs.

100mA, 20mA, 2mA, 200 μ A, 20 μ A, and 2 μ A ranges

Model 6220 and Model 6221 slow mode:

$$ST = 10^{[\log(1 + 0.5 \times Ifs \times RI) + 1]}$$

Where:

ST is the settling time in microseconds.

Ifs is the full scale of range current in amps.

RI is the load resistance in ohms.

Model 6221 fast mode:

For peak-to-peak voltage swings <100Vpk-pk:

$$ST = 10^{\log(1 + 0.5 \times Ifs \times RI)}$$

Where:

ST is the settling time in microseconds.

Ifs is the full scale of range current in amps.

RI is the load resistance in ohms.

For peak-to-peak voltage swings >100Vpk-pk (output slew rate limitation based upon 5V/μs):

$$ST = 10^{\log(1 + 0.5 \times Ifs \times RI)} + (Vpp - 100) \times 0.2$$

Where:

ST is the settling time in microseconds.

Ifs is the full scale of range current in amps.

RI is the load resistance in ohms.

Vpp is the peak-to-peak voltage step (100V < Vpp < 210V).

200nA, 20nA, and 2nA ranges (Models 6220 and 6221)

The step response for these ranges is largely determined by the impedance of the load, which is primarily made up of the load resistance and parasitic load capacitance. The construction of the DUT may also contribute capacitance and/or inductance.

Cable capacitance can also contribute to settling time. Using a guarded triax cable (Cable Guard) can significantly reduce the effects of cable capacitance but will not eliminate it. For details, see “[Triax Cable Guard](#),” on page 2-9.

Another typical source of capacitance and leakage resistance is the test fixture. These effects can be significantly reduced by using a guard plate in the test fixture. For details, see “[Guarded DUT mounting plate](#),” on page 2-11.

Even if a load has zero capacitance, there will still be approximately 10pF of capacitance present for these low current source ranges. This is capacitance that is inherent to the Model 622x and cannot be reduced or eliminated by guarding or any other technique.

The following equation to calculate settling time assumes the use of short, guarded cables. It also assumes that the shunt capacitance at the load is known.

$$ST = 5 \times 10^6 \times RI \times C$$

Where:

ST is the settling time in microseconds.

RI is the load resistance in ohms.

C is the load capacitance plus 10pF (inherent to the 622x).

NOTE After calculating settling time (ST), compare it to the published settling time specification in [Appendix A](#). The larger of the two settling times will apply.

Setting source and compliance

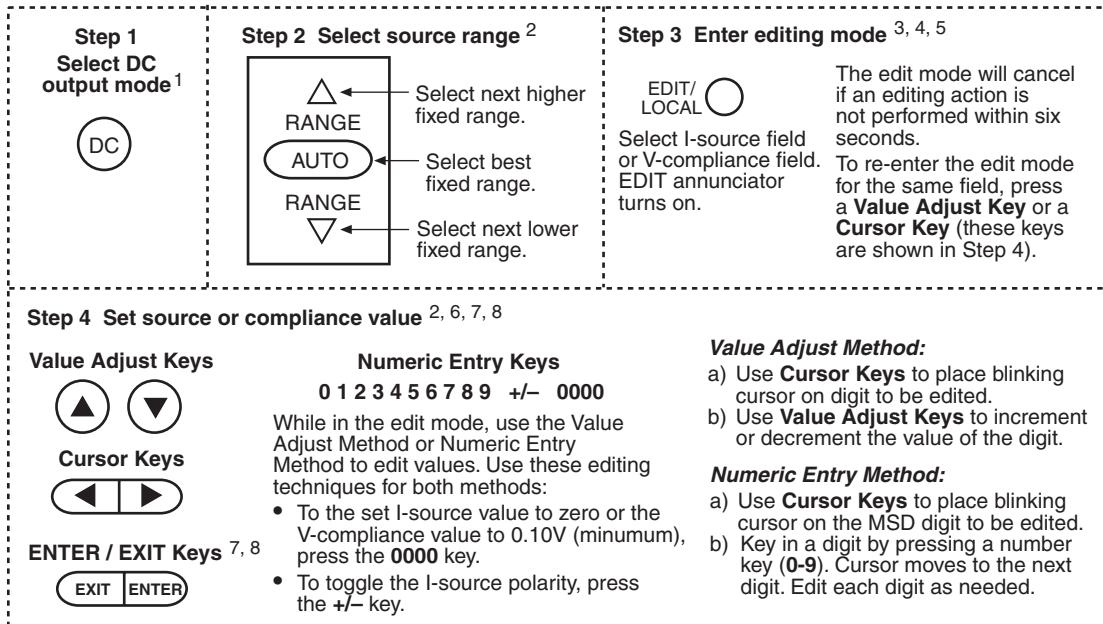
Source and compliance editing from the front panel cannot be performed from the front panel if the Model 622x is in remote. To return to the local state, press the **LOCAL** key.

For **remote programming**, commands to select source range and set source and compliance values are documented in [Table 3-2](#). Programming examples are also provided in the procedure for “[Sourcing current](#),” on [page 3-14](#).

Source and compliance editing

[Figure 3-3](#) shows 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 3-11](#).

Figure 3-3
Source and compliance editing – Model 6220



Value Adjust Method:

- Use **Cursor Keys** to place blinking cursor on digit to be edited.
- Use **Value Adjust Keys** to increment or decrement the value of the digit.

Numeric Entry Method:

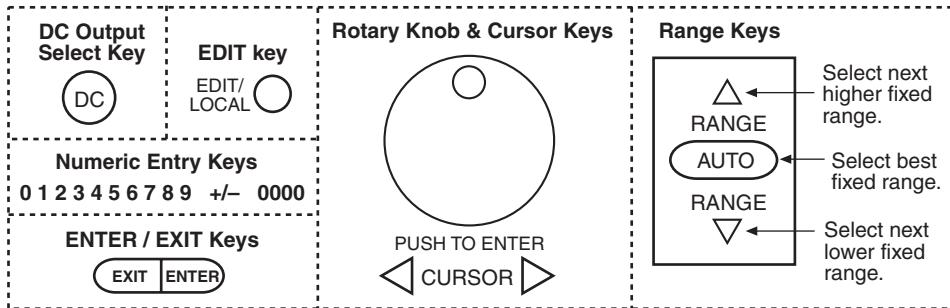
- Use **Cursor Keys** to place blinking cursor on the MSD digit to be edited.
- Key in a digit by pressing a number key (**0-9**). Cursor moves to the next digit. Edit each digit as needed.

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 3-13](#).
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, do 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., $\pm 2.1000\text{mA}$ 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.

Figure 3-4
Source and compliance editing – Model 6221



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 3-11](#).

- 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 techniques 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 (+01.000mA 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 have 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** Δ or ∇ 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 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.

NOTE **Source preset values are not 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:

```
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](#),” on 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:

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

NOTE If the output was on when attempting to access the output response menu, the output will turn off. Repeat Step above to access the output response menu.

- Using the controls for “[Menu navigation](#),” on page 1-20, select the **FAST** or **SLOW (6220 STYLE)** response speed.

For **remote programming**, the commands to set output response are documented in [Table 3-2](#). The following example demonstrates proper syntax.

Example – Enables the analog filter and, for the Model 6221, sets the output response to fast:

```
CURRent:FILTer ON           ' Enables the analog filter.  
OUTPut:RESPonse 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 documented 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

Command	Description	Default
CLEar	Turns output off and sets output level to zero.	
CURRent : RANGE <n>	Sets current source range (amps). ^{1, 2} <n> = -105e-3 to 105e-3	100e-3
CURRent : RANGE : AUTO 	Enables or disables source autorange. = ON or OFF	OFF
CURRent <n>	Sets DC current source output level (amps). <n> = -105e-3 to 105e-3	0.0
CURRent : COMPliance <NRf>	Sets voltage compliance (volts). <NRf> = 0.1 to 105	10.0
CURRent : FILTer 	Enables or disables the output analog filter. = ON or OFF	OFF
OUTPut : RESPonse <name>	Select fast or slow output response speed for 6221. <name> = FAST or SLOW ^{3, 4}	FAST
OUTPut 	Turn output on or off. = ON or OFF	OFF
SourceMeter	Sets output to zero, then turns the output off. ⁴	

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:

CLClear	' 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.

4

Sweeps

Section 4 topics

[Overview](#), page 4-2

Section overview, page 4-2

Sweep overview, page 4-2

[Sweep characteristics](#), page 4-4

Linear staircase sweeps, page 4-4

Logarithmic staircase sweeps, page 4-5

Custom sweeps, page 4-6

Setting sweep parameters, page 4-8

Custom sweep editing, page 4-8

Using auto-copy with custom sweeps, page 4-8

Source ranging, page 4-9

Sweep delay, page 4-9

Sweep count, page 4-9

[Remote sweep operation](#), page 4-14

Running a linear staircase sweep, page 4-15

Running a log staircase sweep, page 4-16

Running a custom sweep, page 4-17

SCPI commands — sweeps, page 4-18

Coupled sweep commands, page 4-22

Sweep status model events, page 4-23

[Front panel sweep operation](#), page 4-10

Using the sweep configuration menu, page 4-10

Performing a linear staircase sweep, page 4-11

Performing a log staircase sweep, page 4-12

Performing a custom sweep, page 4-13

Overview

Section overview

Following a brief “[Sweep overview](#)” of the three types of sweeps (linear staircase, logarithmic staircase, and custom), the documentation in this section provides detailed information on characteristics, front panel operation, and SCPI command programming for each type of sweep as follows:

- “[Linear staircase sweeps](#)”, page 4-4
- “[Logarithmic staircase sweeps](#)”, page 4-5
- “[Custom sweeps](#)”, page 4-6
- “[Front panel sweep operation](#)”, page 4-10
- “[Remote sweep operation](#)”, page 4-14

Sweep overview

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

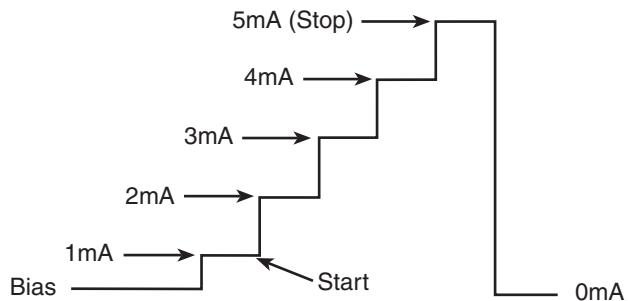
Linear staircase sweep – With this sweep type, the current increases or decreases in specific steps, beginning with a start current and ending with a stop current. [Figure 4-1A](#) shows an increasing linear staircase sweep from a 1mA start current to a 5mA stop current in 1mA steps. The bias current 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.

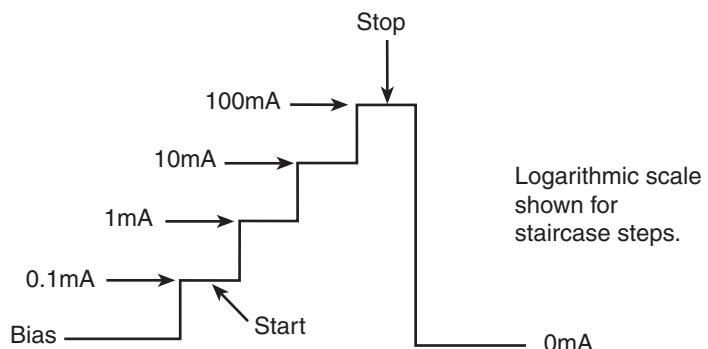
[Figure 4-1B](#) shows an increasing log staircase sweep from a 0.1mA start current to a 100mA stop current with logarithmic steps. Again, the bias current is the fixed current setting just prior to the start of the sweep. The current output will remain at the last point in the sweep after completion.

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.

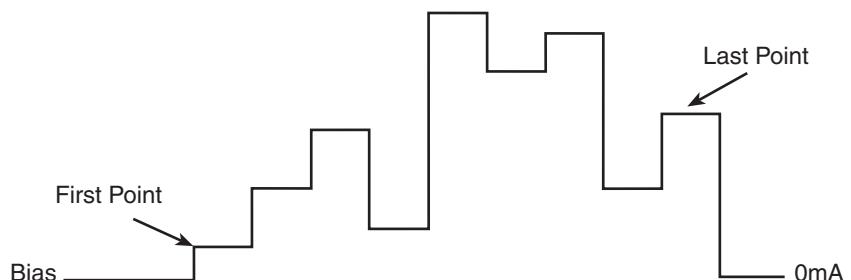
Figure 4-1
Comparison of sweep types



A. Linear Staircase Sweep



B. Logarithmic Staircase Sweep



C. Custom Sweep

Sweep characteristics

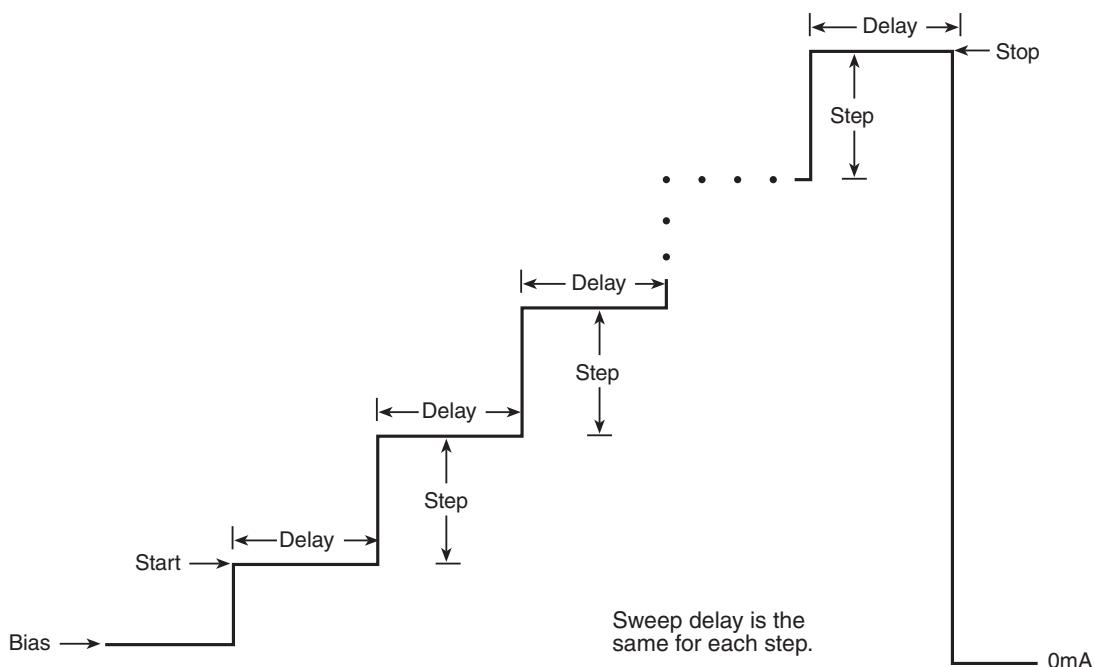
NOTE Jitter – Step-to-step sweep timing may jitter as much as 1ms. This jitter can be eliminated by disabling the front panel. For details, see “Step-to-step timing jitter,” on page 1-18.

Linear staircase sweeps

As shown in Figure 4-2, this sweep type steps from a start current value to an ending (stop) current source value. Programmable parameters include the start, stop, and step current source levels.

When this sweep is triggered to start, the output will go from the bias level to the start source current level. The output will then change in equal steps until the stop current level is reached. The current output remains at the last point when the sweep is done. The sweep delay parameter determines the time duration of each sweep step. For linear staircase sweeps, the sweep delay period is the same for all steps.

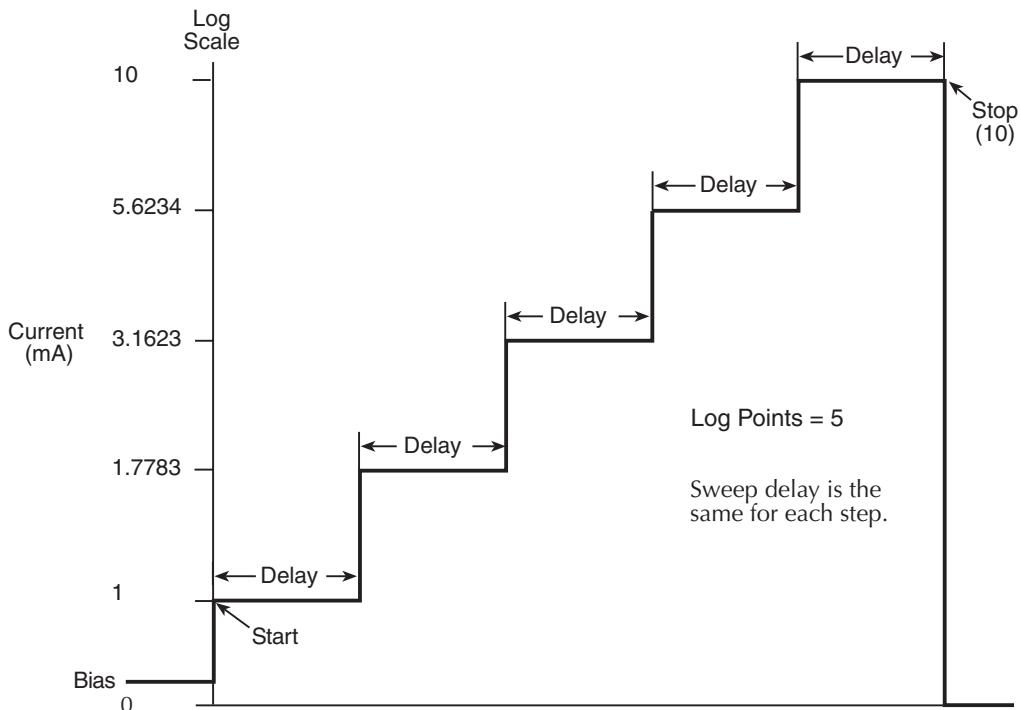
Figure 4-2
Linear staircase sweep



Logarithmic staircase sweeps

This sweep is similar to the linear staircase sweep. The steps, however, are done on a logarithmic scale as shown in the example sweep in [Figure 4-3](#). This example is a 5-point log sweep from 1mA to 10mA. The sweep delay parameter determines the time period for each step. As with the linear staircase sweep, the sweep delay period is the same for all steps.

Figure 4-3
Logarithmic staircase sweep (example 5-point sweep from 1mA to 10mA)



The programmable parameters for a log sweep include the start and stop current levels, the number of measurement points for the sweep, and the sweep delay. The specified start, stop, and point parameters determine the logarithmic step size for the sweep. Step size for the sweep in [Figure 4-3](#) is calculated as follows:

$$\begin{aligned}\text{Log Step Size} &= \frac{\log_{10}(\text{stop}) - \log_{10}(\text{start})}{\text{Points} - 1} \\ &= \frac{\log_{10}(10) - \log_{10}(1)}{5 - 1} \\ &= \frac{(1 - 0)}{4} \\ &= 0.25\end{aligned}$$

Thus, the five log steps for this sweep are 0, 0.25, 0.50, 0.75, and 1.00mA. The actual current source levels at these points are listed in [Table 4-1](#) (the current level is the anti-log of the log step).

**Table 4-1
Logarithmic sweep points**

Measure point	Log step	Source level (mA)
Point 1	0	1
Point 2	0.25	1.7783
Point 3	0.50	3.1623
Point 4	0.75	5.6234
Point 5	1.0	10

When this sweep is triggered to start, the output will go from the bias level to the start current source level (1mA) and sweep through the symmetrical log points and then remain at the last point when the sweep is done. The time duration at each step is determined by the sweep delay.

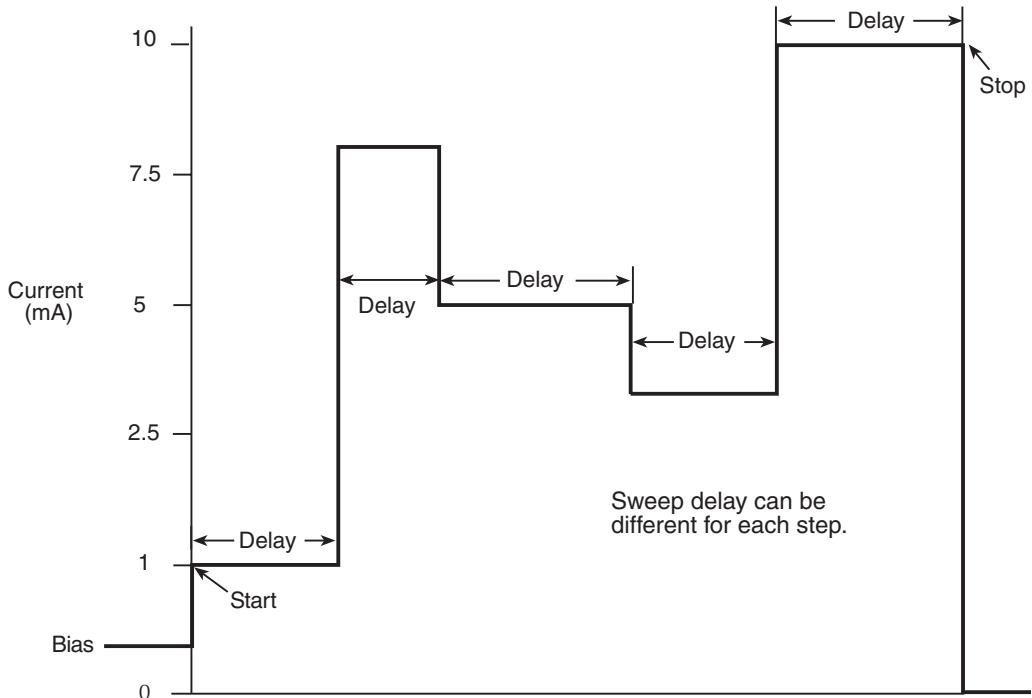
Custom sweeps

This sweep type lets you configure a customized sweep. Programmable parameters include the number of measurement points (steps) in the sweep, the current source level at each point, the delay period at each step, and the compliance setting at each step.

When this sweep is started, the current output goes from the bias level to the first point in the sweep. The sweep will continue through the current source steps in the order they were programmed and stop after the last step. The time duration at each step is determined by the delay setting for each point, which can be set to a different value for each point.

Figure 4-4 shows an example of a custom sweep over the range of 1mA to 10mA with arbitrary steps. When the sweep is triggered, the current goes from the bias level to the first point in the sweep. The unit cycles through the sweep points in the programmed order. The current output remains at the last step when the sweep is done. Note that the sweep delay period is different for each step.

Figure 4-4
Custom sweep example (1mA to 10mA, arbitrary steps)



Setting sweep parameters

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, you should 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.

As the point number is changed, the current, delay, and compliance values will change to reflect the settings for the new point. Move the cursor to the right to edit the current value. Continued movement to the right will highlight the range prefix. A right arrow keypress then takes the editing into the bottom line for the delay value. Continued right arrow key presses take you into the compliance value.

Values can be freely entered, but they do not take effect for that point until ENTER is pressed. After pressing ENTER, the cursor is set back at the point index. Of course, you can also use the left arrow keys to freely move back and forth between the different values until you have adjusted the source level, delay, and compliance to their desired values. If, however, you change the point number without having pressed ENTER, then any values you entered for source, compliance, and delay are lost and must be reentered.

Using auto-copy with custom sweeps

Editing a custom sweep of more than a few points can be cumbersome, especially if you must constantly enter the compliance and delay values for each point. Therefore, an “auto-copy” feature is included to help reduce keystrokes. 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.

Example:

Consider a 10-point sweep of points 0-9. Assume that points 0-4 are to have a 1 second delay and 25V compliance, while points 5-9 will have a 1.5 second delay and 30V compliance. If you enter point #00000 with a 1 second delay and 25V compliance, these two values (but not the I value) are copied to all points 0-9. When you then edit point #00005 and change the compliance to 30V and the delay to 1.5 seconds, these compliance and delay values will be automatically copied to points 5-9. See [“Performing a custom sweep,” on page 4-13](#) for the complete procedure.

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. For example, if the minimum and maximum source levels in the sweep are 1mA and 30mA, the 100mA source range will be used.
- **AUTO** — With this option, the Model 622x will select the most sensitive source range for each source level in the sweep. For example, for a 1 μ A source level, the 2 μ A source range will be used, and for a 3 μ A source level, the 20 μ A source range will be used. 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. For example, if the source is on the 2mA range when the sweep is started, it will remain on the 2mA range for the entire sweep. If the configured sweep points are 1mA, 2mA, 3mA, 4mA, and 5mA, the sweep will be 1mA, 2mA, 2.1mA, 2.1mA, and 2.1mA.

NOTE The **FIXED** mode should be used when optimum sweep speed is a consideration.

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.

Sweep count

This setting determines how many sweeps to perform:

- **FINITE** — Use this option to enter a discrete number of sweeps to perform.
- **INFINITE** — Select this option to continuously repeat the configured sweep. Use the EXIT key to stop the sweep.

Front panel sweep operation

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 armed.

Using the sweep configuration menu

To configure sweeps, press CONFIG then SWP, and then make your selections from [Table 4-2](#) below. See the detailed procedures for each sweep type in the following paragraphs.

Table 4-2
Sweep configuration menu

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

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

Performing a linear 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, and then press ENTER to choose a linear staircase sweep.
 - d. At the prompts, enter the desired START, STOP, STEP, and DELAY values.
 - e. From the CONFIGURE SWEEPS menu, select SWEEP-COUNT, press ENTER, and 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 log 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, and 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, and then press ENTER.
 - c. Select LOG, and then press ENTER to choose a logarithmic staircase sweep.
 - d. At the prompts, enter the desired START, STOP, NO OF POINTS, and DELAY values.
 - e. From the CONFIGURE SWEEPS menu, select SWEEP-COUNT, press ENTER, and then choose FINITE or INFINITE as desired.
 - f. Again from the CONFIGURE SWEEPS menu, choose SOURCE-RANGING, press ENTER, and 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, and then press ENTER.
 - c. Select CUSTOM, and then press ENTER to choose a custom sweep.
 - d. Select #-POINTS, press ENTER, and then enter the number of sweep points (64,000 maximum).
 - e. Choose AUTO-COPY, press ENTER, and then enable (YES) or disable (NO) auto copy. With auto copy enabled, compliance and delay values will be automatically copied to all sweep point locations.
 - f. Select ADJUST-POINTS, and then set the current value, compliance, and delay for the first sweep point.
 - g. Set the current value, and (if not using auto copy) compliance, and delay for each remaining sweep point.
 - h. From the CONFIGURE SWEETS menu, select SWEEP-COUNT, press ENTER, and then choose FINITE or INFINITE as desired.
 - i. Again from the CONFIGURE SWEETS menu, choose SOURCE-RANGING, press ENTER, and then select BEST, AUTO, or FIXED as appropriate.
 - j. From the CONFIGURE SWEETS menu, select COMPLIANCE-ABORT, press ENTER, and 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.

NOTE A custom sweep cannot be saved as a user setup. Attempting to do so will generate error +528
Cannot save CUSTOM sweep setup.

Remote sweep operation

Procedures for programming and running a sweep for each of the three sweep types are given on the following pages. Each of these procedures includes commands for a typical sweep example. [Table 4-3 summarizes parameters for each of these examples.](#) See “[SCPI commands — sweeps,](#)” on page [4-18](#) for details on sweep commands.

NOTE

User setups cannot be saved or recalled while sweep is armed or running. The *SAV and *RCL commands will generate error +413 Not allowed with mode armed.

Table 4-3
Sweep example parameters

Sweep type	Parameters for sweep examples
Linear staircase sweep (page 4-15)	Start current: 1mA Stop current: 10mA Step current: 1mA Delay: 1s Source range: best fixed Compliance abort: off Sweep count: 1 Bias current: 100µA Compliance: 10V
Logarithmic staircase sweep (page 4-16)	Start current: 1mA Stop current: 10mA # points: 5 Delay: 2s Source range: best fixed Compliance abort: off Sweep count: 1 Bias current: 10µA Compliance: 5V
Custom (list) sweep (page 4-17)	# points: 5 Points: 3mA, 1mA, 4mA, 5mA, 2mA Delay: 3s, 1s, 4s, 5s, 2s Compliance: 3V, 1V, 4V, 5V, 2V Source range: auto Compliance abort: off Sweep count: 1 Bias current: 50µA

Running a linear staircase sweep

1. Configure source functions.

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

*RST	‘ Restore 622x defaults.
SOUR:CURR 1e-4	‘ Set bias current to 100 μ A
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	‘ 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	‘ 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 log staircase sweep

1. Configure source functions.

Examples – The following commands restore defaults, set the bias current to 10 μ A, and the compliance to 5V:

*RST	‘ Restore 622x defaults.
SOUR:CURR 1e-5	‘ Set bias current to 10 μ A
SOUR:CURR:COMP 5	‘ Set compliance to 5V.

2. Configure the sweep.

Examples – The following commands configure a single logarithmic staircase sweep from 1mA to 10mA with five points using a 2s delay, best fixed source range, and compliance abort disabled:

SOUR:SWE:SPAC LOG	‘ Select log staircase sweep.
SOUR:CURR:STAR 1e-3	‘ Set start current to 1mA.
SOUR:CURR:STOP 1e-2	‘ Set stop current to 10mA.
SOUR:SWE:POIN 5	‘ # points = 5.
SOUR:DEL 2	‘ Set delay to 2s.
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	‘ 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 50 μ A:

```
*RST                                ' Restore 622x defaults.  
SOUR:CURR 5e-5                      ' Set bias current to 50 $\mu$ A
```

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                  ' Select custom sweep.  
SOUR:SWE:RANG AUTO                 ' Select auto source range.  
SOUR:LIST:CURR 3e-3,1e-3,4e-3,    ' Sweep points: 3mA, 1mA, 4mA,  
      5e-3,2e-3                     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.  
SOUR:SWE:CAB OFF                  ' Disable compliance abort.
```

3. Arm and run the sweep:

```
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
```

NOTE	A custom sweep cannot be saved as a user setup. Attempting to do so will generate error +528 Cannot save CUSTOM sweep setup.
-------------	--

SCPI commands — sweeps

Commands for linear and logarithmic staircase sweeps are listed in [Table 4-4](#), while commands for custom (list) sweeps are listed in [Table 4-5, page 4-21](#). Additional information for each command is provided in notes that follow the tables.

Table 4-4

Staircase sweep commands (linear and logarithmic)

Command	Description	Default
SOURce [1] : CURRent : START <n>	Sets start current. ¹ <n> = -0.105 to 0.105 (A)	0
SOURce [1] : CURRent : STOP <n>	Sets stop current. ¹ <n> = -0.105 to 0.105 (A)	0.1
SOURce [1] : CURRent : STEP <n>	Sets step current*. ¹ <n> = 1e-13 to 0.105 (A)	1e-2
SOURce [1] : CURRent : CENTER <n>	Sets center current. ² <n> = -0.105 to 0.105 (A)	0
SOURce [1] : CURRent : SPAN <n>	Sets span current. ² <n> = 2e-13 to 0.210 (A)	0.1
SOURce [1] : DELay <n>	Sets source delay. ³ <n> = 0.001 to 999999.999 (s)	1
SOURce [1] : SWEep : ARM	Prepare for running the sweep. ⁴	
SOURce [1] : SWEep : ABORT	Abort sweep immediately. ⁵	
SOURce [1] : SWEep : SPACing <name>	Selects sweep type. ⁶ <name>=LINear, LOGarithmic, or LIST	LINear
SOURce [1] : SWEep : POINTs <n>	Sets sweep points. ⁷ <n> = 1 to 65535	11
SOURce [1] : SWEep : RANGing <name>	Selects sweep source ranging. ⁸ <name>=AUTO, BEST, or FIXed	BEST
SOURce [1] : SWEep : CABort 	Sets compliance sweep abort state. ⁹ = ON or OFF	OFF
SOURce [1] : SWEep : COUNT <NRf>	Sets sweep count. ¹⁰ <NRf> = 1 to 9999 or INFinite	1

* Set step parameter negative for negative-going sweep.

1. SOUR:CURR:STAR<n> ‘ Set start current
SOUR:CURR:STOP <n> ‘ Set stop current
SOUR:CURR:STEP <n> ‘ Set step current

Use these commands to set the start and stop currents for linear and logarithmic staircase sweeps and to set the step current for linear staircase sweeps. Setting the stop value more positive than the start value will result in a positive-going sweep. Conversely, setting the stop value more negative than the start value will result in a negative-going sweep. Setting the step current negative will also create a negative-going sweep.

The STEP value is subject to the condition that the total number of points calculated does not exceed the maximum number of points allowed in the sweep. For example, even though 1e-13 is technically allowed, if STARt and STOP are 0 and 100 mA, a STEP of 1e-13 will return an error.

2. SOUR:CURR:CENT <n> ‘ Set center current
SOUR:CURR:SPAN <n> ‘ Set span current

These commands give an alternate method of setting sweep parameters. Note that the CENTER value will be checked against the start and stop values, resulting in errors if out of that range. For those sweeps that are specified using the CENTER and SPAN commands, the STARt point will be the lower point, and the sweep will always run from low to high. You can sweep from high value to low value only by using the STARt and STOP commands to set the higher value as the STARt point.

For example, if the center current is 50mA and the span is 100mA, the sweep will range from 0mA to 100mA.

3. SOUR:DEL <n> ‘ Set source delay for sweep

This command allows you to set a time delay to allow the source value to settle. This delay is used for all steps of linear and log sweeps, but it does not apply for custom sweeps since they use individual values (see [Table 4-5](#)).

4. SOUR:SWE:ARM ‘ Prepare (arm) sweep to run

After being armed, the sweep will begin with the next appropriate trigger. If the Differential Conductance or Delta Mode is presently armed, this command will “un-arm” that sequence and arm a sweep. If either Differential Conductance or Delta is already running, however, Error -221 Settings Conflict is returned. When a sweep is armed, the two-second message SWEEP ARMED appears on the display, and the ARM annunciator is turned on. When the sweep has completed a finite count, the source is left on and zero is output. When the sweep is aborted (by either the EXIT key or SOUR:SWE:ABORT), the source is set to zero and turned off.

If the sweep spacing has been set to LOGarithmic, problems would occur when calculating the sweep table when either the start or stop points equal zero. In these cases, if the SOUR:SWE:STAR or SOUR:SWE:STOP value is zero, it will be adjusted automatically to the smallest adjustable value,

1.0E-13, and Error +420 Log sweep zero adjusted will be issued. Note that start or stop values are not restored back to zero if the SPACing is subsequently changed back to LINEar, so make sure the start and stop values are correct after sending the SOUR:SPACing command.

When the sweep is armed with the ARM command, an internal sweep table of output DAC values is processed. During this build, the unit cannot respond to key presses or remote commands. If there are more than 3,000 points in the sweep table, the message “Building Sweep table Please wait....” is shown on the display and remains until the sweep table is built. A 10,000 point sweep will require about eight seconds to build.

5. SOUR:SWE:ABOR ‘ Abort sweep immediately
Terminates any sweep in progress and sets the source value to zero and the operate state to OFF. Starting another sweep after the SOUR:SWEep:ABORT command will require re-arming. Note that this command is also used to exit Differential Conductance or Delta mode and resume normal current source operation.
6. SOUR:SWE:SPAC <name> ‘ Select sweep type
This command chooses the LINEar staircase, LOGarithmic staircase, or LIST (custom) sweep type. See [Table 4-5](#) and following notes for details on custom sweep commands.
7. SOUR:SWE:POIN <n> ‘ Set sweep points
Use this command to set the number of sweep points for staircase sweeps (65,535 maximum). The number of points in a custom sweep is determined by the LIST parameters (see [Table 4-5](#)).
8. SOUR:SWE:RANG <name> ‘ Set source ranging for sweeps
Selects how the source range will be handled with sweeps. AUTO selects the best source range at each point, and FIXed leaves the source at the range the unit was on when the sweep started (Error -221 Settings Conflict will occur if the sweep is started from a source range that is too low). BEST causes the source range to be set to the correct range for the highest point in the sweep.
9. SOUR:SWE:CAB ‘ Abort sweep on compliance
When set to ON, terminates any sweep in progress when compliance is detected during a sweep. The source value is set to zero, and the operate state is set to OFF.
10. SOUR:SWE:COUN <n> ‘ Set sweep count
Use this command to set the number of sweeps to run. An INFinite sweep count will select continuously repeating sweeps.

Table 4-5
Custom (list) sweep commands

Command	Description
SOURce [1] :LIST:CURREnt <NRf> [,<NRf>, ...<NRf>]	Defines list of currents. ¹ <NRf> = -0.105 to 0.105 (A)
SOURce [1] :LIST:CURREnt:APPend <NRf> [,<NRf>, ...<NRf>]	Adds current points to existing list. ¹ <NRf> = -0.105 to 0.105 (A)
SOURce [1] :LIST:DELay <NRf> [,<NRf>, ...<NRf>]	Defines list of delay values. ² <NRf> = 0 to 999.9999 (s)
SOURce [1] :LIST:DELay:APPend <NRf> [,<NRf>, ...<NRf>]	Adds to list of delay values. ² <NRf> = 0.001 to 999999.999 (s)
SOURce [1] :LIST:COMPliance <NRf> [,<NRf>, ...<NRf>]	Defines list of compliance values. ³ <NRf> = 0.1 to 105 (V)
SOURce [1] :LIST:COMPliance:APPend <NRf> [,<NRf>, ...<NRf>]	Adds to list of compliance values. ³ <NRf> = 0.1 to 105 (V)
SOURce [1] :LIST:CURREnt:POINTs?	Query # of current list points. ⁴
SOURce [1] :LIST:DELay:POINTs?	Query # of delay list points. ⁴
SOURce [1] :LIST:COMPliance:POINTs?	Query # of delay list points. ⁴

1. SOUR:LIST:CURR <NRf>[,<NRf>,...<NRf>] ‘ Define current list
 SOUR:LIST:CURR:APP <NRf>[,<NRf>,...<NRf>] ‘ Append to current list
 Use these commands to initially define a current list and to add current points to an existing list. Note that the maximum number of sweep points is 64,000.
2. SOUR:LIST:DEL <NRf>[,<NRf>, ...<NRf>] ‘ Define delay list
 SOUR:LIST:DEL:APP <NRf>[,<NRf>, ...<NRf>] ‘ Append to delay list
 These commands create a delay list and add delays to an existing list. Delay values match up one-for-one with the current source values above in the current list. These delays apply only to list (custom) sweeps. Note that defaults are 1 second the same as regular source delay, and the minimum accepted value is 0.001 seconds.
3. SOUR:LIST:COMP <NRf>[,<NRf>, ...<NRf>] ‘ Define compliance list
 SOUR:LIST:COMP:APP <NRf>[,<NRf>, ...<NRf>] ‘ Append compliance list
 These commands create a compliance list and add compliance values to an existing list. Compliance values match up one-for-one with the current source values above in the current list.

- | | |
|-------------------------|-----------------------------|
| 4. SOUR:LIST:CURR:POIN? | ‘ Query current list length |
| SOUR:LIST:DEL:POIN? | ‘ Query delay list length |
| SOUR:LIST:COMP:POIN? | ‘ Query compliance list |

These commands query the length of the current source, delay, and compliance lists. The number of current values determines the length of the list sweep; the other two POINts? queries are for reference only.

Coupled sweep commands

A number of sweep commands are coupled together, and changing certain parameters also changes others. The following is a list of coupled commands.

When SPAN or CENTer changes:

SPAN = SPAN
CENTer = CENTer
STOP = CENTer + (SPAN/2)
STARt = CENTer - (SPAN/2)
SWEep:POINts= SWEep:POINts
STEP = SPAN / (SWEep:POINts -1)

When STARt or STOP changes:

STARt = STARt
STOP = STOP
CENTer = (STARt + STOP)/2
SPAN = STOP - STARt
SWEep:POINts= SWEep:POINts
STEP = SPAN / (SWEep:POINts -1)

When SWEep:POINts changes:

STARt = STARt
STOP = STOP
CENTer = CENTer
SPAN = SPAN
STEP = SPAN / (SWEep:POINts -1)

When STEP changes:

STARt = STARt
STOP = STOP
CENTer = CENTer
SPAN = SPAN
SWEep:POINts= SPAN / STEP + 1

When spacing is set to LOG:

POINts/DECADE = (SWEep:POINts - 1)/SPAN (in decades)

Sweep status model events

Three status model events are available for monitoring sweep progress, all of which set bits in the Operation Condition Register (see Section 11 for complete details on the status model).

[Table 4-6](#) summarizes the sweep status bits in the Operation Condition Register.

Table 4-6
Sweep status model bits

Bit	Status event
1	+122 “Sweep done”
2	+123 “Sweep aborted”
3	+124 “Device sweeping”

The Device Sweeping event is set at each point in the sweep, so queries of the Operation event register (STAT:OPER:EVENT?) will continue to show this bit set throughout the entire sweep. Note, however, that if you send the query twice while the sweep is on the same point, the second query will not show the bit set because the first query cleared it, and the bit will not be reset until the next point in the sweep.

The Sweep Aborted event occurs whenever a sweep is aborted before being allowed to finish, and the Sweep Done event occurs after the requested number of sweeps (SOUR:SWE:COUN or SOUR:DELT:COUN) has completed. For the purposes of these events, Delta and Differential Conductance (Section 5) are also considered sweeps and will set these events and bits accordingly. Pulse Delta is not considered a sweep unless you have enabled Pulse Sweeps (SOUR:PDEL:SWE:STAT ON). Model 6221 Arbitrary waveforms (Section 7) are not considered sweeps and do not affect these status events.

Delta, Pulse Delta, and Differential Conductance

Section 5 topics

Part 1

(page 5-2)

Overview, page 5-2

Section overview, page 5-2

Operation overview, page 5-2

Test systems, page 5-4

Keithley instrumentation requirements, page 5-4

System configurations, page 5-4

System connections, page 5-6

DUT test connections, page 5-8

Configuring communications, page 5-10

Arming process, page 5-11

Interlock, page 5-13

Data flow and read commands, page 5-13

Data flow, page 5-13

Read commands, page 5-15

Measurement units, page 5-16

Volts, ohms, power or conductance, page 5-16

Setting measurement units, page 5-17

Display readings, page 5-17

Error and status messages, page 5-18

Part 2

(page 5-20)

Delta, page 5-20

Basic measurement process, page 5-20

Model 622x measurement process, page 5-21

Configuration settings, page 5-24

Arming process, page 5-24

Triggering sequence, page 5-25

Operation, page 5-27

Setup commands, page 5-30

Pulse Delta, page 5-32

Model 6221 measurement process, page 5-32

Pulse Delta outputs, page 5-35

Configuration settings, page 5-39

Arming process, page 5-42

Triggering sequence, page 5-43

Operation, page 5-44

Setup commands, page 5-49

Differential Conductance, page 5-51

Basic measurement process, page 5-51

Model 622x measurement process, page 5-51

Configuration settings, page 5-55

Arming process, page 5-56

Triggering sequence, page 5-58

Operation, page 5-59

Setup commands, page 5-64

Part 1

Overview

[“Keithley instrumentation requirements”](#) for Delta, Pulse Delta, and Differential Conductance are explained on [page 5-4](#).

Section overview

This section is divided into two parts:

- The topics in **Part 1** provide support information for all three delta tests.
- The topics in **Part 2** ([page 5-20](#)) provide the details for each delta test.

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.

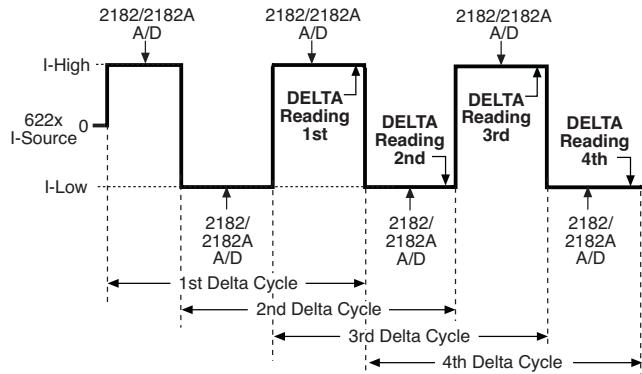
As shown in [Figure 5-1A](#), the first three Model 2182/2182A A/D conversions (measurements) yields the first Delta reading. Each subsequent Model 2182/2182A A/D conversion then yields a single Delta reading. Every Delta reading uses the three previous A/Ds to calculate Delta.

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).

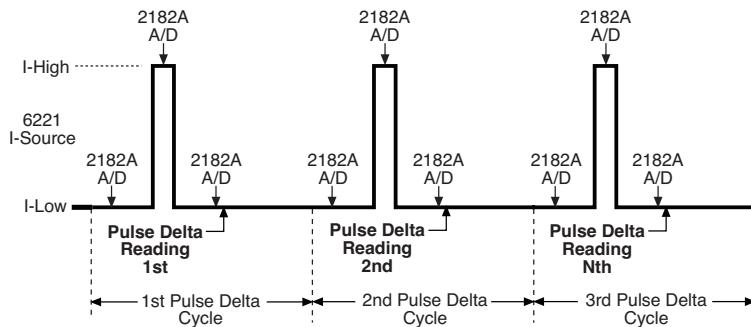
Differential Conductance – The Model 622x outputs a differential current (dI) sweep and measures differential voltage (dV). This function uses a 3-point moving average algorithm to calculate dV . With dI known and dV calculated, the Model 622x can then calculate differential conductance (dG) or differential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

Figure 5-1
Delta, Pulse Delta, and Differential Conductance measurements

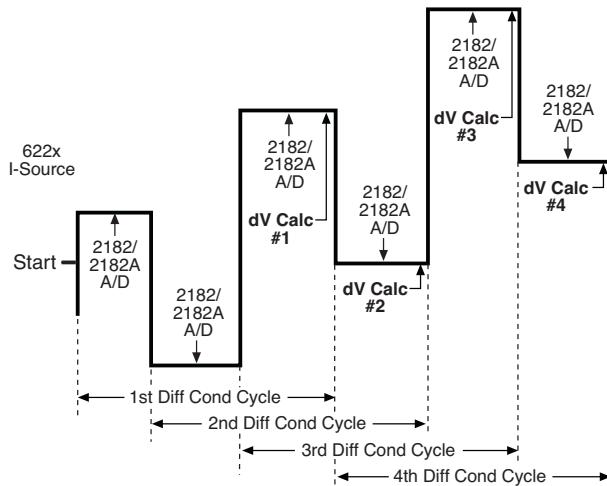
A) Delta measurements



B) Pulse Delta measurements



C) Differential Conductance measurements



Test systems

NOTE Supplied example software allows you to control Model 622x delta tests from any PC using simple mouse-clicks through a virtual front panel. For details, see “Using the example software: on page 10-36.

Keithley instrumentation requirements

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

- **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

NOTE The firmware version of the Model 2182 must be A10 or higher.

The firmware version of the Model 2182A must be C01 or higher.

System configurations

There are two system configurations that can be used for Delta, Pulse Delta, and Differential Conductance operation and are shown in [Figure 5-2](#). One is for front panel stand-alone operation and the other is for remote programming (PC control system). Both systems use serial communications (via RS-232 interface) between the Model 622x and the Model 2182/2182A.

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).

Delta setup and operation are controlled from the Model 622x. The RS-232 interface is used for communications between the Model 622x and the Model 2182/2182A. The Model 622x sends setup commands to the Model 2182/2182A, and the Model 2182/2182A sends Delta, Pulse Delta, or Differential Conductance readings to the buffer of the Model 622x. See “[Serial communications](#)” for more details.

Once the test is started, trigger synchronization between the two instruments is controlled by the Trigger Link.

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).

The test setup and operation is controlled by the PC using remote programming via the IEEE-488 bus or the Ethernet (Model 6221). The RS-232 interface is used for communications between the Model 622x and the Model 2182/2182A. The Model 622x sends setup commands to the Model 2182/2182A, and the Model 2182/2182A sends Delta, Pulse Delta, or Differential Conductance readings to the buffer of the Model 622x. See “[Serial communications](#)” for more details.

Once the test is started, trigger synchronization between the two instruments is controlled by the Trigger Link.

Serial communications

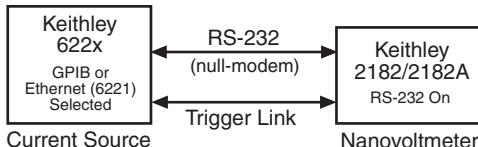
In order to perform Delta, Pulse Delta, or Differential Conductance measurements, the Model 622x must communicate to the Model 2182/2182A over the serial (RS-232) interface. With serial communications properly configured and connected, the Model 622x will automatically send setup commands to the Model 2182/2182A when Delta, Pulse Delta, or Differential Conductance is armed. The “[Arming process](#)” is explained on [page 5-11](#).

Also, 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.

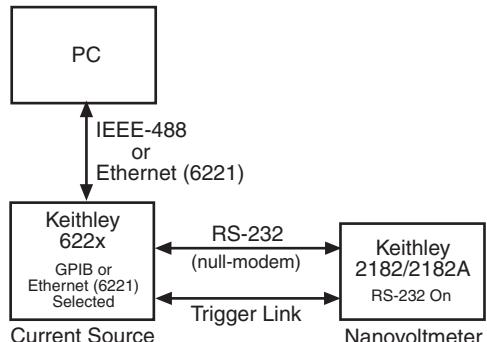
Figure 5-2

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. The Model 622x sends setup commands to the Model 2182/2182A, and receives data (readings) from the Model 2182/2182A. Make sure to use a null-modem RS-232 cable for this connection.

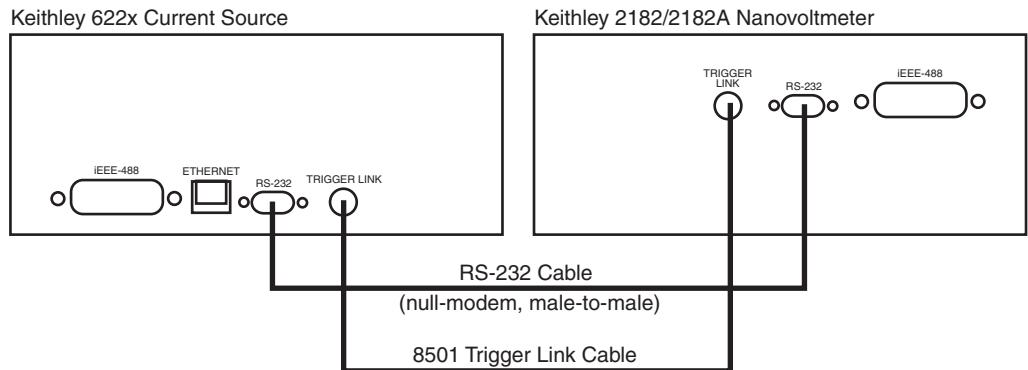
Trigger Link – The Trigger Link synchronizes triggering between the Current Source and the Nanovoltmeter. Trigger Link connections assume that the Model 2182/2182A is using the factory default (hard-wired) configuration:

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

CAUTION **Delta, Pulse Delta, and Differential Conductance will not work if the Model 2182/2182A is not using the default Trigger Link configuration.**

The hard-wired default configuration for the Trigger Link lines of the Model 2182/2182A can be changed by qualified service personnel. To return the Model 2182/2182A to the default 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



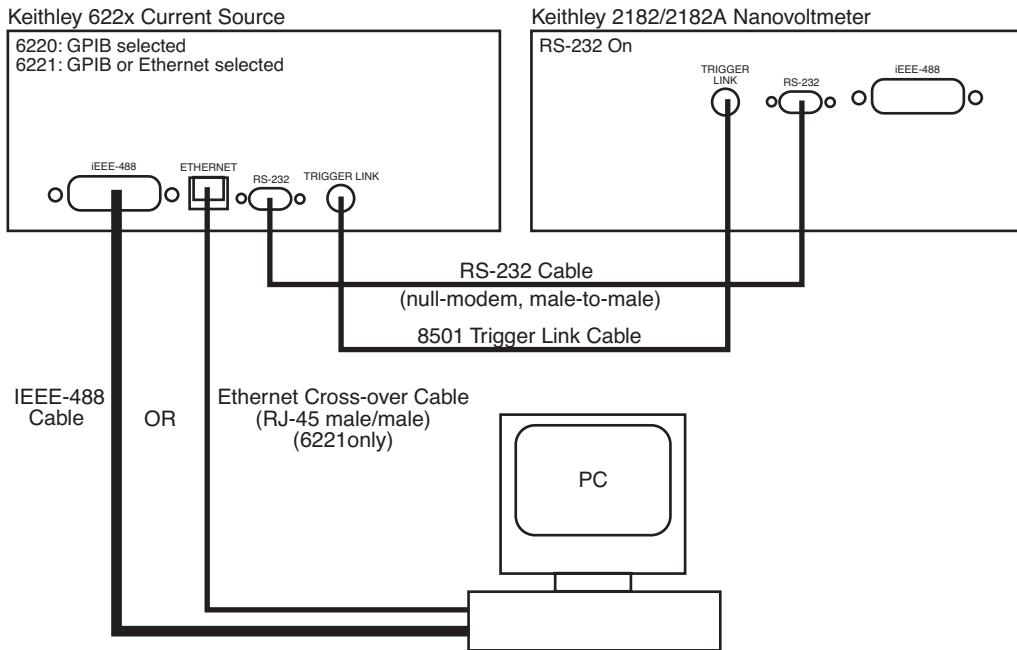
Connections – PC control system

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. See “[Connections – stand-alone system](#)” for details on these system connections.

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



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 guarding and an earth grounded test fixture that is equipped with an interlock switch.

Guarding

The purpose of guarding is to eliminate the effects of leakage current and cable capacitance that exist between output high and output low. In the absence of guard, leakage and cable capacitance can adversely affect the performance of the Model 622x. Guarding can be used for all DUT testing and is most effective when sourcing low current and/or testing high impedance DUT.

In order to use guarding as shown in [Figure 5-5](#), the driven guard must be connected to the inner shield of the OUTPUT connector of the Model 622x. Use the following procedure to connect the inner shield to Guard.

Inner shield connection for OUTPUT

NOTE By default, the inner shield of the OUTPUT connector of the Model 622x is connected to output low. For details on the inner shield connections for the OUTPUT connector, see [Section 2](#).

The inner shield of the Model 622x OUTPUT connector can be connected to the driven guard or to output low as follows:

1. On the Model 622x, press the **TRIAX** key to display the menu for the INNER SHIELD.
2. Using the CURSOR controls, place the blinking cursor on **GUARD** or **OUTPUT LOW (220 STYLE)** and press the **ENTER** key.
3. Press the **EXIT** key to return to the normal display state.

Remote programming – Commands for inner shield connection for OUTPUT:

<code>OUTPut:ISHield?</code>	' Query connection on inner shield of 622x ' OUTPUT connector.
<code>OUTPut:ISHield <name></code>	' Connect inner shield to guard or output low. ' <name> = GUARd or OLOW

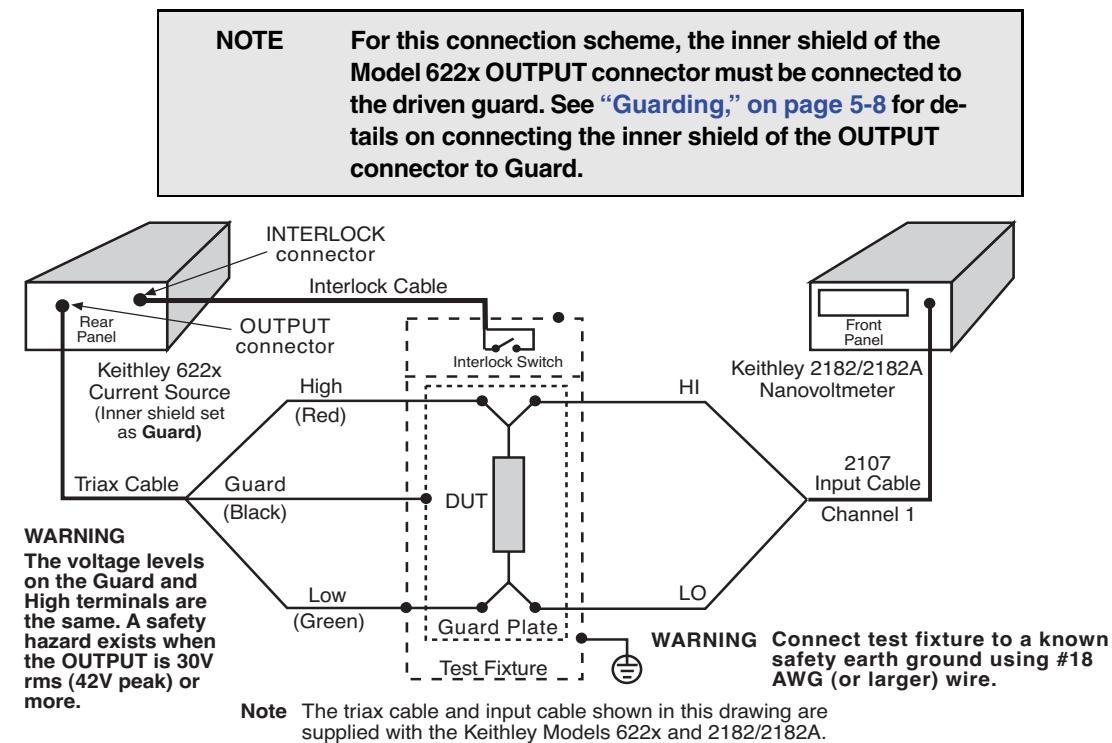
Example – Connects the inner shield of the OUTPUT connector to the driven guard:

```
OUTPut:ISHield GUARD
```

Safety test fixture

To prevent electric shock, an earth grounded test fixture should be used to prevent inadvertent contact with live circuitry. With proper use of Interlock, the output of the Model 622x will be interrupted when the lid of the test fixture is open. See [Section 2](#) for details on using Interlock with a test fixture.

Figure 5-5

Guarded test connections**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 (see “Interface selection and configuration,” on page 10-3).

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.

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. For details on RS-232 configuration for the Model 622x, see [Section 10](#).

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. See [Section 10](#) for details on configuring the GPIB and Ethernet.

Arming process

After a delta test is configured, it must be armed before it can be run. The details to configure, arm, and run each delta test are provided in [Part 2 \(page 5-20\)](#) of this section. The arming operations that are common to all three delta tests (Delta, Pulse Delta, and Differential Conductance) are covered here.

Additional arming information that is unique to each delta test, can be found at the following locations:

- Additional “Arming process” information for Delta is provided on [page 5-24](#).
- Additional “Arming process” information for Pulse Delta is provided on [page 5-42](#).
- Additional “Arming process” information for Differential Conductance is provided on [page 5-56](#).

Communications test and setup commands

- If a sweep or delta test is already running, sending an arm command causes error -221 Settings Conflict.
- The Model 622x performs communication tests with the Model 2182/2182A.
 - If a Model 2182/2182A is not detected, error -241 Hardware Missing is reported.
 - If RS-232 is the selected interface for the Model 622x, error +809 Not Allowed with RS-232 occurs. Select a different interface for the Model 622x.
 - If communications over the Trigger Link cannot be established, error +419 Trigger Link cable not connected. Check that the Trigger Link cable is properly connected between the Model 622x and the Model 2182/2182A.
- The Model 622x sends setup commands to the Model 2182/2182A. This includes the command to disable Front Autozero on the Model 2182/2182A to increase system speed.
- On the Model 2182/2182A, the REM (remote) annunciator turns on and all front panel controls are locked out while Differential Conductance is armed or running.

Internal sweep table

During the arming process, the Model 622x builds an internal sweep table of source output values to be used in the test. During this build, the unit will not respond to key presses or remote commands. If there are more than 3,000 points to be placed in the table, the message “Building Sweep table Please wait ...” will be displayed during the table build. A 10,000 point sweep takes around eight seconds to build.

Armed message

After the delta test is successfully armed, the Model 622x will briefly display a message indicating that the test is armed and ready to be started.

User setups

User setups cannot be saved or recalled while Delta, Pulse Delta, or Differential Conductance is armed or running. Attempting to do so from the front panel or using remote operation (*SAV and *RCL commands) will generate error +413 Not allowed with mode armed.

Aborting the delta test

A delta test that is armed (or running) can be aborted by pressing the **EXIT** key or sending the **SOUR:SWE:ABOR** command.

Interlock

In order to start an armed Delta, Pulse Delta, or Differential Conductance test, a test fixture 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.

Data flow and read commands

Data flow

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.

[Figure 5-6A](#) shows data flow for front panel operation. The delta reading is calculated as a voltage (V) reading, but can be changed into its equivalent watts (W), ohms (Ω), or siemens (S) reading. See [page 5-16](#) for details on “[Measurement units](#)”.

The reading can then be filtered and/or modified by a built-in math calculation. An averaging filter can be used to stabilize noisy readings (see “[Error and status messages](#),” on page 5-18 and [Section 6](#) for details). With math enabled, the $mX+b$, or $m/X+b$ calculation is applied to the delta reading (see [Section 6](#) for details). When the filter and/or math is disabled, the delta reading simply fall through to the next block in the diagram.

For front panel operation, readings are automatically stored in the buffer and displayed. Stored readings, as well as buffer statistics for those readings, can be displayed (recalled). See [Section 6](#) for details.

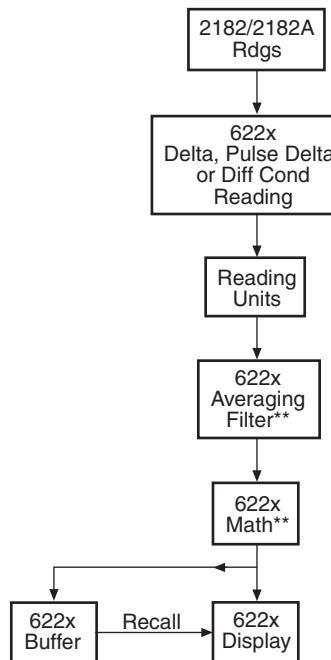
[Figure 5-6B](#) shows data flow for remote operation. It is similar to data flow for front panel operation with the following enhancements:

- **Compliance testing** – The current source can be tested for compliance. The test can be set to fail when the source enters the compliance condition. See [Section 9](#) for details.
- **Buffer control** – When enabled, buffer feed can be pre-math readings or post-math readings. When disabled, readings will not be stored in the buffer. See [Section 6](#) for details.

NOTE

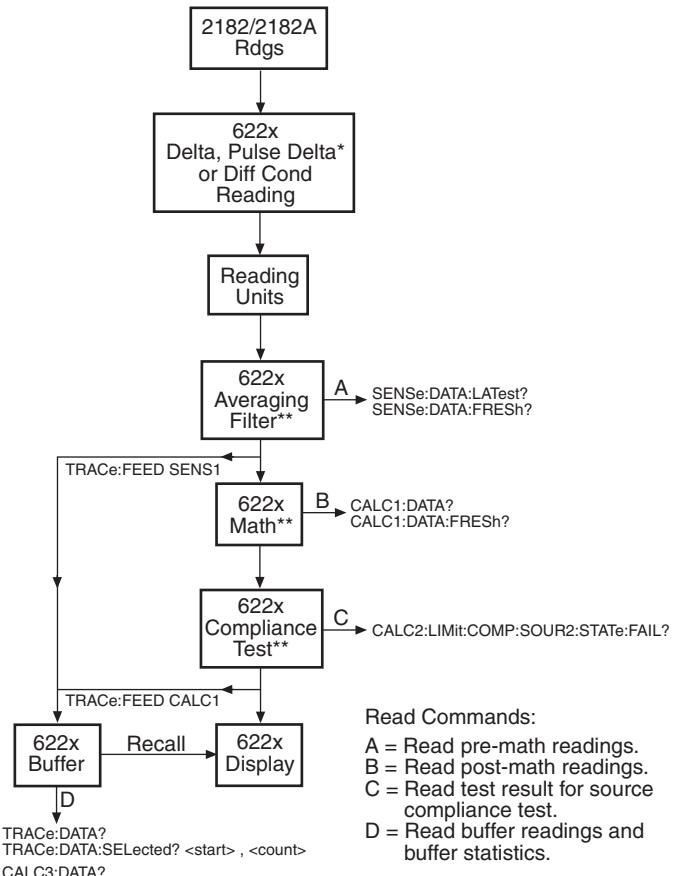
The SMPL annunciator blinks on and off for every other reading that is acquired from the Model 2182/2182A. The blinking annunciator indicates that communications with the Model 2182/2182A are working properly. That is, the Model 2182/2182A is performing voltage measurements and successfully sending them to the Model 622x.

Figure 5-6
Data flow and read commands

A) Front panel operation

* Pulse Delta can only be performed by the Model 6621.

**Feature can be enabled or disabled. When disabled, reading falls through to next block in the diagram.

B) Remote operation

Read commands

Figure 5-6B also shows the read commands that can be used for remote programming.

A 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.

B Post-math readings

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

While Delta, Pulse Delta, or Differential Conductance is running and Math is enabled, the CALC1:DATA? command can be sent to read the latest (last) post-math reading processed by the Model 622x. If this read command is sent before a new reading is available, the last reading will again be returned.

The CALC1:DATA:FRESH? command is the same as the CALC1:DATA? 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 CALC1:DATA:FRESH? is sent, error -230 Data corrupt or stale will occur.

C Compliance test result

CALCulate3:LIMit[1]:FAIL?

While Delta, Pulse Delta, or Differential Conductance is running, source compliance for a reading can be tested. The test can be set to fail when the source enters or exits the compliance condition. A returned value of "0" indicates a pass condition, and "1" indicates a fail condition.

D Buffer readings

TRACe:DATA?
 TRACe:DATA:TYPE?
 TRACe:DATA:SElected? <start>, <count>
 CALCulate2:DATA?

With readings stored in the buffer, use TRACe:DATA? to return all readings. Use TRACe:DATA:TYPE? to determine the type of readings stored in the buffer (returns NONE, DELT, DCON, or PULS).

Use the TRACe:DATA:SElected? command to specify a list of consecutive buffer readings to return. For this command, the start and count are specified. The first reading in the buffer is Rdg #0.

Example to return the first 10 buffer readings:

TRACe:DATA:SElected? 0, 10 ‘ Returns Rdg #0 through Rdg #9.

The CALC2:DATA? command is used to read the selected buffer statistic (mean, standard deviation, maximum, minimum, or peak-to-peak).

See [Section 6](#) for details on the buffer.

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:

$$\Omega = V/I$$

$$S = I/V$$

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:

Delta:	Pulse Delta: ¹	Differential Conductance: ²
$W = I \times V$	$W_{PEAK} = I \times V$	$W = I_{AVG} \times V_{AVG}$
	$W_{AVG} = I \times V \times \text{Duty Cycle}$	

1. See [page 5-34](#) for details on “Peak power and average power” for Pulse Delta.
2. See [page 5-54](#) for details on “Average Voltage and Power” for Differential Conductance.

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 1-20](#)) 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 for the Model 622x are listed in [Table 5-1](#).

Table 5-1
Measurement unit commands

Command	Description	Default
UNIT [:VOLT] [:DC] <name>	Specify reading units*. <name> = V, OHMS, W, or SIEMens	V
UNIT:POWER [:TYPE] <name>	Set power units reading type for 6221 Pulse Delta. <name> = AVERage or PEAK	PEAK
UNIT:POWER [:TYPE] ?	Query power units reading type.	

* 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

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 “[Peak power and average power](#),” on [page 5-34](#) for details).
2. For remote operation, the returned reading string for a Delta Pulse power reading does indicate 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.

Error and status messages

Common errors associated with remote programming for Delta, Pulse Delta, and Differential Conductance are listed in [Table 5-2](#).

Table 5-2
Error/status codes and messages

Code and Message	Description	Remedy
-221 Settings Conflict	<p>Occurs when sending the :NVPResent? command with the RS-232 interface selected for the Model 622x.</p> <p>Occurs when an :ARM command is sent while a sweep or a delta test is running.</p> <p>Occurs when attempting to start Pulse Delta while on a FIXED range that is too low.</p>	<p>Select a different interface and then send query.</p> <p>Do not send an :ARM command while a sweep or delta test is already running.</p> <p>Select a higher source range.</p>
-225 Out of Memory	Occurs when trying to :ARM Differential Conductance with too many measure points in the sweep.	Reconfigure the Differential Conductance sweep such that it does not exceed the maximum number of measure points (65,536).
-241 Missing Hardware	Occurs when trying to :ARM Delta, Pulse Delta, or Differential Conductance and a Model 2182A is not detected.	Check RS-232 connections. For the 2182A, make sure the RS-232 interface is selected.
+408 Diff. Conductance truncated	Occurs when trying to :ARM Differential Conductance with a sweep level(s) that will exceed $\pm 105\text{mA}$.	Reconfigure the Differential Conductance sweep such that all sweep levels do not exceed $\pm 105\text{mA}$.
+410 Model 2182A required	Occurs when trying to :ARM Pulse Delta with an older Model 2182 that does not support Pulse Delta.	Use a Model 2182A with the Model 622x to run Pulse Delta.

Table 5-2 (cont.)

Error/status codes and messages

+411 Diff. Conductance step error	Occurs if two adjacent Diff Conductance values use the same source value. The algorithm to calculate Diff. Cond. voltage divides by zero and generates a NAN (not a number) reading (+9.9e37). This error does not abort the test but does indicate that corrupt data has been acquired.	Reduce the number of steps by increasing the step size or widen the start-step interval.
+412 Diff. Conductance upranged	The Model 6221 selects the BEST range based on the set start, stop, and step parameters. For example, if start is -20µA, stop is +20µA, and step is 1µA, the Model 6221 will select the 20µA source range. If using a Delta value that will cause the last output value to exceed 21µA, the next higher range will be selected during the arming process.	This is not an error. It is only an indication that a source uprange has occurred during the arming process.
+416 Step size too small	Differential Conductance – Occurs if the step size is so small, it rounds down to zero. An actual step size of zero would result in a test that would never finish. When using the repeat averaging filter, the actual step size is the user entered step size value divided by the filter count value. This error occurs during the arming process. Differential Conductance will not arm.	Use an actual step size that does not get rounded to zero. Avoid using repeat filter that has a large filter count. Also avoid using a small start-to-stop span.
+419 Trigger Link cable not connected	This error occurs during the arm process.	Make sure the Trigger Link cable is properly connected.
+809 Not Allowed with RS-232	Occurs when trying to :ARM Delta, Pulse Delta or Differential Conductance with the RS-232 interface selected for the Model 622x.	Select a different interface and then arm Delta, Pulse Delta, or Differential Conductance.

Part 2

Delta

Basic measurement process

Delta voltage measurements use a current-reversal technique to cancel the effects of thermal EMFs in the voltmeter test lead connections. The simplest algorithm for a delta measurement uses the following 2-point source/measure process:

1. Source a positive current through the DUT and measure the voltage (V_1).
2. Source a negative current through the DUT and measure the voltage (V_2).
3. Calculate the delta reading as follows:

$$\text{delta} = (V_1 - V_2) / 2$$

Each voltage measurement will include the thermal EMF. When the two measurements (V_1 and V_2) are averaged, the thermal EMF will effectively be cancelled out of the delta reading.

For example, assume the DUT is exactly 0.1Ω and the test current is 1mA . Ideally, the voltage across the DUT would measure exactly $100\mu\text{V}$.

However, assume that the voltage measurement test circuit has $+10\mu\text{V}$ of EMF. For a positive test current, the voltage measurement will be $+110\mu\text{V}$ ($100\mu\text{V} + 10\mu\text{V}$). For a negative test current, the voltage measurement will be $-90\mu\text{V}$ ($-100\mu\text{V} + 10\mu\text{V}$).

When using the fundamental delta process, the two voltage readings (V_1 and V_2) are averaged to cancel the $10\mu\text{V}$ of EMF:

$$\begin{aligned}\text{delta} &= (V_1 - V_2) / 2 \\ &= [+110\mu\text{V} - (-90\mu\text{V})] / 2 \\ &= (110\mu\text{V} + 90\mu\text{V}) / 2 \\ &= 200\mu\text{V} / 2 \\ &= 100\mu\text{V}\end{aligned}$$

The Keithley Models 2182 and 2182/2182A can perform fundamental Delta measurements using a conventional bipolar current source. For details on the fundamental Delta process, see “Delta” in Section 5 of the Model 2182/2182A User’s Manual.

NOTE The previous discussion on the fundamental Delta process is provided as background information to summarize delta measurements using a conventional bipolar current source.

The following information refers to an enhanced Delta operation using the Model 622x with a Model 2182/2182A.

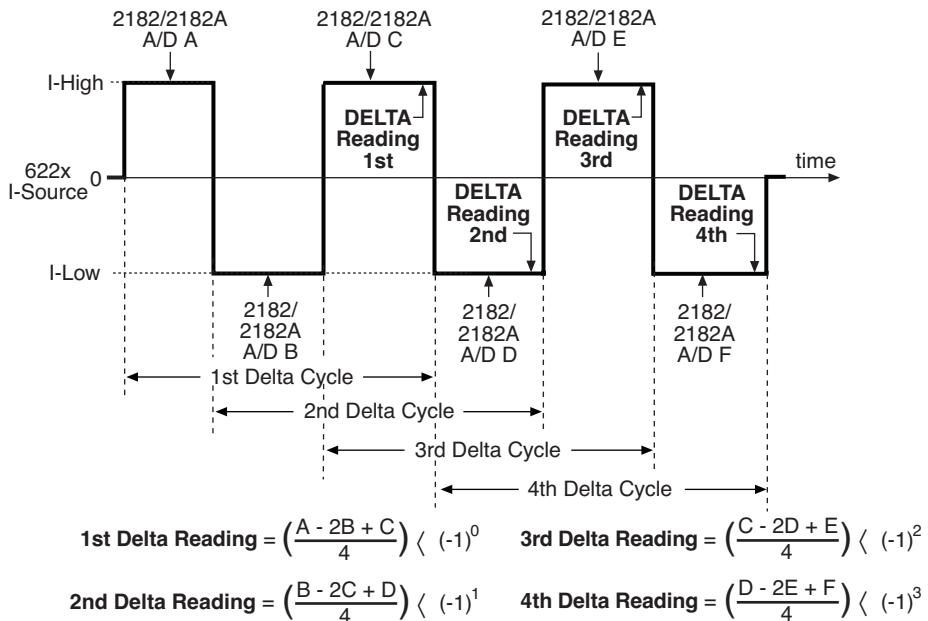
Model 622x measurement process

When the Model 622x Current Source is used with the Model 2182/2182A to perform Delta measurements, an advanced, moving-average algorithm is used for the Delta process. This process provides improved accuracy (3-point voltage measurements) and increased speed over the fundamental Delta process.

Delta measurement technique

The Delta process is shown in [Figure 5-7](#). 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 1st 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 5-7
Delta measurement technique



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

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

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

$$n = \text{Delta Cycle Number} - 1$$

Example – Calculate the 21st Delta reading:

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

$$\begin{aligned} n &= \text{Delta Cycle Number} - 1 \\ &= 21 - 1 \\ &= 20 \end{aligned}$$

Therefore:

$$\begin{aligned} \text{Delta} &= \left(\frac{X - 2Y + Z}{4} \right) \bullet (-1)^{20} \\ &= \frac{X - 2Y + Z}{4} \end{aligned}$$

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.

Delta calculation example

Assume you want to measure the voltage across a 1Ω DUT using a constant $+10\text{mA}$ current source and a voltmeter. Ideally, the measured voltage would be 10mV ($V = I \times R$). However, due to a $10\mu\text{V}$ thermal EMF in the test leads, the voltmeter actually reads 10.01mV (0.1% error due to EMF).

The error contributed by EMF can be eliminated by using Delta. Assume the square wave output of the Model 622x is set to 10mA (high) and -10mA (low) and the following Model 2182/2182A measurement conversions (A/Ds) are made for the first Delta cycle.

$$\text{A/D A} = 10.01\text{mV}$$

$$\text{A/D B} = -9.99\text{mV}$$

$$\text{A/D C} = 10.01\text{mV}$$

The first Delta reading is calculated as follows:

$$\begin{aligned}\text{Delta} &= \left(\frac{\text{A} - 2\text{B} + \text{C}}{4} \right) \bullet (-1)^0 \\ &= \left(\frac{10.01\text{mV} - 2(-9.99\text{mV}) + 10.01\text{mV}}{4} \right) \bullet 1 \\ &= \left(\frac{40\text{mV}}{4} \right) \\ &= 10\text{mV}\end{aligned}$$

The 10mV Delta reading effectively cancelled the $10\mu\text{V}$ EMF to provide a more accurate measurement.

Measurement units

The fundamental measurement for Delta is voltage (Volts; V). However, the voltage reading can be converted into a conductance (Siemens; S), resistance (Ohms; Ω), or power (Watts; W) reading. See [page 5-16](#) for details on selecting “**Measurement units**”.

With Ohms, Siemens or Watts measurement units selected, the reading is calculated as follows:

$$\Omega = V/I$$

$$S = I/V$$

$$W = I \times V$$

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 5-3](#).

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 (see [Figure 5-8](#)), 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 [Figure 8-2](#)). 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).

NOTE Jitter – For Delta, 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 1-18](#).

Arming process

After Delta is configured, the test is armed by pressing the **DELTA** key or sending SOUR:DELT:ARM. During the arming process, the Model 622x establishes communications with the Model 2182/2182A and performs a series of operations.

Communications, setup commands, and sweep table

- The Model 622x performs a communications test and sends setup commands to the Model 2182/2182A. These operations are explained in “[Communications test and setup commands](#),” on page 5-12.
- The Model 622x builds a sweep table of source values to be used for the Differential Conductance test. For details, see “[Internal sweep table](#),” on page 5-12.

Model 2182/2182A measurement rate

The speed (rate) setting of the Model 2182/2182A is queried. If the NPLC speed setting is not an integer value, it will be changed to 1 PLC (examples of non-integer values are 0.1, 1.3, and 17.5).

Armed message

- The following message is displayed briefly when Delta is armed and ready to run:

DELTA ARMED
Press TRIG to start

Aborting Delta

After Delta is armed (or running), it can be aborted by pressing the **EXIT** key or sending the SOUR:SWE:ABOR command.

Triggering sequence

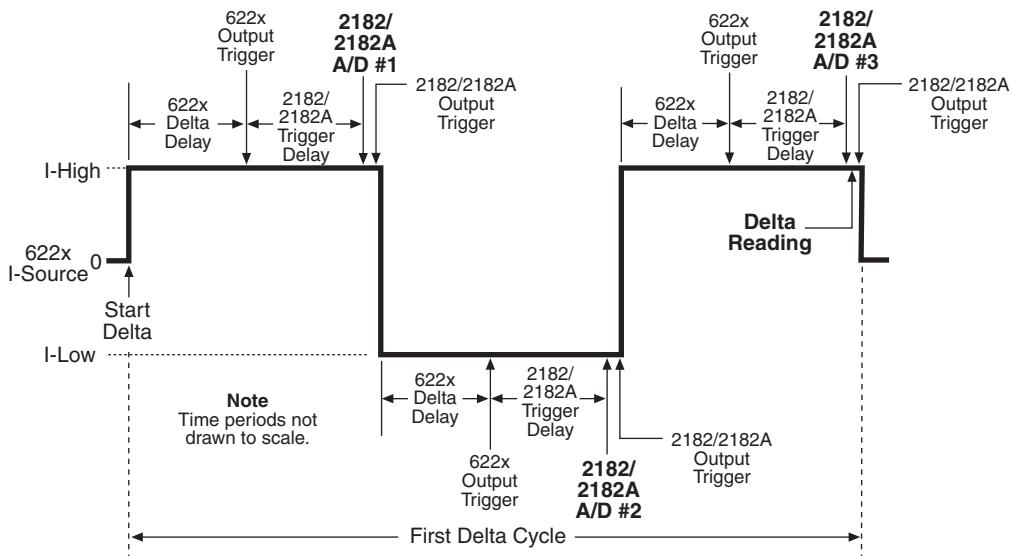
The Trigger Link is used to synchronize source-measure triggering operations of the Models 622x and 2182/2182A. See “[System connections](#),” on page 5-6 for details on Trigger Link connections.

The triggering sequence for the first Delta cycle is shown in [Figure 5-8](#) and is explained as follows:

- **Model 622x** – When Delta is started from the Model 622x, it outputs the high (I-High) current level. After its Delta Delay expires, an output trigger pulse is sent to the Model 2182/2182A to start its operations.
- **Model 2182/2182A** – After its Trigger Delay expires, the Model 2182/2182A performs a measurement conversion (A/D #1). An output trigger pulse is then sent back to the Model 622x.
- **Model 622x** – The Model 622x outputs the programmed low (I-Low) current level. After the Delta Delay expires, an output trigger is sent back to the Model 2182/2182A. The Delta Delay is used to allow the current source to settle after a polarity change.

- **Model 2182/2182A** – After its Trigger Delay expires, the Model 2182/2182A performs another measurement conversion (A/D #2). An output trigger pulse is then sent back to the Model 622x.
- **Model 622x** – The Model 622x outputs the programmed high (I-High) current level. After the Delta Delay expires, an output trigger is sent back to the Model 2182/2182A.
- **Model 2182/2182A** – After its Trigger Delay expires, the Model 2182/2182A performs another measurement conversion (A/D #3). Delta is then calculated by the Model 622x. The Model 2182/2182A outputs a trigger pulse to the Model 622x to start the next Delta cycle (if Delta count is >1). Otherwise, Delta will stop. [Figure 5-6](#) shows the data (reading) flow process from the Model 2182/2182A to the Model 622x.

Figure 5-8
Delta triggering sequence



Operation

NOTE Delta readings from the Model 2182/2182A will be unfiltered. Noisy Delta readings can be filtered by the Model 622x before sending them into the buffer. See [Section 6](#) for details.

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 figures. All power must be removed from all components in the system before making connections:
 - [Figure 5-3, page 5-7](#) – System connections.
 - [Figure 5-5, page 5-10](#) – DUT test connections.
2. Configure communications for the Models 2182/2182A and 622x as explained in “[Configuring communications](#),” on [page 5-10](#).
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 5-24](#).
 - 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 “[Measurement units](#),” on [page 5-16](#) 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.

Details on the “[Arming process](#)” are provided on [page 5-24](#). 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 figures. All power must be removed from all components in the system before making connections:
 - [Figure 5-4, page 5-8 – System connections](#).
 - [Figure 5-5, page 5-10 – Test connections](#).
2. Configure communications for the Models 2182/2182A and 622x as explained in [“Configuring communications,” on page 5-10](#).
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:RANG?"	' Send range query.
SYST:COMM:SER:ENT?	' Return response to query.
SYST:COMM:SER:SEND "VOLT:NPLC 1"	' Set rate to 1PLC for 2182/2182A.
SYST:COMM:SER:SEND "VOLT:NPLC?"	' Send rate query.
SYST:COMM:SER:ENT?	' 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 5-16 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	Select ohms measurement units.
-----------	--------------------------------

5. **Set up, arm, and run Delta** – Details on the commands to set up and arm Delta are provided in [Table 5-3](#). 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. A
SOUR:DELT:ARM	' Arms Delta.
INIT:IMM	' Starts Delta measurements. B

- 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:

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. See [Table 5-2](#) for details on errors associated with Delta operation.

NOTE Details on using Model 622x “[Read commands](#)” are provided on [page 5-15](#).

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

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:

TRACe : DATA? ‘ Read Delta readings stored in 622x buffer.

Setup commands

Delta setup and arm commands

Commands to set up and arm Delta are listed in [Table 5-3](#).

Table 5-3
Delta commands

Command	Description	Default
[SOURce [1]] :DELTa:NVPReSt?	Queries connection to 2182A. ¹ 1 = yes, 0 = no	
[SOURce [1]] :DELTa:HIGH <NRf>	Sets high source value (amps). ² <NRf> = 0 to 105e-3	1e-3
[SOURce [1]] :DELTa:LOW <NRf>	Sets low source value (amps). ² <NRf> = 0 to -105e-3	-1e3
[SOURce [1]] :DELTa:DELay <NRf>	Sets Delta delay (seconds). ² <NRf> = 0 to 9999.999 or INFinity	0
[SOURce [1]] :DELTa:COUNT <NRf>	Sets the number of cycles to run. ² <NRf> = 1 to 65536 (finite count) or INFinity	INF
[SOURce [1]] :SWEep:COUNT <NRf>	Sets the number of measurement sets to repeat. ² <NRf> = 1 to 65536 (finite count) or INFinity	1
[SOURce [1]] :DELTa:CSWitch 	Enable cold switching mode. ² = 0 or OFF, 1 or ON	0
[SOURCE [1]] :DELTa:CAbort 	Enable or disable Compliance Abort. ² = 0 or OFF, 1 or ON	0
[SOURce [1]] :DELTa:ARM	Arms Delta. ³	
[SOURce [1]] :DELTa:ARM?	Queries Delta arm. 1 = armed, 0 = not armed.	

1. Use the :NVPReSt 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 5-24](#) 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. Details on the “[Arming process](#)” are provided on [page 5-24](#).

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

The query form for the arm command (SOUR:DELT: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

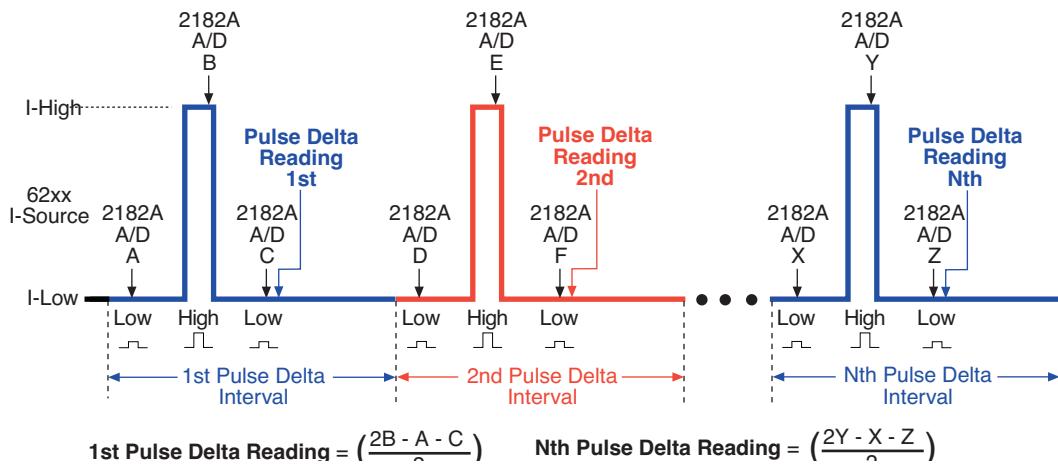
Pulse Delta measurements

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 5-9](#), every three pulses yields a single Pulse Delta voltage reading.

Figure 5-9

Pulse Delta 3-point measurement technique



In cases where the high pulse will cause heating of the 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:

$$\text{Pulse Delta} = (2Y - 2X) / 2$$

Where: Y is the measurement at the high pulse.

X is the measurement at the first low pulse.

Pulse Delta calculation example

3-point measurement technique – Assume you want to measure the voltage across a low power 1Ω DUT. The Pulse Delta process will reduce DUT heating and eliminate the effects of thermal EMFs.

Assume the Model 6221 is configured to output +10mA and 0mA pulses. Due to a 10 μ V thermal EMF in the test leads, the following Model 2182A measurement conversions (A/Ds) are made for the first Pulse Delta cycle.

$$\text{A/D A} = 0.01\text{mV}$$

$$\text{A/D B} = 10.01\text{mV}$$

$$\text{A/D C} = 0.01\text{mV}$$

The first Pulse Delta reading (using the 3-point measurement technique) is calculated as follows:

$$\begin{aligned}\text{PulseDelta} &= \left(\frac{2B - A - C}{2} \right) \bullet (-1)^0 \\ &= \frac{2(10.01) - (0.01) - (0.01)}{2} \\ &= \frac{20\text{mV}}{2} \\ &= 10\text{mV}\end{aligned}$$

The above 3-point measurement technique effectively eliminated the 10 μ V thermal EMF from the Pulse Delta reading.

2-point measurement technique – Assume for the above example that DUT heating causes the A/D measurement at point C to be 1.01mV. Using the 3-point measurement technique, Pulse Delta (by calculation) would instead be 9.5mV. This results in 5% measurement error due to heating.

The affects of heating can be eliminated by not performing the measurement at point C (low pulse). For this 2-point measurement technique, Pulse Delta is calculated as follows:

$$\begin{aligned}\text{PulseDelta} &= \left(\frac{2B - 2A}{2} \right) \bullet (-1)^0 \\ &= \frac{2(10.01) - 2(0.01)}{2} \\ &= \frac{20\text{mV}}{2} \\ &= 10\text{mV}\end{aligned}$$

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 5-16](#).

With Ohms or Siemens measurement units selected, the reading is calculated as follows:

$$\begin{aligned}W &= V/I \\ S &= I/V\end{aligned}$$

The calculation for power depends on the power reading type that is presently selected (Peak or Average) and is discussed as follows.

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.

[Figure 5-9](#) shows how Pulse Delta voltage is calculated. Peak power is calculated using the basic power equation ($W = IV$), where I is the high pulse current (I -High) and V is the calculated Pulse Delta voltage.

The average power over the entire Pulse Delta cycle can calculated by factoring in the duty cycle. Duty cycle is the percentage of time that the pulse is high during the Pulse Delta cycle. For example, assume the period of the Pulse Delta cycle is 1ms. If the pulse is high for 0.25ms, then duty cycle is 25%.

Mathematically, duty cycle is expressed as follows:

$$\text{Duty Cycle (in \%)} = \text{Pulse Width} / \text{Pulse Interval} \times 100$$

Where: Pulse Width = Time that the pulse is high.

Pulse Interval = Time period of the Pulse Delta cycle.

Average power is then calculated as follows:

$$W \text{ (average power)} = I \times V \times \text{Duty Cycle}$$

Example – Assume the following for Pulse Delta:

- Pulse Delta voltage is 5V
- Pulse high (I-High) current is 1mA
- Pulse low (I-Low) current is 0mA
- Duty cycle is 25%

With Watts as the selected measurement units, the Peak power reading is calculated as follows:

$$\begin{aligned} W \text{ (peak power)} &= I \times V \\ &= 1\text{mA} \times 5\text{V} \\ &= 5\text{mW} \end{aligned}$$

Average power is calculated as follows:

$$\begin{aligned} W \text{ (Average power)} &= I \times V \times \text{Duty Cycle} \\ &= 1\text{mA} \times 5\text{V} \times 0.25 \\ &= 1.25\text{mW} \end{aligned}$$

Pulse Delta power calculation restriction

The algorithm for the Pulse Delta power calculation requires that the low pulse level (I-Low) be very near zero. If the low pulse is more than ± 6 counts (at 3-1/2 digit resolution) away from zero, the validity of the power reading will be in question. For example, on the 2mA source range, the set low pulse (I-Low) level must be 0nA $\pm 600\text{nA}$.

The Model 6221 will report the questionable power reading but will not generate any front panel error messages. However, bit B4 (Power Questionable) of the Questionable Event Status Register will set. For details, see [Section 11, "Status Structure](#).

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 is used to output a staircased, logarithmic or user-specified (custom) pulse sweep.

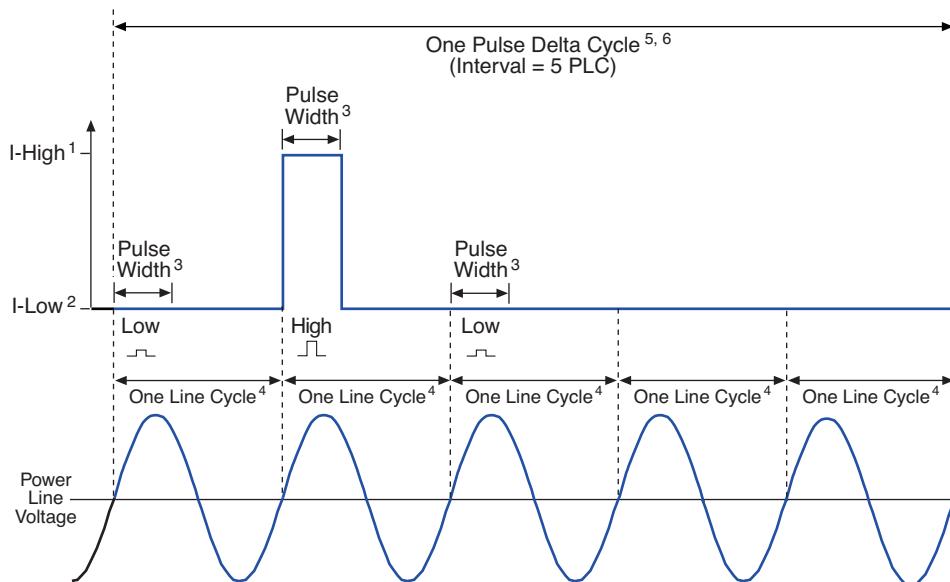
Fixed output

[Figure 5-10](#) 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 5-10](#) 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.

Figure 5-10

Pulse timing



Notes:

- 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).

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 5-10](#), 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 5-11](#).

Staircase sweep – [Figure 5-11A](#) 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.

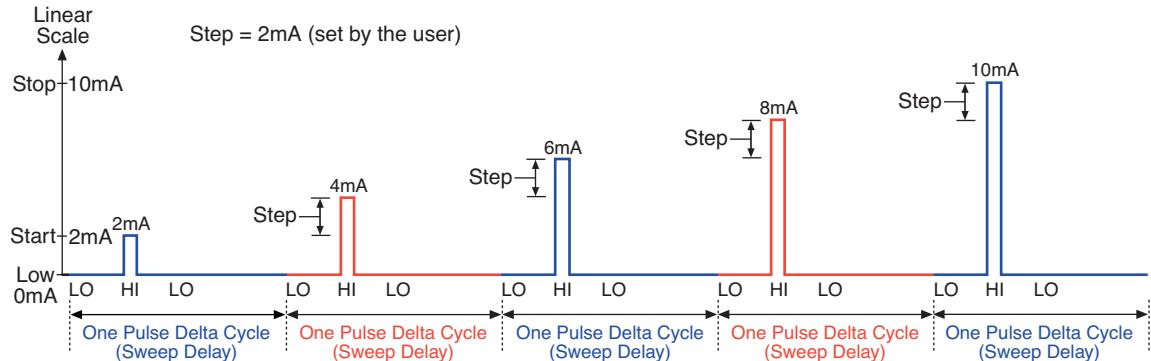
Logarithmic sweep – [Figure 5-11B](#) shows an example of a logarithmic Sweep output. The sweep is configured to output five high pulses (points). The first high pulse starts at 1mA and logarithmically steps to 10mA. The low pulse level for this sweep is 0mA.

Custom sweep – [Figure 5-11C](#) shows an example of a custom Sweep output. The sweep is configured to output five high pulses (points). The level for each high pulse is specified by the user. The high pulse levels for this output are 1mA, 2mA, 4mA, 8mA, and 16mA. The low pulse level for this sweep is 0mA.

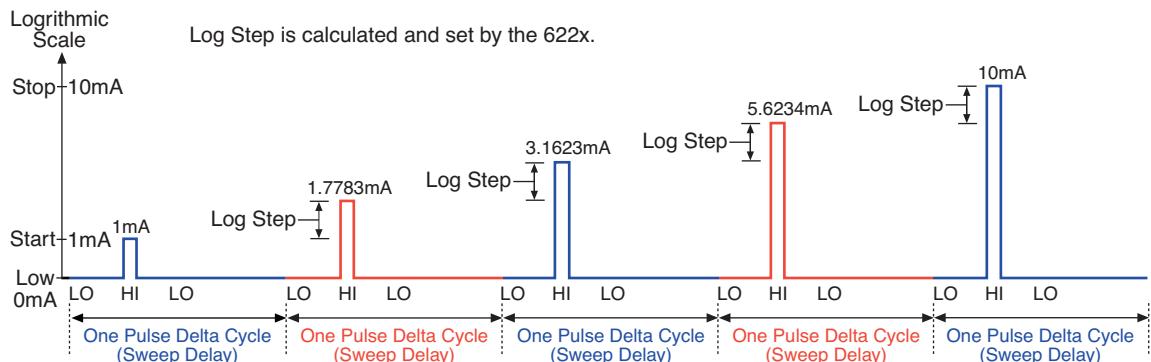
Notice that the time period for each Pulse Delta cycle is determined by the set sweep delay. The sweep (including sweep delay) is configured from the CONFIGURE SWEEPS menu. See [Section 4](#) for details.

Figure 5-11 **Pulse sweep output examples**

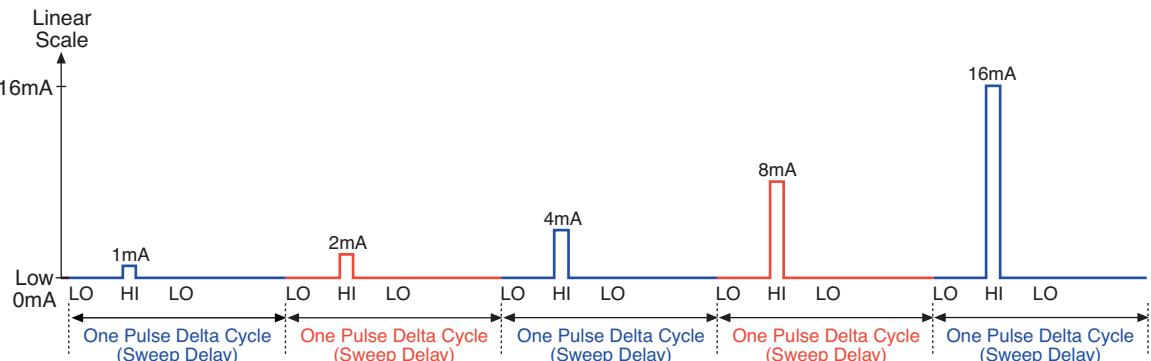
A) Staircase sweep pulse train: 2 to 10mA in 2mA steps



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:

$$\begin{aligned}\text{Pulse Delta cycle time period} &= 5 \times 16.667\text{ms} \\ &= 83.33\text{ms}\end{aligned}$$

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 5-4](#).

Fixed output settings

These 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 50 μ s to 12ms. The default setting for pulse width is 110 μ s.

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 16 μ s (default setting) to 11.966ms.

Pulse width and source delay are shown in [Figure 5-12](#). Note that 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 whatever range is 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 5-4](#).

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 pulse low as shown in [Figure 5-9](#). As explained in the process for “[Pulse Delta measurements](#),” [on page 5-32](#), 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 (previously described) 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 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.

Arming process

After Pulse Delta (Fixed output or Sweep output) is configured, the test is armed by pressing the **PULSE** key or sending SOUR:PDEL:ARM. During the arming process, the Model 6221 establishes communications with the Model 2182A and performs a series of operations.

Communications, setup commands, sweep table, and moving filter

- The Model 6221 performs a communications test and sends setup commands to the Model 2182A. These operations are explained in “[Communications test and setup commands](#),” on page 5-12.
- The Model 6221 builds a sweep table of source values to be used for the Pulse Delta test. For details, see “[Internal sweep table](#),” on page 5-12.
- If using a Model 2182, error +410 Model 2182A required occurs when trying to arm Pulse Delta.
- Pulse Delta using a Sweep output – Only the moving average filter can be used (if enabled). If the repeating average filter is enabled, the filter type will change to moving when Pulse Delta is armed. See [Section 6](#) for details see on the moving average filter.

Fixed source range

When using the FIXED source range, error -221 Settings Conflict occurs if Pulse Delta is armed while on a source range that is too small. Select a higher source range before arming Pulse Delta.

Armed messages

One of the following messages is displayed briefly when Pulse Delta is armed and ready to run:

Message for Pulse Delta with sweep disabled:

PULSE MODE ARMED
Press TRIG to start

Message for Pulse Delta with sweep enabled:

PULSE SWEEP ARMED
Press TRIG to start

Aborting Pulse Delta

While Pulse Delta is armed or running, the test can be aborted by pressing the **EXIT** key or sending SOUR:SWE:ABOR. The current source will set to zero and turn off.

Triggering sequence

The Trigger Link is used to synchronize source-measure triggering operations of the Models 6221 and 2182A. See “[System connections](#),” on page 5-6 for details on Trigger Link connections.

As previously explained, Model 6221 output pulses are synchronized to the frequency of the power line voltage. A low or high pulse is generated on the positive-going edge of each line cycle.

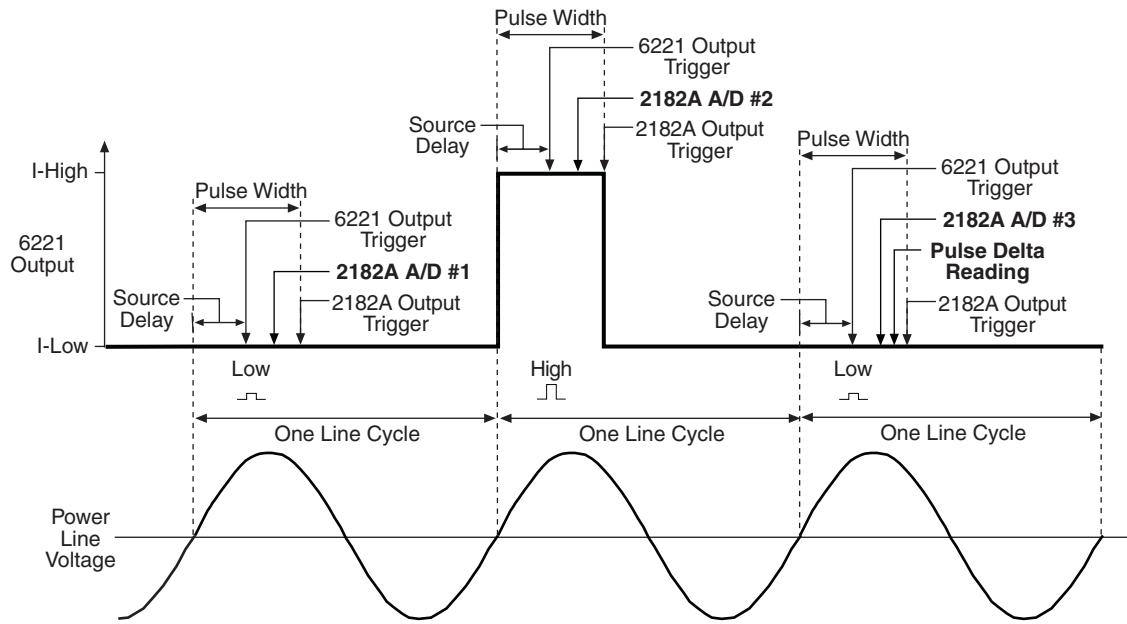
The triggering sequence for the 3-point measurement method (two lows measured) is shown in [Figure 5-12](#) and is explained as follows. Note that this diagram assumes that the trigger delays for both the Model 6221 and 2182A are set to zero. Since the trigger delays are zero, they are not shown.

- **Model 6221** – When Pulse Delta is started from the Model 6221, it outputs a low (I-Low) current pulse. After the programmed Source Delay of the Model 6221 expires, an output trigger is sent to the Model 2182A to start its operations. Source Delay is used to allow the pulse to settle.

NOTE The programmed Pulse Width and Source Delay determines the integration time for Model 2182A measurements. The integration time for the Model 2182A is automatically set when Pulse Delta is armed.

- **Model 2182A** – The Model 2182A performs a measurement conversion (A/D #1), and an output trigger is sent back to the Model 6221.
- **Model 6221** – At the start of the next line cycle, the Model 6221 outputs the programmed high (I-High) current pulse. After the Source Delay expires, an output trigger is sent back to the Model 2182A.
- **Model 2182A** – The Model 2182A performs a measurement conversion (A/D #2), and an output trigger is sent back to the Model 6221.
- **Model 6221** – At the start of the third line cycle, the Model 6221 again outputs the programmed low (I-Low) current pulse. After the Source Delay expires, an output trigger is sent back to the Model 2182A.
- **Model 2182A** – If measuring the second low pulse, the Model 2182A performs another measurement conversion (A/D #3) and Pulse Delta is then calculated by the Model 6221. The Model 2182A sends an output trigger to the Model 6221 to start the next Pulse Delta cycle (if Pulse Delta count is >1). Otherwise, Pulse Delta will stop. [Figure 5-6](#) shows the data (reading) flow process from the Model 2182A to the Model 6221.

Figure 5-12
Pulse Delta triggering sequence (two lows measured)



Operation

NOTE Pulse Delta readings from the Model 2182A will be unfiltered. Noisy readings can be filtered by the Model 622x before sending them into the buffer. See [Section 6](#) for details.

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 5-7](#) – System connections
 - [Figure 5-5, page 5-10](#) – DUT test connections
2. Configure communications for the Models 2182A and 6221 as explained in “[Configuring communications](#),” on [page 5-10](#).
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 5-39](#).
 - 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 5-16](#) for details.

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.

Details on the “[Arming process](#)” are provided on [page 5-42](#). 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 5-8](#) – System connections
 - [Figure 5-5, page 5-10](#) – Test connections
2. Configure communications for the Models 2182A and 6221 as explained in [“Configuring communications,” on page 5-10](#).
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:

SYST: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:

SYST: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.  
SYST:COMM:SER:SEND "VOLT:RANG?"        ' Send range query.  
SYST:COMM:SER:ENT?                      ' Return response to query.
```

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 5-16 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 5-4](#). 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:COUN 200	' Sets pulse count to 200.
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
SOUR:PDEL:ARM	' Arms Pulse Delta.
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 previous 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. See [Table 5-2](#) for details on errors associated with Pulse Delta operation.

NOTE [Details on using Model 6221 “Read commands” are provided on page 5-15.](#)

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 5-4](#).

Table 5-4

Pulse Delta commands

Command	Description	Default
SOURce [1] :PDELta:NVPReSent?	Queries if 2182A is connected. ¹ 1 = yes, 0 = no	
SOURce [1] :PDELta:HIGH <NRf>	Sets high pulse value (amps). ² <NRf> = -105e-3 to 105e-3	1e-3
SOURce [1] :PDELta:LOW <NRf>	Sets low pulse value (amps). ² <NRf> = -105e-3 to 105e-3	0
SOURCe [1] :PDELta:WIDTh <NRf>	Sets pulse width (seconds). ² <NRf> = 50e-6 to 12e-3	110e-6
SOURce [1] :PDELta:SDELay <NRf>	Sets pulse delay (seconds). ^{2, 3} <NRf> = 16e-6 to 11.996e-3	16e-6
SOURce [1] :PDELta:RANGing <name>	Selects fixed pulse range. ^{2, 4} <name> = BEST or FIXed	BEST
SOURce [1] :SWEep:RANGing <name>	Selects pulse sweep range. ^{2, 4} <name> = AUTO, BEST or FIXed	BEST
SOURce [1] :PDELta:COUNT <NRf>	Sets the number of Pulse Delta intervals to perform. ² <NRf> = 1 to 65536 (finite count) or INFinity count.	INF
SOURce [1] :PDELta:INTerval <NRf>	Sets cycle time for fixed pulse (PLCs). ² <NRf> = 5 to 999999	5
SOURCe [1] :DELay <NRf>	Sets cycle time for lin/log sweep (seconds). ^{2, 3} <NRf> = 1e-3 to 999999.999	1
SOURce [1] :LIST:DELay <NRf> [, NRf, ...<NRf>]	Sets cycle time for custom sweep (seconds). ^{2, 3} <NRf> = 1e-3 to 999999.999	1
SOURce [1] :PDELta:SWEep [:STATe] 	Enable or disable Sweep output mode. ² = ON or OFF	OFF
SOURce [1] :PDELta:LMEasure <NRf>	Set number of low measurements. ² <NRf> = 1 or 2	2
SOURce [1] :PDELta:ARM	Arms Pulse Delta. ⁴	
SOURce [1] :PDELta:ARM?	Queries Pulse Delta arm. 1 = armed, 0 = not armed	

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. 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. Details on the “[Configuration settings](#)” are provided on [page 5-39](#).
3. When using a Fixed output, use the SOUR:PDEL:INT command to set the Pulse Delta cycle time period (in PLCs).
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 above setup commands, the :ARM command arms Pulse Delta. During the arming process, the Model 622x communicates with the Model 2182A. Details on the “[Arming process](#)” are provided on [page 5-42](#).

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.

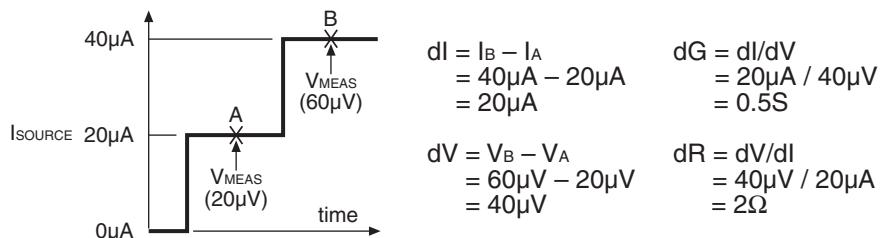
Differential Conductance

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

Basic measurement process

The basic process for differential voltage measurements is shown by the example in [Figure 5-13](#). As shown, two current steps are applied to a device and voltage is measured at each step. From these two source-measure points (A and B), differential current (dI), differential voltage (dV), differential conductance (dG), and differential resistance (dR) can be calculated as shown in the illustration. These measurements examine the straight-line slope between points A and B.

Figure 5-13
Basic differential measurements



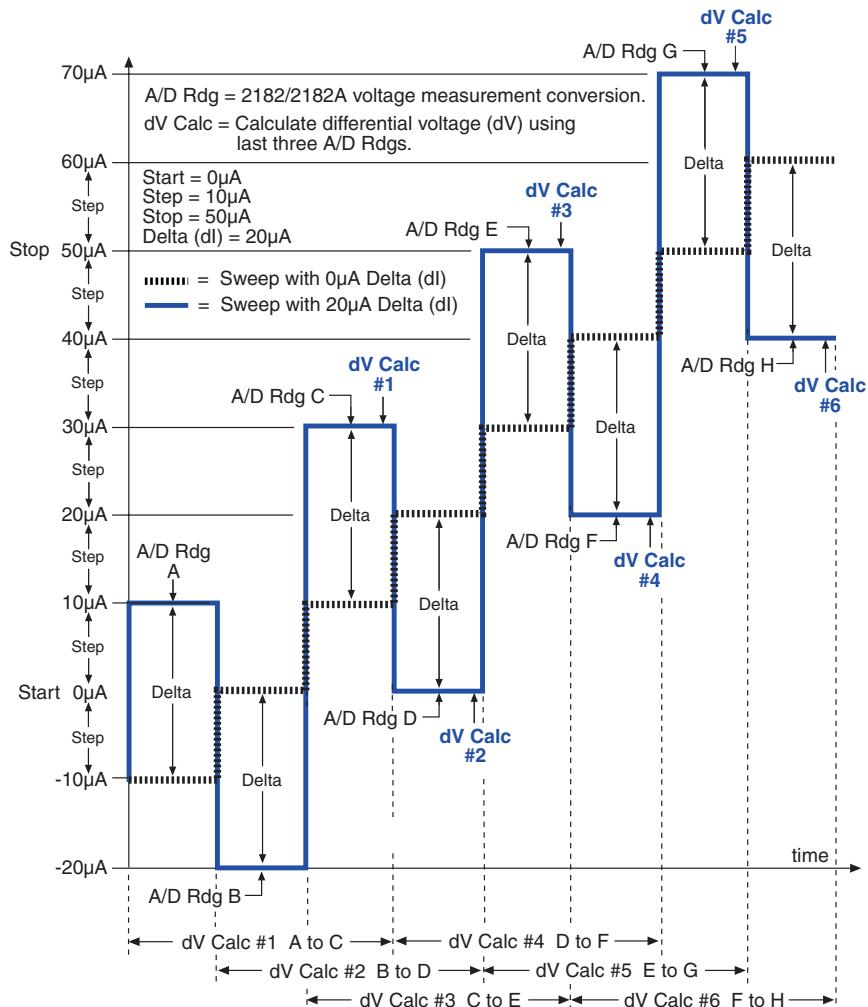
Model 622x measurement process

When using the Model 2182/2182A with the Model 622x, a more sophisticated process is used to perform differential measurements. The delta 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.

This differential measurement process is shown in [Figure 5-14](#). The Model 622x is configured to output a stepped sweep with a specified Delta, which is the differential current (dI). As shown in the illustration, Delta is added to and subtracted from each subsequent step in the sweep. The solid line in [Figure 5-14](#) 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 dI (Delta) is the same for all calc points. With dI known and dV calculated, the Model 622x can also calculate, display, and store the differential conductance (dG) or differential resistance (dR) for each calc point.

Figure 5-14
Differential Conductance measurement process



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).

$$dV \#1 = \frac{[(A-B)/2] + [(C-B)/2]}{2} \bullet (-1)^0$$

$$dV \#2 = \frac{[(B-C)/2] + [(D-C)/2]}{2} \bullet (-1)^1$$

$$dV \#3 = \frac{[(C-D)/2] + [(E-D)/2]}{2} \bullet (-1)^2$$

$$dV \#4 = \frac{[(D-E)/2] + [(F-E)/2]}{2} \bullet (-1)^3$$

$$dV \#5 = \frac{[(E-F)/2] + [(G-F)/2]}{2} \bullet (-1)^4$$

$$dV \#6 = \frac{[(F-G)/2] + [(H-G)/2]}{2} \bullet (-1)^5$$

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 5-14](#), the following formula can be used to calculate any dV reading in the test:

$$dV = \frac{\frac{(X - Y)}{2} + \frac{(Z - Y)}{2}}{2} \bullet (-1)^n$$

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

$$n = \text{Reading Number} - 1$$

Example – Calculate the 21st dV reading:

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

$$n = \text{Reading Number} - 1$$

$$= 21 - 1$$

$$= 20$$

Therefore;

$$dV = \frac{\frac{(X - Y)}{2} + \frac{(Z - Y)}{2}}{2} \bullet (-1)^{20}$$

$$= \frac{\frac{(X - Y)}{2} + \frac{(Z - Y)}{2}}{2}$$

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:

$$dV = \frac{\frac{X - Y + Z - Y}{2}}{2} \bullet (-1)^n$$

$$dV = \frac{X - 2Y + Z}{4} \bullet (-1)^n$$

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 5-16](#) for details on selecting “[Measurement units](#)”.

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

$$dR = dV/dI$$

$$dG = dI/dV$$

With Power measurement units selected, power is calculated using Average Voltage and Average Current and is explained in the following paragraphs.

Average Voltage and Power

Average Voltage calculation

Average Voltage is the average bias voltage that was present across the device when the corresponding Differential Conductance reading was taken. For remote operation, the Average Voltage reading for Differential Conductance will be included in the returned data string when the AVOLTage data element is selected. See “[FORMAT subsystem](#),” on [page 13-4](#) for details on selecting data elements.

Average Voltage is calculated as follows:

$$\text{AvgVolt} = \frac{\frac{(X + Y)}{2} + \frac{(Z + Y)}{2}}{2}$$

$$\boxed{\text{AvgVolt} = \frac{X + 2Y + Z}{4}}$$

Where: AvgVolt is the Average Voltage corresponding to a given Differential Voltage (dV) reading.

X, Y and Z are the three A/D measurements for the dV reading.

Power calculation

With WATTS (power) measurement units selected, power for Differential Conductance is calculated using Average Voltage (see “[Average Voltage calculation](#)” above) and Average Current.

Average Current is calculated by the Model 622x as follows:

$$\text{AvgCurr} = \frac{\frac{(X + Y)}{2} + \frac{(Z + Y)}{2}}{2}$$

$$\boxed{\text{AvgCurr} = \frac{X + 2Y + Z}{4}}$$

Where: AvgCurr is the Average Current corresponding to a given Differential Conductance reading.

X, Y, and Z are the three current levels for the Differential Conductance reading.

With Average Voltage and Average Current known (calculated by the Model 622x), power is then calculated as follows:

$$\boxed{\text{Power} = \text{AvgVolt} \times \text{AvgCurr}}$$

Configuration settings

Differential Conductance settings from the front panel are described as follows. These parameters are set from the DIFF CONDUCTANCE menu that 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 5-5](#).

Step – The step size specifies the size increment for each step of the sweep. In [Figure 5-14](#), the 10 μ A 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 1 μ A.

Start – The start level for the sweep applies to the middle step of the first cycle. As shown in [Figure 5-14](#), the 0 μ A 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 -10 μ A.

Stop – The stop level for the sweep applies to the middle step of the last cycle. As shown in [Figure 5-14](#), the 50 μ A 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 +10 μ A.

Delta – The specified Delta is the differential current (dl) for the sweep. It is alternately added to and subtracted from each subsequent step in the sweep. As shown in [Figure 5-14](#), 10 μ A is added to the odd numbered steps and then subtracted from the even numbered steps. Model 2182/2182A A/D readings are per-

formed 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 1 μ A.

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. This delay is shown in [Figure 5-15](#). 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](#),” on [page 5-59](#).

NOTE	The source range for the Model 622x is automatically set to the best fixed range when Differential Conductance is armed.
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NOTE	Jitter – For 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 1-18.
-------------	---

Arming process

After Differential Conductance is configured, the test is armed by pressing the **COND** key or sending **SOUR:DCON:ARM**. During the arming process, the Model 622x establishes communications with the Model 2182/2182A and performs a series of operations.

Communications, setup commands, sweep table, and repeating filter

The Model 622x performs a communications test and sends setup commands to the Model 2182/2182A. These operations are explained in “[Communications test and setup commands](#),” on [page 5-12](#).

The Model 622x builds a sweep table of source values to be used for the Differential Conductance test. For details, see “[Internal sweep table](#),” on [page 5-12](#).

For Differential Conductance, only the repeating average filter can be used (if enabled). If the moving average filter is enabled, the filter type will change to repeating when Differential Conductance is armed. See [Section 6](#) for details, refer to the repeating average filter.

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

Step Size (repeating filter) = Programmed Step Size / Filter Count

For example, assume the programmed step size is $10\mu\text{A}$ and the Filter Count is 10. When the Differential Conductance test is run, the actual step size will be $1\mu\text{A}$ ($10\mu\text{A} / 10$).

Model 2182/2182A measurement rate

The speed (rate) setting of the Model 2182/2182A is queried. If the NPLC speed setting is not an integer value, it will be changed to 1 PLC (examples of non-integer values are 0.1, 1.3, and 17.5).

Voltage offset compensation

Disabling Front Autozero on the Model 2182/2182A results in high voltage offset for voltage measurements. To compensate for this offset, the Model 622x performs the following action:

- The Model 622x acquires the voltage offset (V-zero) value from the Model 2182/2182A and will factor it into the calculations for Differential Conductance voltage. This technique effectively compensates for Model 2182/2182A offset voltage. During V-zero acquisition, the message "Acquiring V-Zero ..." will be briefly displayed.

Depending on the integration time for the Model 2182/2182A, it may take several seconds for the Model 622x to acquire the V-zero value. With the Model 2182/2182A set for 5 PLC, V-zero acquisition will take approximately three seconds.

Configuration checks

The Model 622x performs a number of checks on the configuration for Differential Conductance and generates the following error and status messages:

If any of the following errors occur, Differential Conductance will still run, but it will not perform the complete test that was configured:

- Error -225 Out of Memory
- Error +408 Conductance truncated

If the following error occurs, Differential Conductance will still run, but corrupt data will be acquired:

- Error +411 Diff. Conductance step error

The occurrence of the following status message does not abort the test:

- Status +412 Diff. Conductance upranged

The following error aborts the arming process:

- Error +416 Step size too small

NOTE **Table 5-2** explains these coded error and status messages.
This table also provides remedies for the errors.

Armed message

The following message is displayed briefly when Differential Conductance is armed and ready to run:

DIFF COND ARMED
Press TRIG to start

Aborting Differential Conductance

After Differential Conductance is armed (or running), it can be aborted by pressing the **EXIT** key or sending the SOUR:SWE:ABOR command.

Triggering sequence

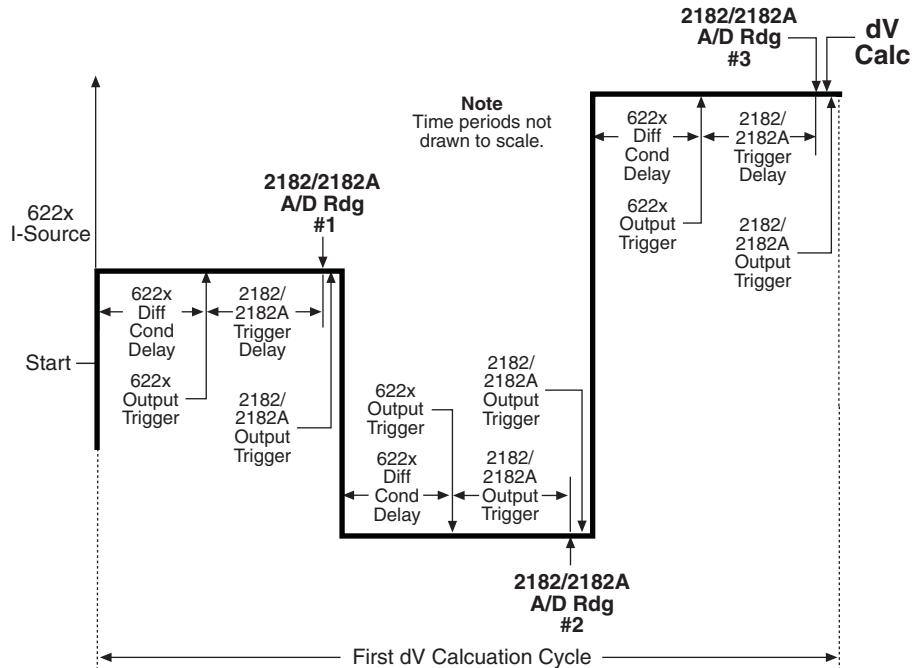
The Trigger Link is used to synchronize source-measure triggering operations of the Models 622x and 2182/2182A. See “[System connections](#),” on page 5-6 for details on Trigger Link connections.

The triggering sequence for the first Differential Conductance cycle is shown in [Figure 5-15](#) and is explained as follows:

- **Model 622x** – When Differential Conductance is started from the Model 622x, it outputs the first stepped delta current level. After the Differential Conductance Delay expires, an output trigger pulse is sent to the Model 2182/2182A to start its operations.
- **Model 2182/2182A** – After its Trigger Delay expires, the Model 2182/2182A performs a measurement conversion (A/D Rdg #1). An output trigger pulse is then sent back to the Model 622x.
- **Model 622x** – The Model 622x outputs the next stepped delta current level. After the Differential Conductance Delay expires, an output trigger is sent back to the Model 2182/2182A. The Differential Conductance Delay is used to allow the current source to settle after a level change.
- **Model 2182/2182A** – After its Trigger Delay expires, the Model 2182/2182A performs another measurement conversion (A/D Rdg #2). An output trigger pulse is then sent back to the Model 622x.
- **Model 622x** – The Model 622x outputs the third stepped delta current level. After the Differential Conductance Delay expires, an output trigger is sent back to the Model 2182/2182A.

- **Model 2182/2182A** – After its Trigger Delay expires, the Model 2182/2182A performs another measurement conversion (A/D Rdg #3). The differential voltage (dV) is then calculated by the Model 622x. The Model 2182/2182A outputs trigger pulse back to the Model 622x to output the next stepped current level. [Figure 5-6](#) shows the data (reading) flow process from the Model 2182/2182A to the Model 622x.

Figure 5-15
Differential Conductance triggering sequence



Operation

NOTE Differential Conductance readings from the Model 2182/2182A will be unfiltered. Noisy readings can be filtered by the Model 622x before sending them into the buffer. See [Section 6](#) for details.

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 5-7 – System connections](#)
 - [Figure 5-5, page 5-10 – DUT test connections](#)
2. Configure communications for the Models 2182/2182A and 622x as explained in [“Configuring communications,” on page 5-10](#).
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 5-55](#) 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 5-16](#) 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. Details on the [“Arming process”](#) are provided on [page 5-56](#). 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 5-8](#) – System connections
 - [Figure 5-5, page 5-10](#) – Test connections
2. Configure communications for the Models 2182/2182A and 622x as explained in “[Configuring communications](#),” on page 5-10.
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:

```
SYST:COMM: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:

```
SYST:COMM: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:

SYST:COMM:SER:SEND "VOLT:RANG 2"	' Select 2V range for 2182/2182A.
SYST:COMM:SER:SEND "VOLT:RANG?"	' Send range query.
SYST:COMM:SER:ENT?	' Return response to query.
SYST:COMM:SER:SEND "VOLT:NPLC 1"	' Set rate to 1PLC for 2182/2182A.
SYST:COMM:SER:SEND "VOLT:NPLC?"	' Send rate query.
SYST:COMM:SER:ENT?	' 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 [5-16](#) 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:

UNIT S ‘ 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 5-5](#). The following demonstrates the proper command sequence to set up, arm, and run Differential Conductance for the example in [Figure 5-14](#):

*RST	‘ Restores 622x defaults.
SOUR:DCON:START 0	‘ Sets start value to 0µA.
SOUR:DCON:STEP 10e-6	‘ Sets step size to 10µA.
SOUR:DCON:STOP 50e-6	‘ Sets stop value to 50µA.
SOUR:DCON:DELTA 20e-6	‘ Sets delta value to 20µA.
SOUR:DCON:DELAY 1e-3	‘ Sets delay to 1ms.
SOUR:DCON:CAB ON	‘ Enables Compliance Abort.
TRAC:POIN 6	‘ Sets buffer size to six points. ^A
SOUR:DCON:ARM	‘ Arms Differential Conductance.
INIT:IMM	‘ Starts measurements. ^B

- 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 Delta 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. See [Table 5-2](#) for details on errors associated with Differential Conductance operation.

NOTE Details on using Model 622x “[Read commands](#)” are provided on [page 5-15](#).

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

SOUR : SWE : ABOR ‘ Stops Delta 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 readings stored in
‘ 622x buffer.

Setup commands

Setup and arm commands

Commands sent from the PC to the Model 622x to set up and arm Differential Conductance are listed in [Table 5-3](#). Additional information for each command are provided in notes that follow the table.

Table 5-5

Differential Conductance commands

Command	Description	Default
SOURce [1] :DCONductance:NVPReSent?	Queries if 2182/2182A is connected. ¹ 1 = yes, 0 = no	
SOURce [1] :DCONductance:STARt <NRf>	Sets start value (amps). ² <NRf> = -105e-3 to 105e-3	-10e-6
SOURce [1] :DCONductance:STEP <NRf>	Sets step size (amps). ² <NRf> = 0 to 105e-3	1e-6
SOURce [1] :DCONductance:STOP <NRf>	Sets stop value (amps). ² <NRf> = -105e-3 to 105e-3	10e-6
SOURce [1] :DCONductance:DELTa <NRf>	Sets delta value (amps). ² <NRf> = 0 to 105e-3	1e-6
SOURce [1] :DCONductance:DELay <NRf>	Sets delay (seconds). ² <NRf> = 1e-3 to 9999.999	0.002
SOURCE [1] :DCONductance:CABort 	Enable or disable Compliance Abort. ² = 0 or OFF, 1 or ON	0
SOURce [1] :DCONductance:ARM	Arms Differential Conductance. ³	
SOURce [1] :DCONductance:ARM?	Queries Diff Cond arm. ³ 1 = armed, 0 = not armed.	
SOURce [1] :DCONductance:NVZero?	Queries V-zero value acquired from 2182/2182A. 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](#).
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 5-55 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. Details on the “[Arming process](#)” are provided on [page 5-56](#).

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.

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. See “[Voltage offset compensation](#),” on [page 5-57](#) for more information.

6

Averaging Filter, Math, and Buffer

Section 6 topics

Averaging filter, page 6-2

Averaging filter characteristics, page 6-2

Filter setup and control, page 6-8

Remote programming – Averaging filter, page 6-8

Math, page 6-11

$mX+b$ and $m/X+b$ (reciprocal), page 6-9

Configuring and controlling $mX+b$ and $m/X+b$, page 6-9

Remote programming – Math, page 6-10

Buffer, page 6-11

Buffer characteristics, page 6-12

Storing readings, page 6-14

Recall, page 6-14

Remote programming – Buffer, page 6-15

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.

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. Data (reading) flow from the Model 2182/2182A through the averaging filter is explained in “[Data flow](#), [on page 5-13](#).”

[Table 6-1](#) lists the filter types that can (yes) and cannot (no) be used with the various delta tests. Note that the filter must be enabled before arming the delta test.

Table 6-1
Average filter types

Average Filter	Moving	Repeating
Delta	Yes	Yes
Pulse Delta: Fixed output Sweep output	Yes Yes	Yes No ²
Differential Conductance	No ¹	Yes

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 6-5](#) for details).

Filter type

There are two averaging filter types: moving and repeating. These filter types are shown in [Figure 6-1](#).

Moving filter

Basic moving filter operation – For the moving filter, every delta reading yields a filtered Delta reading. The moving filter uses a first-in, first-out memory stack. As a new Delta reading is placed in the stack, the oldest delta reading is removed from the stack, and a filtered reading is calculated.

When the averaging filter is enabled, the first A/D conversion is placed into the stack and copied to the other locations in the memory stack to fill it. For example, if filter count is 10, then the first A/D reading and nine copies are loaded into the stack. The readings are averaged to yield the first reading.

Settled filtered readings will not occur until all the “copied” A/D readings are purged out of the stack. For filter count 10, the first nine averaged readings will be unsettled.

[Figure 6-1](#)A shows the moving filter process. For filter count 10, settled filtered readings begin with the 10th averaged reading.

The Filter Settled status bit (B8) of the Operation Status Register indicates if the reading is settled or not. The bit will set (1) when the first settled filtered reading occurs. For details on status structure, see [Section 11](#).

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:

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

Example – Assume the filter count for the moving average filter is set to 10 and Delta is configured to perform 25 cycles (readings). When Delta is started, the following operations are performed:

1. The asterisk (*) annunciator turns on and the first 10 Delta cycles fill the stack of the moving average filter with Delta readings.
2. Bit B8 (Filter Settled) of the Operation Event Register sets to 1 to indicate that the filter is settled. See [Section 11](#) for details on status registers.

NOTE

Up to this point, no readings have been stored in the buffer yet.

3. With the filter settled, the storage of filtered Delta readings begin. The next 25 Delta cycles yields 25 filtered readings, which are stored in the buffer.
4. After the 25th Delta reading is stored in the buffer, the Delta test stops.

For the above example, 35 Delta cycles were performed. The first 10 Delta cycles filled the filter stack, and the next 25 Delta cycles filled the buffer.

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.

As shown in [Figure 6-1B](#), 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.

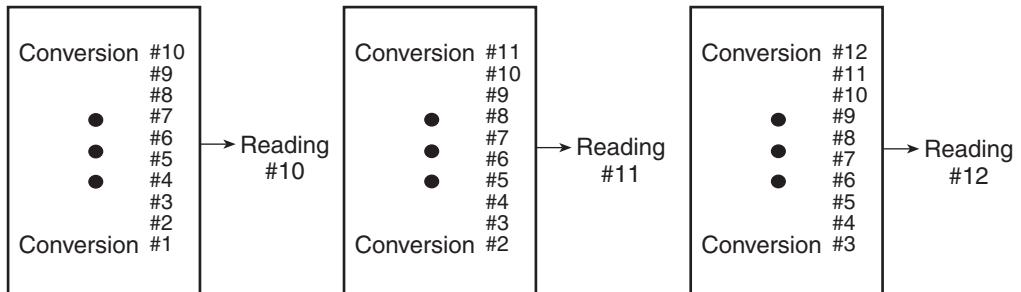
Differential Conductance – When using the repeating filter, the actual step size run for the test is the programmed step size divided by the filter count:

Step Size (repeating filter) = Programmed Step Size / Filter Count

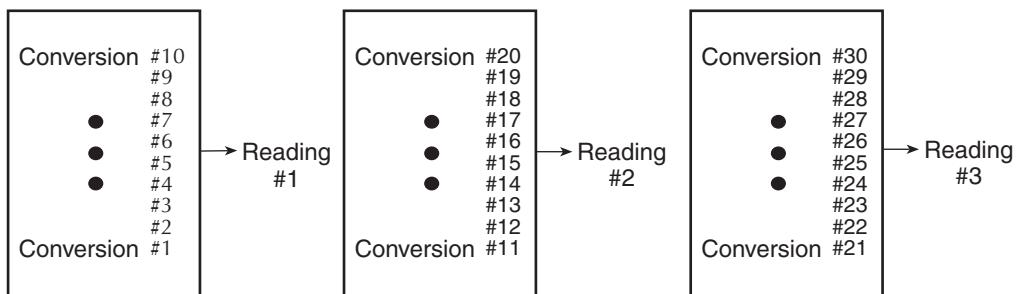
For example, assume the programmed step size is 10 μ A and the Filter Count is 10. When the Differential Conductance test is run, the actual step size will be 1 μ A (10 μ A / 10).

Figure 6-1
Digital filter types: moving and repeating

A) Moving filter (count = 10)



B) Repeating filter (count = 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 $\pm 1V$.

The noise window for the two filter types are compared in [Figure 6-2](#). For the filters using the Filter Window (1%), it also shows a window violation occurring after the sixth A/D conversion. When the voltage makes the transition from Voltage A to Voltage B, the window violation causes the “A” A/D conversions to be flushed out of the stack and replaced with copies of the first “B” A/D conversion.

NOTE The noise window cannot be set from the front panel. It can only be set using remote programming.

Filter example

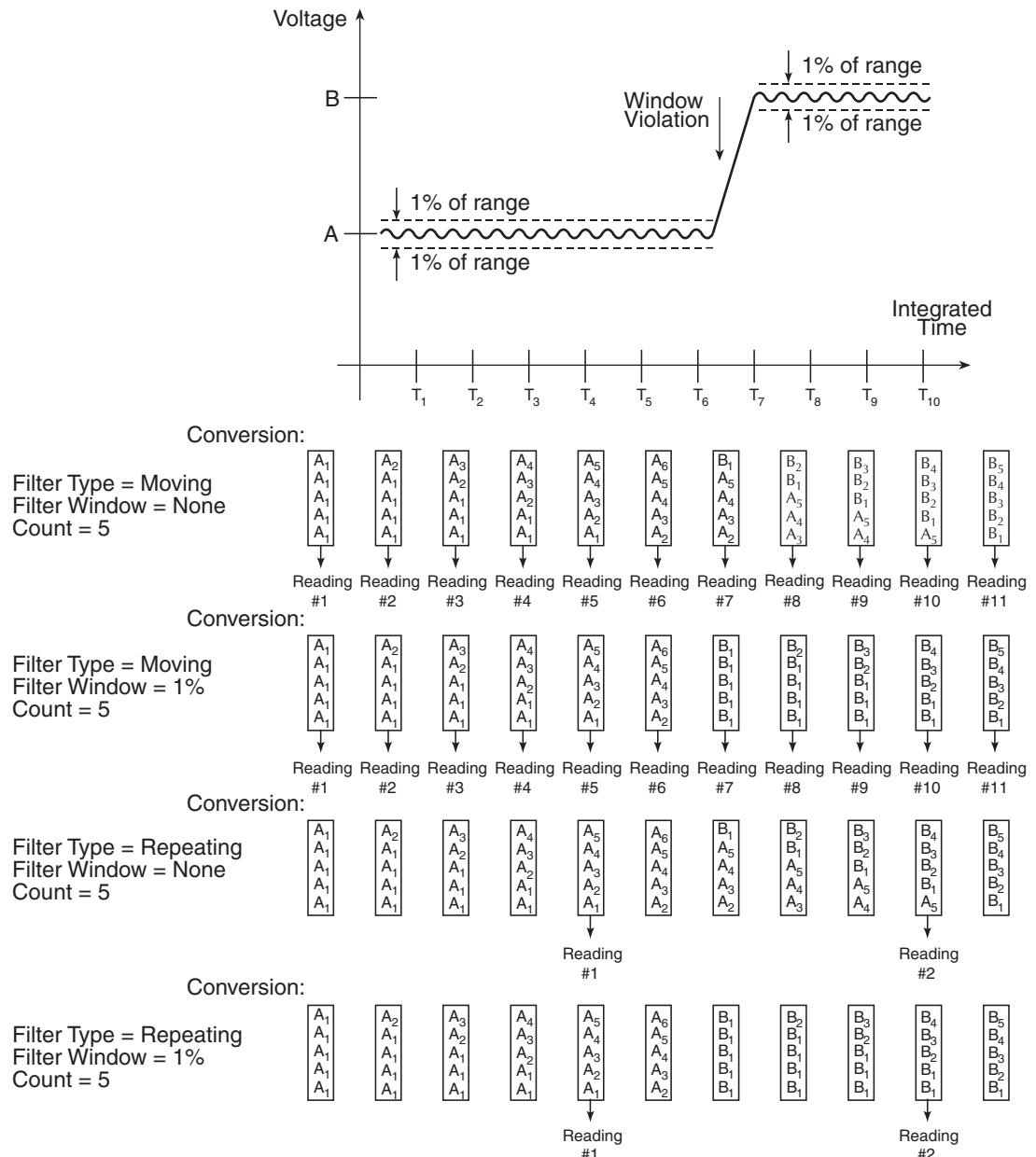
Filter Type - Moving

Filter Window = 0.01% of range

Filter Count = 10

Ten readings fill the stack to yield a filtered reading. Assume the next reading (which is the 11th) is outside the window. A reading will be processed (displayed); however, the stack will be loaded with that same reading. Each subsequent valid reading will then displace one of the loaded readings in the stack. The FILT annunciator will flash until 10 new readings fill the stack.

Figure 6-2
Filter window



Filter setup and control

When the averaging filter is enabled, the FILT annunciator turns on and bit B8 (Filter Settled) of the Operation Event Register resets to 0 (see [Section 11](#) for details on status structure).

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. The filter is configured from the average configuration menu as follows:

NOTE **The noise window cannot be set from the front panel. It can only be set using remote programming.**

1. Press the **CONFIG** key and then press the **AVG** key to access the filter configuration menu. Use the editing controls to make selections.
2. From the **TYPE** menu item, select the **MOVING** or **REPEAT** filter and press **ENTER**.
3. From the **COUNT** menu item, set the filter count (2 to 300) and press **ENTER**.
4. 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.

Table 6-2

Averaging filter commands

Command	Description	Default
SENSe [1] :AVERage:TCONtrol <name>	Select filter control. <name> = MOVing or REPeat	MOV
SENSe [1] :AVERage:WINDOW <NRf>	Set filter window as % of range: <NRf> = 0 to 10 (0 selects no window).	0.00
SENSe [1] :AVERage:COUNT <NRf>	Specify filter count (size). <NRf> = 2 to 300	10
SENSe [1] :AVERage [:STATe] 	Enable or disable averaging filter.	OFF

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) from the model 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 and controlling mX+b and m/X+b

To configure and control either of these math calculations, perform the following steps:

1. Press **CONFIG** and then **MATH** to enter the math configuration menu.
2. From the math menu, use the edit controls to select **NONE** (no math), **MX+B**, or **M/X+B**. Selecting **NONE** exits the menu structure.
3. After selecting a math calculation, the present scale factor will be displayed (factory default is M: +1.000000 ^).
4. Use the edit controls to set the scale factor digits, range multiplier*, and toggle the polarity sign.

* Range multipliers: P = 10^{-12} , $\eta = 10^{-9}$, $\mu = 10^{-6}$, $m = 10^{-3}$, $\wedge = 10^0$, K = 10^3 , M = 10^6 , G = 10^9 , T = 10^{12}

5. Press **ENTER** to enter the M value and display the offset (B) value (factory default is B: +0.000000 P).
6. Key in the offset value.
7. Press **ENTER** to set the B value and exit the menu.
8. To enable math, press the **MATH** key from the normal display. The MATH annunciator will turn on and the result of the calculation will be displayed.

Remote programming – Math

Commands for mX+b and m/X+b math calculations are listed in [Table 6-3](#).

Table 6-3
Math commands

Command	Description	Default
CALCulate [1] :FORMAT <name>	Select math format. ¹ <name> = NONE, MXB or RECiprocal	MXB
CALCulate [1] :KMATH:MMFactor <NRf>	Set “m” factor for mX+b and m/X+b. <NRf> = -9.99999e20 to 9.99999e20	1.0
CALCulate [1] :KMATH:MA1Factor <NRf>	Set “m” factor for mX+b and m/X+b. (same as MMFactor)	1.0
CALCulate [1] :KMATH:MBFactor <NRf>	Set “b” factor for mX+b and m/X+b. <NRf> = -9.99999e20 to 9.99999e20	0.0
CALCulate [1] :KMATH:MA0Factor <NRf>	Set “b” factor for mX+b and m/X+b. (same as MBFactor)	0.0
CALCulate [1] :STATE 	Enable or disable CALC1 calculation	OFF
CALCulate [1] :DATA [:LATest] ?	Return the latest CALC1 result. ²	
CALCulate [1] :DATA:FRESH?	Same as CALC1:DATA? except a reading can only be returned once. ²	

1. MXB selects the mX+b calculation and RECiprocal selects the m/X+b calculation.
2. While Delta, Pulse Delta, or Differential Conductance is running and Math is enabled, the CALC1:DATA:LAT? command can be sent to read the latest (last) post-math reading processed by the Model 622x. If this read command is sent before a new reading is available, the last reading will again be returned.

The CALC1:DATA:FRESH? command is the same as the CALC1:DATA:LAT? 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 CALC1:DATA:FRESH? is sent, error -230 Data corrupt or stale will occur.

For more information on these read commands, see “Data flow and read commands,” on page 5-13.

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 (see "[Buffer data elements," on page 6-12](#)). 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 (see "[Buffer statistics," on page 6-12](#)).

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 (see "[Buffer timestamp," on page 6-13](#)).

NOTE	Data (reading) flow from the Model 2182/2182A to the buffer of the Model 622x is explained in "Data flow," on page 5-13 and illustrated in Figure 5-6.
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Buffer characteristics

Buffer size

The buffer size automatically sets to accommodate the number 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.

The buffer size can be changed using **remote programming**. Buffer commands are documented in [Table 6-4](#). The following command demonstrates proper syntax to set buffer size.

Example – Configure buffer to store 500 delta readings:

```
TRACe:POINTs 500          ' Set buffer size to 500.
```

Buffer data elements

Data elements are stored along with each delta reading. The data elements for **front panel operation** are shown in [Figure 6-3](#). 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:

$$\text{PK-PK} = \text{MAX} - \text{MIN}$$

- **Mean** is the mean average of the buffer readings. Mean is calculated as follows:

$$y = \sum_{i=1}^n \frac{X_i}{n}$$

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:

$$y = \sqrt{\frac{\sum_{i=1}^n (Avg - X_i)^2}{n-1}}$$

Where: X_i is a stored reading.
 n is the number of stored readings.
 Avg is the mean of the buffer readings.

NOTE If any readings stored in the buffer are the result of an overflow or compliance condition, the buffer statistics calculation will not be performed. Buffer recall via front panel operation will show a series of dashes in place of the requested buffer statistics value. For remote operation, the corresponding buffer statistics will be represented by the value +9.91e37.

See "Recall," on page 6-14 for details on recalling buffer statistics.

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. For **front panel operation**, the absolute timestamp is used for every buffer reading.

For **remote programming**, the timestamp can be set for absolute or delta. The delta timestamp indicates the time between readings. Buffer commands are documented in [Table 6-4](#). The following command demonstrates proper syntax to set the timestamp.

Example – Select the delta timestamp:

TRACe:TSTamp:FORMAT DELta ' Select the delta timestamp.

Storing readings

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

For **remote programming**, buffer feed can be pre-math readings or post-math readings, or the buffer can be disabled.

The buffer commands are documented in [Table 6-4](#). The following example demonstrates a simple command sequence to configure the buffer.

Example – Configure the buffer to store pre-math delta readings. Storage will start when Delta, Pulse Delta, or Differential Conductance is started.

```
TRACe : CLE          ' Clear buffer of readings.  
TRACe : FEED SENS1    ' Set buffer feed for pre-math delta readings.  
TRACe : FEED:CONTrol NEXT ' Enable buffer.
```

Recall

For **front panel operation**, perform the following steps to view stored readings and buffer statistics:

1. Press **RECALL**. The reading stored in buffer location 0 will be displayed along with the current source value and the timestamp.
2. As shown in [Figure 6-3](#), use the edit keys to navigate through the buffer to view stored readings.

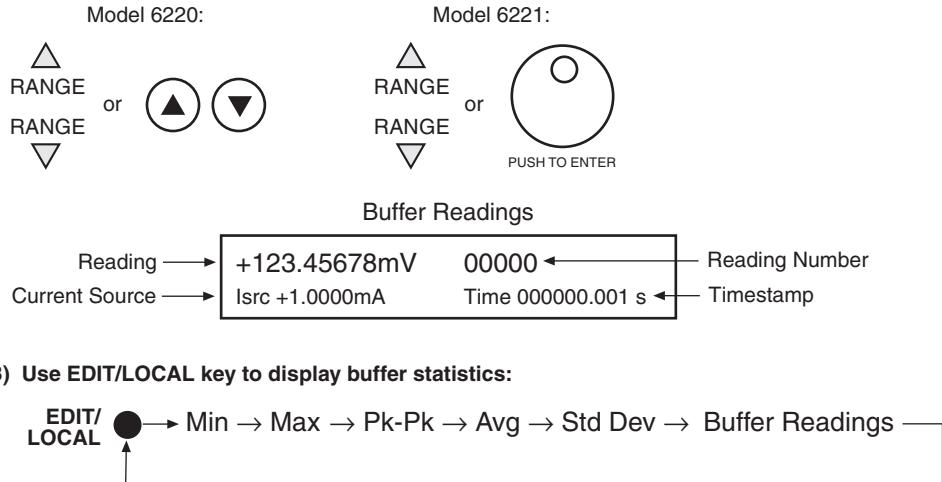
NOTE For front panel operation, compliance is not indicated for buffer readings. For remote programming, the compliance state (in or out) for each reading is returned if the COMP (compliance) data element is enabled. For details on data elements, see “[FORMAT subsystem](#),” on [page 13-4](#).

3. To view buffer statistics, use the **EDIT/LOCAL** key. 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.
4. When finished, press **EXIT** to return to the normal display.

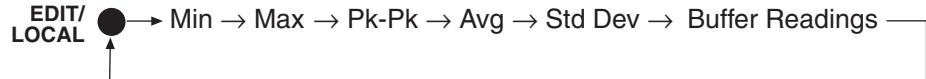
NOTE The buffer can be cleared by pressing the **CONFIG** key and then the **RECALL** key. With the “CLEAR BUFFER?” message displayed, select YES.

Figure 6-3
Buffer recall

A) Front panel edit keys to display buffer readings:



B) Use EDIT/LOCAL key to display buffer statistics:



For **remote programming**, the commands to recall delta readings and statistics are documented in [Table 6-4](#). The following example demonstrates the command sequence read buffer readings and statistics.

Example – Request all stored delta readings, and calculate and return the mean average:

TRACe:DATA?	‘ Request all stored delta readings.
CALC2:FORMAT MEAN	‘ Select the mean buffer calculation.
CALC2:STATE ON	‘ Enable buffer calculation.
CALC2:IMMEDIATE	‘ Perform the mean calculation.
CALC2:DATA?	‘ Request the result of the mean calculation.

Remote programming – Buffer

The commands associated with buffer operation are listed in [Table 6-4](#).

Table 6-4
Buffer commands

Command	Description	Default
TRACe : CLear	Clear readings from buffer.	Note 1
TRACe : FREE?	Query memory bytes available in buffer.	
TRACe : POINTs <n>	Specify buffer size (number of readings to store). <n> = 1 to 65536	Note 2
TRACe : POINTs : ACTual?	Query number readings stored in the buffer.	
TRACe : NOTify <NRf>	Specify number of stored readings that will set the Trace Notify bit (B6) of the measurement event register. Must be less than the TRACe:POINTs value. ¹ <NRf> = 1 to (TRAC:POIN -1)	Note 3
TRACe : FEED <name>	Select source (feed) for buffer readings. ² <name> = SENS1,CALC1 or NONE	CALC1
TRACe : FEED : CONTrol <name>	Set buffer control. ³ <name> = NEXT or NEVer	NEV
TRACe : TStamp : FORMat <name>	Select timestamp format ⁴ <name> = ABSolute or DELTa	ABS
TRACe : DATA?	Request all readings in buffer ⁵	
TRACe : DATA : TYPE?	Query type of readings stored in buffer. ⁵ Returns NONE, DELT, DCON, or PULS	
TRACe : DATA : SElected? <start>, <count>	Request list of stored readings. ⁵ Requires a start value and count value.	
FORMAT : ELEMents <list>	Specify data elements for TRACe:DATA? response. <list> = READING, TStamp, UNITS, RNUMBER, SOURCE, COMPliance, AVOLTage. Also accepts DEFault or ALL	READ, TST
CALCulate2 : FORMat <name>	Select buffer statistic: <name> = MEAN, SDEVIation, MAXimum, MINimum, or PKPK ⁶	MEAN
CALCulate2 : STATE 	Enable or disable calculation: = ON or OFF	OFF
CALCulate2 : IMMEDIATE	Perform the selected calculation on buffer readings.	
CALCulate2 : DATA?	Read the result of the buffer statistic ⁷	

Notes:

1. SYSTEM:PRESet and *RST have no effect on the TRACe commands in this table. The listed defaults are power on defaults.
2. The buffer size is set to equal the number of delta readings to be performed (see "Buffer size," on page 6-12).
3. The default parameter is one-half the set buffer size (TRACe:POINTs / 2).

1. TRACe:NOTify <NRf>
<NRf> = 1 to (TRAC:POIN -1)

Use this command to specify the number of stored readings that will set bit B6 (Trace Notify) of the Measurement Event Register. With Service Request Enable Register properly configured, an SRQ will be generated when the specified Trace Notify value is exceeded. See [Section 11](#) for details on status structure.

The maximum valid parameter value for this command is one less than the present buffer size (which can be set by the TRACe:POINTs command). For example, assume a delta test is configured to store 1000 readings. For this buffer size, the maximum valid parameter value for TRACe:NOTify is 999 (1000-1). When an invalid parameter value is specified, the command is ignored and causes error -222 Parameter data out of range.

When the delta test is configured for infinite cycles, Bit B6 (Trace Notify) of the measurement event register will clear after the 65,536th reading is stored and the buffer wraps around to the beginning.

2. TRACe:FEED <name> parameters:

SENS1 – Pre-math delta readings are stored in the buffer.

CALC1 – Post-math delta readings. These are the results of the mX+b or m/X+b (see "[Math, on page 6-9](#) for details).

NONE – Disables the buffer.

3. TRACe:FEED:CONTrol <name> parameters:

NEXT – Enables the buffer and turns on the asterisk (*) annunciator. After the buffer fills, the asterisk annunciator turns off.

NEVer – Disables the buffer.

4. TRACe:TStamp:FORMAT <name> parameters:

ABSolute – Each timestamp is referenced to the first reading stored in the buffer.

DELTa – Timestamps provide the time between each buffer reading.

Note that the timestamp will only appear in a buffer reading if TStamp is one of the selected data format elements. See [Section 13](#) for details on Format.

5. Buffer read commands:

TRACe:DATA? – Use this read command to return all stored buffer readings. The data elements that are included for each buffer reading depends on the selected elements for FORMAT:ELEMENTS command (see [Section 13](#) for details).

TRACe:DATA:TYPE? – Use this query command to determine what kind of readings are stored in the buffer. It returns NONE (no reading in buffer), DELT (Delta readings), DCON (Differential Conductance readings, or PULS (Pulse Delta readings).

TRACe:DATA:SELected? <start>, <count> – With this read command, you can specify a list of consecutive buffer readings to return. Two parameters are required for this command: <start> and <count>. The first reading in the buffer is Rdg #0. Example: To return the first 20 readings in the buffer, send the following command: TRACe:DATA:SELected? 0, 20.

6. Buffer data elements:

The following seven data elements can be included for each buffer location: READING, TStamp, UNITS, RNUMBER, SOURce, COMPliance, and AVOLtage.

Elements in the list must be separated by a comma. At least one element must be in the list. Elements not listed will not be included in response message for TRACe:DATA?.

As an alternative to listing the data elements, the DEFault or ALL parameter can be used. DEFault selects the READING and TStamp elements, and ALL selects all seven elements.

NOTE Details on data elements are provided in [Section 13](#).

7. Buffer statistics read command:

CALC2:DATA? – Use this read command to read the result of the calculation. If there is a significant amount of data in the buffer, some statistic operations may take too long and cause a bus timeout error. To avoid this, send CALC2:DATA? and then wait for the MAV (message available) bit in the Status Byte Register to set before addressing the Model 622x talk. See [Section 6](#) for details.

Wave Functions (6221 Only)

Section 7 topics

Overview, page 7-2

Section overview, page 7-2

Wave function overview, page 7-2

Wave function characteristics, page 7-3

Setting waveform parameters, page 7-4

Editing parameters, page 7-4

Amplitude and offset editing, page 7-4

Amplitude, page 7-5

Frequency, page 7-6

Offset, page 7-6

Duty cycle, page 7-7

Amplitude units, page 7-7

Phase marker, page 7-9

Duration, page 7-10

Arbitrary waveforms, page 7-10

Using the external low jitter trigger mode,
page 7-10

Front panel wave function operation, page 7-14

Using the wave function menu, page 7-14

Generating a sine wave, page 7-16

Generating a square wave, page 7-17

Generating a ramp waveform, page 7-18

Generating an arbitrary waveform, page 7-19

Using the external trigger mode, page 7-20

Remote wave function operation, page 7-21

Programming sine waves, page 7-22

Programming square waves, page 7-23

Programming ramp waveforms, page 7-24

Programming arbitrary waveforms, page 7-25

Programming an externally triggered waveform,
page 7-25

SCPI commands — wave functions, page 7-27

Overview

Section overview

Following a brief “[Wave function overview](#)” for the four types of waveforms (sine, square wave, ramp, and arbitrary), the documentation in this section provides detailed information on characteristics, front panel operation, and SCPI command programming for each type of wave function as follows:

- [Wave function characteristics, page 7-3](#)
- [Front panel wave function operation, page 7-14](#)
- [Remote wave function operation, page 7-21](#)

Wave function overview

The Model 6221 Current Source can generate four general types of current waveforms. The amplitude range for all functions is from 1pA to 105mA peak (210mA peak-to-peak). Waveform types include:

Sine function – The Model 6221 can generate sine wave currents with a frequency range from 1mHz to 100kHz.

Square wave function – The frequency range for square waves is 1mHz to 100kHz with variable duty cycle.

Ramp wave function – The Model 6221 can generate ramp or triangle waves with a frequency from 1mHz to 100kHz with variable duty cycle.

Arbitrary waveform function – The Model 6221 can store up to four user-defined arbitrary waveforms with 2 to 65,535 points with a frequency range of 1mHz to 100kHz. Note that arbitrary waveforms can be defined only via remote, but once defined, can be selected from the front panel.

Wave function characteristics

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

Wave function	Characteristics
Sine wave	Frequency: 1mHz to 100kHz (page 7-5) Amplitude: 1pA to 105mA peak (page 7-5) Range: 2nA to 100mA (page 7-5) Offset: 0 to \pm 105mA (page 7-6) Phase marker: 0° to 360° (page 7-9) Duration: 100ns to 999999.999s (page 7-10)
Square wave	Frequency: 1mHz to 100kHz (page 7-5) Amplitude: 1pA to 105mA peak (page 7-5) Range: 2nA to 100mA (page 7-5) Offset: 0 to \pm 105mA (page 7-6) Duty cycle: 0 to 100% (page 7-7) Phase marker: 0° to 360° (page 7-9) Duration: 100ns to 999999.999s (page 7-10)
Ramp wave	Frequency: 1mHz to 100kHz (page 7-5) Amplitude: 1pA to 105mA peak (page 7-5) Range: 2nA to 100mA (page 7-5) Offset: 0 to \pm 105mA (page 7-6) Duty cycle: 0 to 100% (page 7-7) Phase marker: 0° to 360° (page 7-9) Duration: 100ns to 999999.999s (page 7-10)
Arbitrary wave	Frequency: 1mHz to 100kHz (page 7-5) Amplitude: 1pA to 105mA peak (page 7-5) Range: 2nA to 100mA (page 7-5) Offset: 0 to \pm 105mA (page 7-6) Number of points: 2 to 65,535 Phase marker: 0° to 360° (page 7-9) Duration: 100ns to 999999.999s (page 7-10)

Setting waveform parameters

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 menu.

Examples:

- Press FREQ while editing the 1's digit on 001000.000 Hz line. Press FREQ again while the 0 is flashing, and the cursor moves to the 0.1 place.
- Press AMPL, and the 100's place is flashing for Amplitude. Press AMPL to edit the sign or FREQ to edit the 10's place.

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). Note that the offset menu formatting will be the same as the last Amplitude range. The offset menu formatting cannot be changed with the range arrows. It is locked to be on the same range format as you had for setting the Amplitude. If you need more flexibility, such as the ability to have 1 μ A offset and 100mA source amplitude, use remote operation.

The range formatting of the amplitude and offset is a convenience. It does not dictate the actual range that will be used for waveform operation. The range used is controlled by the RANGING menu (or SOUR:WAVE:RANGing command). Note that if a previously set offset value is too high to fit in the offset menu after changing the Amplitude range, then the offset menu will show the limit value instead. This is illustrated in the following example:

1. Start by setting the Amplitude range to 100mA and an Amplitude value of 50mA.
2. Go into CONFIG->WAVE->OFFSET, and set an offset of 10mA.
3. Return to the Amplitude menu, and now select an amplitude of 100nA.
4. When you return to the CONFIG->WAVE->OFFSET menu, the display will suggest +210 nA, the maximum allowed on this range.

Amplitude

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.

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. For example, if the amplitude setting is 50mA, the 100mA source range will be used.
- **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. The examples below will help to clarify.

Example 1

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.

Example 2

Ranging: BEST

Amplitude: 10mA peak

Offset: 0mA

ARB values: range from 0.5 to -0.5

These settings will generate the same waveform as Example 1 except the peak-to-peak value will be 10mA on the 20mA range.

Example 3

Ranging: BEST

Amplitude: 20mA peak

Offset: 0.2mA

ARB values: range from +0.1 to -0.1

These settings will generate a waveform with a peak-to-peak value of 4mA on the 20mA range. Note that this waveform with no offset would use the 2mA range but uses the 20mA range since the range is set based on the amplitude and offset values.

Example 4

Ranging: BEST

Amplitude: 1mA

Offset: 0mA

ARB values: range from +1 to -1

These settings will generate a waveform with a peak-to-peak value of 2mA on the 2mA range.

Example 5

Ranging: FIXED

Amplitude: 1mA

Offset: 0mA

ARB values: range from +1 to -1

Current range: 20mA

These settings will generate a waveform with a peak-to-peak value of 2mA on the 20mA range. Note that if BEST was used for ranging, the waveform would have been generated on the 2mA range as in Example 4 above.

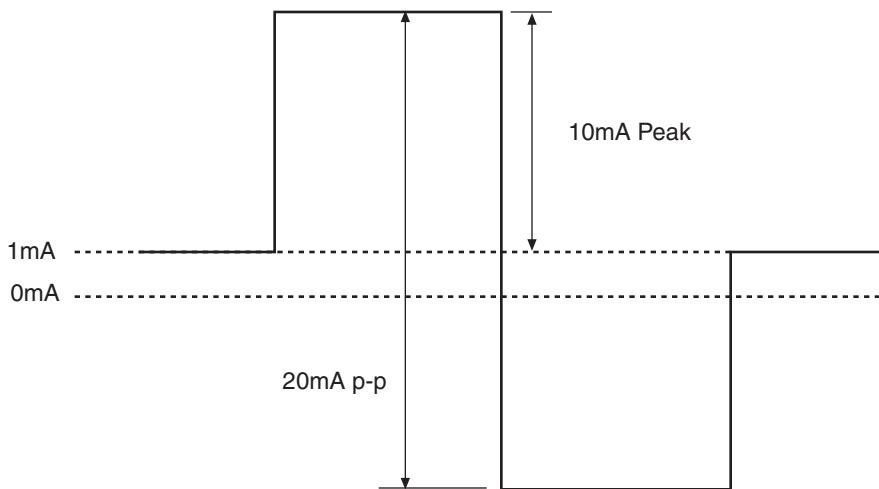
Frequency

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

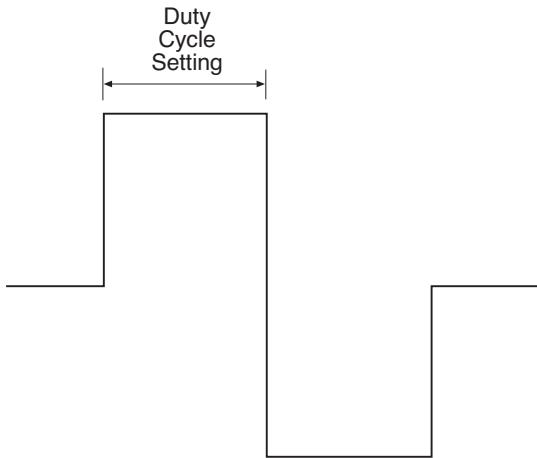
For a square wave (Figure 7-2A), the duty cycle setting is the portion of the total cycle that the wave is high relative to the period of the waveform. For a ramp waveform (Figure 7-2B), the duty cycle corresponds to the fraction of the total wave cycle that is rising. A 50% duty cycle corresponds to a symmetric triangle wave. The left waveform in Figure 7-2B has a 100% duty cycle, the center waveform has 0% duty cycle, and the right waveform has a 50% duty cycle.

Amplitude units

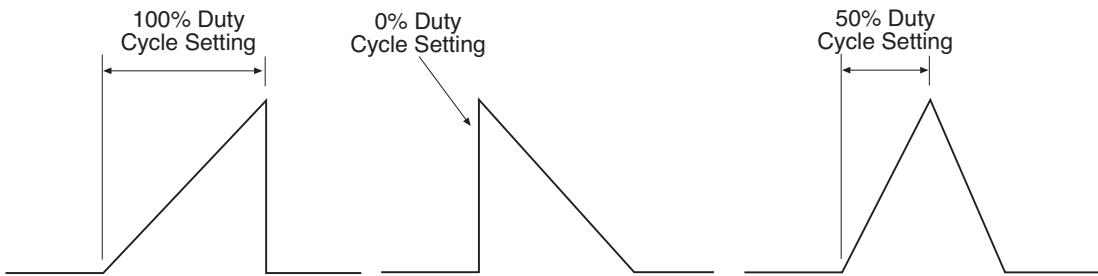
The front panel allows setting wave amplitude in either RMS or peak units. The default is peak. The RMS selection will only apply for sine wave ($RMS = 0.70710678 \times \text{peak}$) or triangle wave ($RMS = 0.57735027 \times \text{peak}$) and be ignored for other waveform types. The wave amplitude units are available for front panel only; remote operations always receive and return the units in peak. The choice between RMS and peak from the front panel is not saved as part of a stored setup. Power cycling the instrument always resets the front panel menu to the default of peak. When editing the wave amplitude, the label "Peak" or "RMS" will be displayed if the waveform type is affected by the RMS vs. peak selection (ramp or sine waves only).

Figure 7-2
Duty cycle

A. Square Wave Duty Cycle



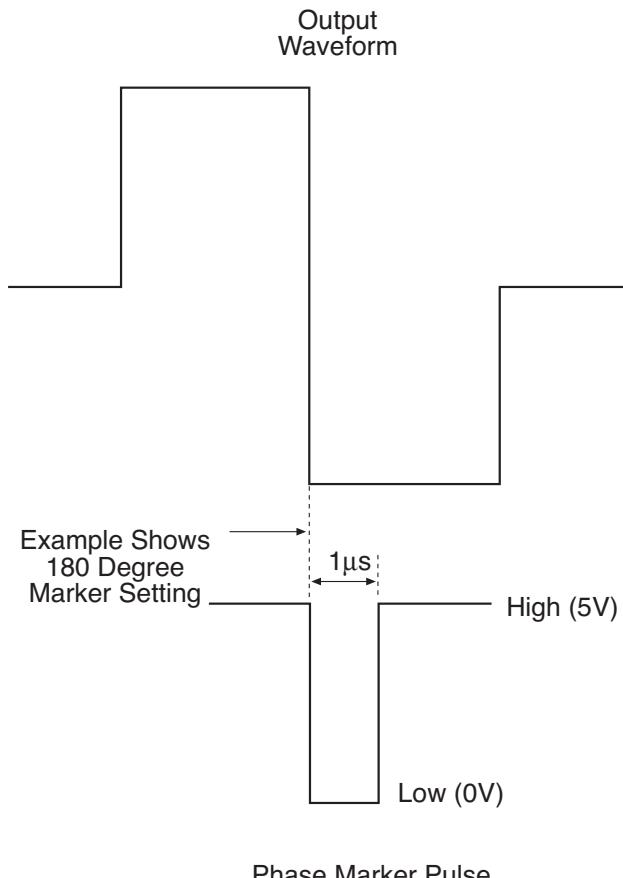
B. Ramp Wave Duty Cycle



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 1 μ s pulse that appears on the selected line of the external trigger connector (see “External trigger connector,” on page 8-13 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 9999999900 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 9999999900.

If you change from INFinite from the front panel to a numeric setting, the duration will default to 10 seconds or 10000 cycles as determined by the last selected duration type (time or cycles).

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.

Arbitrary waveforms

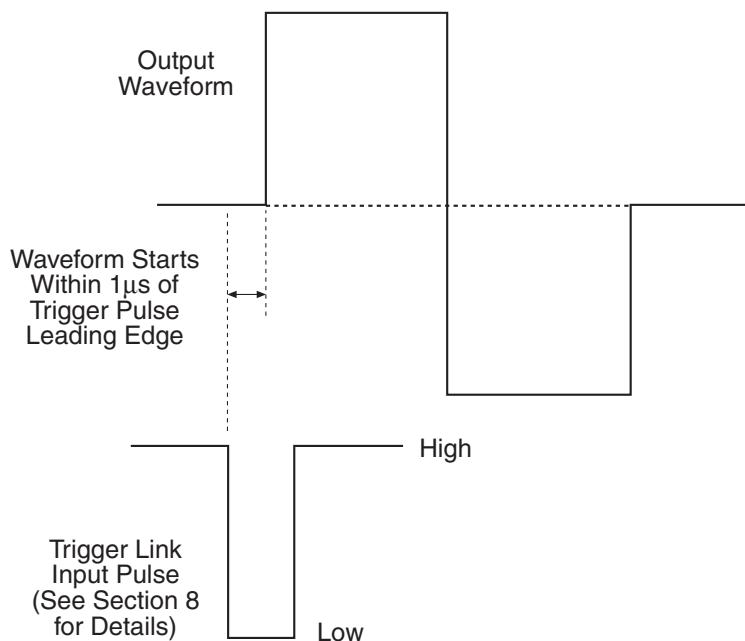
A total of five arbitrary waveforms can be defined via remote. One is designated as volatile and is stored in location 0. Locations 1-4 are stored in flash memory and saved across power cycles. At power-up, location 0 is empty and cannot be used until it is populated with waveform data. In order to save arbitrary data points, you must first store them in location 0 and then copy them to the desired location 1-4.

Using the external low jitter trigger mode

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 (see “[External triggering](#),” on page [8-13](#) for detailed information). 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 1μs of the falling edge of the trigger pulse (see [Figure 7-4](#)).

To use this mode, you must first enable it using a remote command or from the front panel. If the front panel approach is taken, the desired trigger link line can also be set at that time. A separate command is required to select the trigger link input line over the bus.

Figure 7-4
Waveform triggering



Front panel external trigger control

External trigger selections are included with the waveform configuration menu shown in [Table 7-2 on page 7-15](#). An example of how to set up this mode is detailed in “[Using the external trigger mode](#),” on page 7-20.

Remote external trigger control

Remote commands to control the external trigger mode are listed in [Table 7-4 on page 7-27](#), and a program example is shown in “[Programming an externally triggered waveform](#),” on page 7-26.

Controlling waveform retriggering behavior

By default, the waveform will restart immediately upon each sequential external hardware trigger in this mode. If the waveform output has not yet run to completion, a new hardware trigger will preempt the current waveform and restart the waveform immediately (see [Figure 7-5A](#)). Alternatively, the unit can be configured to ignore triggers while a waveform is in process. If set this way, the current waveform will be output to completion before the unit will accept another trigger (see [Figure 7-5B](#)). Whether or not the unit will ignore attempts to retrigger it while running can be controlled over the front panel or bus.

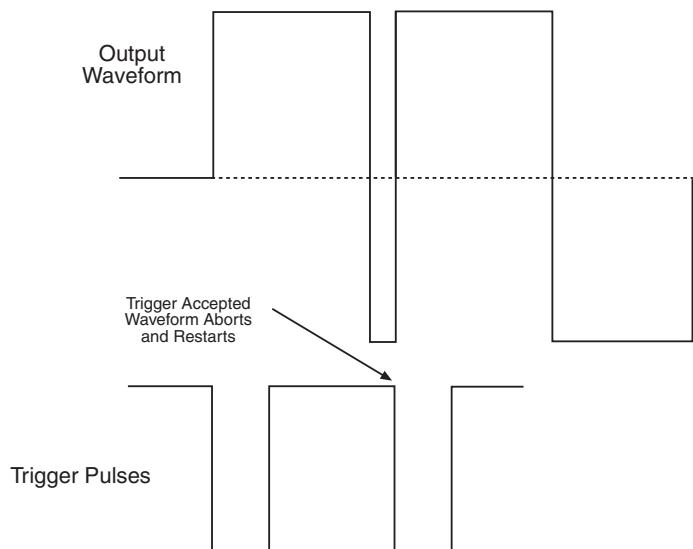
Setting the inactive value

In the external trigger mode, the output remains enabled while the unit waits for an external trigger. Before and after triggered waveforms, the inactive value will control the current output. It can be set to any value between -1.00 and +1.00. The value is interpreted the same as data values used to specify arbitrary waveform definitions where -1 represents the maximum negative current flow and +1 represents the maximum positive current. Any value in between is linearly mapped between these two extremes to one of 65,536 discrete levels.

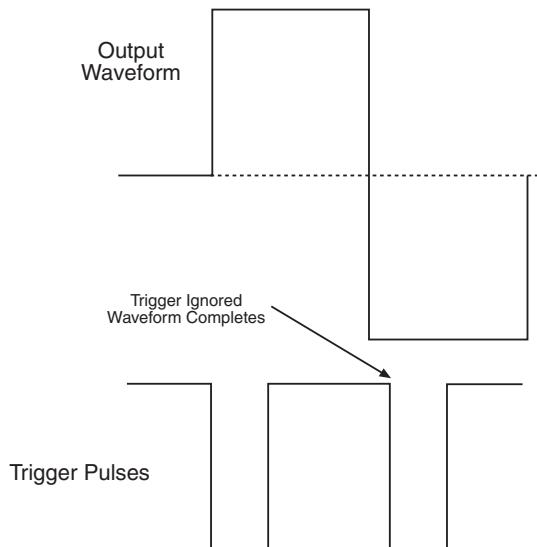
Using the wave generator in external low jitter trigger mode

Under normal operation, the waveform generator is armed and then triggered to begin outputting the waveform immediately. In the external low jitter trigger mode, the Model 6221 must be similarly armed and triggered. Triggering the unit will turn on the output, but it will not start the waveform. Once armed and triggered in the this mode, the unit will wait for an external trigger pulse on the specified trigger link line before starting the waveform.

Figure 7-5
Waveform retrigerring



A. Waveform Aborts in Restart Mode (Default)



B. Waveform Completes in Ignore Mode

Front panel wave function operation

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 armed.

Using the wave function menu

To configure wave functions, press CONFIG then WAVE, then make your selections from [Table 7-2](#). See the detailed procedures for each wave function type.

Table 7-2
Wave function configuration menu

Menu selection	Description
TYPE SINE SQUARE RAMP ARBx	Select waveform type: Select sine wave. Select square wave. Select ramp wave. Select user-defined arbitrary wave. * Where: x = 0 to 4.
OFFS	Enter DC offset (0 to $\pm 105\text{mA}$).
AMPL-UNIT	Select amplitude units (PEAK or RMS). (Front panel only.)
DUTY-CYCLE	Enter duty cycle (0 to 100%; square and ramp only).
PH-MKR STATE OUTPUT-POINT OUTPUT-LINE	Select phase marker and line: Turn phase marker ON or OFF. 0 to 360° Set trigger output line (OFF, #1 to #6).
DURATION INFINITE SET-TIME SET-CYCLES	Set duration of waveform: Continuous waveform. Set duration in time (0.001s to 999999.999s). Set duration in cycles (0.001 to 9999999900).
RANGING BEST-FIXED FIXED	Select ranging for selected wave function: Select best range based on wave amplitude. Stay on fixed range when waveform is armed.
MORE	Expand to show additional menu items:
TRIG-MODE MAN/BUS NONE TLNK-#1 #2 #3 #4 #5 #6	Configure low jitter external waveform triggering: Disable external trigger mode (default). Enables external trigger mode with no line selected. Enables external trigger on trigger link line 1. Enables external trigger on trigger link line 2. Enables external trigger on trigger link line 3. Enables external trigger on trigger link line 4. Enables external trigger on trigger link line 5. Enables external trigger on trigger link line 6.
RE-TRIG IGNORE-TRIG RESTART-IMMEDIATELY	Configure response to external retriggering: Ignore subsequent triggers while outputting a wave. Restart waveform immediately upon each trigger.
INACTIVE-VAL	Set output value before and after triggered waveforms.

* Arbitrary waveforms can only be defined via remote. Waveform triggering with firmware A03 and later.

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 a square 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 SQUARE, then press ENTER to choose a square wave.
 - d. To add a DC offset, select OFFSET from the CONFIGURE WAVEFORM menu, then set the offset as desired.
 - e. To set the duty cycle, select DUTY-CYCLE from the CONFIGURE WAVEFORM menu, then set the duty cycle as desired.
 - f. 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.
 - g. Again from the CONFIGURE WAVEFORM menu, choose RANGING, press ENTER, then select BEST-FIXED or FIXED as desired.
 - h. From the CONFIGURE WAVEFORM menu, select DURATION, then set the desired waveform duration.
 - 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 a ramp waveform

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 RAMP, then press ENTER to choose a square wave.
 - d. To add a DC offset, select OFFSET from the CONFIGURE WAVEFORM menu, then set the offset as desired.
 - e. To set the duty cycle, select DUTY-CYCLE from the CONFIGURE WAVEFORM menu, then set the duty cycle as desired.
 - f. 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.
 - g. Again from the CONFIGURE WAVEFORM menu, choose RANGING, press ENTER, then select BEST-FIXED or FIXED as desired.
 - h. From the CONFIGURE WAVEFORM menu, select DURATION, then set the desired waveform duration.
 - i. From the CONFIGURE WAVEFORM menu, select AMPL-UNIT, then set the desired amplitude units (PEAK or RMS).
 - j. 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

NOTE

Arbitrary waveforms cannot be defined from the front panel, but they can be generated once defined by using the general procedure below.

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.

Using the external trigger mode

1. Set up the desired waveform operation using the previous procedures.
2. **Enable the external trigger mode:**
 - a. Press CONFIG then WAVE to enter the wave function configuration menu.
 - b. Navigate the MORE and TRIG-MODE menu selections.
 - c. To disable the external trigger mode (normal operation), select MAN/BUS.
 - d. To enable the external trigger mode, select NONE (no trigger link line). or choose the desired trigger link line # (1-6) to use as the input trigger source.
3. **Set retrigger behavior:**
 - a. Navigate the MORE menu, then select RE-TRIG.
 - b. Select IGNORE-TRIG to ignore retrigger attempts and allow the running waveforms to complete.
 - c. If RESTART IMMEDIATELY is selected, another trigger will cause the waveform to restart immediately when retrigged.
4. **Set inactive value (value before and after triggered waveforms):**
 - a. Navigate the MORE menu, then select INACTIVE-VAL.
 - b. Using the arrow keys, set the value between -1.0000 and +1.0000.
5. **Arm and trigger the waveform:**
 - a. Press WAVE to arm the waveform generator.
 - b. Press TRIG to trigger the unit. The Model 6221 will turn on its output and begin to source an amount of current controlled by the inactive value. When an external trigger is detected on the specified trigger link line, the generator will begin to output the waveform.

Remote wave function operation

Procedures for programming and generating waveforms for each of the four 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](#),” on [page 7-27](#) for details on wave function commands.

NOTE User setups cannot be saved or recalled while Wave is armed or running. The *SAV and *RCL commands will generate error +413 Not allowed with mode armed.

Table 7-3
Waveform example parameters

Waveform	Parameters for waveform examples
Sine wave (page 7-22)	Frequency: 1kHz Amplitude: 10mA Offset: 1mA Phase marker: off Duration: 5s
Square wave (page 7-23)	Frequency: 10kHz Amplitude: 1mA Offset: 0 Duty cycle: 50% Phase marker: 180°, line 1 Duration: 10s
Ramp wave (page 7-24)	Frequency: 50kHz Amplitude: 5mA Offset: 0 Duty cycle: 25% Phase marker: 90°, line 1 Duration: 15s
Arbitrary wave (page 7-25)	Arbitrary points: -0.5, -0.25, 0, 0.3, 0.4 Range: best fixed Frequency: 100kHz Amplitude: 25mA Offset: 0 Phase marker: Off Duration: 20s

Programming sine waves

1. Restore defaults with this command:

```
*RST
```

2. Configure the waveform.

Examples – The following commands configure 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 square waves

1. Restore defaults with this command:

```
*RST
```

2. Configure the waveform.

Examples – The following commands configure a 10kHz square wave with an amplitude of 1mA, 0mA offset, 50% duty cycle, 180° phase marker, and 10 second duration:

SOUR:WAVE:FUNC SQU	' Select square wave.
SOUR:WAVE:FREQ 1e4	' Set frequency to 10kHz.
SOUR:WAVE:AMPL 1e-3	' Set amplitude to 1mA.
SOUR:WAVE:OFFS 0	' Set offset to 0.
SOUR:WAVE:DCYC 50	' Set duty cycle to 50%.
SOUR:WAVE:PMAR:STAT ON	' Turn on phase marker.
SOUR:WAVE:PMAR 180	' Set phase marker to 180°.
SOUR:WAVE:PMAR:OLIN 1	' Use line 1 for phase marker.
SOUR:WAVE:DUR:TIME 10	' 10 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 ramp waveforms

1. Restore defaults with this command:

```
*RST
```

2. Configure the waveform.

Examples – The following commands configure a 50kHz ramp wave with an amplitude of 5mA, 0mA offset, 25% duty cycle, 90° phase marker, and 15 second duration:

SOUR:WAVE:FUNC RAMP	‘ Select ramp wave.
SOUR:WAVE:FREQ 5e4	‘ Set frequency to 50kHz.
SOUR:WAVE:AMPL 5e-3	‘ Set amplitude to 5mA.
SOUR:WAVE:OFFS 0	‘ Set offset to 0mA.
SOUR:WAVE:DCYC 25	‘ Set duty cycle to 25%.
SOUR:WAVE:PMAR:STAT ON	‘ Turn on phase marker.
SOUR:WAVE:PMAR 90	‘ Set phase marker to 90°.
SOUR:WAVE:PMAR:OLIN 1	Use line 1 for phase marker.
SOUR:WAVE:DUR:TIME 15	15 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 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, ' Define arbitrary data points in  
0, 0.3, 0.4 ' 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.
```

Programming an externally triggered waveform

1. Restore defaults with this command:
*RST
2. Configure the desired waveform using one of the procedures previously described for a sine, square, ramp, or arbitrary waveform.
3. Configure the low jitter external trigger mode.

Examples – The following commands configure the selected waveform to be output following each pulse received on trigger link line 1. If a subsequent trigger pulse is received while the waveform is being output, the Model 6221 will immediately terminate the current wave and restart the waveform. In between waveforms, the unit will output zero current.

```
SOUR:WAVE:EXTR:ENAB ON      ' Turn on external trigger mode.  
SOUR:WAVE:EXTR:ILIN 1       ' Use TLINK Line 1 as input trigger.  
SOUR:WAVE:EXTR:IGN OFF      ' Restart wave on retrigger attempts.  
SOUR:WAVE:EXTR:IVAL 0.00     ' Output zero current between waves.
```

4. Arm and trigger the waveform to enable the output. The Model 6221 will wait for an external trigger pulse on the specified trigger link line and start the waveform within 1 μ s:

```
SOUR:WAVE:ARM              ' Arm waveform.  
SOUR:WAVE:INIT              ' Enable output, wait on external triggers.
```

5. To stop the Model 6221 from responding to triggers and immediately stop any waveform being generated by turning the source output off, send this command:

```
SOUR:WAVE:ABOR              ' Stop generating waveforms.
```

SCPI commands — wave functions

Commands for wave functions are listed in [Table 7-4](#). Additional information for each command is provided in notes that follow the tables.

Table 7-4
Waveform function commands

Command	Description	Default
SOURce [1] :WAVE:FUNCTION <name>	Selects wave function. ¹ <name> = SINusoid, SQUare, RAMP, or ARbitraryX	SIN
SOURce [1] :WAVE:DCYCLE <NRf>	Sets duty cycle. ² <NRf> = 0 to 100 (%)	50
SOURce [1] :WAVE:AMPLitude <NRf>	Sets amplitude. ³ <NRf> = 2e-12 to 0.105 (A peak)	1e-3
SOURce [1] :WAVE:FREQuency <NRf>	Sets frequency. ⁴ <NRf> = 0 to 1e5 (Hz)	1e3
SOURce [1] :WAVE:OFFset <NRf>	Sets offset. ⁵ <NRf> = -0.105 to 0.105 (A)	0
SOURce [1] :WAVE:RANGing <name>	Selects ranging mode. ⁶ <name> = BEST or FIXed	BEST
SOURce [1] :WAVE:PMARk <NRf>	Sets marker phase. ⁷ <NRf> = 0 to 360 (deg.)	180
SOURce [1] :WAVE:PMARk:STATE 	Enables/disables phase marker. ⁷ = ON or OFF	OFF
SOURce [1] :WAVE:PMARk:OLIne <NRf>	Sets phase marker trigger line. ⁷ <NRf> = 1 to 6	3
SOURce [1] :WAVE:ARBitrary:DATA <NRf> [,<NRf>, ... <NRf>]	Defines arbitrary data points. ⁸ <NRf> = -1 to +1 (100 points max.)	
SOURce [1] :WAVE:ARBitrary:APPend <NRf> [,<NRf>, ... <NRf>]	Appends arbitrary data points. ⁹ <NRf> = -1 to +1 (100 points max. per instance of command)	
SOURce [1] :WAVE:ARBitrary:COPY <NRf>	Copies arbitrary points to NVRAM. ¹⁰ <NRf> = 1 to 4	
SOURce [1] :WAVE:ARBitrary:POINTs?	Queries # of arbitrary data points. ¹¹	

Table 7-4 (cont.)
Waveform function commands

Command	Description	Default
SOURce [1] :WAVE:ARM	Arms 6221 for waveform output. ¹²	
SOURce [1] :WAVE:INITiate	Starts waveform output. ¹³	
SOURce [1] :WAVE:ABORT	Aborts waveform output. ¹⁴	
SOURce [1] :WAVE:DURation:TIME <NRf>	Sets waveform time duration. ¹⁵ <NRf> = 100e-9 to 999999.999 (s) or INFinity	INFinity
SOURce [1] :WAVE:DURation:CYCles <NRf>	Sets waveform duration in cycles. ¹⁶ <NRf> = 0.001 to 9999999900 or INFinity	INFinity
SOURce [1] :WAVE:EXTRig[:ENABLE] 	Enables/disables mode to externally trigger the waveform generator. ¹⁷ = ON or OFF	OFF
SOURce [1] :WAVE:EXTRig:ILINE <NRf>	Specify trigger link input trigger line. ¹⁸ <NRf> = 0 (none) or 1 to 6	0
SOURce [1] :WAVE:EXTRig:IGNore 	Sets whether or not to restart waveform upon retriggering. ¹⁹ = ON or OFF	OFF
SOURce [1] :WAVE:EXTRig:IVALue <NRf>	Sets inactive value to output before/after waveform. ²⁰ <NRf> = -1 to +1	0.00

1. SOUR:WAVE:FUNC <name> ‘Select wave function
As soon as this command is received, the waveform takes effect. After the wave mode is armed (SOUR:WAVE:ARM), the SOUR:WAVE:INIT command is required to start the function output. For ARBArbitrary, X = 0-4. If no X is supplied, then ARB0 is selected. Location 0 is the volatile waveform memory location. If this command is sent when the waveform is armed, the Model 6221 will re-arm itself. If the waveform must be reloaded while the output is enabled, the inactive value will be output during this period.
An error +525 Cannot save ARB0 as user setup is returned when you try to save a setup with the WAVE function set to ARB0. This limitation is necessary because ARB0 is stored in volatile memory and will not be valid after the unit is power-cycled. When you attempt to do so, the WAVE function will be changed to SINE (default), this error will be generated, and the save will then proceed normally.

2. SOUR:WAVE:DCYC <NRf> ‘ Set duty cycle

This command sets the duty cycle for square and ramp waveforms. For a square wave, the duty cycle is the portion of the total cycle that the wave is high. For a ramp waveform, the duty cycle corresponds to the fraction of the total wave cycle that is rising. If this command is sent when the waveform is armed, the Model 6221 will re-arm itself. If the waveform must be reloaded while the output is enabled, the inactive value will be output during this period. The duty cycle selection only applies for square and ramp waveforms and is ignored for others.

3. SOUR:WAVE:AMPL <NRf> ‘ Set amplitude

This command sets the peak amplitude for all waveforms. The peak amplitude is one-half the peak-to-peak value. For example, an amplitude of 100mA results in a peak-to-peak value of 200mA. For fixed ranging, the offset plus peak amplitude cannot exceed the selected range.

4. SOUR:WAVE:FREQ <NRf> ‘ Set frequency

This command sets the frequency for all waveforms. The maximum frequency for all waveforms is 100kHz.

5. SOUR:WAVE:OFFS <NRf> ‘ Set offset

This command allows you to add a DC offset to a waveform. For fixed ranging, the offset plus amplitude cannot exceed the selected range.

6. SOUR:WAVE:RANG <name> ‘ Set range mode

Selects whether to use the best-fixed range or whether to use a fixed range. If best range is selected, the source range will automatically be selected based on the source values. For fixed range, the source range will be left on the range it was at when the waveform is started. If the present current range is too low when the waveform is started, Error -222 Parameter Out of Range is generated, and the waveform does not initiate. This command is not accepted while the wave is armed (Error +404 Not allowed with Wave Armed).

7. SOUR:WAVE:PMAR <NRf> ‘ Set marker phase

SOUR:WAVE:PMAR:STAT

‘ Enable/disable phase marker

SOUR:WAVE:PMAR:OLIN <NRf> ‘ Set phase marker output line

Use these commands to enter the point in degrees (0-360) at which a 1 μ s output trigger pulse will be issued, enable/disable the phase marker, and select the phase marker output line on the trigger connector. Note that the phase marker output line cannot be the same as the trigger layer output trigger line (usually 2 at default) or the waveform external trigger line. Attempts to set the phase marker line to the same line as either of these returns Error -221 Settings Conflict. See “[External trigger connector](#),” on page 8-13 for trigger connector details.

8. SOUR:WAVE:ARB:DATA <NRf>[,NRf,...NRf] ‘ Define arbitrary points
This command creates the points list for the arbitrary waveform. The data must be in the range -1 to 1. The maximum number of points allowed in this command is 100; use APPend to add more points. Note that points are stored in volatile RAM (memory location 0). To save them to locations 1 to 4, you must use the COPY command (below).
9. SOUR:WAVE:ARB:APP <NRf>[,NRf,...NRf] ‘ Append arbitrary points
This command appends the points list for the arbitrary waveform. The data must be in the range -1 to 1. The maximum number of points allowed in this command is 100; use another APPend to add more points (65,535 maximum). Note that points are appended to those stored in volatile RAM (memory location 0). To save all points to locations 1 to 4, you must use the COPY command (below).
10. SOUR:WAVE:ARB:COPY <NRf> ‘ Copy waveform points to NVRAM
This command copies the arbitrary waveform from volatile RAM (location 0) into nonvolatile RAM location 1-4. The location number is the one to be used by the SOUR:WAVE:FUNC ARB command above.
11. SOUR:WAVE:ARB:POIN? ‘ Query points in arbitrary waveform
This command queries the number of points in the arbitrary waveform.
12. SOUR:WAVE:ARM ‘ Arm waveform function
This command arms the 6221 for waveform output. Note that error checking is performed when the waveform is armed. Use SOUR:WAVE:INIT below to start the wave output. Note that whatever value the source is at will get set to zero at this time. The old source value and range are not recalled when you exit the wave (SOUR:WAVE:ABOR or EXIT key), but instead the source will be left on the new range and the output will be returned to zero.
13. SOUR:WAVE:INIT ‘ Start waveform function
This command normally starts the programmed waveform function. Note that the output must be on (OUTP ON) for the waveform signal to appear at the output terminals. If the external trigger mode is enabled, the waveform will not start until an external trigger is received. The inactive value will be output until then.
14. SOUR:WAVE:ABOR ‘ Abort waveform function
This command immediately aborts the waveform and returns the Model 6221 to the DC mode with the output off and the source set to zero. Note that this command has the same effect as SOUR:SWEep:ABORT (see “[SCPI commands — sweeps](#),” on page 4-18).

15. SOUR:WAVE:DUR:TIME <NRf> ‘ Set duration of waveform in time
This command sets the time duration in seconds that the waveform will run after being started with the INIT command. The default setting is INFInity seconds, and valid choices range from 100e-9 seconds to 999999.999 seconds, or INFInity. The last duration type sent takes precedence. This command is not accepted while the wave is armed (Error +404 Not allowed with Wave Armed).
16. SOUR:WAVE:DUR:CYCL <NRf> ‘ Set duration of waveform in cycles
This command sets the time duration in number of cycles that the waveform will run after being started with the INIT command. The default setting is INFInity, and valid choices range from 0.001 cycles to 99999999900 cycles, or INFInity. The last duration type sent takes precedence. This command is not accepted while the wave is armed (Error +404 Not allowed with Wave Armed).
17. SOUR:WAVE:EXTR ‘ Enable/disable external triggering
Firmware version A03 and greater supports an external trigger mode to trigger the arbitrary waveform generator using the Model 6221's trigger link lines. When enabled, this mode waits for an external trigger pulse on a specified trigger link line and starts the configured waveform within 1 μ s of the falling edge of the trigger. This mode cannot be changed while the wave is armed (Error +404 Not allowed with Wave Armed).
18. SOUR:WAVE:EXTR:ILINE <NRf> ‘ Set external trigger link line
This command sets the trigger link line that will be used as an input to trigger the arbitrary waveform generator. It only applies if the external trigger mode is enabled. Any of the six trigger link lines (1 to 6) can be used provided that the specified line has not already been assigned as the phase marker output (Error -221 Settings Conflict). If a value of 0 is used, no trigger link line will be assigned as an input, and nothing will trigger the waveform generator until another assignment is made.

**19. SOUR:WAVE:EXTR:IGN ** ‘ Set retrigger behavior

When this command is disabled (OFF), the waveform will restart immediately upon each sequential external hardware trigger. If the waveform output has not yet run to completion, a new hardware trigger will preempt the current waveform and restart the waveform immediately. Alternatively, the unit can be configured to ignore triggers while a waveform is in process. If set this way (ON), the current waveform will be output to completion before the unit will look for another trigger. This setting only applies if the external trigger mode is enabled.

For example, assume the Model 6221 is configured to output a single cycle of a sine wave at 1Hz, external triggering is enabled, and external triggers spaced 500ms apart are input. The first trigger will start the waveform generator output. If the ignore mode is ON, every other trigger will be ignored since it occurs while the waveform output is in progress. This will produce a continuous sine wave. If the ignore mode is OFF, every trigger will restart the waveform so that only the first 180° of the sine wave is output. This will produce a continuous full wave positive rectified sine wave.

20. SOUR:WAVE:EXTR:IVAL <NRf> ‘ Set inactive value

When the external trigger mode is on, the output remains enabled while the unit waits for an external trigger. The inactive value controls the current output before and after triggered waveforms. It can be set to any value between -1.00 and +1.00. The value is interpreted the same as data values used to specify arbitrary waveform definitions where -1 represents the maximum negative current flow and +1 represents the maximum positive current. Any value in between is linearly mapped between these two extremes to one of 65,536 discrete levels.

8 Triggering

Section 8 topics

Trigger models, page 8-2

- Front panel trigger model, page 8-2
- Trigger model operation, page 8-3
- Trigger model operation, page 8-4

Front panel trigger operation, page 8-7

- Using the trigger configuration menu, page 8-7
- Configuring triggering, page 8-8

Remote trigger operation, page 8-9

- Programming triggering, page 8-9
- SCPI commands — triggering, page 8-10

External triggering, page 8-13

- External trigger connector, page 8-13
- Input trigger requirements, page 8-13
- Output trigger specifications, page 8-14
- External trigger example, page 8-15

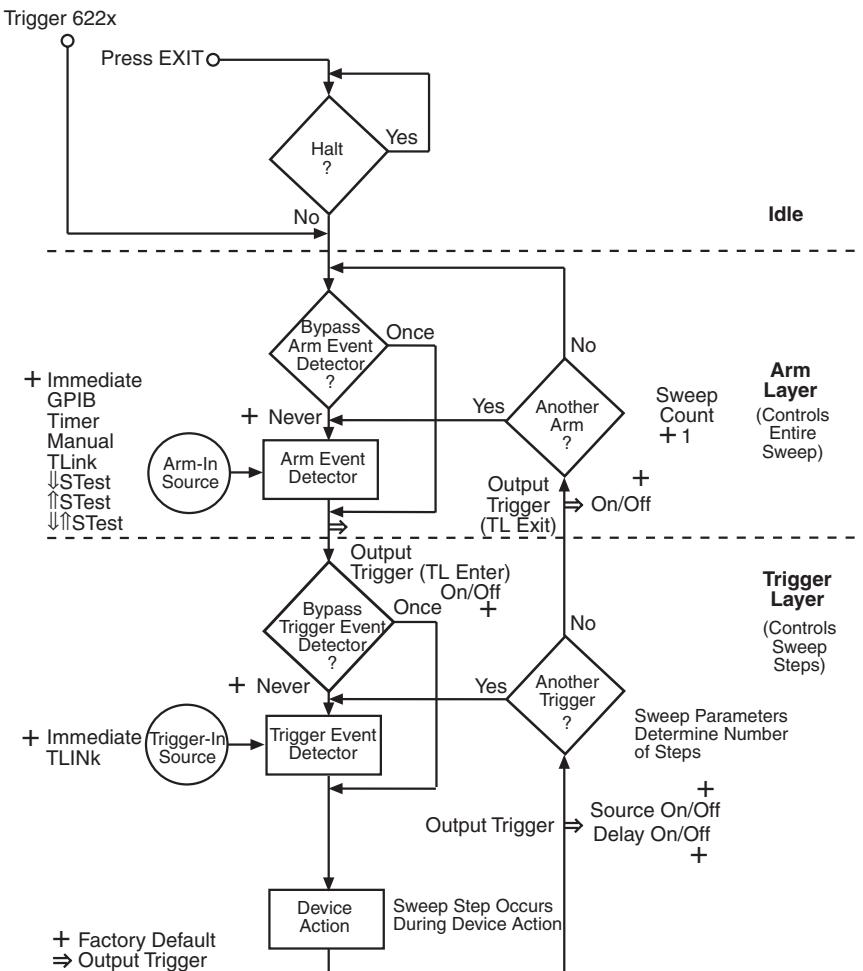
Trigger models

The trigger models control when to switch to the next point in a sweep and how many sweeps to perform (see [Section 4](#) for details on sweeps). Note that the trigger configuration does not affect other Model 622x operation including normal output currents and Model 6221 wave functions.

Front panel trigger model

The front panel trigger model is shown in [Figure 8-1](#).

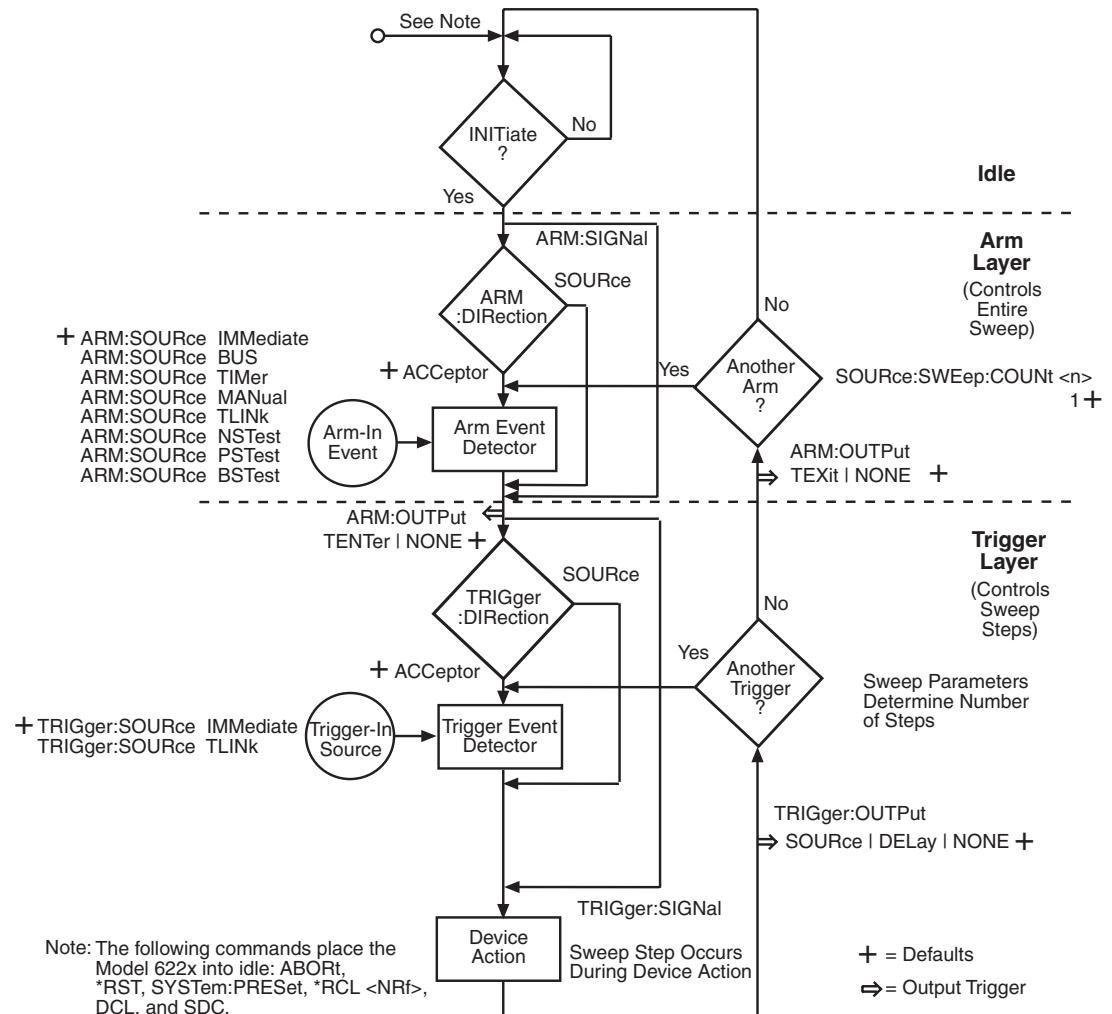
Figure 8-1
Trigger model for front panel operation



Remote trigger model

The trigger model for remote operation is shown in [Figure 8-2](#).

Figure 8-2
Trigger model for remote operation



Trigger model operation

Idle and initiate

While in the idle state, the instrument cannot perform sweeps. Once the Model 622x is taken out of idle, operation proceeds through the trigger model to perform sweeps and sweep steps.

Front panel operation — As shown in [Figure 8-1](#), the Model 622x immediately leaves the idle state when triggered to do so. Operation remains in the arm and trigger layers of the trigger model until the sweep is done. Operation cycles through the arm layer once for each sweep and cycles through the trigger layer once per sweep step.

The Model 622x can be put into the idle state at any time by pressing EXIT. To take the instrument out of idle, press the TRIG key.

Remote operation — As shown in [Figure 8-2](#), an initiate command is required to take the instrument out of idle. The following command performs an initiate operation:

INITiate

Once taken out of idle, operation cycles through the arm layer once for each sweep and cycles through the trigger layer once per sweep step. While operating within the trigger model (not in idle), most commands will not be executed until the instrument completes all of its programmed operations and returns to the idle state. The ABORt command can be sent to return the instrument to idle and halt the sweep. The IFC, SDC, and DCL commands can be executed under any circumstance while operating within the trigger model. They will abort any other command or query.

The following commands can be executed while operating within the trigger model:

- ABORt
- SYSTem:PRESet
- *TRG or GET
- *RST
- *RCL <NRf>

NOTE	For fastest response, use SDC or DCL to return to idle (see Section 12 for details on general bus commands).
-------------	---

Event detectors and control sources

A control source holds up operation until the programmed event occurs and is detected. Note that there are four detector bypasses (two of which are one-time bypasses). A bypass around a detector is only enabled if the appropriate TLink control source is selected. See TLink control source (Arm-In and Trigger-In) as follows for details.

Arm-In source — The Arm-In control sources, which control entire sweeps, are explained as follows:

- **IMMEDIATE** (ARM:SOURce IMMEDIATE) — Event detection for the arm layer is satisfied immediately allowing operation to continue into the trigger layer.
- **GPIB** (ARM:SOURce BUS) — Event detection for the arm layer is satisfied when a bus trigger (GET or *TRG) is received by the Model 622x. Note that GET is a general bus command (see [Section 10](#)) and not a three-letter command word.
- **TIMER** (ARM:SOURce TIMER) — Event detection for the arm layer is immediately satisfied after the instrument leaves the idle state. Detection for each subsequent pass is satisfied when the programmed timer interval elapses. The timer resets to its initial state when the instrument goes back into idle.
- **MANUAL** (ARM:SOURce MANUAL) — Event detection for the arm layer is satisfied by pressing the TRIG key. The Model 622x must be in the local mode for it to respond to the TRIG key. Press LOCAL to place the Model 622x in local.
- **TLINK** (ARM:SOURce TLINK) — Event detection for the arm layer is satisfied when an input trigger via the TRIGGER LINK connector is received by the Model 622x. Note that if the source bypass is set to ONCE (ARM:DIRECTION SOURce), operation will initially loop around the source detector after the instrument leaves the idle state. Detection for each subsequent pass is satisfied by an input trigger. The bypass resets when the instrument goes into idle.
- **↓STEST** (ARM:SOURce NSTest) — Event detection for the arm layer is satisfied when a negative-going pulse (via the SOT line of the Digital I/O) is received. (See “[Digital I/O port](#),” on page 9-5.)
- **↑STEST** (ARM:SOURce PSTest) — Event detection for the arm layer is satisfied when a positive-going pulse (via the SOT line of the Digital I/O) is received. (See “[Digital I/O port](#),” on page 9-5.)
- **↓↑STEST** (ARM:SOURce BSTest) — Event detection for the arm layer is satisfied when either a positive-going or a negative-going pulse (via the SOT line of the Digital I/O) is received. (See “[Digital I/O port](#),” on page 9-5.)
- **ARM:SIGNAl** (remote only) — Used as a one-time bypass for the ARM layer control source and move on to the next layer in the trigger model (the TRIGger layer event detection in this case).

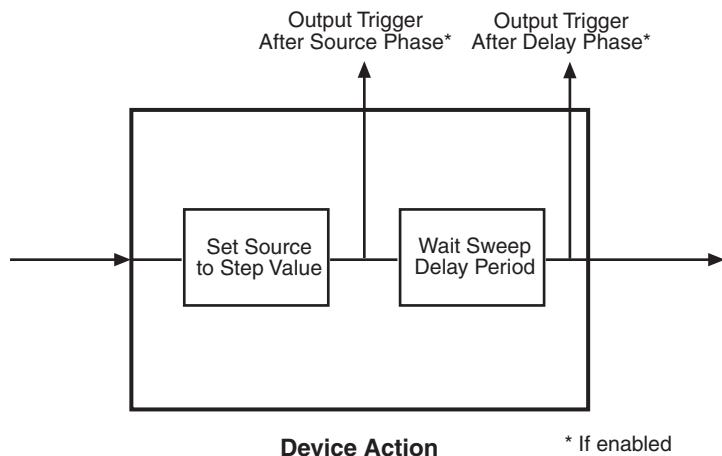
Trigger-In source — The Trigger-In control sources, which control individual sweep steps, are explained as follow:

- **IMMEDIATE** (TRIGger:SOURce IMMEDIATE) — Event detection for the trigger layer is satisfied immediately allowing operation to continue to perform a sweep step.
- **TRIGGER LINK** (TRIGger:SOURce TLINK) — Event detection for the trigger layer is satisfied when an input trigger via the TRIGGER LINK connector is received by the Model 622x. Note that if the source bypass is set to ONCE (TRIGger:DIRection SOURce), operation will loop around the source detector on the initial pass through the arm layer. Detection for each subsequent pass is satisfied by an input trigger. The bypass resets when the Model 622x leaves the trigger layer.
- **TRIGger:SIGNal (remote only)** — Used as a one-time bypass for the TRIGGER layer control source and move on to the next layer in the trigger model (the device action in this case).

Device action

The device action block of the trigger model is where a sweep step is performed ([Figure 8-3](#)). Each step sets the current source to the programmed value, and the unit then waits the programmed sweep delay before going on to the next step. See “[Sweep delay](#),” on page [4-9](#) for more information.

Figure 8-3
Device action block of trigger model



Output triggers

The Model 622x can send out an output trigger (via the rear panel TRIGGER LINK connector) right after the source and delay phase of the device action and/or when operation enters or exits the trigger layer. An output trigger can be used to trigger another instrument to perform an operation (e.g., select the next scanner channel). See “[External triggering](#),” on page 8-13 for details on using external triggering.

Front panel trigger operation

Using the trigger configuration menu

To configure trigger functions, press CONFIG then TRIG, then make your selections from [Table 8-1](#) below. See the detailed procedures for setting up triggering on [page 8-8](#).

Table 8-1
Trigger configuration menu

Menu selection	Description
ARM-LAYER ARM-IN TIMER TLINK EVENT DETECT BYPASS ARM-OUT LINE EVENTS TRIG-LAYER-EXIT TL-ENTER	Configure arm layer: Set arm-in events: IMMEDIATE, GPIB, TIMER, MANUAL, TLINK, ↓STEST, ↑STEST, ↓↑STEST. Set timer INVERVL: 0 to 99999.999s. Set trigger link line (1 to 6). Select ONCE or NEVER. Set arm out line and events: Set trigger out line (1 to 6). Select arm out events. Select ON or OFF. Select ON or OFF.
TRIG-LAYER TRIGGER-IN IMMEDIATE TRIGGER-LINK EVENT DETECT BYPASS TRIGGER-OUT LINE EVENTS SOURCE DELAY	Configure trigger layer: Set trigger in events: Immediate trigger. Select trigger link and line (1 to 6). Set event bypass (ONCE or NEVER) Set trigger out events: Set trigger out line (1 to 6). Set trigger output events. Select ON or OFF. Select ON or OFF.

Configuring triggering

The following is a typical example of using trigger configuration to fine-tune sweeps. For further details on the steps for sweep configuration, see “[Front panel sweep operation,](#) [on page 4-10](#). When setting trigger model parameters, keep the following in mind:

- The arm layer controls the entire sweep.
 - The trigger layer controls individual sweep steps.
1. Press CONFIG then TRIG to enter the trigger configuration menu.
 2. Select ARM-LAYER. Press ENTER, then set your parameters as follows:
 - a. ARM-IN: Choose the ARM-IN EVENT, set TIMER interval (if using timer), TLINK line (1-6), and EVENT DETECT BYPASS (ONCE or NEVER).
 - b. ARM-OUT: Set the LINE (1-6), and EVENTS (TRIG-LAYER-EXIT ON or OFF, TL-ENTER ON, or OFF).
 3. From the main trigger configuration menu, select TRIGGER-LAYER, then press ENTER and set your parameters as follows:
 - a. TRIGGER-IN: Set the TRIGGER-IN SOURCE, TRIGGER LINK line (1-6), and EVENT DETECT BYPASS (ONCE or NEVER).
 - b. TRIGGER-OUT: Set the trigger LINE (1-6) and events (SOURCE ON/OFF, DELAY ON/OFF).
 4. Configure and run your sweep as outlined in “[Front panel sweep operation,](#) [on page 4-10](#). Depending on how you configured the trigger model, you may have to apply triggers from the appropriate sources to start the sweep and to cycle through the sweep steps.

Remote trigger operation

The following is a typical example of using remote trigger configuration to enhance sweeps. For further details on the steps for sweep programming, see “[Remote sweep operation](#),” on page 4-14. When setting trigger model parameters, keep the following in mind:

- The arm layer controls the entire sweep.
- The trigger layer controls individual sweep steps.

See “[SCPI commands — triggering](#),” on page 8-10 for details on trigger commands.

Programming triggering

1. Restore defaults with this command:

```
*RST
```

2. Configure the arm layer.

Examples – The following commands configure the bus trigger source, set the trigger output line to #1, and enable a trigger output pulse and then operation leaves the trigger layer:

ARM:SOUR BUS	‘ Select BUS trigger (*TRG or GET).
ARM:OLIN 1	‘ Set arm output trigger to line #1.
ARM:OUTP TEX	‘ Output trigger on exit of trig layer.

3. Configure the trigger layer.

Examples – The following commands configure the trigger link as the trigger input source, select line #2 on the trigger link for input, select line #4 as output, and enable triggers after both source and delay phases of the device action block:

TRIG:SOUR TLIN	‘ Select Tlink for input trigger.
TRIG:ILIN 2	‘ Set trigger input to line #2.
TRIG:OLIN 4	‘ Set trigger output to line #4
TRIG:OUTP SOUR,DEL	‘ Output trigger after source/delay.

4. Configure and run your sweep as outlined in “[SCPI commands — triggering](#),” on page 8-10. With the above configuration, a *TRG or GET is required to start the sweep, and an external trigger pulse applied to line 2 of the trigger link is required to trigger each sweep step.

SCPI commands — triggering

Triggering commands are listed in [Table 8-2](#). Additional information for each command is provided in notes that follow the tables.

Table 8-2
Trigger commands

Command*	Description	Default
INITiate	Initiate one trigger cycle. ¹	OFF
ABORT	Reset trigger system. ²	
<i>Arm layer commands:</i>		
ARM:SOURce <name>	Select event detector control source. ³ <name> = IMMEDIATE, TIMer, BUS, TLINK, NSTest, PTest, NSTest, or MANUAL.	IMM
ARM:SIGNAl	Bypass ARM control source. ⁴	
ARM:TIMer <n>	Set timer interval (0 to 99999.99 sec). 1 msec resolution. ⁵	0.1
ARM:DIRECTION <name>	Control ARM source bypass. ⁶ <name> = SOURce or ACCeptor	ACC
ARM:ILINe <NRf>	Set ARM layer input signal line (1-6). ⁷	1
ARM:OLINe <NRf>	Set ARM layer output signal line (1-6). ⁸	2
ARM:OUTPut <name>	Enable/disable ARM layer output trigger. ⁹ <name> = TENTer, TEXit, or NONE	NONE
<i>Trigger layer commands:</i>		
TRIGger:SOURce <name>	Select event detector control source. ¹⁰ <name> = IMMEDIATE or TLINK.	IMM
TRIGger:SIGNAl	Bypass TRIG control layer. ¹¹	
TRIGger:DIRECTION <name>	Control TRIG source bypass. ¹² <name> = SOURce or ACCeptor	ACC
TRIGger:ILINe <NRf>	Set TRIG layer input signal line (1-6). ¹³	1
TRIGger:OLINe <NRf>	Set TRIG layer output signal line (1-6). ¹⁴	2
TRIGger:OUTPut <name>	Select TRIG layer output trigger. ¹⁵ <name> = SOURce[1], DELay, or NONE	NONE

* Arm layer commands control entire sweep. Trigger layer commands control individual sweep steps.

1. INIT ‘ Initiate one trigger cycle
This command is used to initiate one trigger cycle and take the unit out of the idle state.
2. ABOR ‘ Reset trigger system
This command resets the trigger system. If a sweep is in progress, it will be halted and the source value set to zero. The operate state, however, will be left on. The sweep is still armed, and can be started again with another INIT command (i.e., - no re-arming is needed).
3. ARM:SOUR <name> ‘ Select ARM layer control source.
This command selects the ARM layer event detector control source: IMMEDIATE, TIMER, BUS, TLINK, NSTEST, PSTEST, BSTEST, or MANUAL.
4. ARM:SIGN ‘ Bypass ARM layer control source.
This command is used to bypass the ARM layer control source and move on to the next layer in the trigger model (the TRIGger layer event detection in this case).
5. ARM:TIM <n> ‘ Set ARM layer timer interval.
This command selects the ARM layer timer interval in the range of 0 to 99999.99 sec. with 1 msec resolution.
6. ARM:DIR <name> ‘ Set ARM source bypass.
This command enables (SOURce) or disables (ACCeptor) the ARM source bypass.
7. ARM:ILIN <NRf> ‘ Set ARM layer trigger input line.
This command selects the ARM layer input signal line: 1, 2, 3, 4, 5, or 6.
8. ARM:OLIN <NRf> ‘ Set ARM layer trigger output line.
This command selects the ARM layer input signal line: 1, 2, 3, 4, 5, or 6. Note that for the Model 6221 only, the trigger output line and phase marker (SOUR:WAVE:PMAR:OLIN) lines cannot be the same, or a -221 Settings Conflict error will occur. (See “[Phase marker](#),” on page 7-9.).
9. ARM:OUTP <name> ‘ Select when to output ARM trigger.
This command selects when to output the ARM layer trigger. Available selections include TEXit (output when exiting trigger layer), TENTer (output when entering trigger layer), or NONE (disabled).
10. TRIG:SOUR <name> ‘ Select TRIG layer control source.
This command selects the TRIG layer event detector control source: IMMEDIATE and TLINK.
11. TRIG:SIGN ‘ Bypass TRIG layer control source.
This command is used to bypass the TRIGger layer control source and move on to the next layer in the trigger model (the device action block in this case).

12. TRIG:DIR <name> ‘ Set TRIG source bypass.
This command enables (SOURce) or disables (ACCeptor) the TRIG source bypass.
13. TRIG:ILIN <NRf> ‘ Set TRIG layer TRIG input line.
This command selects the TRIG layer input signal line: 1, 2, 3, 4, 5, or 6.
14. TRIG:OLIN <NRf> ‘ Set TRIG layer TRIG output line.
This command selects the TRIG layer input signal line: 1, 2, 3, 4, 5, or 6. Note that for the Model 6221 only, the TRIG output line and phase marker (SOUR:WAVE:PMAR:OLIN) lines cannot be the same, or a -221 Settings Conflict error will occur. (See “[Phase marker](#),” on page 7-9).
15. TRIG:OUTP <name> ‘ Select when to output trigger.
This command selects when to output the TRIG layer TRIG. Available selections include SOURce[1] (output after source), DELay (output after sweep delay), or NONE (disabled).

External triggering

External trigger connector

Input and output triggers are received and sent via the rear panel TRIGGER LINK connector. The trigger link has six lines. At the factory, line #2 is selected for output triggers and line #1 is selected for input triggers. These input/output assignments can be changed as previously explained in this section. The connector pinout is shown in [Figure 8-4](#).

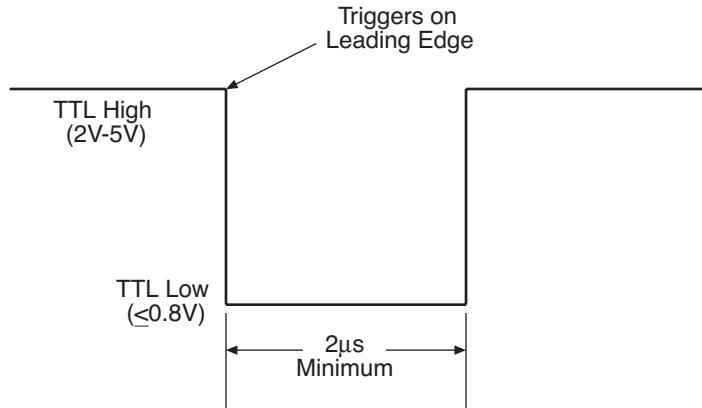
Figure 8-4
Trigger link connection operation

Rear Panel Pinout	Pin Number	Description
 Trigger Link	1	Trigger Link 1
	2	Trigger Link 2
	3	Trigger Link 3
	4	Trigger Link 4
	5	Trigger Link 5
	6	Trigger Link 6
	7	Ground
	8	Ground

Input trigger requirements

An input trigger is used to satisfy event detection for a trigger model layer that is using the TLINK control source. The input requires a falling-edge, TTL-compatible pulse with the specifications shown in [Figure 8-5](#).

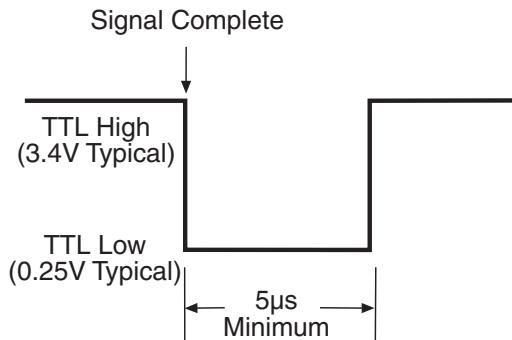
Figure 8-5
Trigger link input pulse specifications



Output trigger specifications

The Model 622x can be programmed to output a trigger immediately after the source or delay phase of the device action and/or when operation enters or exits the trigger layer of the trigger model. The output trigger provides a TTL-compatible output pulse that can be used to trigger other instruments. The specifications for this trigger pulse are shown in Figure 8-6.

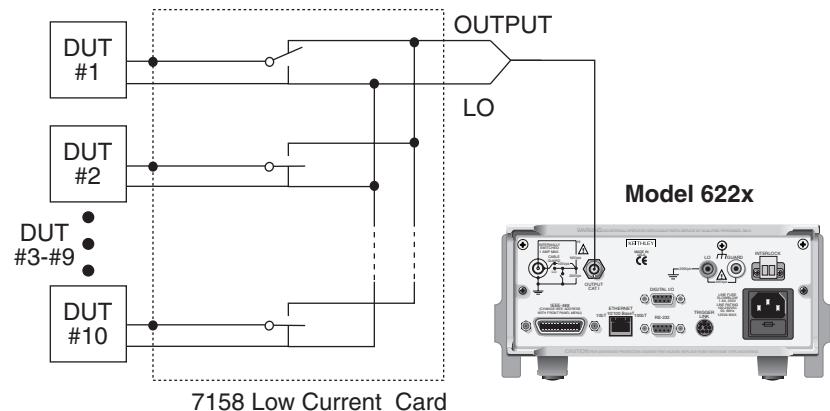
Figure 8-6
Trigger link output pulse specifications



External trigger example

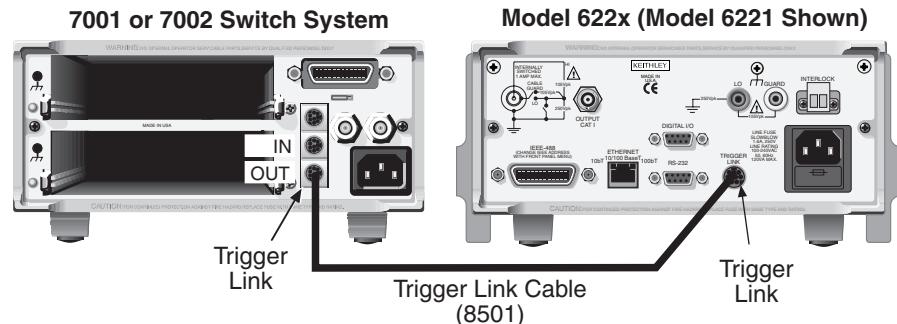
In a simple test system, you may want to close a switching channel and source the current to a DUT connected to that channel. Using sweeps, the current to each DUT can be set to a different value. Such a test system is shown in [Figure 8-7](#). This example uses a Model 622x to source current to 10 different DUTs switched by a Model 7158 low current card in a Model 7001 or 7002 switch system.

Figure 8-7
DUT test system



The trigger link connections for this test system are shown in [Figure 8-8](#). The trigger link of the Model 622x is connected to the trigger link (IN or OUT) of the switching mainframe. Note that with the default trigger settings of both the switching mainframe and the Model 622x, line #1 is an input and line #2 is an output. Thus, the trigger lines for one of the instruments must be changed.

Figure 8-8
Trigger link connections



For this example, the Model 622x and switching mainframe are configured as follows:

Model 622x

Factory Defaults Restored
 Trig-In Event = TLink
 Trigger Input Line = #2
 Trigger Output Line = #1
 Trigger Output Delay Event = ON
 Configure Sweep ([Section 4](#))

Switching Mainframe

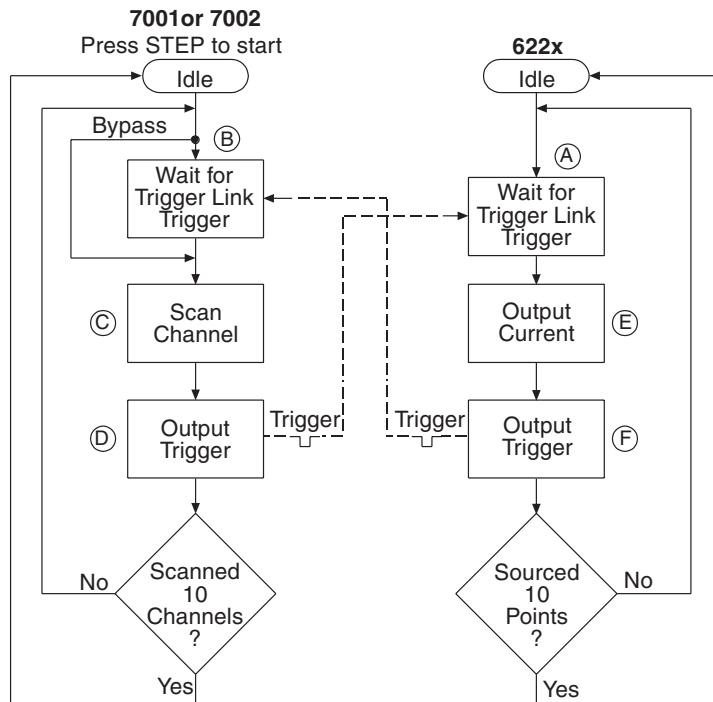
Factory Defaults Restored
 Scan List = 1!1-1!10
 Number of Scans = 1
 Channel Spacing = TrigLink

To run this test properly, set up the sweep with 10 points with the desired currents (see [Section 4](#)).

To start the test, press STEP on the switching mainframe to take it out of idle and start the scan. The switching mainframes output pulse triggers the Model 622x to output the sweep point current. The Model 622x then sends an output trigger pulse to the switching mainframe to close the next channel. This process continues until all 10 sweep points are swept and channels are sequentially scanned.

Details of this testing process are explained in the following paragraphs and are referenced to the operation model shown in [Figure 8-9](#).

Figure 8-9
Operation model for triggering example



- A. Operation of the Model 622x starts at point A in the flowchart where it waits for an external trigger.
- B. Pressing STEP takes Model 7001/7002 out of idle and places operation at point B in the flowchart.
- C. For the first pass through Model 7001/7002, the scanner does not wait at point B. Instead, it closes the first channel (point C).
- D. After the relay settles, Model 7001/7002 outputs a trigger pulse, and operation loops back to point B where it waits for an input trigger.
- E & F. With the Model 622x at point A, the output trigger pulse from Model 7001/7002 triggers a measurement of DUT #1 (point E). After the source current is ready, the Model 622x outputs a trigger pulse and then loops back to point A where it waits for another input trigger.

The trigger applied to Model 7001/7002 from the Model 622x closes the next channel in the scan, which then triggers the Model 622x to output the sweep point current to that DUT. This process continues until all 10 channels are scanned.

Limit Test and Digital I/O

Section 9 topics

Limit test, page 9-2

Overview, page 9-2

Programming limit testing, page 9-2

SCPI commands — limit testing, page 9-3

Digital I/O port, page 9-5

Digital I/O connector, page 9-5

+5V output, page 9-5

SOT line, page 9-6

Simplified schematic, page 9-6

Sink mode — controlling external devices, page 9-6

Source mode — logic control, page 9-8

Setting digital output lines, page 9-8

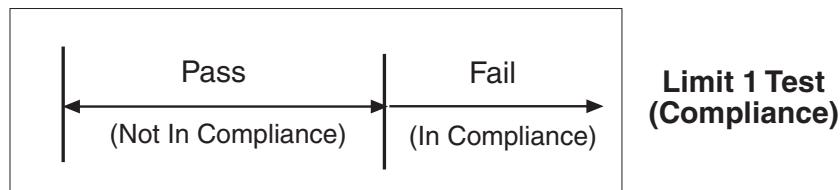
SCPI commands — force digital I/O pattern, page 9-9

Limit test

Overview

As shown in [Figure 9-1](#), there is one limit test that can be performed on a DUT. Limit 1 is used to test whether or not the Model 622x current source is in or out of compliance. If the source is not in compliance (limit test PASS), all four lines of the digital I/O port will be low. The Model 622x can be programmed to apply a specific 4-bit fail pattern on the digital I/O lines ([“Digital I/O connector,” on page 9-5](#)) if the source is in compliance (limit test FAIL).

Figure 9-1
Limit 1 test (compliance)



Programming limit testing

The example below shows how to enable limit testing and set a failure pattern of 9 (1001). The FAIL? query is also used to determine if the limit test has passed or failed.

CALC3: LIM: STAT ON	' Enable limit test.
CALC3: LIM: SOUR2 9	' Set fail pattern to 9 (1001).
CALC3: LIM: FAIL?	' Query pass/fail of limit test.

With the above programming, a binary pattern of 1001 will appear on the digital I/O lines if the limit test fails (source in compliance), and the FAIL? query will return 1. A binary pattern of 0000 will appear on the digital I/O lines when the source is not in compliance (limit test passes), and the FAIL? query will return a 0.

SCPI commands — limit testing

Limit test commands are listed in [Table 9-3](#). Additional information for each command is provided in notes that follow the tables.

Table 9-1
Limit test commands

Command	Description	Default
CALCulate3:LIMIT [1] [:STATe] 	Enable/disable limit 1 test. ¹ = ON or OFF.	OFF
CALCulate3:LIMIT [1] :SOURce2 <NRf>	Set limit test fail pattern. ² <NRf> = 0 to 15	15 (1111)
CALCulate3:LIMIT [1] :FAIL?	Query limit test pass/fail. ³ 0= PASS; 1= FAIL	

1. CALC3:LIM[:STAT] ‘ Enable/disable limit 1 compliance test
This command turns limit testing ON (1) or OFF (0).
2. CALC3:LIM:SOUR2 <NRf> ‘ Set I/O fail pattern
This command specifies the four bit digital output value (0 to 15) used when the limit test fails (i.e., whenever the source goes into compliance). When not in compliance, all lines will be off (output pattern of 0) unless otherwise controlled by the CALCULATE3:FORCe:STATe command discussed on [page 9-9](#).
Digital I/O port fail pattern values are shown in [Table 9-2](#).
3. CALC3:LIM:FAIL? ‘ Query limit fail/pass
This query returns result of the limit test: 0 (PASS); 1 (FAIL).

Table 9-2
Limit test fail pattern values

Value*	Out 4	Out 3	Out 2	Out 1
0	L	L	L	L
1	L	L	L	H
2	L	L	H	L
3	L	L	H	H
4	L	H	L	L
5	L	H	L	H
6	L	H	H	L
7	L	H	H	H
8	H	L	L	L
9	H	L	L	H
10	H	L	H	L
11	H	L	H	H
12	H	H	L	L
13	H	H	L	H
14	H	H	H	L
15	H	H	H	H

*L = Grounded

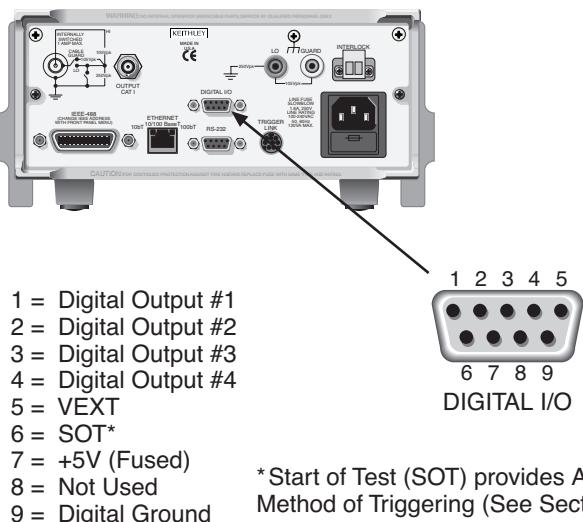
H ≥ +3V

Digital I/O port

Digital I/O connector

The Model 622x Digital I/O port is a male DB-9 connector located on the rear panel. The port location and pin designations are shown in [Figure 9-2](#). The four active-low, digital output lines and one input line are used to control external circuitry.

Figure 9-2
Digital I/O port



Typical applications for the digital I/O port include the following:

- **External device control** — Each digital output can be used as a control switch for an external device (i.e., relay) circuit. Each output line can sink up to 500mA. Drive voltage is provided by an external source (+5V to +33V to pin 5 VEXT).
- **Logic Control** — The four digital outputs can be used as inputs to logic devices.

+5V output

The digital I/O port provides a +5V output that can be used to drive external logic or relays. Maximum current for this line is 500mA. This line is protected by a self-resetting fuse (one hour recovery time).

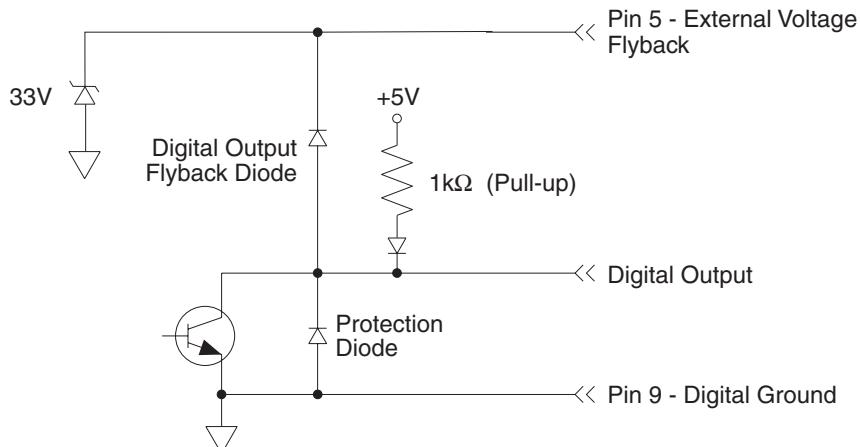
SOT line

The SOT (start-of-test) line provides an alternate method of triggering the unit. You can set up the unit to trigger on a positive-going, negative-going, or a both positive and negative-going pulse. See triggering in [Section 8](#) for complete details.

Simplified schematic

The simplified schematic for the digital outputs is shown in [Figure 9-3](#). Note that this illustration shows the schematic for one digital output. All four digital output circuits are identical.

Figure 9-3
Digital I/O port simplified schematic



Sink mode — controlling external devices

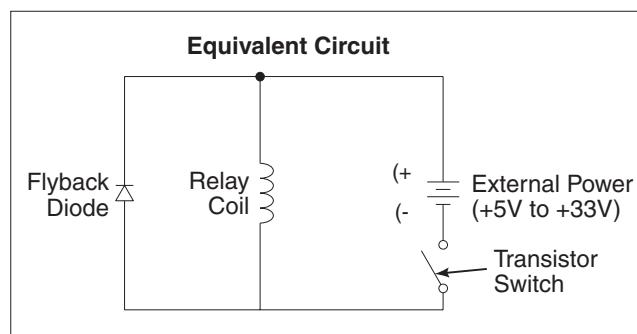
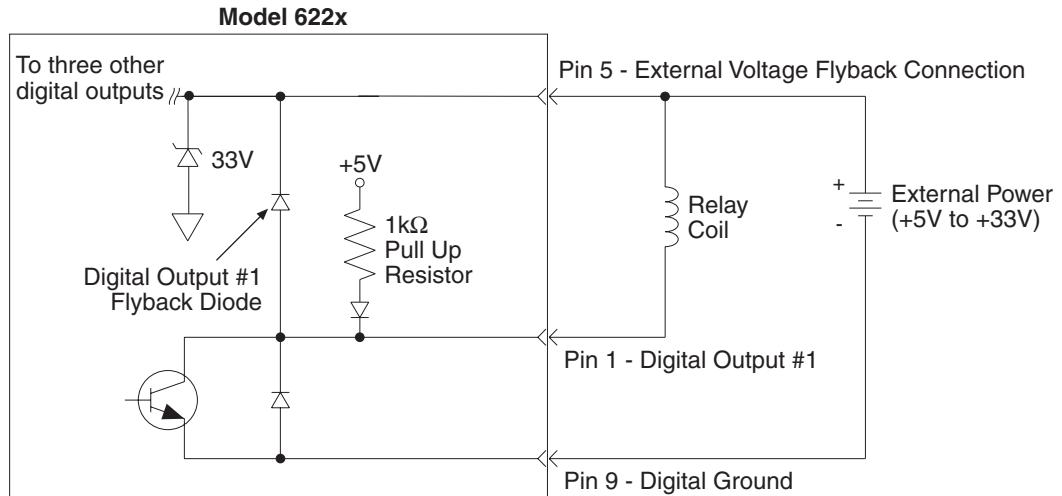
Each output can be operated from an external supply (voltage range from +5V to +33V applied through the external device being driven). The high current sink capacity of the output driver allows direct control of relays, solenoids, and lamps (no additional circuitry needed).

As shown in [Figure 9-3](#), each of the four digital, open-collector outputs includes a built-in pull up resistor to +5V. The output transistor is capable of sinking 500mA from voltages up to +33V. Each output channel contains a flyback diode for protection when switching inductive loads (such as a low power solenoid or relay coils). To use these flyback diodes, connect the external supply voltage to pin 5 of the digital I/O port. Make sure the external supply voltage is between +5V and +33V and the current required by the device does not exceed 500mA.

CAUTION Do not exceed +33V maximum voltage on pin 5 of the digital I/O port and do not use any output line to sink >500mA. Exceeding these limits may cause damage to the instrument that is not covered by the warranty.

An externally powered relay connected to the digital output port is shown in [Figure 9-4](#). Other externally powered devices can be similarly connected by replacing the relay with the device. When the output line is set LO (0V), the output transistor sinks current through the external device. In the HI state, the output transistor is off (transistor switch open). This interrupts current flow through the external device.

Figure 9-4
Controlling externally powered relays



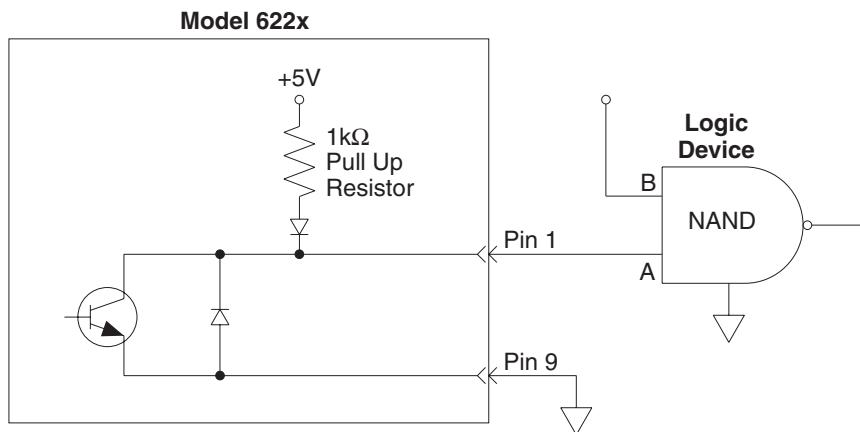
Source mode — logic control

The digital outputs can be used as logic inputs to active TTL, low-power TTL, or CMOS inputs. For this mode of operation, the output lines can source up to ~5mA.

[Figure 9-5](#) shows how to connect a logic device to one of the output lines. When the output line is set HI, the transistor will turn off (transistor switch open) to provide a reliable logic high output (>3.75V). When the output line is set LO, the transistor turns on (transistor switch closed) to route current to digital ground. As a result, a low logic output (~0V) is provided at the output.

If the second input (B) of the NAND gate is connected to another output line of the port, the output of the NAND gate will go to logic 0 when both digital outputs are set HI.

Figure 9-5
NAND gate control



Setting digital output lines

Digital output lines are set by selecting a decimal value (0 to 15) that corresponds to the 4-bit BCD pattern of the output. To determine the value, add up the decimal weight values for the desired HI lines:

Output HI Line:	Out 4	Out 3	Out 2	Out 1
Decimal Weight:	8	4	2	1

For example, to set output lines 3 and 1 HI (0101 bit pattern), set the output value to 5 (4 +1).

For example, send these commands to force a digital I/O pattern of 0101 (5) by remote:

CALC3:FORC:STAT ON	' Enable I/O pattern force.
CALC3:FORC:PATT 5	' Set I/O to 5 (0101)

SCPI commands — force digital I/O pattern

Digital I/O commands are listed in [Table 9-3](#). Additional information for each command is provided in notes that follow the tables.

**Table 9-3
Digital I/O commands**

Command*	Description	Default
CALCulate3:FORCe:STATe 	Enable/disable I/O pattern force state. ¹ = 1 or 0.	0
CALCulate3:FORCe:PATTERn <NRf>	Set I/O pattern. ² <NRf> = 0 to 15	15

1. CALC3:FORC:STAT ' Enable/disable I/O pattern force state
If true, then ignore all limit results from the limit commands ([page 9-3](#)) and take the CALC3:FORC:PATT value described below and force it on the digital output lines. When turned on with the FORCe:STATe, the FORCe:PATTERn supersedes any results from the compliance limit described in "[Limit test](#)," on [page 9-2](#).
2. CALC3:FORC:PATT <NRf> ' Set I/O pattern
Pattern to be forced on the digital output connector. Note that the actual digital output value assumes active high logic which cannot be changed, so sending 12 (binary 1100) will result in bits 0 and 1 low and bits 2 and 3 high. Digital I/O port values are shown in [Table 9-4](#).

Table 9-4
Digital I/O port values

Value*	Out 4	Out 3	Out 2	Out 1
0	L	L	L	L
1	L	L	L	H
2	L	L	H	L
3	L	L	H	H
4	L	H	L	L
5	L	H	L	H
6	L	H	H	L
7	L	H	H	H
8	H	L	L	L
9	H	L	L	H
10	H	L	H	L
11	H	L	H	H
12	H	H	L	L
13	H	H	L	H
14	H	H	H	L
15	H	H	H	H

*L = Grounded

H ≥ +3V

10

Remote Operations

Section 10 topics

- | | |
|---|--|
| Selecting and configuring an interface , page 10-2 | RS-232 interface reference , page 10-25 |
| Interfaces, page 10-2 | Sending and receiving data, page 10-24 |
| Languages, page 10-3 | RS-232 settings, page 10-25 |
| Interface selection and configuration, page 10-3 | RS-232 connections, page 10-27 |
|
 |
 |
| Programming syntax , page 10-12 | Ethernet interface reference , page 10-29 |
| Command words, page 10-12 | Ethernet standards, page 10-29 |
| Program messages, page 10-15 | Typical Ethernet systems, page 10-29 |
| Response messages, page 10-17 | Ethernet connections, page 10-31 |
|
 | Ethernet settings, page 10-33 |
| GPIB interface reference , page 10-19 |
 |
| GPIB bus standards, page 10-19 | Using the example software , page 10-35 |
| GPIB bus connections, page 10-19 | |
| Primary address, page 10-21 | |
| General IEEE-488 bus commands, page 10-22 | |
| Front panel GPIB operation, page 10-24 | |

Selecting and configuring an interface

Interfaces

The Model 6220 supports two built-in remote interfaces:

- GPIB interface
- RS-232 interface

The Model 6221 supports three built-in remote interfaces:

- GPIB interface
- RS-232 interface
- Ethernet interface

You can communicate to the Model 622x using one interface at a time. At the factory, the GPIB bus is selected. The interface selection is stored in non-volatile memory; it does not change when power has been off or after a remote interface reset.

NOTE Even if the GPIB or Ethernet interface is selected, you can still use SYST:COMM:SER:SEND and SYST:COMM:SER:ENTER? to send and receive commands to another instrument through the Model 622x RS-232 interface. See “[Remote interface configuration commands](#),” on page 10-6

GPIB interface — The GPIB is the IEEE-488 interface. The Model 622x must be assigned a unique primary address. At the factory the address is set to 12, but it can be set to any value from 0 to 30. However, the address cannot conflict with the address assigned to other instruments in the system. You can use either the SCPI or KI-220 DDC (Model 220 DDC emulation) language to program the instrument.

RS-232 interface — When using the Model 622x RS-232 interface, you must set baud rate, terminator, and flow control. For the RS-232 interface, you can use only the SCPI language to program the instrument.

Ethernet interface (6221 only) — When using the Ethernet interface, you must manually set the IP address, Ethernet gateway, and subnet mask if DHCP is not used. The MAC address is fixed and cannot be changed by the user. For the Ethernet interface, you can use only the SCPI language to program the instrument.

Languages

For the GPIB interface, there are two programming languages to choose from:

- SCPI language (488.2)
- KI-220 DDC language

NOTE For the RS-232 and Ethernet interfaces, only the SCPI language can be used to program the instrument. When the RS-232 or Ethernet interface is selected, the language automatically defaults to SCPI.

SCPI language — Standard Commands for Programmable Instruments (SCPI) is fully supported by the GPIB, RS-232, and Ethernet interfaces.

DDC language — The Model 622x implements most DDCs (device-dependent commands) available in the Keithley Model 220 current source. The available commands are provided in Section 15. See the Model 220 Instruction Manual for details on operation. This manual is available for download at www.keithley.com.

NOTE The unit will reset if the language is changed (SCPI or KI-220 DDC).

Interface selection and configuration

When you select (enable) a new interface, the presently selected interface disables. Select the interface from the COMM menu structure (access by pressing the COMM key while in local). Select the desired interface (RS-232, GPIB, or ETHERNET for the 6221) by placing the cursor on your selection. Press ENTER to save the change. You can also select the interface using the SYST:COMM:SEL command (see [Table 10-2](#)).

NOTE When the interface is changed, the unit will perform a power-on reset.

Using the communications menu

To access the communications menu, press COMM, and then choose the desired interface and selections as shown in [Table 10-1](#). As indicated earlier, if you change to a different interface, the Model 622x will perform a power-on reset, and you must re-enter the menu to configure the selected interface.

Table 10-1
Communications menu

Menu item	Description
GPIB ADDRESS SELECT LANGUAGE	Select/configure GPIB interface. Set primary address (0-30), default 12. Select SCPI or KI-220 language.
RS-232 BAUD TERMINATOR FLOW-CTRL	Select/configure RS-232 interface. Set baud rate (300, 600, 1200, 2400, 4800, 9600, 19.2K, 38.4K, 57.6K, or 115.2K). Select terminator (<CR>, <CR+LF>, <LF>, or <LF+CR>). Select flow control (NONE or XON-XOFF).
ETHERNET MAC IP GATEWAY SUBNET DHCP	Select/configure Model 6221 Ethernet interface. ¹ Display MAC address. ² Typical:123.456.789.012.345.678 Set/view IP address. ³ Format: IP: 000.000.000.000 Set/view Ethernet gateway. ³ Format: GW: 000.000.000.000 Set/view subnet mask. ³ Format: SN: 000.000.000.000 Select DHCP control (ON or OFF). ⁴
PASSWORD NO YES	Select whether to clear communications password. ⁵ Do not clear password. Clear password.

1. The Ethernet interface is not available on the Model 6220.
2. The MAC address is displayed only and cannot be changed by the user. Typical decimal notation address shown.
3. Formats shown only for example. Actual numeric values depend on settings.
4. It is not necessary to manually set the IP address, Ethernet gateway, and subnet mask if DHCP control is ON, and the LAN has a DHCP server. See “[Ethernet settings](#),” on page 10-33.
5. See “[Password](#),” on page 10-6 and [Table 10-2](#) for password details.

Configuring the GPIB interface

1. Press the COMM key, select GPIB, and press ENTER.
2. If you are changing to the GPIB from a different interface, the Model 622x will perform a power-on reset, and you must re-enter the COMM menu.
3. Set the primary ADDRESS to the desired value (0–30; default: 12), and then press ENTER.
4. Choose SELECT LANGUAGE, press ENTER, and then chose either the SCPI (SCPI 1996.0 which includes 488.2) or KI-220 (DDC) language. Press ENTER to complete your selection.

See “[GPIB interface reference](#),” on page 10-19 for full details on using the GPIB interface.

Configuring the RS-232 interface

1. Press the COMM key, select RS-232, and press ENTER.
2. If you are changing to the RS-232 interface from a different interface, the Model 622x will perform a power-on reset, and you must re-enter the COMM menu.
3. Select BAUD, then press ENTER. Enter the baud rate (300, 600, 1200, 2400, 4800, 9600, 19.2K, 38.4K, 57.6K, or 115.2K), and press ENTER to complete your selection.
4. Select TERMINATOR, then press ENTER. Set the terminator (<CR>, <CR+LF>, <LF>, or <LF+CR>), then press ENTER.
5. Select FLOW, then press ENTER. Set the flow control (NONE or XON-XOFF), then press ENTER.
6. Press EXIT to return to normal display.

See “[RS-232 interface reference](#),” on page 10-25 for more information on the RS-232 interface.

Configuring the Model 6221 Ethernet interface

1. Press the COMM key, select ETHERNET, and press ENTER.
2. If you are changing to the ETHERNET interface from a different interface, the Model 622x will perform a power-on reset, and you must re-enter the COMM menu.
3. Select DHCP, then press ENTER to set the Dynamic Host Control Protocol to ON or OFF. Press ENTER after making a change. With DHCP ON, and when a DHCP server is used on the LAN, it is not necessary to manually enter the IP address, gateway, or subnet mask. If you select DHCP ON, the Model 6221 will reset and then attempt to connect to a DHCP server. If unsuccessful, press EXIT to abort the process. If you select DHCP OFF, complete steps 4 through 7 below.
4. Select IP then press ENTER to enter the IP address. Press ENTER after you enter the IP address.
5. Select GATEWAY, then press ENTER to enter the Ethernet gateway. Press ENTER to complete gateway programming.
6. Select SUBNET, then press ENTER to input the subnet mask. Press ENTER to complete mask programming.
7. Press EXIT to return to normal display after completing Ethernet setup.

See “Ethernet interface reference,” on page 10-29 for more information on the Ethernet interface.

NOTE When the IP address, the Ethernet gateway, or subnet mask is changed, the unit will perform a power-on reset when leaving the menu.

Password

A user-defined password can be used to disable protected commands. Most Model 622x commands are protected (see Table 10-3 for a list of unprotected commands). When the use of password is enabled, there are commands to either disable or enable the protected commands (Table 10-2).

At the factory, the Model 622x is assigned the following password name:

“DEFAULT”

The password is case sensitive and must be enclosed in quotes, as shown above. From the front panel, the password can be cleared by using the PASSWORD selection in the communications menu (see Table 10-1) as follows:

1. Press the COMM key, select PASSWORD, and press ENTER.
2. To clear the password, select YES, then press ENTER. The “PASSWORD CLEARED” message will be displayed.

Remote interface configuration commands

Commands to select the GPIB, RS-232, and Model 6221 Ethernet interface, to control the password, and to configure the RS-232 and Ethernet interfaces by remote are listed in Table 10-2. Additional information for each command is provided in notes that follow the table. See “RS-232 interface reference,” on page 10-25 for more RS-232 information, and “Ethernet interface reference,” on page 10-29 for more Ethernet information.

Table 10-2
Remote interface configuration commands

Command	Description
SYSTem:COMMUnicatE:SElect <name>	Selects remote interface. ¹ <name> = SERial, GPIB, or ETHernet.
<i>GPIB interface command:</i>	
SYSTem:COMMUnicatE:GPIB:ADDReSS <NRf>	Sets GPIB primary address. ² <NRf> = 0 to 30, default 12.
<i>RS-232 interface commands:</i>	
SYSTem:COMMUnicatE:SERial:CONTrol:RTS <name>	Selects handshaking. ³ <name> = IBFull, RFR, or OFF
SYSTem:COMMUnicatE:SERial:PACE <name>	Sets flow control. ⁴ <name> = XON or OFF
SYSTem:COMMUnicatE:SERial:TERMinator <name>	Sets output terminator. ⁵ <name> = CR, LF, CRLF, or LFCR.
SYSTem:COMMUnicatE:SERial:BAUD <n>	Sets baud rate. ⁶ <n> = 300, 600, 1200, 2400, 4800, 9600, 19.2k, 38.4K, 57.6K, or 115.2K
SYSTem:COMMUnicatE:SERial:SEND <data>	Sends data via RS-232. ⁷
SYSTem:COMMUnicatE:SERial:ENTer?	Reads data from serial port. ⁸
SYSTem:LOCal	Takes 622x out of remote. ⁹
SYSTem:REMote	Puts 622x in remote. ⁹
SYSTem:RWLock 	Enables or disables local lockout. ⁹ = ON or OFF

Table 10-2 (cont.)

Remote interface configuration commands

Command	Description
<i>Ethernet interface commands (6221 only):</i>	
SYSTem:COMMunicate:ETHernet:ADDResS <string>	Sets IP address of 6221. ¹⁰ <string> = “n.n.n.n”
SYSTem:COMMunicate:ETHernet:MASK <string>	Sets subnet mask of 6221. ¹¹ <string> = “n.n.n.n”
SYSTem:COMMunicate:ETHernet:GATEway <string>	Sets Ethernet gateway of 6221. ¹² <string> = “n.n.n.n”
SYSTem:COMMunicate:ETHernet:DHCp 	Enables/disables DHCP. ¹³ = ON or OFF
SYSTem:COMMunicate:ETHernet:MAC?	Queries 6221 MAC address. ¹⁴
SYSTem:COMMunicate:ETHernet:SAVE	Saves Ethernet setting changes. ¹⁵
<i>Password commands:</i>	
SYSTem:PASSword[:CENable] <string>	Sends password to enable protected commands. ¹⁶ <string> = “password”
SYSTem:PASSword:CDISable <string>	Disables protected commands. ¹⁷ <string> = “password”
SYSTem:PASSword:ENABLE 	Enables/disables use of password. ¹⁸ = ON or OFF
SYSTem:PASSword:STATE?	Queries protected command state. ¹⁹ 0 = disabled; 1 = enabled
SYSTem:PASSword:NEW <string>	Sets new password. ²⁰ <string> = “password”

1. SYST:COMM:SEL <name> ‘ Select interface.
This command selects the interface: SERial, GPIB, or ETHernet (6221 only). The Model 622x will perform a power-on reset when the interface is changed.
2. SYST:COMM:GPIB:ADDR <NRf> ‘ Set GPIB primary address.
This command sets the GPIB primary address (0-30, default 12). You must be using the GPIB as the communication interface, or this command is ignored. Note that address 21 is often used as a controller address, so 21 should be avoided.

3. SYST:COMM:SER:CONT:RTS <name> ‘ Select hardware handshaking.
This command enables (IBFull or RFR) or disables (OFF) hardware handshaking.
4. SYST:COMM:SER:PACE <name> ‘ Set flow control.
This command sets software flow control; XON to enable or OFF (default) to disable.
5. SYST:COMM:SER:TERM <name> ‘ Set terminator.
This command selects the output terminator, CR, LF (default), CRLF, or LFCR.
6. SYST:COMM:SER:BAUD <n> ‘ Set baud rate.
Sets RS-232 baud rate: 300, 600, 1200, 2400, 4800, 9600, 19.2k (default), 38.4K, 57.6K, or 115.2K.
The following two commands cannot be sent to the Model 622x over the RS-232 interface, but instead make use of the instrument to send and receive data through the GPIB or 6221 Ethernet interface via the 622x RS-232 port to another instrument such as a Model 2182 (purchased separately).
7. SYST:COMM:SER:SEND <data> ‘ Send serial data.
Sends data from one instrument to another through the serial port. Strings, such as commands to another instrument must be delineated with quotes ("").
8. SYST:COMM:SER:ENT? <name> ‘ Read serial data.
Reads data from another instrument through the serial port.
9. SYST:LOC ‘ Take unit out of remote.
SYST:REM ‘ Put unit in remote.
SYST:RWL ‘ Enable/disable local lockout.
These three commands work with the RS-232 interface only. REMote is the same as the IEEE-488 REN command and puts the unit in remote. LOCal works like the IEEE-488 GTL command and takes it out of remote and returns it local. RWLock is similar to the IEEE-488 LLO command and enables or disables local lockout. See “[General IEEE-488 bus commands](#),” on page 10-22 for more information.
10. SYST:COMM:ETH:ADDR <string> ‘ Set IP address.
This command sets the IP address of the Model 6221. The address parameter is of the form “n.n.n.n”, where each n is a decimal representation of a single byte with a value of 0 to 255. Note that the IP address parameter must be enclosed in quotes. Example: SYST:COMM:ETH:ADDR “145.90.120.240”.
11. SYST:COMM:ETH:MASK <string> ‘ Set subnet mask.
This command sets the subnet mask of the Model 6221. The mask parameter is of the form “n.n.n.n”, where each n is a decimal representation of a single byte with a value of 0 to 255. Note that the mask parameter must be enclosed in quotes. Example: SYST:COMM:ETH:MASK “255.255.255.0”.

12. SYST:COMM:ETH:GAT <string> ‘ Set Ethernet gateway.

This command sets the Ethernet gateway of the Model 6221. The gateway parameter is of the form “n.n.n.n”, where each n is a decimal representation of a single byte with a value of 0 to 255. Note that the parameter must be enclosed in quotes. Example: SYST:COMM:ETH:GAT “145.90.120.1”.

**13. SYST:COMM:ETH:DHCP ** ‘ Enable/disable DHCP.

This command enables (ON) or disables (OFF) DHCP (Dynamic Host Control Protocol). When DHCP is enabled and used on a network with a DHCP server, the Model 6221 IP address, subnet mask, and Ethernet gateway will be automatically assigned by the server.

14. SYST:COMM:ETH:MAC? ‘ Query MAC address.

This query requests the MAC address from the unit. The returned value is in the form of hexadecimal values separated by colons (for example, 00:60:1A:00:04:0B). The MAC address is assigned at the factory and cannot be changed by the user.

15. SYST:COMM:ETH:SAVE ‘ Save Ethernet setting changes.

This command saves the Ethernet address changes and reboots the instrument. When the IP address, Ethernet gateway, or subnet mask is changed, the change does not take effect until either the SYST:COMM:ETH:SAVE command is sent or the next time the Model 6221 is power-cycled.

16. SYST:PASS[:CEN] <string> ‘ Enable protected commands.

This command enables protected commands. (Commands that are *not* protected are listed in [Table 10-3](#).) Send the password as a string of characters. The password is case sensitive and can include both standard ASCII and non-ASCII characters from 1 to 255. Make sure to enclose the password in quotes. For example, with the default password, the following would be sent: SYST:PASS “DEFAULT”. Note that the password and command protection state are not affected by *RST or SYSTem:PRESet.

17. SYST:PASS:CDIS <string> ‘ Disable protected commands.

This command disables protected commands. All commands except those listed in [Table 10-3](#) will be disabled when this command is sent with the correct password. The password is case sensitive and can include both standard ASCII and non-ASCII characters from 1 to 255. It must be enclosed in quotes. For example, with the default password, the following would be sent to disable all protected commands: SYST:PASS:CDIS “DEFAULT”.

**18. SYST:PASS:ENAB ** ‘ Enable/disable password.

Use this command to enable or disable the use of a password. Disabling the use of a password enables all protected commands. For example, to enable the password, send this command: SYST:PASS:ENAB ON.

19. SYST:PASS:STAT? ‘ Query state of password.
This query requests the state of password protection. “0” will be returned if password protected commands are disabled; “1” will be returned if the password protected commands are enabled.
20. SYST:PASS:NEW <string> ‘ Set new password.
Use this command to set a new password. The password is case sensitive and can include both standard ASCII and non-ASCII characters from 1 to 255. It must be enclosed in quotes. For example, to change the password to “PASSWORD”, send this command: SYST:PASS:NEW “PASSWORD”. Note that the password and command protection state are not affected by *RST or SYSTem:PRESet.

Table 10-3
Unprotected commands and queries

Common commands	SCPI commands
*ESE? *ESR? *IDN? *OPC *OPC? *OPT? *SRE *SRE? *STB? *WAI	OUTP:STAT OFF OUTP:STAT? STAT:QUE:NEXT? SYST:ABO:REV? SYST:DBO:REV? SYST:ABO:SNUM? SYST:DBO:SNUM? SYST:ERR? SYST:LFR? SYST:LOC SYST:PASS:CDIS SYST:PASS:CEN SYST:PASS:CEN:STAT? SYST:REM SYST:VER?

Programming syntax

The following paragraphs cover syntax for both common commands and SCPI commands. For more information, see the IEEE-488.2 and SCPI standards.

Command words

Program messages are made up of one or more command words.

Commands and command parameters

Common commands and SCPI commands may or may not use a parameter. The following are some examples:

*SAV <NRf>	Parameter (NRf) required.
*RST	No parameter used.
:DISPlay:ENABLE 	Parameter required.
:SYSTem:PRESet	No parameter used.

Put at least one space between the command word and the parameter.

- **Brackets []** — Some command words are enclosed in brackets ([]). These brackets are used to denote an optional command word that does not need to be included in the program message. For example:

:INITiate[:IMMEDIATE]

These brackets indicate that :IMMEDIATE is implied (optional) and does not need to be used. Thus, the above command can be sent in one of two ways:

:INITiate or :INITiate:IMMEDIATE

Notice that the optional command is used without the brackets. When using optional command words in your program, do not include the brackets.

- **Parameter types** — The following are some of the common parameter types:

	Boolean — Used to enable or disable an instrument operation. 0 or OFF disables the operation and 1 or ON enables the operation.
-----	--

:DISPLAY:ENABLE ON	Enable the display
--------------------	--------------------

<name>	Name parameter — Select a parameter name from a listed group.
	<name> = MXB = RECiprocal
	:CALCulate:FORMAT MXB Select Mx + B calculation
<NRf>	Numeric representation format — A number that can be expressed as an integer (e.g., 8), a real number (e.g., 23.6), or an exponent (e.g., 2.3E6).
	:SOURce:SWEep:COUNT 10 Set sweep count to 10
<NDN>	Non-decimal numeric — A non-decimal value that can be used to program status enable registers. A unique header identifies the format: #B (binary), #H (hexadecimal), and #Q (octal).
	*SRE #B10001 Set bits B0 and B4 of Service Request Enable Register
<n>	Numeric value — Can consist of an NRf number or one of the following name parameters: DEFault, MINimum, or MAXimum. When the DEFault parameter is used, the instrument is programmed to the *RST default value. When the MINimum parameter is used, the instrument is programmed to the lowest allowable value. When the MAXimum parameter is used, the instrument is programmed to the largest allowable value.
	:ARM:TIMER 0.1 Sets timer to 100 msec. :ARM:TIMER DEFault Sets timer to 0.1 sec. :ARM:TIMER MINimum Sets timer to 0s. :ARM:TIMER MAXimum Sets timer to 99999.99 sec.

- **Angle brackets <>** — Used to denote a parameter type. Do not include the brackets in the program message.

:DISPLAY:ENABLE

The indicates that a Boolean type parameter is required. Thus, to enable the display, you must send the command with the ON or 1 parameter as follows.

:DISPLAY:ENABLE ON or 1

Query commands

The query command requests the presently programmed status. It is identified by the question mark (?) at the end of the fundamental form of the command. Most commands have a query form.

:ARM:TIMER? Queries the timer interval

Most commands that require a numeric parameter (<n>) can also use the DEFault, MINimum, and MAXimum parameters for the query form. These query forms are used to determine the *RST default value and the upper and lower limits for the fundamental command.

:ARM:TIMER? DEFault Queries the *RST default value

:ARM:TIMER? MINimum Queries the lowest allowable value

:ARM:TIMER? MAXimum Queries the largest allowable value

Case sensitivity

Common commands and SCPI commands are not case sensitive. You can use upper or lower case and any case combination. Examples:

*RST = *rst

:SYSTem:PRESet= :system:preset

Long-form and short-form versions

A SCPI command word can be sent in its long-form or short-form version. The command tables in this manual use the long-form version. However, the short-form version is indicated by upper case characters.

:SYSTem:PRESet long-form

:SYST:PRE short form

:SYSTem:PRE long-form and short-form combination

Note that each command word must be in either long-form or short-form. For example, :SYSTe:PRESe is illegal and will generate an error. The command will not be executed.

Short-form rules

Use the following rules to determine the short-form version of any SCPI command:

- If the length of the command word is four letters or less, no short form version exists.

:auto = :auto

These rules apply to command words that exceed four letters:

- If the fourth letter of the command word is a vowel, delete it and all letters after it.
`immediate = :imm`
- If the fourth letter of the command word is a consonant, retain it but drop all the letters after it.
`:format = :form`
- If the command contains a question mark (?) or a non-optional number included in the command word, you must include it in the short-form version.
`:delay? = :del?`
- Command words or characters that are enclosed in brackets ([]) are optional and need not be included in the program message.

Program messages

A program message is made up of one or more command words sent by the computer to the instrument. Each common command is a three letter acronym preceded by an asterisk (*). The following SCPI commands from the STATus subsystem are used to help explain how command words are structured to formulate program messages.

Command structure	
<code>:STATus</code>	Path (Root)
<code>:OPERation</code>	Path
<code>:ENABLE <NRf></code>	Command and parameter
<code>:ENABLE?</code>	Query command
<code>:PRESet</code>	Command

Single command messages

The above command structure has three levels. The first level is made up of the root command (:STATus) and serves as a path. The second level is made up of another path (:OPERation) and a command (:PRESet). The third path is made up of one command for the :OPERation path. The three commands in this structure can be executed by sending three separate program messages as follows:

```
:stat:oper:enab <NRf>
:stat:oper:enab?
:stat:pres
```

In each of the above program messages, the path pointer starts at the root command (:stat) and moves down the command levels until the command is executed.

Multiple command messages

You can send multiple command messages in the same program message as long as they are separated by semicolons (;). The following is an example showing two commands in one program message:

```
:stat:oper; :stat:oper:enab <NRF>
```

When the above is sent, the first command word is recognized as the root command (:stat). When the next colon is detected, the path pointer moves down to the next command level and executes the command. When the path pointer sees the colon after the semicolon (;), it resets back to the root level and starts over.

Commands that are on the same command level can be executed without retyping the entire command path. Example:

```
:stat:oper:enab <NRF>; enab?
```

After the first command (:enab) is executed, the path pointer is at the third command level in the structure. Since :enab? is also on the third level, it can be entered without repeating the entire path name. Notice that the leading colon for :enab? is not included in the program message. If a colon were included, the path pointer would reset to the root level and expect a root command. Since :enab? is not a root command, an error would occur.

Command path rules

- Each new program message must begin with the root command, unless it is optional. If the root is optional, treat a command word on the next level as the root.
- The colon (:) at the beginning of a program message is optional and need not be used.

```
:stat:pres = stat:pres
```

- When the path pointer detects a colon (:), it moves down to the next command level. An exception is when the path pointer detects a semicolon (;), which is used to separate commands within the program message.
- When the path pointer detects a colon (:) that immediately follows a semicolon (;), it resets to the root level.
- The path pointer can only move down. It cannot be moved up a level. Executing a command at a higher level requires that you start over at the root command.

Using common commands and SCPI commands in the same message

Both common commands and SCPI commands can be used in the same message as long as they are separated by semicolons (;). A common command can be executed at any command level and will not affect the path pointer.

```
:stat:oper:enab <NRf>; *ESE <NRf>
```

Program Message Terminator (PMT)

Each program message must be terminated with an LF (line feed), EOI (end or identify), or an LF+EOI. The interface will hang if your computer does not provide this termination. The following example shows how a program message must be terminated:

```
:sour:swe:poin 10 <PMT>
```

Command execution rules

- Commands execute in the order they are presented in the program message.
- An invalid command generates an error and is not executed.
- Valid commands that precede an invalid command in a multiple command program message are executed.
- Valid commands that follow an invalid command in a multiple command program message are ignored.
- For fastest command execution:
 1. Do not use optional command words.
 2. Do not use the colon (:) at the beginning of a program message.
 3. Always use the short-form versions of commands and parameters.
 4. Minimize the amount of “white” space in command strings.
 5. Keep numeric parameters simple (i.e., 1 vs. 1.000e + 00).
 6. Use all uppercase.

Response messages

A response message is the message sent by the instrument to the computer in response to a query command program message.

Sending a response message

After sending a query command, the response message is placed in the output queue. The response message is sent from the output queue to the computer.

Multiple response messages

If you send more than one query command in the same program message (see “[Multiple command messages](#),” on page 10-16), the multiple response messages for all the queries are sent to the computer when the Model 622x is addressed to talk. The responses are sent in the order that the query commands were sent and are separated by semicolons (;). Items within the same query are separated by commas (,). The following example shows the response message for a program message that contains four single item query commands:

```
0; 1; 1; 0
```

Response Message Terminator (RMT)

Each response is terminated with an LF (line feed) and EOI (end or identify). The following example shows how a multiple response message is terminated:

```
0; 1; 1; 0; <RMT>
```

Message exchange protocol

Two rules summarize the message exchange protocol:

- Rule 1.** Always tell the Model 622x what to send to the computer. The following two steps must always be performed to send information from the instrument to the computer:
 1. Send the appropriate query command(s) in a program message.
 2. Address the Model 622x to talk (GPIB only).
- Rule 2.** The complete response message must be received by the computer before another program message can be sent to the Model 622x.

GPIB interface reference

GPIB bus standards

The GPIB bus is the IEEE-488 instrumentation data bus with hardware and programming standards originally adopted by the IEEE (Institute of Electrical and Electronic Engineers) in 1975. The Model 622x conforms to these standards:

- IEEE-488.1-1987
- IEEE-488.2-1992

These standards define a syntax for sending data to and from instruments, how an instrument interprets this data, what registers should exist to record the state of the instrument, and a group of common commands.

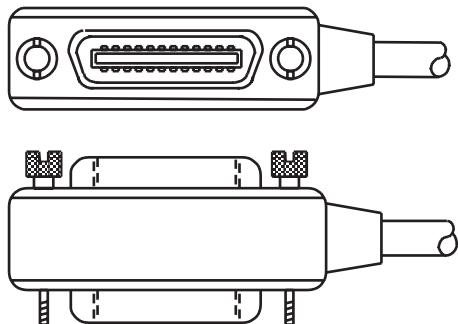
The standard below defines a command language protocol. It goes one step further than IEEE-488.2-1992 and defines a standard set of commands to control every programmable aspect of an instrument.

- SCPI 1996.0 (Standard Commands for Programmable Instruments)

GPIB bus connections

To connect the Model 622x to the GPIB bus, use a cable equipped with standard IEEE-488 connectors as shown in [Figure 10-1](#).

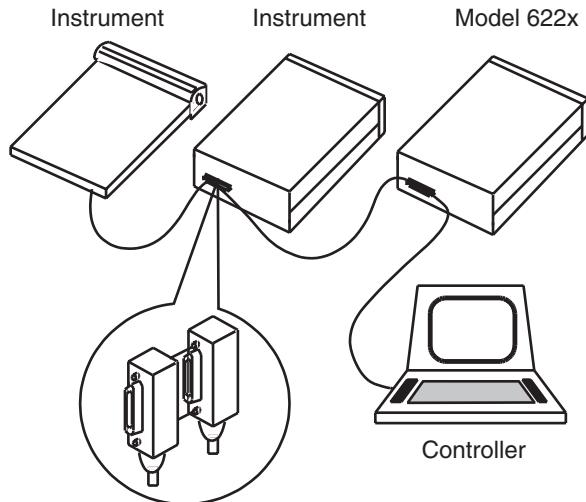
Figure 10-1
IEEE-488 connector



To allow many parallel connections to one instrument, stack the connector. Two screws are located on each connector to ensure that connections remain secure.

Figure 10-2 shows a typical connecting scheme for a multi-unit test system.

Figure 10-2
Multi-unit connections



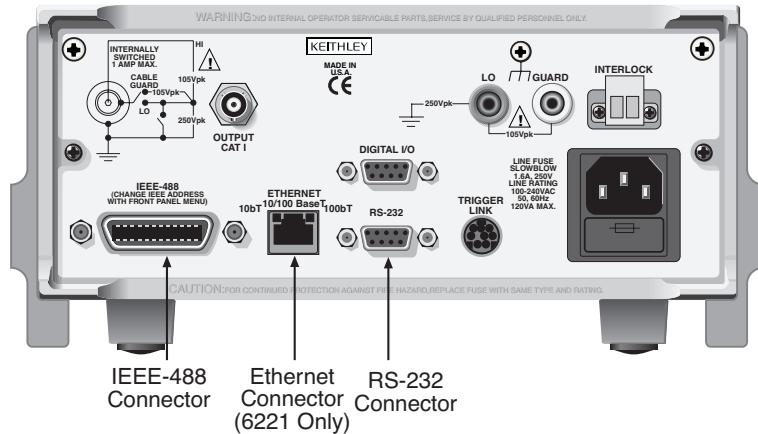
To avoid possible mechanical damage, stack no more than three connectors on any one unit.

NOTE To minimize interference caused by electromagnetic radiation, use only shielded IEEE-488 cables. Available shielded cables from Keithley are Models 7006, 7007, and 7708.

To connect the Model 622x to the IEEE-488 bus, follow these steps:

1. Line up the cable connector with the connector located on the rear panel. The connector is designed so it will fit only one way. [Figure 10-3](#) shows the location of the IEEE-488 connector.

**Figure 10-3
IEEE-488, Ethernet (6221 only), and RS-232 connector locations**



2. Tighten the screws securely, making sure not to over-tighten them.
3. Connect any additional connectors from other instruments as required for your application.
4. Make sure the other end of the cable is properly connected to the controller. Most controllers are equipped with an IEEE-488 style connector, but a few may require a different type of connecting cable. See your controller's instruction manual for information about properly connecting to the IEEE-488 bus.

NOTE You can only have 15 devices connected to an IEEE-488 bus, including the controller. The maximum cable length is either 20 meters or two meters times the number of devices, whichever is less. Not observing these limits may cause erratic bus operation.

Primary address

The Model 622x ships from the factory with a GPIB address of 12. When the instrument powers up, it momentarily displays the primary address. You can set the address to a value of 0-30. Do not assign the same address to another device or to a controller that is on the same GPIB bus.

Usually controller addresses are 0 or 21 but see the controller's instruction manual for details. Make sure the address of the controller is the same as that specified in the controller's programming language. To make sure the unit's interface is properly selected and configured or to check or change the setting, see “[Interface selection and configuration](#),” on page 10-3.

General IEEE-488 bus commands

Commands and associated statements

General commands are those commands, such as DCL, that have the same general meaning regardless of the instrument. [Table 10-4](#) lists the general bus commands.

Table 10-4
General bus commands

Command	Effect on Model 622x
REN	Goes into remote when next addressed to listen.
IFC	Reset interface; all devices go into talker and listener idle states.
LLO	LOCAL key and OUTPUT ON locked out.
GTL	Cancel remote; restore front panel operation for Model 622x.
DCL	Returns all devices to known conditions.
SDC	Returns Model 622x to known conditions.
GET	Initiates a trigger.
SPE, SPD	Serial polls Model 622x.

REN (remote enable)

The remote enable command is sent to the Model 622x by the controller to set up the instrument for remote operation. Generally, the instrument should be placed in the remote mode before you attempt to program it over the bus. Simply setting REN true does not actually place the instrument in the remote state. You must address the instrument to listen after setting REN true before it goes into remote. Note that the instrument does not have to be in remote to be a talker.

Note that all front panel controls, except for LOCAL, POWER, and OUTPUT OFF are inoperative while the instrument is in remote (OUTPUT ON is inoperative in remote). You can restore normal front panel operation by pressing the LOCAL key.

IFC (interface clear)

The IFC command is sent by the controller to place all instruments on the bus in the local, talker, listener idle states. The Model 622x responds to the IFC command by canceling front panel TALK or LSTN lights, if the instrument was previously placed in one of those states. Note that this command does not affect the status of the instrument; settings, data, and event registers are not changed.

To send the IFC command, the controller must set the IFC line true for a minimum of 100µs.

LLO (local lockout)

Use the LLO command to prevent local operation of the instrument. After the unit receives LLO, all its front panel controls except POWER and OUTPUT OFF are inoperative (OUTPUT ON is inoperative in LLO). In this state, pressing LOCAL will not restore control to the front panel. The GTL command restores control to the front panel.

GTL (go to local)

Use the GTL command to put a remote mode instrument into local mode. The GTL command also restores front panel key operation.

DCL (device clear)

Use the DCL command to clear the GPIB interface and return it to a known state. Note that the DCL command is not an addressed command, so all instruments equipped to implement DCL will do so simultaneously. When the Model 622x receives a DCL command, it clears the input buffer and output queue, cancels deferred commands, and clears any command that prevents the processing of any other device command. A DCL does not affect instrument settings and stored data.

SDC (selective device clear)

The SDC command is an addressed command that performs essentially the same function as the DCL command. However, since each device must be individually addressed, the SDC command provides a method to clear only selected instruments instead of clearing all instruments simultaneously, as is the case with DCL.

GET (group execute trigger)

GET is a GPIB trigger that is used as an event to control operation. The Model 622x reacts to this trigger if it is the programmed control source. The control source is programmed from the SCPI TRIGger subsystem.

SPE, SPD (serial polling)

Use the serial polling sequence to obtain the Model 622x serial poll byte. The serial poll byte contains important information about internal functions. Generally, the serial polling sequence is used by the controller to determine which of several instruments has requested service with the SRQ line. However, the serial polling sequence may be performed at any time to obtain the status byte from the Model 622x.

Front panel GPIB operation

The following paragraphs describe aspects of the front panel that are part of GPIB operation, including messages, status indicators, and the LOCAL key.

Error and status messages

See Appendix B for a list of error and status messages associated with IEEE-488 programming. The instrument can be programmed to generate an SRQ and command queries can be performed to check for specific error conditions.

GPIB status indicators

The REM (remote), TALK (talk), LSTN (listen), and SRQ (service request) annunciators show the GPIB bus status. Each of these indicators is described below.

- **REM** — This indicator shows when the instrument is in the remote state. REM does not necessarily indicate the state of the REM line, as the instrument must be addressed to listen with REM true before the REM indicator turns on. When the instrument is in remote, all front panel keys, except for the LOCAL key and OUTPUT OFF, are locked out. When REM is turned off, the instrument is in the local state, and front panel operation is restored.
- **TALK** — This indicator is on when the instrument is in the talker active state. Place the unit in the talk state by addressing it to talk with the correct MTA (My Talk Address) command. TALK is off when the unit is in the talker idle state. Place the unit in the talker idle state by sending a UNT (Untalk) command, addressing it to listen, or sending the IFC (Interface Clear) command.
- **LSTN** — This indicator is on when the Model 622x is in the listener active state, which is activated by addressing the instrument to listen with the correct MLA (My Listen Address) command. LSTN is off when the unit is in the listener idle state. Place the unit in the listener idle state by sending UNL (Unlisten), addressing it to talk, or sending the IFC (Interface Clear) command over the bus.
- **SRQ** — You can program the instrument to generate a service request (SRQ) when one or more errors or conditions occur. When this indicator is on, a service request has been generated. This indicator stays on until the serial poll byte is read or all the conditions that caused SRQ have ceased to exist.

LOCAL key

The LOCAL key cancels the remote state and restores local operation of the instrument. Pressing the LOCAL key also turns off the REM indicator and returns the display to normal if a user-defined message was displayed. If the LLO (Local Lockout) command is in effect, the LOCAL key is also inoperative.

RS-232 interface reference

Sending and receiving data

The RS-232 interface transfers data using eight data bits, one stop bit and no parity. When using the RS-232 interface, the unit will not respond to DDC or general GPIB commands. See Appendix B for RS-232 error messages.

RS-232 settings

The procedure to select and configure the RS-232 interface is provided in “[Interface selection and configuration](#),” on page 10-3. Make sure the controller you connect to the Model 622x also uses these settings.

NOTE You can break data transmissions by sending a ^C or ^X character string to the Model 622x. This clears any pending operation and discards any pending output.

Baud rate

The baud rate is the rate at which the Model 622x and the programming terminal communicate. You can choose from one of the following rates: 115.2k, 57.6k, 38.4k, 19.2k, 9600, 4800, 2400, 1200, 600, or 300. The default is 19.2k.

Make sure the programming terminal that you are connecting to the Model 622x can support the baud rate you selected. Both the Model 622x and the other device must be configured for the same baud rate.

Data bits, stop bits, and parity

The RS-232 interface settings for data bits, stop bits, and parity are fixed at eight data bits, one stop bit, and no parity. These settings cannot be changed.

Terminator

The Model 622x can be configured to terminate each program message that it transmits to the controller with any of the following combinations of <CR> and <LF>:

- LF line feed (default)
- CR carriage return
- LFCR line feed, carriage return
- CRLF carriage return, line feed

Flow control (signal handshaking)

Signal handshaking between the controller and the instrument allows the two devices to communicate to each other regarding being ready or not ready to receive data.

Software flow control

Software flow control is in the form of X_ON and X_OFF characters and is enabled when XonXoff is selected from the RS-232 FLOW-CTRL menu. When the input queue of the Model 622x becomes more than 3/4 full, the instrument issues an X_OFF command. The control program should respond to this and stop sending characters until the Model 622x issues the X_ON, which it will do once its input buffer has dropped below 1/2 full. The Model 622x recognizes X_ON and X_OFF sent from the controller. An X_OFF will cause the Model 622x to stop outputting characters until it sees an X_ON. Incoming commands are processed after the <CR> character is received from the controller.

If NONE is the selected flow control, then there will be no signal handshaking between the controller and the Model 622x. Data will be lost if transmitted before the receiving device is ready. The default setting is NONE.

NOTE

For RS-232 operation, *OPC or *OPC? should be used with slow responding commands. See Section 12.

Even with X_ON/X_OFF selected, the computer may still lose data from the Model 622x if the return string is large (>30,000 characters) and one of the higher baud rates is selected. With no flow control (NONE selected), the error occurs with a much smaller return string. Use some type of error checking in your program to avoid these situations.

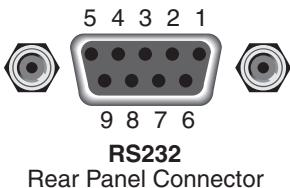
Hardware flow control

Hardware handshaking can be used instead for flow control. The RS-232 interface provides two control lines (RTS and CTS) for this purpose (see [Figure 10-4](#) and [Table 10-5](#)). When the Model 622x is ready to send (RTS) data, it will transmit when it receives the clear to send (CTS) signal from the computer.

RS-232 connections

The RS-232 serial port can be connected to the serial port of a computer using a straight-through RS-232 cable terminated with DB-9 connectors. **Do not use a null modem cable.** The serial port uses the transmit (TXD), receive (RXD), ready to send (RTS), clear to send (CTS), and signal ground (GND) lines of the RS-232 standard. [Figure 10-4](#) shows the rear panel connector for the RS-232 interface and [Table 10-5](#) shows the pinout for the connector. The connector location on the rear panel is shown in [Figure 10-3](#).

Figure 10-4
RS-232 interface connector



If your computer uses a DB-25 connector for the RS-232 interface, you will need a cable or adapter with a DB-25 connector on one end and a DB-9 connector on the other, wired straight through (not null modem). [Table 10-6](#) provides pinout identification for the 9-pin (DB-9) or 25-pin (DB-25) serial port connector on the computer (PC).

Table 10-5
RS-232 connector pinout

Pin number	Description
1	No connection
2	TXD, transmit data
3	RXD, receive data
4	No connection
5	GND, signal ground
6	Not used
7	RTS, ready to send
8	CTS, clear to send
9	No connection

Table 10-6
PC serial port pinout

Signal*	DB-9 pin number	DB-25 pin number
DCD, data carrier detect	1	8
RXD, receive data	2	3
TXD, transmit data	3	2
DTR, data terminal ready	4	20
GND, signal ground	5	7
DSR, data set ready	6	6
RTS, ready to send	7	4
CTS, clear to send	8	5
RI, ring indicator	9	22

* The Model 622x does not use all RS-232 signals. See [Table 10-5](#).

Ethernet interface reference

Ethernet standards

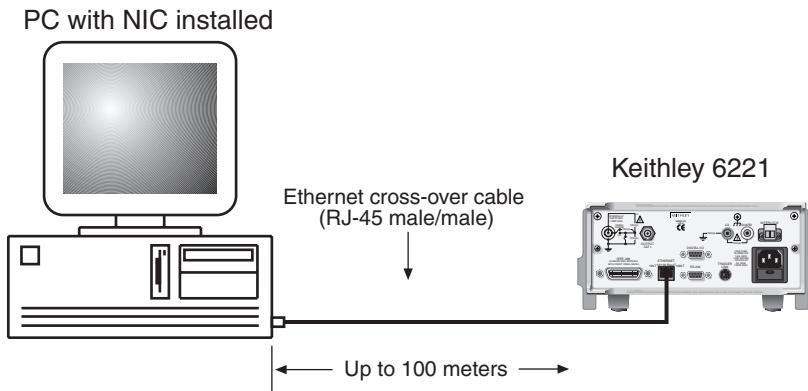
The Model 6221 conforms to these standards:

- TCP/IP
- IEEE-802.3
- SCPI 1996.0 (Standard Commands for Programmable Instruments)

Typical Ethernet systems

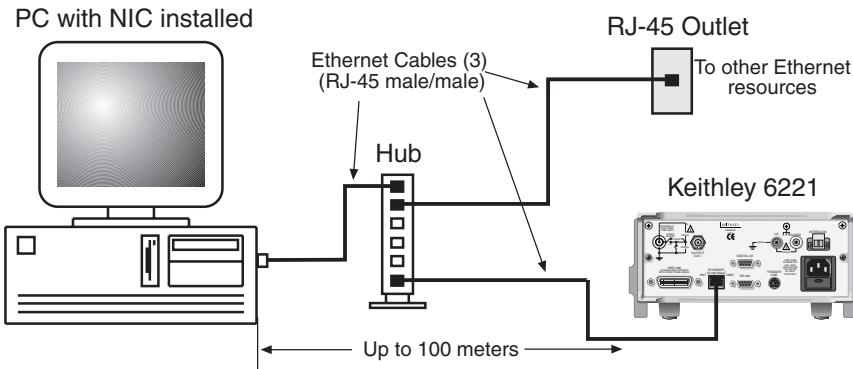
The four typical Ethernet systems using a Model 6221 are shown in Figures 10-5 through 10-8. The simplest system connects a Model 6221 directly to a PC equipped with a NIC (Network Interface Card) as shown in [Figure 10-5](#). The Ethernet cable can be up to 100 meters in length. Note that a cross-over cable must be used for a direct PC connection.

Figure 10-5
Direct 6221 connection to PC



Adding a hub as shown in [Figure 10-6](#), expands the system into a small LAN (Local Area Network). The hub allows additional Ethernet instruments to be connected to the PC.

**Figure 10-6
Small LAN system using a hub**



Adding a second NIC in the PC, as shown in [Figure 10-7](#), expands the network system and provides improved performance because there is no corporate LAN data traffic on the instrument LAN. It also provides additional security between two groups of users. Finally, [Figure 10-8](#) shows a simplified diagram of a network system using a router or servers.

**Figure 10-7
Isolated LAN system using two NICs (Network Interface Cards)**

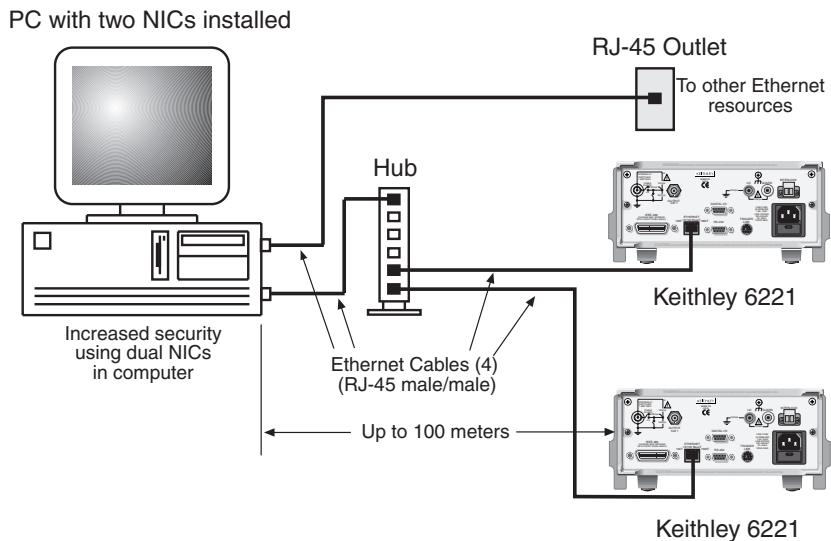
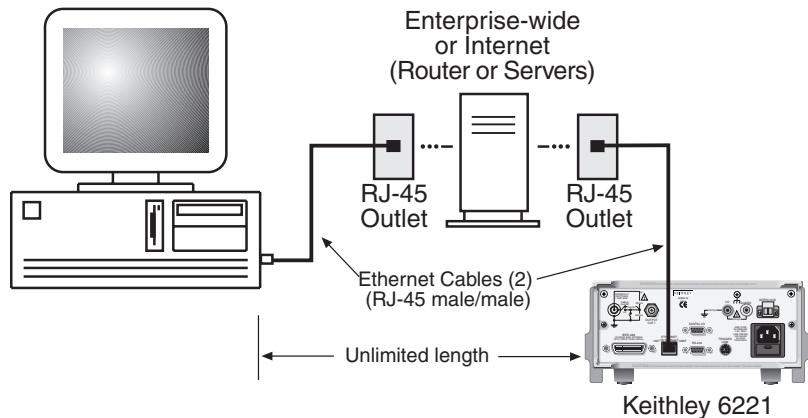


Figure 10-8 shows a simplified diagram of a network system using a router or servers.

**Figure 10-8
Enterprise-wide or internet network system**

PC with NIC installed



Ethernet connections

The Model 6221 is connected to the Ethernet using a male-to-male RJ-45 Ethernet cable (see Figure 10-9). The Ethernet connector for the Model 6221 is shown in Figure 10-10. With power off, connect one end of the cable to the Model 6221 and connect the other end to the Ethernet connector of the PC, hub, or receptacle.

**Figure 10-9
RJ-45 Ethernet cable (male/male)**



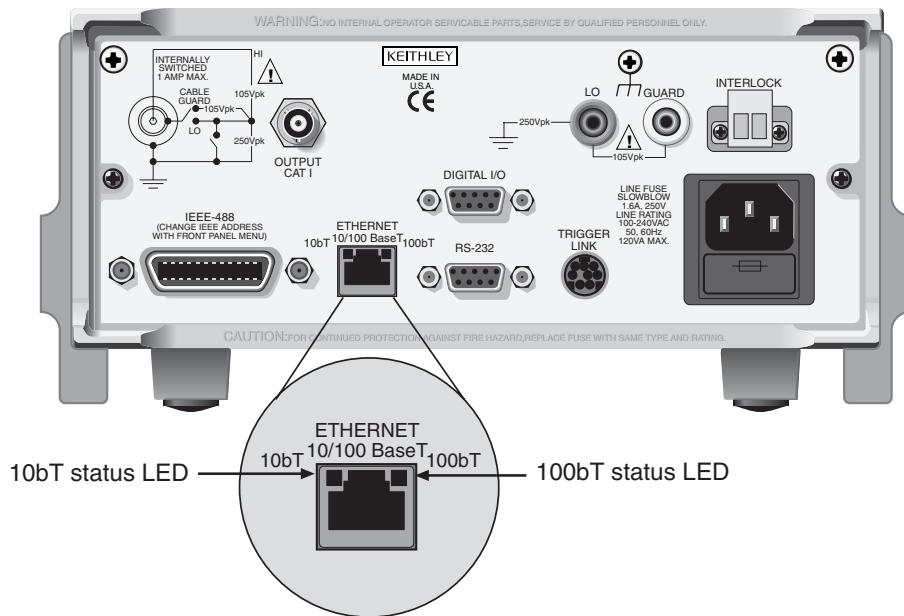
RJ-45 connector status LEDs

The female RJ-45 connector (shown in Figure 10-10) has two status LEDs located at the top of the connector. These LEDs provide the following status:

LED	State	Ethernet status
10bT	On	Network connected (10 mb/s connection).
10bT	Blinking	Traffic is traversing the port (10 mb/s connection).
10bT	Off	10 mb/s network is NOT connected.
100bT	On	Network connected (100 mb/s connection).
100bT	Blinking	Traffic is traversing the port. (100 mb/s connection).
100bT	Off	100 mb/s network is NOT connected.

Figure 10-10
Model 6221 Ethernet connector

Model 6221



Ethernet settings

Ethernet settings include the following:

- Dynamic Host Control Protocol (DHCP) – enable or disable
- IP address
- Subnet mask
- Ethernet gateway
- MAC address of the 6221 – This fixed address for the 6221 cannot be changed.

Ethernet settings can be made from the front panel using the COMM menu (see [Table 10-1](#) for the communications menu and “[Configuring the Model 6221 Ethernet interface,](#)” on page 10-5 for more information) or via remote (see “[Remote interface configuration commands,](#)” on page 10-6).

TCP/IP protocol

The TCP/IP Protocol is the protocol the Model 6221 uses to communicate over the Ethernet connection to the PC. The Model 6221 TCP/IP settings may be configured either manually (through the Model 6221 COMM menu or via remote), or through the use of a DHCP (Dynamic Host Configuration Protocol) server when connected to a local area network (LAN). The IP settings consist of an IP address, subnet mask, and gateway address.

A Network Administrator is required to provide the IP settings (addresses) if the connection is made to a LAN. If the network will be isolated from the LAN, the connection can be made without a Network Administrator. Refer to “[Manual IP configuration,](#)” on page 10-34 below for information on manual configuration of IP settings.

Using DHCP for automatic IP configuration

The Model 6221 supports DHCP. If a DHCP server is present on the network, it will automatically provide the correct settings to the Model 6221 if the 6221 is powered up while connected to the network. Note, however, that DHCP must be enabled (see “[Configuring the Model 6221 Ethernet interface,](#)” on page 10-5).

When adding the device to a network, if a DHCP server is available, the DHCP server will download the IP address, subnet mask, and gateway address to the Model 6221 upon powering it up on the network. Contact the IS/IT department for access to the DHCP server. The network parameters acquired from the DHCP can be viewed from the Model 6221 front panel COMM/ETHERNET menu, or accessed by remote. If no DHCP server is available, these values must be manually assigned to ensure proper operation of the device and to avoid conflicts with other devices on the network.

Manual IP configuration

When connecting the Model 6221 directly to the Ethernet port of a PC or to a hub that is not part of a larger network, the IP address and subnet mask must be configured manually (the gateway address is not usually relevant for smaller networks).

The IP address is a 32-bit identifier consisting of four one-byte (8-bits) sections, commonly identified in dotted decimal format (i.e., 145.90.120.240). The subnet mask is a second 32-bit identifier that designates what portion of the IP address identifies the subnet and what portion identifies the device (i.e., 255.255.255.0). In this example, 145.90.120 is the network address, and 240 is the device address. Gateway addresses are typically the device address 1 (for example, 145.90.120.1).

Networks are commonly grouped into three classes based on the first byte of the address shown in [Table 10-7](#).

Table 10-7
Network classes

Class	First byte	Typical subnet mask	IP address example
A	1 to 127	255.0.0.0	100.1.1.1
B	128 to 191	255.255.0.0	128.1.1.1
C	192 to 223	255.255.255.0	191.1.1.1

Address restrictions

NOTE Different available IP addresses are required for each node (this includes each Model 6221 and each network interface card connected to the instruments network).

The following IP addresses are reserved; do not assign them to any device (either interface card or Model 6221).

Do not assign:

- Any address beginning (first byte) with 0 or 127 (reserved for loopback test)
- Any address beginning (first byte) with 224 through 255
- Any address ending (last byte) with 0 or 255.

Other than the restricted addresses, any dis-similar address may be assigned to the PC's Ethernet interface card and to each Model 6221. Keep in mind that when creating and assigning an address, the one assigned to the Model 6221 must be of the same class as the network. For example, if you want the Model 6221's IP address to be 192.168.0.2, the subnet mask should be 255.255.255.0. Also, to communicate with the Model 6221, the PC's Ethernet interface card must be set to the same class (same subnet mask and Network ID).

NOTE **Without the correct subnet mask or Network ID,
the direct network will not function.**

Using the example software

NOTE **The example software is available for free download at www.keithley.com.**

The example software allows you to control a Model 6220/6221 from any PC using simple mouse-clicks through a virtual front panel, as well as perform delta mode, differential conductance, pulsed IV measurements, and to control Model 6221 arbitrary waveforms. See the online documentation in the software for details.

Several typical screens for the example software are shown on the following pages. Note that your software may be slightly different due to upgrades. Examples screens include:

- [Figure 10-11](#): Main screen
- [Figure 10-12](#): Instrument connection wizard
- [Figure 10-13](#): Virtual front panel

Figure 10-11
Example software typical main screen

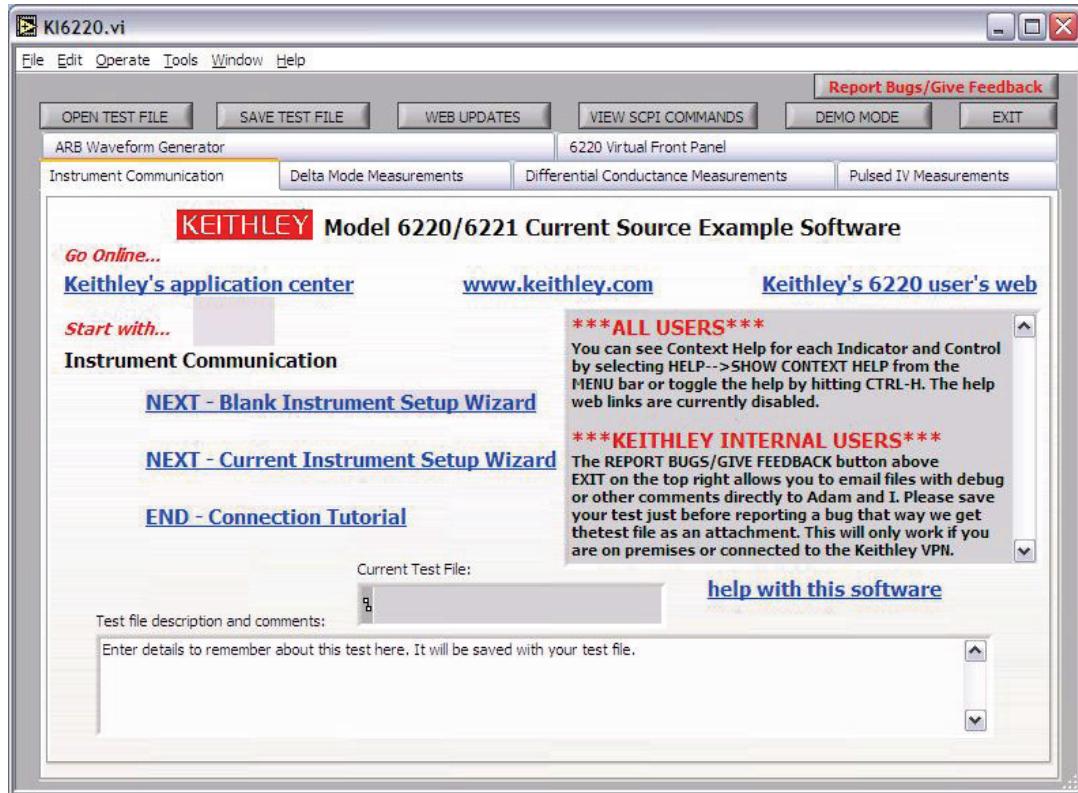


Figure 10-12
Typical instrument connection setup wizard

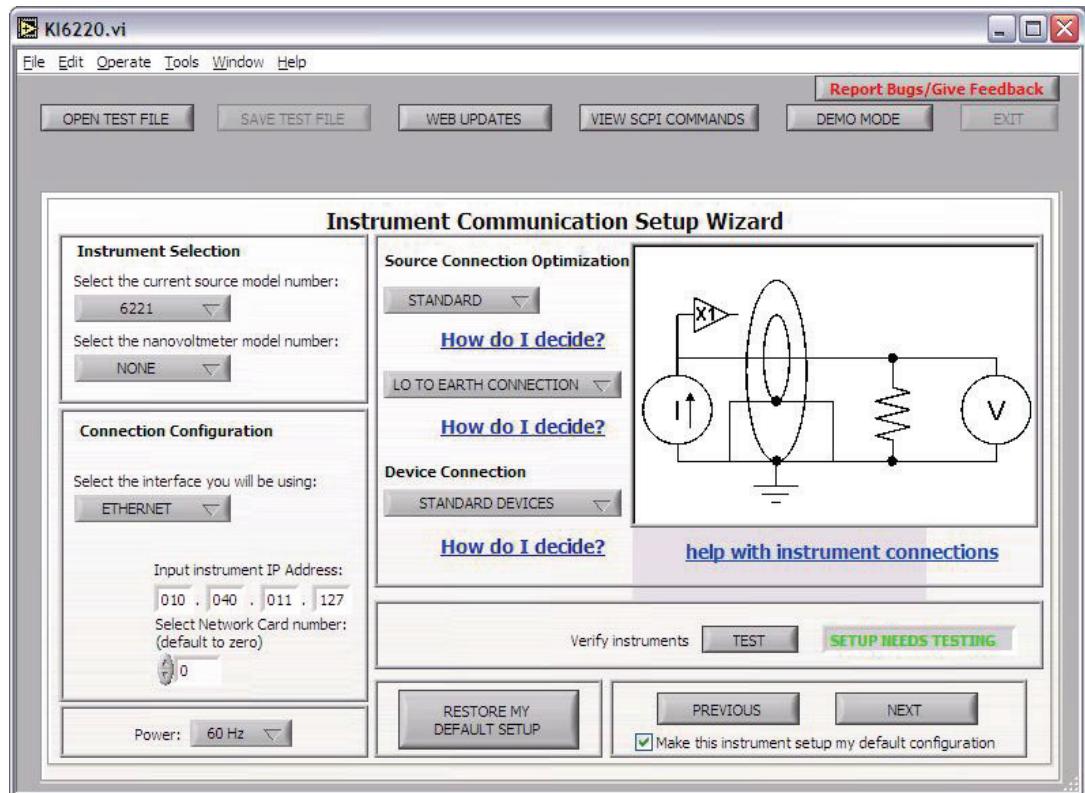
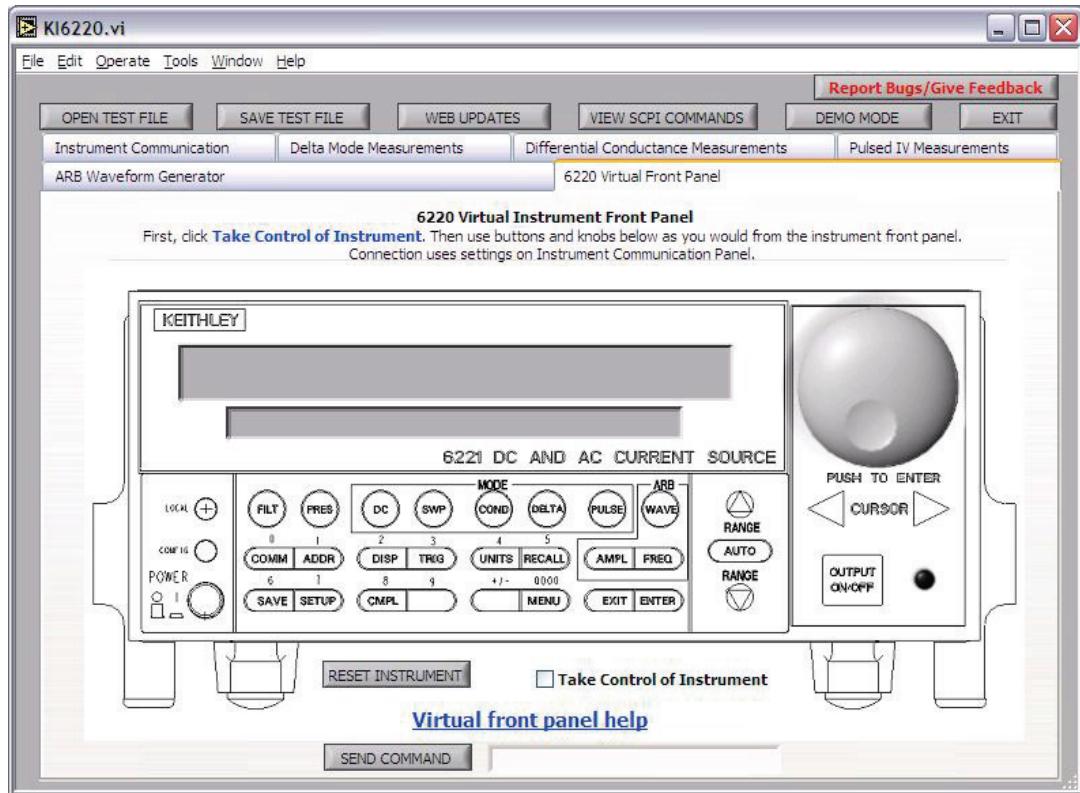


Figure 10-13
Typical virtual front panel



11

Status Structure

Section 11 topics

[Overview](#), page 11-2

[Clearing registers and queues](#), page 11-4

[Programming and reading registers](#), page 11-5

 Programming enable registers, page 11-5

 Reading registers, page 11-6

[Status byte and service request \(SRQ\)](#), page 11-7

 Status byte register, page 11-7

 Service request enable register, page 11-8

 Serial polling and SRQ, page 11-9

 Status byte and service request commands, page 11-9

[Status register sets](#), page 11-10

 Register bit descriptions, page 11-10

[Queues](#), page 11-20

 Output queue, page 11-20

 Error queue, page 11-20

Overview

The Model 622x provides a series of status registers and queues allowing the operator to monitor and manipulate the various instrument events. The status structure is shown in [Figure 11-1](#). The heart of the status structure is the status byte register. This register can be read by the user's test program to determine if a service request (SRQ) has occurred and what event caused it.

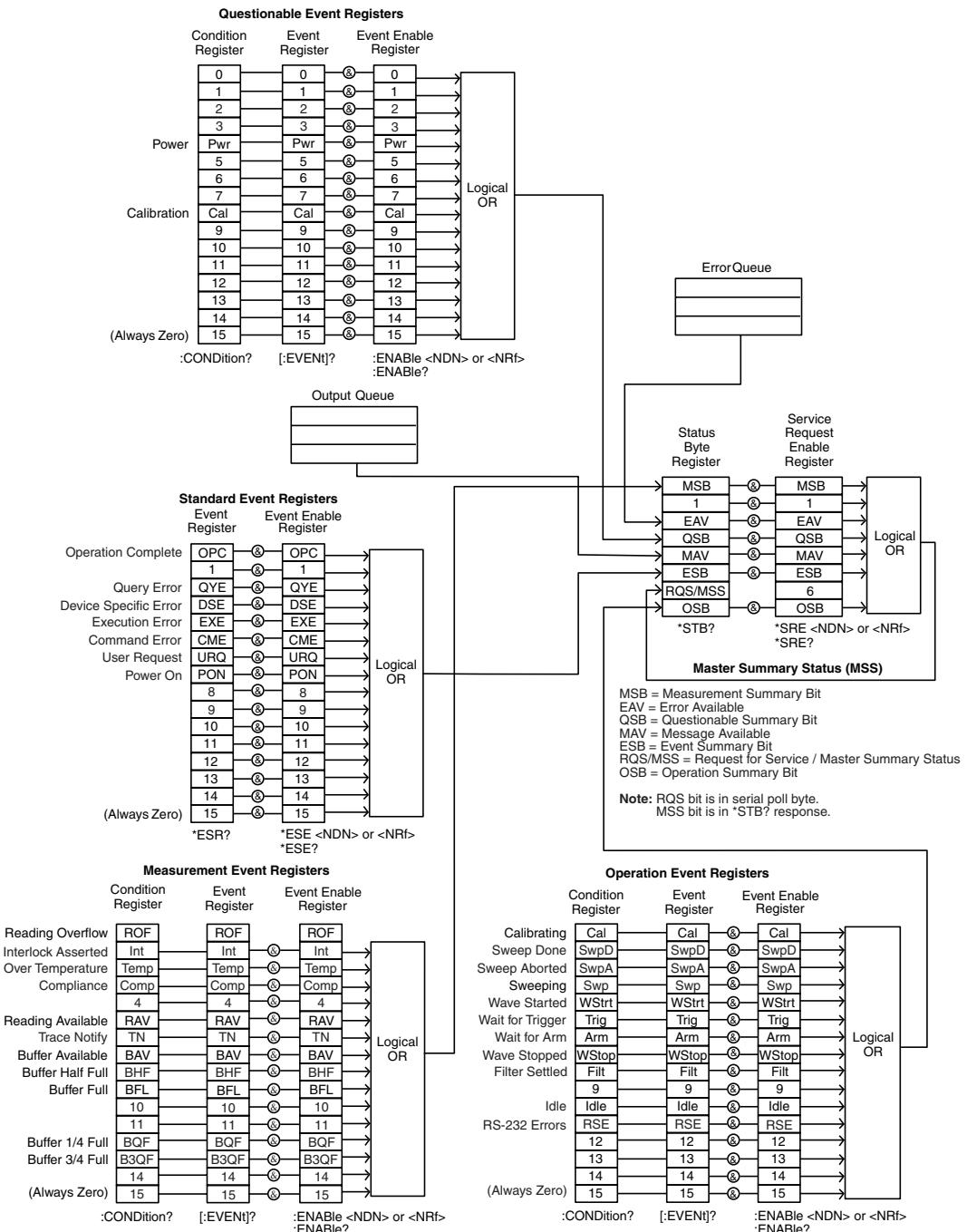
Status byte and SRQ — The status byte register receives the summary bits of four status register sets and two queues. The register sets and queues monitor the various instrument events. When an enabled event occurs, it sets a summary bit in the status byte register. When a summary bit of the status byte is set and its corresponding enable bit is set (as programmed by the user), the RQS/MSS bit will set to indicate that an SRQ has occurred.

Status register sets — A typical status register set is made up of a condition register, an event register, and an event enable register. A condition register is a read-only register that constantly updates to reflect the present operating conditions of the instrument.

When an event occurs, the appropriate event register bit sets to 1. The bit remains latched to 1 until the register is reset. When an event register bit is set and its corresponding enable bit is set (as programmed by the user), the output (summary) of the register will set to 1, which in turn sets the summary bit of the status byte register.

Queues — The Model 622x uses an output queue and an error queue. The response messages to query commands are placed in the output queue. As various programming errors and status messages occur, they are placed in the error queue. When a queue contains data, it sets the appropriate summary bit of the status byte register.

Figure 11-1
Model 622x status mode structure



Clearing registers and queues

When the Model 622x is turned on, the bits of all registers in the status structure are clear (reset to 0) and the two queues are empty. Commands to reset the event, event enable registers, and the error queue are listed in [Table 11-1](#). In addition to these commands, any enable register can be reset by sending the 0 parameter value with the individual command to program the register.

NOTE **SYSTem:PRESet and *RST have no effect on status structure registers and queues.**

Table 11-1
Common and SCPI commands — reset registers and clear queues

Commands	Description	Reference
To reset registers: *CLS STATus :PRESet	Reset all bits of the following event registers to 0: Standard event register Operation event register Measurement event register Questionable event register STATus subsystem: Reset all bits of the following enable registers to 0: Operation event enable register Measurement event enable register Questionable event enable register	Note 1
To clear error queue: *CLS STATus :QUEue :CLEar SYSTem :ERRor :CLEar	Clear all messages from error queue. STATus subsystem: Error queue: Clear messages from error queue. SYSTem subsystem: Error queue: Clear messages from error queue.	Note 2
		Note 3

Notes:

1. The standard event enable register is not reset by STATus:PRESet or *CLS. Send the 0 parameter value with *ESE to reset all bits of that enable register to 0 (see “[Status byte and service request \(SRQ\)](#),” on page 11-7).
2. STATus:PRESet has no effect on the error queue.
3. Use either of the two clear commands to clear the error queue.

Programming and reading registers

Programming enable registers

The only registers that can be programmed by the user are the enable registers. All other registers in the status structure are read-only registers. The following explains how to ascertain the parameter values for the various commands used to program enable registers. The actual commands are covered later in this section ([Table 11-3](#) through [Table 11-6](#)).

A command to program an event enable register is sent with a parameter value that determines the desired state (0 or 1) of each bit in the appropriate register. An enable register can be programmed using any of the following data formats for the parameter value: binary, decimal, hexadecimal, or octal.

The bit positions of the register ([Figure 11-1](#)) indicate the binary parameter value. For example, if you wish to set bits B4, B3, and B1, the binary value would be 11010 (where B4=1, B3=1, B1=1, and all other bits are 0). When you use one of the other formats, convert the binary number to its decimal, hexadecimal, or octal equivalent:

Binary 11010 = Decimal 26 = Hexadecimal 1A = Octal 32

Note that [Figure 11-2](#) includes the decimal weight for each register bit. To set bits B4, B3, and B1, the decimal parameter value would be the sum of the decimal weights for those bits (16+8+2 = 26).

**Figure 11-2
16-bit status register**

A. Bits 0 through 7

Bit Position	B7	B6	B5	B4	B3	B2	B1	B0
Binary Value	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
Decimal Weights	128 (2^7)	64 (2^6)	32 (2^5)	16 (2^4)	8 (2^3)	4 (2^2)	2 (2^1)	1 (2^0)

B. Bits 8 through 15

Bit Position	B15	B14	B13	B12	B11	B10	B9	B8
Binary Value	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
Decimal Weights	32768 (2^{15})	16384 (2^{14})	8192 (2^{13})	4096 (2^{12})	2048 (2^{11})	1024 (2^{10})	512 (2^9)	256 (2^8)

The <NDN> (non-decimal numeric) parameter type is used to send non-decimal values. These values require a header (#B, #H, or #Q) to identify the data format being sent. The letter in the header can be upper or lower case. The <NRf>

(numeric representation format) parameter type is used to send decimal values and does not use a header. The following examples show the proper parameter syntax for setting bits B5, B3, and B2:

#b101100	Binary format	(<NDN> parameter type)
#h2C	Hexadecimal format	(<NDN> parameter type)
#q54	Octal format	(<NDN> parameter type)
44	Decimal format	(<NRf> parameter type)

Valid characters for the non-decimal parameter values are shown as follows:

<NDN> format	Valid characters
Binary	1's and 0's
Hexadecimal	0 through 9 and A through F
Octal	0 through 7

Reading registers

Any register in the status structure can be read by using the appropriate query (?) command. The following explains how to interpret the returned value (response message). The actual query commands are covered later in this section ([Table 11-3](#) through [Table 11-6](#)).

The response message will be a value that indicates which bits in the register are set. That value (if not already binary) must be converted to its binary equivalent. For example, for a binary value of 100101, bits B5, B2, and B0 are set.

The returned value can be in the binary, decimal, hexadecimal, or octal format. The FORMat:SREGister command is used to select the data format for the returned value ([Table 11-2](#)).

For non-decimal formats, one of the following headers will accompany the returned value to indicate which format is selected:

- #B = Header for binary values,
- #H = Header for hexadecimal values,
- #Q = Header for octal values.

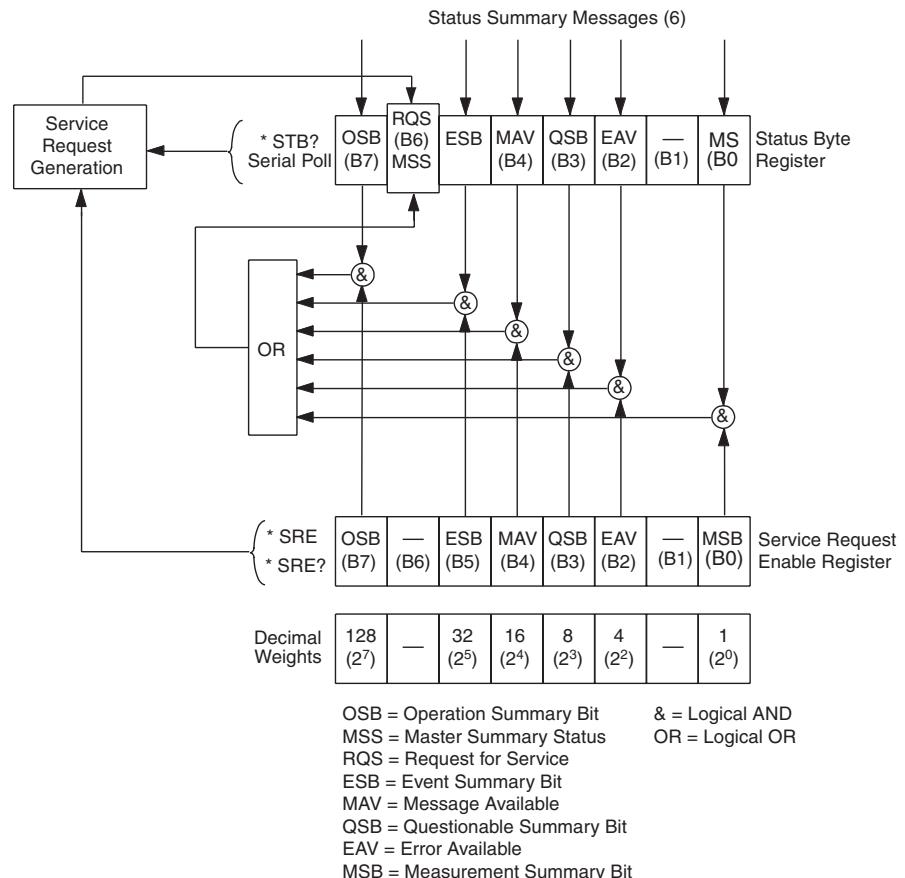
Table 11-2
SCPI command — data formats for reading status registers

Command	Description	Default
:FORMat :SREGister <name>	FORMat subsystem Select data format for reading status registers: <name> = ASCII Decimal format HEXadecimal Hexadecimal format OCTal Octal format BINary Binary format	ASCii

Status byte and service request (SRQ)

Service request is controlled by two 8-bit registers: the status byte register and the service request enable register. [Figure 11-3](#) shows the structure of these registers.

Figure 11-3
Status byte and service request



Status byte register

The summary messages from the status registers and queues are used to set or clear the appropriate bits (B0, B2, B3, B4, B5, and B7) of the status byte register. These summary bits do not latch and their states (0 or 1) are solely dependent on the summary messages (0 or 1). For example, if the standard event register is

read, its register will clear. As a result, its summary message will reset to 0, which in turn will reset the ESB bit in the status byte register.

The bits of the status byte register are described as follows:

- **Bit B0, Measurement Status (MSB)** — Set summary bit indicates that an enabled measurement event has occurred.
- **Bit B1** — Not used.
- **Bit B2, Error Available (EAV)** — Set summary bit indicates that an error or status message is present in the error queue.
- **Bit B3, Questionable Summary Bit (QSB)** — Set summary bit indicates that an enabled questionable event has occurred.
- **Bit B4, Message Available (MAV)** — Set summary bit indicates that a response message is present in the output queue.
- **Bit B5, Event Summary Bit (ESB)** — Set summary bit indicates that an enabled standard event has occurred.
- **Bit B6, Request Service (RQS)/Master Summary Status (MSS)** — Set bit indicates that an enabled summary bit of the status byte register is set.
- **Bit B7, Operation Summary (OSB)** — Set summary bit indicates that an enabled operation event has occurred.

Depending on how it is used, bit B6 of the status byte register is either the request for service (RQS) bit or the master summary status (MSS) bit:

- When using the serial poll sequence of the Model 622x to obtain the status byte (also known as serial poll byte), B6 is the RQS bit. See “[Serial polling and SRQ](#),” on page 11-9 for details on using the serial poll sequence.
- When using the *STB? command ([Table 11-3](#)) to read the status byte, B6 is the MSS bit.

Service request enable register

The generation of a service request is controlled by the service request enable register. This register is programmed by the user and is used to enable or disable the setting of bit B6 (RQS/MSS) by the status summary message bits (B0, B2, B3, B4, B5, and B7) of the status byte register. As shown in [Figure 11-3](#), the summary bits are logically AND'ed (&) with the corresponding enable bits of the service request enable register. When a set (1) summary bit is AND'ed with an enabled (1) bit of the enable register, the logic “1” output is applied to the input of the OR gate and, therefore, sets the MSS/RQS bit in the status byte register.

The individual bits of the service request enable register can be set or cleared by using the *SRE common command. To read the service request enable register, use the *SRE? query command. The service request enable register clears when power is cycled or a parameter value of 0 is sent with the *SRE command (i.e. *SRE 0). The commands to program and read the SRQ enable register are listed in [Table 11-3](#).

Serial polling and SRQ

Any enabled event summary bit that goes from 0 to 1 will set bit B6 and generate an SRQ (service request). In a test program, the status byte can be periodically read to check if an SRQ has occurred and what caused it. If an SRQ occurs, the program can, for example, branch to an appropriate subroutine that will service the request.

Typically, SRQs are managed by the serial poll sequence of the Model 622x. If an SRQ does not occur, bit B6 (RQS) of the status byte register will remain cleared and the program will proceed normally after the serial poll is performed. If an SRQ does occur, bit B6 of the status byte register will set and the program can branch to a service subroutine when the SRQ is detected by the serial poll.

The serial poll automatically resets RQS of the status byte register. This allows subsequent serial polls to monitor bit B6 for an SRQ occurrence generated by other event types. After a serial poll, the same event can cause another SRQ, even if the event register that caused the first SRQ has not been cleared.

The serial poll does not clear MSS. The MSS bit stays set until all status byte summary bits are reset.

SPE, SPD (serial polling)

The SPE, SPD general bus command is used to serial poll the Model 622x. Serial polling obtains the serial poll byte (status byte). Typically, serial polling is used by the controller to determine which of several instruments has requested service with the SRQ line.

Status byte and service request commands

The commands to program and read the status byte register and service request enable register are listed in [Table 11-3](#). For details on programming and reading registers, see “[Programming enable registers](#),” on page [11-5](#) and “[Reading registers](#),” on page [11-6](#).

To reset the bits of the service request enable register to 0, use 0 as the parameter value for the *SRE command (i.e., *SRE 0).

Table 11-3

Common commands — status byte and service request enable registers

Command	Description	Default
*STB?	Read status byte register.	
*SRE <NDN> or <NRf>	Program the service request enable register: <NDN> = #Bxx...x Binary format (each x = 1 or 0) = #Hx Hexadecimal format (x = 0 to FF) = #Qx Octal format (x = 0 to 377) <NRf> = 0 to 255 Decimal format	Note
*SRE?	Read the service request enable register.	

Note: *CLS and STATus:PRESet have no effect on the service request enable register.

Programming example — set MSS (B6) when error occurs

The first command of the following sequence enables EAV (error available). When an invalid command is sent (line 4), bits B2 (EAV) and B6 (MSS) of the status byte register set to 1. The last command reads the status byte register using the binary format (which directly indicates which bits are set). The command to select format (FORMAT:SREGister) is documented in [Table 11-2](#). To determine the exact nature of the error, you will have to read the error queue (see “[Queues](#),” on page [11-20](#)).

*CLS	‘ Clears Error Queue.
*SRE 4	‘ Enables EAV.
FORMAT:SREG BIN	‘ Selects binary format.
BadCommand	‘ Generates error.
*STB?	‘ Read Status Byte Register.

Status register sets

As shown in [Figure 11-1](#), there are four status register sets in the status structure of the Model 622x: standard event status, operation event status, measurement event status, and questionable event status.

Register bit descriptions

When an error or status event occurs, a coded message is briefly displayed and placed in the Error Queue. The occurrence of an error/status event also sets a status register bit. The coded error/status messages are listed in [Appendix B](#).

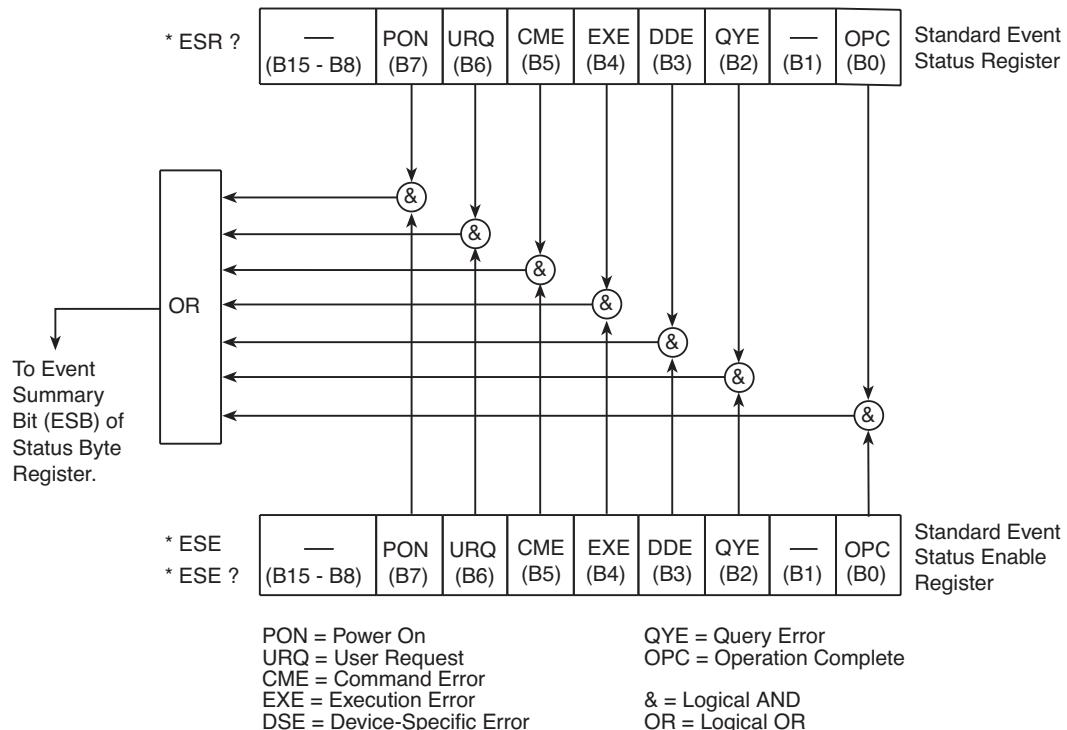
The status register bits are described as follows. Included with the bit descriptions are the codes for the error/status event(s) that caused the bit to set.

Standard event status

The used bits of the standard event register ([Figure 11-4](#)) are described as follows:

- **Bit B0, Operation Complete (OPC)** — Set bit indicates that all pending selected device operations are completed and the Model 622x is ready to accept new commands. This bit only sets in response to the *OPC? query command. See [Section 12](#) for details on *OPC and *OPC?.
Error/status code: +101
- **Bit B2, Query Error (QYE)** — Set bit indicates that an attempt was made to read data from an empty output queue.
Error/status codes: -430, -420, -410
- **Bit B3, Device-Specific Error (DSE)** — Set bit indicates that an instrument operation did not execute properly due to some internal condition.
Error/status codes: -363, -350, -314, +500 through +558, +700, +900
- **Bit B4, Execution Error (EXE)** — Set bit indicates that the Model 622x detected an error while trying to execute a command.
Error/status codes: -260 through -220, +401 through +420
- **Bit B5, Command Error (CME)** — Set bit indicates that a command error has occurred.
Command errors include:
 - **IEEE-488.2 syntax error** — The Model 622x received a message that does not follow the defined syntax of the IEEE-488.2 standard.
 - **Semantic error** — The Model 622x received a command that was misspelled or received an optional IEEE-488.2 command that is not implemented.
 - The instrument received a Group Execute Trigger (GET) inside a program message.Error/status codes: -171 through -100
- **Bit B6, User Request (URQ)** — Set bit indicates that the LOCAL key on the Model 622x front panel was pressed.
- **Bit B7, Power ON (PON)** — Set bit indicates that Model 622x has been turned off and turned back on since the last time this register has been read.

Figure 11-4
Standard event status



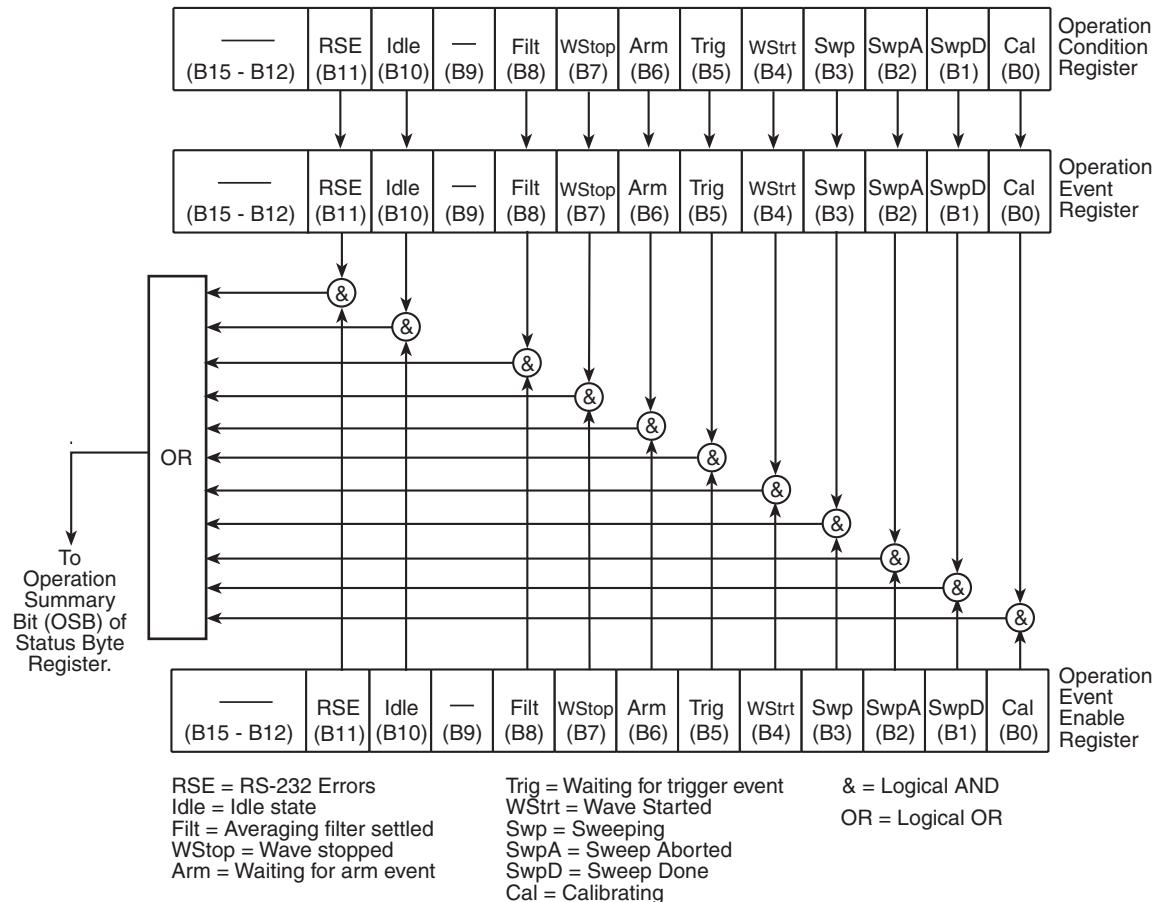
Operation event status

The used bits of the operation event register (Figure 11-5) are described as follows:

- **Bit B0, Calibrating (CAL)** — Set bit indicates that the Model 622x is calibrating.
Error/status code: +121
- **Bit B1, Sweep Done (SwpD)** — Set bit indicates that a sweep, Delta, Differential Conductance, or a pulse sweep for Pulse Delta is finished.
Error/status code: +122
- **Bit B2, Sweep Aborted (SwpA)** — Set bit indicates that a sweep, Delta, Differential Conductance, or a pulse sweep for Pulse Delta has been aborted.
Error/status code: +123

- **Bit B3, Sweeping (Swp)** — Set bit indicates that a sweep, Delta, Differential Conductance, or a pulse sweep for Pulse Delta is running. Status code: +124 Device sweeping.
Error/status code: +124
- **Bit B4, Wave Started (WStrt)** — Set bit indicates that the Wave mode has been started.
Error/status code: +125
- **Bit B5, Waiting for Trigger Event (Trig)** — Set bit indicates that the Model 622x is in the trigger layer waiting for a trigger event to occur.
Error/status code: +171
- **Bit B6, Waiting for Arm Event (Arm)** — Set bit indicates that the Model 622x is in the arm layer waiting for an arm event to occur.
Error/status code: +172
- **Bit B7, Wave Stopped (WStop)** — Set bit indicates that the Wave mode has been aborted.
Error/status code: +126
- **Bit B8, Filter Settled (Filt)** — Arming one of the delta tests will clear (0) this bit. A set bit indicates that the delta test has started and the filter is settled.
Error/status code: +180
- **Bit B10, Idle State (Idle)** — Set bit indicates the Model 622x is in the idle state.
Error/status code: +174
- **Bit B11, RS-232 Error (RSE)** — Set bit indicates that one of the following RS-232 errors has occurred:
 - +800 RS-232 Framing Error detected
 - +802 RS-232 Overrun detected
 - +803 RS-232 Break detected
 - +805 Invalid system communication setting
 - +808 RS-232 Invalid Format Error
 - +809 Not allowed with RS-232Error/status codes: +800 through +809

Figure 11-5
Operation event status



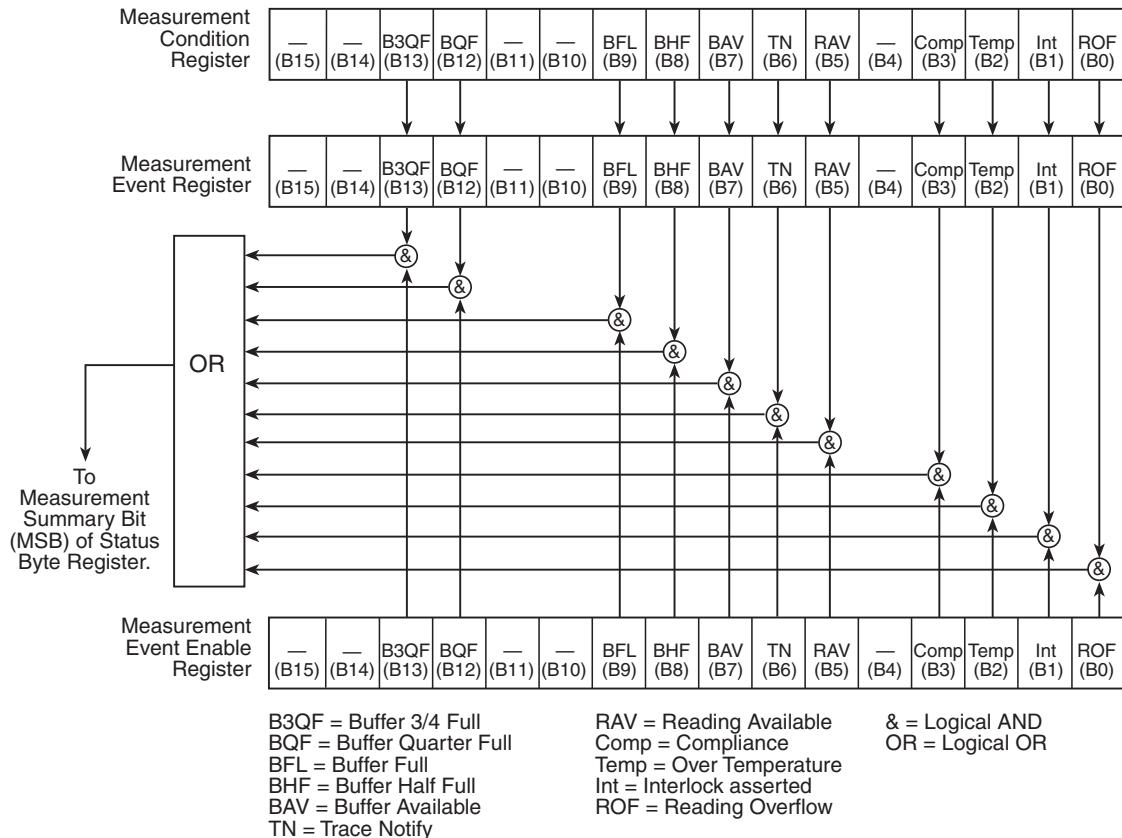
Measurement event status

The used bits of the measurement event register (Figure 11-6) are described as follows:

- **Bit B0, Reading Overflow (ROF)** — Set bit indicates that delta reading exceeds the selected range of the Model 2182A.
Error/status codes: +301
- **Bit B1, Interlock (Int)** — Set bit indicates that the interlock is asserted indicating that the output can be turned on.
Error/status codes: +111

- **Bit B2, Over Temperature (Temp)** — Set bit indicates that the internal temperature limit has been exceeded. Check that the cooling vents are clear and the heat sink is free of dust and dirt.
Error/status code: +112
- **Bit B3, Compliance (Comp)** — Set bit indicates that the Model 622x is in compliance.
Error/status code: +114
- **Bit B5, Reading Available (RAV)** — Set bit indicates that a delta reading has been taken and processed.
Error/status code: +306
- **Bit B6, Trace Notify (TN)** — Set bit indicates that the user-defined reading number has been stored in the buffer (see TRACe:NOTify command in [Section 6](#)).
Error/status code: +307
- **Bit B7, Buffer Available (BAV)** — Set bit indicates that there are at least two readings stored in the buffer.
Error/status code: +308
- **Bit B8, Buffer Half Full (BHF)** — Set bit indicates that the buffer is half full. Keep in mind that buffer size is set by the programmed number of sweep points or delta measurement points (cycles).
Error/status code: +309
- **Bit B9, Buffer Full (BFL)** — Set bit indicates that the buffer is full. Keep in mind that buffer size is set by the programmed number of sweep points or delta measurement points (cycles).
Error/status code: +310
- **Bit B12, Buffer Quarter Full (BQF)** — Set bit indicates that the buffer is quarter full. Keep in mind that buffer size is set by the programmed number of sweep points or delta measurement points (cycles).
Error/status code: +312
- **Bit B13, Buffer 3/4 Full (B3QF)** — Set bit indicates that the buffer is 3/4 full. Keep in mind that buffer size is set by the programmed number of sweep points or delta measurement points (cycles).
Error/status code: +313

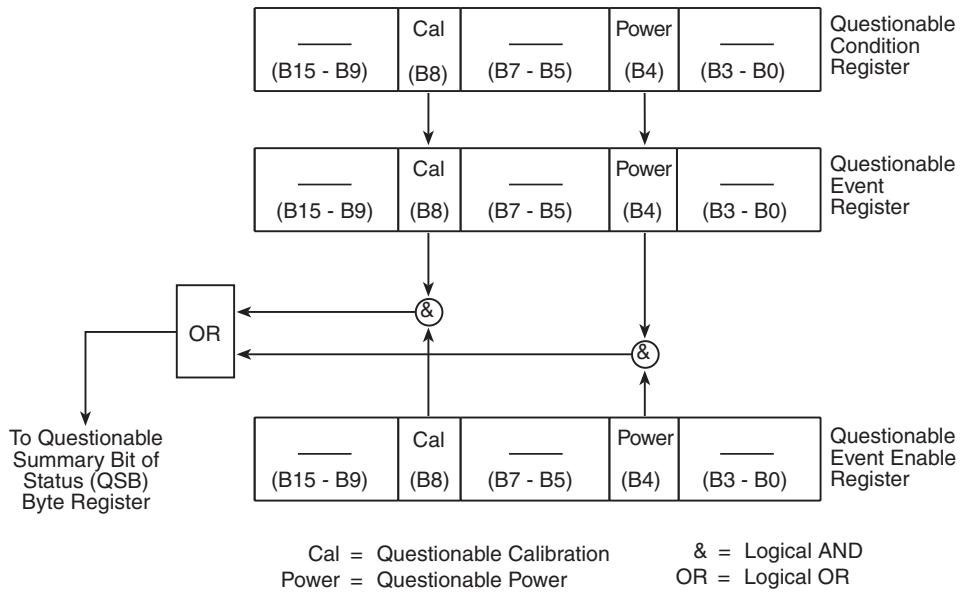
Figure 11-6

Measurement event status**Questionable event status**

The used bits of the questionable event register ([Figure 11-7](#)) are described as follows:

- **Bit B4, Questionable Power** — Set bit indicates that a questionable power reading was calculated for Pulse Delta. See “[Pulse Delta power calculation restriction](#),” on page [5-35](#).
- Error/status code: +611
- **Bit B8, Questionable Calibration (Cal)** — Set bit indicates that a questionable calibration constant was detected during the power-up sequence. This error will clear after successful calibration of the Model 622x.
- Error/status code: +610

Figure 11-7
Questionable event status



Condition registers

As Figure 11-1 shows, each status register set (except the standard event register set) has a condition register. A condition register is a real-time, read-only register that continuously updates to reflect the present operating conditions of the instrument. For example, while the Model 622x is in the idle state, bit B10 (Idle) of the operation condition register will be set. When the instrument is taken out of idle, bit B10 clears.

The commands to read the condition registers are listed in Table 11-4. For details on reading registers, see “[Reading registers](#),” on page 11-6.

Table 11-4
Common and SCPI commands — condition registers

Command	Description
STATus :OPERation:CONDition? :MEASurement:CONDition? :QUEstionable:CONDition?	STATus subsystem: Read operation condition register. Read measurement condition register. Read questionable condition register.

Event registers

As [Figure 11-1](#) shows, each status register set has an event register. When an event occurs, the appropriate event register bit sets to 1. The bit remains latched to 1 until the register is reset. Reading an event register clears the bits of that register. *CLS resets all four event registers.

The commands to read the event registers are listed in [Table 11-5](#). For details on reading registers, see “[Reading registers](#),” on page [11-6](#).

Table 11-5
Common and SCPI commands — event registers

Command	Description
*ESR?	Read standard event status register.
STATus :OPERation[:EVENT]?	STATus subsystem: Read operation event register.
:MEASurement[:EVENT]?	Read measurement event register.
:QUESTIONable[:EVENT]?	Read questionable event register.

Note: Power-up and *CLS resets all bits of all event registers to 0. STATus:PRESet has no effect.

Event enable registers

As [Figure 11-1](#) shows, each status register set has an enable register. Each event register bit is logically AND'ed (&) to a corresponding enable bit of an enable register. Therefore, when an event bit is set and the corresponding enable bit is set (as programmed by the user), the output (summary) of the register will set to 1, which in turn sets the summary bit of the status byte register.

The commands to program and read the event enable registers are listed in [Table 11-6](#). For details on programming and reading registers, see “[Programming enable registers](#),” on page [11-5](#) and “[Reading registers](#),” on page [11-6](#).

NOTE

The bits of any enable register can be reset to 0 by sending the 0 parameter value with the appropriate enable command (i.e., STATus:OPERation:ENABLE 0).

Table 11-6
Common and SCPI commands — event enable registers

Command	Description
*ESE <NDN> or <NRf> *ESE?	Program standard event enable register (see “Parameters” below). Read standard event enable register.
STATus :OPERation :ENABLE <NDN> or <NRf> :ENABLE? :MEASurement :ENABLE <NDN> or <NRf> :ENABLE? :QUEStionable :ENABLE <NDN> or <NRf> :ENABLE?	STATus subsystem: Operation event enable register: Program enable register (see “Parameters” below). Read enable register. Measurement event enable register: Program enable register (see “Parameters” below). Read enable register. Questionable event enable register: Program enable register (see “Parameters” below). Read measurement event enable register.

Parameters:

<NDN>	= #Bxx...x	Binary format (each x = 1 or 0)
	= #Hx	Hexadecimal format (x = 0 to FFFF)
	= #Qx	Octal format (x = 0 to 177777)
<NRf>	= 0 to 65535	Decimal format

Note: Power-up and STATus:PRESet resets all bits of all enable registers to 0. *CLS has no effect.

Programming example — program and read registers

This command sequence programs and reads the measurement registers. Registers are read using the binary format (which directly indicates which bits are set). The command to select format (FORMAT:SREGister) is documented in [Table 11-2](#).

```

FORM:SREG BIN      ' Selects binary format to read registers.
STAT:MEAS:ENAB 512 ' Enables BFL (buffer full).
STAT:MEAS:COND?    ' Reads Measurement Condition Register.
STAT:MEAS?         ' Reads Measurement Event Register.

```

Queues

The Model 622x uses two queues that are first-in, first-out (FIFO) registers:

- Output queue — Used to hold reading and response messages.
- Error queue — Used to hold error and status messages.

The Model 622x status model ([Figure 11-1](#)) shows how the two queues are structured with the other registers.

Output queue

The output queue holds data that pertains to the normal operation of the instrument. For example, when a query command is sent, the response message is placed in the output queue.

When data is placed in the output queue, the message available (MAV) bit in the status byte register sets. A data message is cleared from the output queue when it is read. The output queue is considered cleared when it is empty. An empty output queue clears the MAV bit in the status byte register.

A message is read from the output queue by addressing the Model 622x to talk after the appropriate query is sent.

Error queue

The error queue holds error and status messages. When an error or status event occurs, a message that defines the error/status is placed in the error queue.

When a message is placed in the error queue, the error available (EAV) bit in the status byte register is set. An error/status message is cleared from the error queue when it is read. The error queue is considered cleared when it is empty. An empty error queue clears the EAV bit in the status byte register.

The error queue holds up to 10 error/status messages. The commands to read the error queue are listed in [Table 11-7](#). When you read a single message in the error queue, the “oldest” message is read and then removed from the queue. If the queue becomes full, the message “350, ‘queue overflow’” will occupy the last memory location. On power-up, the error queue is empty. When empty, the message “0, No Error” is placed in the queue.

Messages in the error queue are preceded by a code number. Negative (-) numbers are used for SCPI defined messages and positive (+) numbers are used for Keithley defined messages. The messages are listed in [Appendix B](#).

On power-up, all error messages are enabled and will go into the error queue as they occur. Status messages are not enabled and will not go into the queue. As listed in [Table 11-7](#), there are commands to enable and/or disable messages. For these commands, the <list> parameter is used to specify which messages to

enable or disable. The messages are specified by their codes. The following examples show various forms for using the <list> parameter.

<list> = (-110)	Single message
= (-110:-222)	Range of messages (-110 through -222)
= (-110:-222, -220)	Range entry and single entry (separated by a comma)

When you enable messages, messages not specified in the list are disabled. When you disable messages, each listed message is removed from the enabled list.

To prevent all messages from entering the error queue, send the enable command along with the null list parameter as follows: STATus:QUEue:ENABLE () .

Table 11-7
SCPI commands — error queue

Command	Description	Default
STATus :QUEue [:NEXT]? :ENABLE <list> :ENABLE? :DISable <list> :DISable? :CLEar	STATus subsystem: Read error queue: Read and clear oldest error/status (code and message). Specify error and status messages for error queue. Read the enabled messages. Specify messages not to be placed in queue. Read the disabled messages. Clear messages from error queue.	Note 1 Note 2 Note 2
SYSTem :ERRor? :CLEar	SYSTem subsystem: Read and clear latest error/status (code and message). Clear messages from error queue.	Note 1

Notes:

1. Power-up and *CLS empties the error queue. STATus:PRESet has no effect.
2. Power-up enables error messages and disables status messages. *CLS and STATus:PRESet have no effect.

Programming example — read error queue

The following command reads the error queue:

STAT :QUE ‘ Reads Error Queue.

12

Common Commands

Section 12 topics

[Common commands](#), page 12-2

Common commands

Common commands (summarized in [Table 12-1](#)) are device commands that are common to all devices on the bus. These commands are designated and defined by the IEEE-488.2 standard.

Table 12-1

IEEE-488.2 common commands and queries

Mnemonic	Name	Description	Reference
*CLS	Clear status	Clears all event registers and error queue.	Section 11
*ESE <NRf>	Event enable command	Program the standard event enable register.	Section 11
*ESE?	Event enable query	Read the standard event enable register.	Section 11
*ESR?	Event status register query	Read the standard event enable register and clear it.	Section 11
*IDN?	Identification query	Returns the manufacturer, model number, serial number, and firmware revision levels of the unit.	A
*OPC	Operation complete command	Set the operation complete bit in the standard event register after all pending commands have been executed.	B
*OPC?	Operation complete query	Places an ASCII “1” into the output queue when all pending selected device operations have been completed.	B
*OPT?	Option query	Returns model number of any installed options.	
*RCL <NRf>	Recall command	Returns Model 622x to the user-saved setup.	C
*RST	Reset command	Returns Model 622x to the *RST default conditions.	D
*SAV <NRf>	Save command	Saves the present setup as the user-saved setup.	C
*SRE <NRf>	Service request enable command	Programs the service request enable register.	Section 11
*SRE?	Service request enable query	Reads the service request enable register.	Section 11
*STB?	Status byte query	Reads the status byte register.	Section 11
*TRG	Trigger command	Sends a bus trigger to Model 622x.	E
*TST?	Self-test query	Performs a checksum test on ROM and returns the result.	F
*WAI	Wait-to-continue command	Wait until all previous commands are executed.	G

Note: A, B, C, D, E, F, G references are on the following pages.

A) *IDN? — identification query Reads identification code

The identification code includes the manufacturer, model number, serial number, and firmware revision levels and is sent in the following format:

KEITHLEY INSTRUMENTS INC., MODEL 622x,xxxxxx,yyyyy/zzzzz/w

Where: xxxx is the serial number.

yyyyy/zzzzz is the firmware revision levels of the digital board ROM and display board ROM. Note that yyyy also provides build date and time information. w is the board revision level.

B) *OPC — operation complete Sets OPC bit***OPC? — operation complete query** Places a “1” in output queue

When *OPC is sent, the OPC bit in the standard event register will set after all pending command operations are complete. When *OPC? is sent, an ASCII “1” is placed in the output queue after all pending command operations are complete.

Typically, either one of these commands is sent after the INITiate command. The INITiate command is used to take the instrument out of idle in order to perform measurements. While operating within the trigger model layers, all sent commands (except DCL, SDC, IFC, SYSTem:PRESet, *RST, GET, and ABORt) will not execute.

After all programmed operations are completed, the instrument returns to the idle state at which time all pending commands (including *OPC and/or *OPC?) are executed. After the last pending command is executed, the OPC bit and/or an ASCII “1” is placed in the output queue.

NOTE	For RS-232 operation (and in some cases, GPIB operation), *OPC or *OPC? should be used with SYST:PRE, which is a slow responding command.
-------------	---

Programming example — Assuming the Models 622x and 2182A are configured to perform Delta measurements (as explained in [Section 5](#)), the following command sequence will arm Delta and start Delta measurements. After all Delta measurements are completed, an ASCII “1” will be placed in the output queue.

SOUR:DELTa:ARM

‘ Arms Delta.

INIT:IMM

‘ Starts Delta measurements.

*OPC?

‘ Sends *OPC?

*SAV <NRf> — save	Save present setup in memory
*RCL <NRf> — recall	Return to setup stored in memory

Parameters	0 = Memory location 0 1 = Memory location 1 2 = Memory location 2 3 = Memory location 3 4 = Memory location 4
-------------------	---

Use the *SAV command to save the present instrument setup configuration in memory for later recall. Any control affected by *RST can be saved by the *SAV command. The *RCL command is used to restore the instrument to the saved setup configuration. Three setup configurations can be saved and recalled.

The Model 622x ships from the factory with SYSTem:PRESet defaults loaded into the available setup memory. If a recall error occurs, the setup memory defaults to the SYSTem:PRESet values.

Programming example:

*SAV 2	' Saves present setup in memory location 2.
*RST	' Sets 622x to RST defaults.
*RCL 2	' Returns (recalls) 622x to setup stored in memory location 2.

*RST — reset	Return Model 622x to RST defaults
---------------------	-----------------------------------

When the *RST command is sent, the Model 622x performs the following operations:

1. Returns Model 622x to the RST default conditions (see “Default” column of SCPI tables).
2. Cancels all pending commands.
3. Cancels response to any previously received *OPC and *OPC? commands.

*TRG — trigger	Send bus trigger to Model 622x
-----------------------	--------------------------------

Use the *TRG command to issue a GPIB trigger to the Model 622x. It has the same effect as a group execute trigger (GET).

Use the *TRG command as an event to control operation. The Model 622x reacts to this trigger if BUS is the programmed arm control source. The control source is programmed from the TRIGger subsystem. Details on triggering are covered in [Section 8](#).

Programming example — Assuming the Models 622x and 2182A are configured to perform Delta measurements (as explained in [Section 5](#)), the following command sequence will select the bus control source, arm Delta, and send the trigger command to start Delta measurements.

ARM:SOUR BUS	Selects the bus control source.
SOUR:DELTa:ARM	' Arms Delta.
INIT:IMM	' Takes 622x out of idle.
*TRG	' Triggers start of Delta measurements.

F) *TST? — self-test query Run self-test and read result

Use this query command to perform a checksum test on ROM. The command places the coded result (0 or 1) in the output queue. When the Model 622x is addressed to talk, the coded result is sent from the output queue to the computer.

A returned value of zero (0) indicates that the test passed and a value of one (1) indicates that the test failed.

G) *WAI — wait-to-continue Wait until previous commands are completed

Effectively, the *WAI command is a No-Op (no operation) for the Model 622x and thus, does not need to be used.

Two types of device commands exist:

- **Sequential commands** — A command whose operations are allowed to finish before the next command is executed.
- **Overlapped commands** — A command that allows the execution of subsequent commands while device operations of the overlapped command are still in progress.

The *WAI command is used to suspend the execution of subsequent commands until the device operations of all previous overlapped commands are finished. The *WAI command is not needed for sequential commands.

13

DISPlay, FORMat, and SYSTem Key-Press Codes

Section 13 topics

[DISPlay subsystem](#), page 13-2

[FORMat subsystem](#), page 13-4

[SYSTem key-press codes](#), page 13-9

DISPLAY subsystem

The commands in this subsystem are used to control the display remotely and are listed [Table 13-1](#).

Table 13-1
Display commands

Command	Description	Default
DISPLAY:ENABLE 	Enable/disable display and controls. ¹ = ON or OFF.	Note
DISPLAY:TEXT <a>	Define top line ASCII message "a". ² Up to 20 characters.	Note
DISPLAY:TEXT:STATE 	Enable/disable top line message. ³ = ON or OFF.	Note
DISPLAY:ATTRIBUTES?	Query attributes of top message characters. Blinking (1) or not blinking (0)	
DISPLAY:WINDOW2:TEXT <a>	Define bottom line ASCII message "a". ² Up to 32 characters	Note
DISPLAY:WINDOW2:TEXT:STATE 	Enable/disable bottom line message. ³ = ON or OFF	Note
DISPLAY:ATTRIBUTES?	Query attributes of bottom message characters. Blinking (1) or not blinking (0)	

Note: *RST and SYSTEM:PRESet have no effect on the display circuitry, a text message, or the state of the message modes. Pressing **LOCAL** or cycling power enables (ON) the display circuitry, cancels all text messages, and disables (OFF) the message modes. Pressing **DISP** will also enable the display.

- With front panel circuitry turned off, the instrument operates at a higher speed. While disabled, the display is frozen and all front panel controls (except LOCAL and DISP) are disabled. Normal display operations can be resumed by sending DISPLAY:ENABLE on to enable the display, pressing the **LOCAL** or **DISP** key, or cycling power.

- DISPLAY:TEXT <a>
DISPLAY:WINDOW2:TEXT <a>

Message Types:	String	'aa...a' or "aa...a"
	Indefinite Block	#0aa...a
	Definite Block	#XYaa...a

Where: Y = number of characters in message

X = number of digits that make up Y (1 or 2)

The top display message can be up to 20 characters (ASCII) long, and the bottom display message can be up to 32 characters. A space is counted as a character. Excess message characters result in an error. Note that for the string type, the message must be enclosed by single or double quotes.

An indefinite block message must be the only command in the program message or the last command in the program message. If you include a command after an indefinite block message (on the same line), it will be treated as part of the message and is displayed instead of executed.

3. When the text message mode is enabled, a defined message is displayed. When disabled, the message is removed from the display.

GPIB operation – A user-defined message remains displayed only as long as the instrument is in remote. Taking the instrument out of remote (by pressing **LOCAL** or sending the GTL (go to local) command) or cycling power cancels the message and disables the text message mode.

RS-232 operation – A user-defined message can be cancelled by sending SYSTem:LOCal, pressing **LOCAL**, or cycling power.

Ethernet (6221) operation – A user-defined message remains displayed only as long as the instrument is in remote. Taking the instrument out of remote (by pressing **LOCAL** or **DISP**, or cycling power) cancels the message and disables the text message mode.

FORMAT subsystem

The commands in this subsystem are used to select the format for transferring delta data over the bus and are listed in [Table 13-2](#).

Table 13-2
Format commands

Command	Description	Default
FORMAT <type> [,<length>]	Specify data format. <type> = ASCII, REAL, 32, SREal, DREal, or REAL, 64 <length> = 32 (for REAL type)	ASCII
FORMAT:ELEMENTs <item list>	Specify data elements. <item list> = READING, TStamp, UNITS, RNUMBER, SOURce, COMPliance, AVOLTage, or <item list> = ALL or DEFault	RDG, TST
FORMAT:BORDER <name>	Specify binary byte order. <name> = NORMAL or SWAPPED.	Note
FORMAT:SREGister <name>	Select data format for reading for reading status registers. <name> = ASCII, HEXadecimal, OCTal or BINary. For details, see “ Reading registers ,” on page 11-6.	

Note: *RST default is NORMAL. SYSTEM:PRESet default is SWAPPED.

FORMAT <type>[,<length>]

Parameters	ASCII = ASCII format
	SREal = Binary IEEE-754 single precision format
	REAL, 32 = Binary IEEE-754 single precision format
	DREal = Binary IEEE-754 double precision format
	REAL, 64 = Binary IEEE-754 double precision format

NOTE **<length> is not used for the ASCII, SREal, or DREal parameters.**

The response to a read command can be returned in either the ASCII or binary format. “[Read commands](#)” are covered on [page 5-15](#). All other queries are returned in ASCII, regardless of the selected format. Over the RS-232 interface, only the ASCII format is allowed.

NOTE

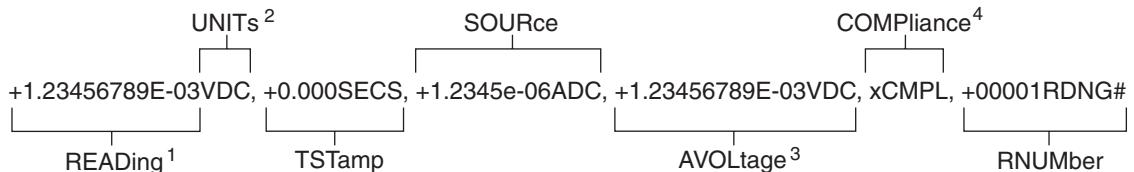
Regardless of which data format for output strings is selected, the instrument will only respond to input commands using the ASCII format.

ASCII data format

The ASCII data format is in a direct readable form for the operator. Most programming languages easily convert ASCII mantissa and exponent to other formats. However, some speed is compromised to accommodate the conversion. [Figure 13-1](#) shows an example ASCII string that includes all the data elements.

[Figure 13-1](#) also shows the byte order of the data string. Data elements not specified by the :ELEMents command are not included in the string.

Figure 13-1
ASCII data format



1. An overflow reading is displayed as +9.9E37.
2. Units for delta readings:

VDC	=	DC Volts
Ω	=	Ohms
W	=	Watts
S	=	Siemens
3. The average voltage data element is only available for Differential Conductance.
4. For compliance, x = T or F:

TCMPL	=	In compliance
FCMPL	=	Not in compliance

IEEE-754 single precision format

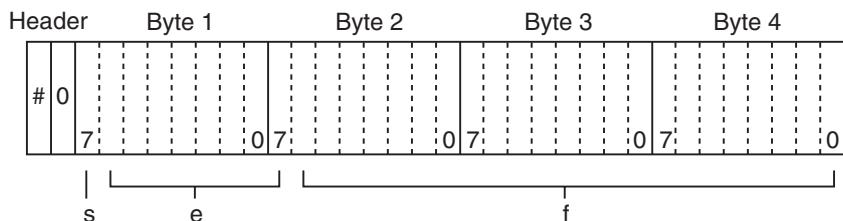
REAL, 32, or SREal will select the binary IEEE-754 single precision data format. [Figure 13-2A](#) shows the normal byte order format for each data element. For example, if three data elements are selected, the data string for each reading conversion is made up of three 4-byte data blocks. Note that the data string for each reading conversion is preceded by a 2-byte header that is the binary equivalent of an ASCII # sign and 0. [Figure 13-2](#) does not show the byte for the terminator that is attached to the end of each data string. Note that the byte order of the data string can be sent in reverse order (see "["FORMAT:ELEMents <item list>"](#) on page 13-7).

IEEE-754 double precision format

REAL, 64, or DReal selects the binary IEEE754 double precision data format and is shown in [Figure 13-2B](#) (normal byte order shown). This format is similar to the single precision format except that it is 64 bits long.

Figure 13-2
IEEE-754 data formats

A) Single precision data format (32 data bits)



s = sign bit (0 = positive, 1 = negative)

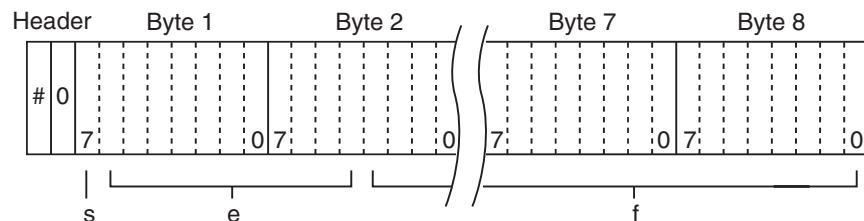
e = exponent bits (8)

f = fraction bits (23)

Normal byte order shown. For swapped byte order, bytes sent in reverse order: Header, Byte 4, Byte 3, Byte 2, Byte 1.

The Header is only sent once for each measurement conversion.

B) Double precision data format (64 data bits)



Bytes 3, 4, 5, and 6 not shown.

s = sign bit (0 = positive, 1 = negative)

e = exponent bits (11)

f = fraction bits (52)

Normal byte order shown. For swapped byte order, bytes sent in reverse order: Header, Byte 8, Byte 7 -- Byte 1.

The Header is only sent once for each measurement conversion.

FORMat:ELEMents <item list>

Parameters	READING	= Reading (Delta, Pulse Delta, or Differential Conductance)
	TSTamp	= Timestamp
	UNITs	= Measurement units
	RNUMber	= Reading number
	SOURce	= Current source level
	COMPliance	= State of compliance
	AVOLtage	= Average voltage (Differential Conductance)
	ALL	= Include all of the above elements
	DEFault	= Includes READING and TSTamp only

The specified elements are included in the data string in response to a read command. “[Read commands](#)” are covered on [page 5-15](#). Elements not specified are not included in the returned data string.

Each element in the item list must be separated by a comma (e.g., send FORM:ELEM READ, TST, UNIT, SOUR, AVOL, COMP, RNUM to include all elements in the string). The elements for the ASCII format are shown in [Figure 13-1](#).

To include all the data elements, the ALL parameter can be used. To include all elements, send FORM:ELEM ALL. To include only the default elements (READING and TSTamp), use the DEFault parameter as follows: FORM:ELEM DEF.

Reading (READ) – The returned reading is for Delta, Pulse Delta (6221), or Differential Conductance. An overflow reading is returned as +9.9E37. When a specified data element has invalid data associated with it, NAN (Not A Number) will be the response. NAN is returned as +9.9E37.

Timestamp (TST) – Timestamp references the returned data string to a point in time. The timestamp operates as a timer that starts at zero seconds when the delta test is started. The first delta reading is timestamped at zero seconds.

For buffer readings, timestamp can be referenced to the first reading stored in the buffer (absolute format), which is timestamped at 0 seconds or to the time between each stored reading (delta format). The TRACe:TSTamp:FORMAT command is used to select the timestamp format (see [Section 6](#)).

Units (UNIT) – The available measurement units are shown in [Figure 13-1](#). The reading from the Model 2182A is in volts. With one of the other measurement units selected (Ω , W, or S), the Model 6221 performs the appropriate calculation to convert the voltage reading to ohms, watts, or siemens.

From the front panel, a Pulse Delta reading can be expressed and displayed as an average power reading or a peak power reading. When Pulse Delta power is read using remote programming, the returned UNITs element does not make the distinction between average and peak. Use the UNIT:POWER? command (see [Table 5-1](#)) to determine if the power reading is peak or average.

Details on selecting “[Measurement units](#)” are provided on [page 5-16](#).

Reading number (RNUM) – The reading counter starts at zero when Delta, Pulse Delta, or Differential Conductance is started. If the delta test is set for an infinite count, the reading number will continue counting up to number 2,147,483,643. If the delta test is still running after that count, the reading counter will reset to zero.

Source (SOUR) – This element is the programmed output current (in amps) of the Model 622x.

Compliance (COMP) – The compliance element reports the compliance state of the current source. If in compliance, a “T” is returned. If not in compliance, an “F” is returned. For the double precision data formats (DREal and REAL, 64), the compliance state is returned as a “1” (in compliance) or a “0” (not in compliance).

The compliance state is polled for every reading and will slow down the reading rate. The COMP element must be selected before the delta test is started. If the COMP element is selected while reading acquisition is in process, the “F” (not in compliance) state will always be returned for each reading string.

Average voltage (AVOL) – A Differential Conductance reading can also be returned as an average voltage reading. See [Section 5](#) for details on how average voltage is calculated.

If the readings being returned are not Differential Conductance readings, nothing is returned in this element position if AVOL is selected as a data element.

FORMat:BORDer <name>

Parameters NORMAL = Normal byte order for IEEE-754 binary format
 SWAPped = Reverse byte order for IEEE-754 binary format

For normal byte order, the data format for each element is sent as follows:

Byte 1	Byte 2	Byte 3	Byte 4	(Single precision)
Byte 1	Byte 2	...	Byte 8	(Double precision)

For reverse byte order, data is sent as follows:

Byte 4	Byte 3	Byte 2	Byte 1	(Single precision)
Byte 8	Byte 7	...	Byte 1	(Double precision)

The “#0” header ([Figure 13-2](#)) is not affected by this command. The header is always sent at the beginning of the data string for each measurement conversion.

The ASCII data format can only be sent in the normal byte order. The SWAPped selection is ignored when the ASCII format is selected.

The SWAPped byte order must be used when transmitting binary data to any IBM PC.

SYSTEm key-press codes

All SYSTEm commands, except the :KEY command, are covered in other sections of the manual. [Table 14-8](#) lists all SYSTEm commands and provides references on where to find more information.

SYSTEm:KEY <NRf>

Parameters	<i>Model 6220 key:</i>	<i>Model 6221 key:</i>
1 =	Range up arrow	1 = Range up arrow
2 =	Source down arrow	2 = WAVE
3 =	Cursor left arrow	3 = AMPL ¹
4 =	MENU	4 = MENU
5 =	SWP	5 = SWP
6 =	DISP	6 = DISP
7 =	SETUP	7 = SETUP
8 =	LOCAL	8 = LOCAL
9 =	AUTO	9 = AUTO
10 =	Cursor right arrow	10 = FREQ ²
11 =	EXIT	11 = EXIT
12 =	COND	12 = COND
13 =	TRIG	13 = TRIG
14 =	TRIAX	14 = TRIAX
15 =	FILT	15 = FILT
16 =	CONFIG	16 = CONFIG
17 =	Range down arrow	17 = Range down arrow
18 =	ENTER	18 = ENTER
19 =	DELTA	19 = DELTA
20 =	UNITS	20 = UNITS
21 =	AVG	21 = AVG
22 =	PRES	22 = PRES
23 =	COMM	23 = COMM
24 =	OUTPUT On/OFF	24 = OUTPUT On/Off
26 =	Source up arrow	26 = PULSE
27 =	RECALL	27 = RECALL
28 =	MATH	28 = MATH
29 =	DC	29 = DC
30 =	ADDR	30 = ADDR
31 =	SAVE	31 = SAVE
33 =	(error -222) ³	33 = Push Rotary Knob
39 =	(error -222) ³	39 = CURSOR right arrow
40 =	(error -222) ³	40 = CURSOR left arrow
43 =	(error -222) ³	43 = Turn Rotary Knob left
45 =	(error -222) ³	45 = Turn Rotary Knob right

Notes:

1. When in a menu, AMPL operates as “Cursor left arrow”.
2. When in a menu, FREQ operates as “Cursor right arrow”.
3. Not used by the Model 6220 (Error -222 Parameter Data Out of Range).

Keycodes 25, 32, 34-38, 41, 42, and 44 are not valid and generate error -220 Parameter Error.

This command is used to simulate front panel key presses. For example, to select the DC function, send the following command to simulate pressing the “DC” key: SYSTEM:KEY 29. The keypress codes for the Model 6220 are also shown in Figure 13-3. The keypress codes for the Model 6220 are also shown in Figure 13-4.

The queue for the :KEY? query command can only hold one key-press. When :KEY? is sent and Model 622X is addressed to talk, the key-press code number for the last key “pressed” is sent to the computer.

Figure 13-3
Model 6220 key-press codes

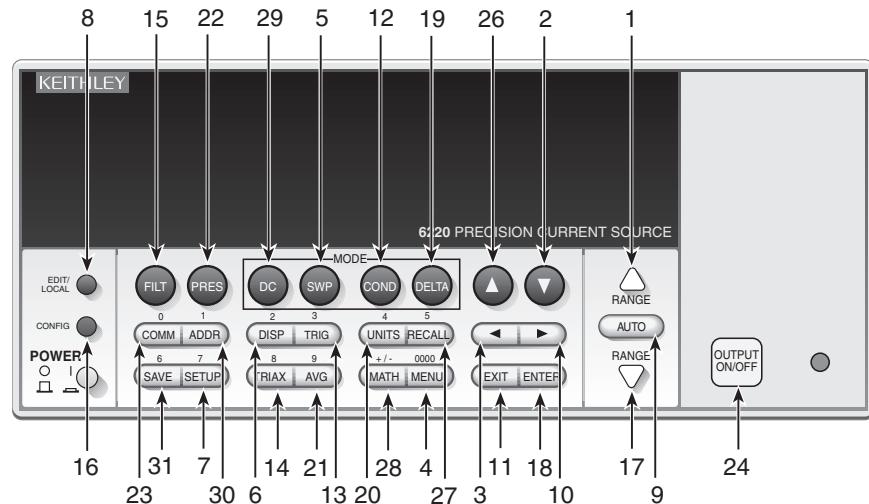
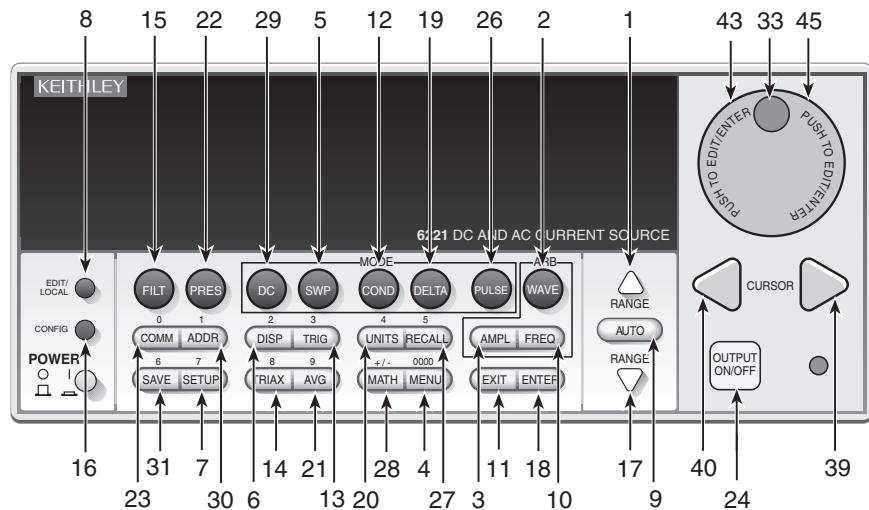


Figure 13-4
Model 6221 key-press codes



Section 14 topics:

- [**Calculate command summary**, page 14-3](#)
- [**Display command summary**, page 14-5](#)
- [**Format command summary**, page 14-6](#)
- [**Output command summary**, page 14-6](#)
- [**Sense command summary**, page 14-7](#)
- [**Source command summary**, page 14-8](#)
- [**Status command summary**, page 14-13](#)
- [**System command summary**, page 14-14](#)
- [**Trace command summary**, page 14-16](#)
- [**Trigger command summary**, page 14-17](#)
- [**Units command summary**, page 14-18](#)

General notes

- Brackets ([]) are used to denote optional character sets. These optional characters do not have to be included in the program message. Do not use brackets in the program message.
- Angle brackets (< >) are used to indicate parameter type. Do not use angle brackets in the program message.
- The Boolean parameter () is used to enable or disable an instrument operation. 1 or ON enables the operation and 0 or OFF disables the operation.
- Uppercase characters indicated the short-form version for each command word.
- Table Headings:
 - **Command** and **Description** — Lists and briefly explains each unabridged SCPI command word and its parameters.
 - **Default** — Listed parameters are both the *RST and SYSTem:PRESet defaults, unless noted otherwise. Parameter notes are located at the end of each table.
 - **Sec** — Refers you to the section (Sec) that provides operation information for that command or command subsystem.
 - **SCPI** — A checkmark (✓) indicates that the command and its parameters are SCPI confirmed. An unmarked command indicates that it is a SCPI command, but does not conform to the SCPI standard set of commands. It is not a recognized command by the SCPI consortium. SCPI confirmed commands that use one or more non-SCPI parameters are explained by notes.

Table 14-1
Calculate command summary

Command	Description	Default	Sec	SCPI
CALCulate[1]	CALC1 commands (math calculations):		6	
:FORMat <name>	Select math format: NONE, MXB (mX+b), or RECiprocal (m/X+b)	MXB		
:FORMat?	Query math format.			
:KMATh	Configure math calculations:			
:MMFactor <NRf>	Set “m” for mX+b and m/X+b calculation: -9.99999e20 to 9.99999e20	1.0		
:MMFactor?	Query “m” factor.			
:MA1Factor <NRf>	Set “m” for mX+b and m/X+b calculation: (same as MMFactor)	1.0		
:MA1Factor?	Query “m” factor.			
:MBFactor <NRf>	Set “b” for mX+b and m/X+b calculation: -9.99999e20 to 9.99999e20	0.0		
:MBFactor?	Query “b” factor.			
:MA0Factor <NRf>	Set “b” for mX+b and m/X+b calculation: (same as MMFactor)	0.0		
:MA0Factor?	Query “b” factor.			
:STATe 	Enable or disable CALC1 calculation.	OFF		✓
:STATe?	Query state of CALC1 calculation.			✓
:DATA	Read calculation:			✓
[:LATest]?	Return latest CALC1 reading.			✓
:FRESh?	Same as CALC1:DATA? except reading can only be returned once.			✓
CALCulate2	CALC2 commands (buffer statistics):	6		
:FORMat <name>	Select buffer statistic: MEAN, SDEViation, MAXimum, MINimum or PKPK	MEAN		✓
:FORMat?	Query selected statistic.			✓
:STATe 	Enable or disable calculation.	OFF		✓
:IMMEDIATE	Perform the selected buffer calculation on buffer contents.			✓
:DATA?	Read the results of the buffer statistic.			✓

Table 14-1 (cont.)

Calculate command summary

Command	Description	Default	Sec	SCPI
CALCulate3	CALC3 commands (limit testing):		9	✓
:LIMit[1]	Stage 1 limit test:			✓
[:STATe] 	Enable or disable limit testing.	OFF		
[:STATe]?	Query state (on or off) of limit testing.			
:SOURce2 <NRf>	Set limit test fail pattern: 0 to 15	15 (1111)		✓
:SOURce2?	Query limit test fail pattern.			✓
:FAIL?	Query limit test pass/fail: 0 = pass, 1 = fail			
:FORCe	Output force commands:	OFF		
[:STATe] 	Enable or disable I/O pattern force state.			
[:STATe]?	Query state (on or off) of I/O pattern force state.			
:PATTern <NRf>	Set I/O pattern: 0 to 15	15 (1111)		
:PATTern?	Query I/O pattern.			

Table 14-2
Display command summary

Command	Description	Default	Sec	SCPI
DISPlay	Display control commands:		13	
:ENABLE 	Enables or disables front panel display and controls.	(Note)		✓
:ENABLE?	Queries state (on or off) of the display and controls.			✓
[:WINDOW[1]]	Top line display characters:			✓
:TEXT	Text message:			✓
[:DATA] <a>	Define ASCII message "a" (up to 20 characters).	(Note)		✓
[:DATA]?	Read text message			✓
:STATe 	Enable or disable text message.	(Note)		✓
:STATe?	Query state (on or off) of text message.			✓
:ATTRibutes?	Query attributes of message characters: Blinking (1) or not blinking (0)			
:WINDOW2	Bottom line display characters:			✓
:TEXT	Text message:			✓
[:DATA] <a>	Define ASCII message "a" (up to 32 characters).	(Note)		✓
[:DATA]?	Read text message			✓
:STATe 	Enable or disable text message.	(Note)		✓
:STATe?	Query state (on or off) of text message.			✓
:ATTRibutes?	Query attributes of message characters: Blinking (1) or not blinking (0)			

Note: *RST and SYSTem:PRESet have no effect on the display circuitry, a text message, or the state of the message modes. Pressing **LOCAL** or cycling power enables (ON) the display circuitry, cancels all text messages and disables (OFF) the message modes. Pressing the **DISP** key will also enable the display.

Table 14-3
Format command summary

Command	Description	Default	Ref Sec	SCPI
FORMAT	Reading format commands:			
[:DATA] <type>[,<length>]	Specify data format: ASCii, REAL,32, SREal, DREal, or REAL,64	ASC	13	
[:DATA]?	Query data format.			
:ELEMENTs <item list>	Specify data elements: READING, TSTamp, UNITS, RNUMBER, SOURce, COMPliance, AVOLtage (or ALL or DEFault)	READ, TST		
:ELEMENTs?	Query data format elements			
:BORDer <name>	Specify byte order: NORMAL or SWAPPED.	(Note)		
:BORDer?	Query byte order.			
:SREGister <name>	Select data format for reading status registers: ASCii, HEXadecimal, OCTal, or BINARY.	ASCii	11	
:SREGister?	Query format for reading status registers.			

Note: *RST default is NORMAL. SYSTEM:PRESet default is SWAPPED.

Table 14-4
Output command summary

Command	Description	Default	Sec	SCPI
OUTPUT[1]	Source output control commands:			
[:STATe] 	Turn output on or off (standby).	OFF	3	
[:STATe]?	Query state (on or off) of output.			
:LTEarth 	Connect output low to earth ground (ON) or float output low (OFF).	OFF	2	
:LTEarth?	Query output low connection.			
:ISHield <name>	Connect triax inner shield to OLOW (output low) or cable GUARD.	OLOW	2	
:ISHield?	Query triax inner shield connection.			
:RESPonse <name>	Set the output response for 6221: FAST or SLOW.	FAST	2	
:RESPonse?	Query output response.			
:INTerlock	Interlock:		2	
:TRIPPed?	Returns a "0" if interlock is tripped (open) or a "1" if interlock is closed (output enabled).			

Table 14-5
Sense command summary

Command	Description	Default	Sec	SCPI
SENSe[1]	Commands for readings from 2182/2182A:		5	
:DATA	Pre-math readings:			
[:LATest]?	Return the latest pre-math delta reading.			
:FRESH?	Same as :LATest? except the reading can only be returned once.			
:AVERage	Averaging filter:		6	
:TCONtrol <name>	Select filter control: MOVing or REPeat.	MOV		
:TCONtrol?	Query filter control.			
:WINDOW <NRf>	Set filter window as % of range: 0 to 10.	0.00		
:WINDOW?	Query filter window.			
:COUNT <NRf>	Specify filter count (size): 2 to 300.	10		
:COUNT?	Query filter count (size).			
[:STATe] 	Enable or disable averaging filter.	OFF		
[:STATe]?	Query state (on or off) of averaging filter.			

Table 14-6
Source command summary

Command	Description	Default	Sec	SCPI
SOURce[1]	Current source output commands:			
:CLEar	Clearing the current source:		3	
[:IMMEDIATE]	Set output to zero and then turn the output off.			
:CURRent	Current source:			
[:LEVel]			3	
[:IMMEDIATE]				
[:AMPLitude] <n>	Set current source output (amps): -105e-3 to 105e-3.	0.0		
:RANGE <n>	Select a fixed source range: -105e-3 to 105e-3.	100e-3	3	
:AUTO 	Enable or disable source auto range.	OFF		
:AUTO?	Query state of auto range.			
:RANGE?	Query present source range.			
:COMPliance <NRf>	Set voltage compliance (volts): 0.1 to 105	10	3	
:COMPliance?	Query voltage compliance.			
:FILTer	Analog filter:		3	
[:STATe] 	Enable or disable analog filter.			
[:STATe]?	Query state of analog filter.	OFF		
:STARt <n>	Set start current (amps): -105e-3 to 105e-3	0	4	
:STARt?	Query start current.			
:STOP <n>	Set stop current (amps): -105e-3 to 105e-3	100e-3	4	
:STOP?	Query stop current.			
:STEP <n>	Set step current (amps): 1e-13 to 105e-3	1e-2	4	
:STEP?	Query step current.			
:CENTer <n>	Set center current (amps): -105e-3 to 105e-3	0	4	
:CENTer?	Query center current.			
:SPAN <n>	Set span current (amps): 2e-13 to 210e-3	100e-3	4	
:SPAN?	Query span current.			
:DELy <n>	Set source delay (seconds): 1e-3 to 999999.999	1	4	
:DELy?	Query source delay.			
:SWEep	Source sweep operation:		4	
:SPACing <name>	Select sweep type: LINEar, LOGarithmic, or LIST	LIN		
:SPACing?	Query sweep type.			
:POINts <n>	Set sweep points: 1 to 65535	11		
:POINts?	Query sweep points.			
:RANGing <name>	Select sweep ranging: AUTO, BEST, or FIXed.	BEST		
:RANGing?	Query sweep ranging.			

Table 14-6 (cont.)
Source command summary

Command	Description	Default	Sec	SCPI
:COUNT <NRf>	Set sweep count: 1 to 9999 or INFinity	1		
:COUNT?	Query sweep count.			
:CABort 	Enable to abort sweep on compliance: ON or OFF	OFF		
:CABort?	Query compliance sweep abort state.			
:ARM	Arm the sweep.			
:ABORT	Abort sweep, Delta, Pulse Delta, or Differential Conductance immediately.			
:LIST	Custom sweep operation:		4	
:CURREnt <NRf> [,<NRf>, ...<NRf>]	Define list of currents (amps): -105e-3 to 105e-3			
:APPend <NRf> [,<NRf>, ...<NRf>]	Add current points to existing list: -105e-3 to 105e-3.			
:POINts?	Query number of current list points.			
:CURREnt?	Query list of current values.			
:DELay <NRf> [,<NRf>, ...<NRf>]	Define list of delay values (secs): 1e-3 to 999999.999.	1		
:APPend <NRf> [,<NRf>, ...<NRf>]	Add delay values to existing list.			
:POINts?	Query number of delay values in list.			
:DELay?	Query list of delay values.			
:COMPliance <NRf> [,<NRf>, ...<NRf>]	Define list of compliance values (volts): 1e-3 to 105.			
:APPend <NRf> [,<NRf>, ...<NRf>]	Add compliance values to existing list: 1e-3 to 105.			
:POINts?	Query number of compliance values in list.			
:COMPliance?	Query list of compliance values.			
:DELta	Delta operation:		5	
:NPVReSent?	Query connection to 2182/2182A: 1 = yes, 0 = no.			
:HIGH <NRf>	Set high source value (amps): 0 to 105e-3.	1e3		
:HIGH?	Query high source value.			
:LOW <NRf>	Set low source value (amps): 0 to -105e-3.	-1e3		
:LOW?	Query low source value.			
:DELay <NRf>	Set Delta delay (seconds): 1e-3 to 9999.999	2e-3		
:DELay?	Query Delta delay.			
:COUNT <NRf>	Set number of cycles to run: 1 to 65536 or INFinity.	INF		
:COUNT?	Query Delta count.			

Table 14-6 (cont.)

Source command summary

Command	Description	Default	Sec	SCPI
:CABort 	Enable to abort test on compliance: ON or OFF	OFF		
:CABort?	Query compliance sweep abort state.			
:CSWitch 	Enable cold switching mode: ON or OFF.	OFF		
:CSWitch?	Query cold switching state.			
:ARM	Arm Delta.			
:ARM?	Query arm. 1 = Delta armed, 0 = not armed.			
:PDELta	Pulse Delta operation:		5	
:NVPResent?	Query connection to 2182A: 1 = yes, 0 = no.			
:HIGH <NRf>	Set high pulse value (amps): -105e-3 to 105e-3.	1e3		
:HIGH?	Query high pulse value.			
:LOW <NRf>	Set low pulse value (amps): -105e-3 to 105e-3.	0		
:LOW?	Query low pulse value.			
:WIDTh <NRf>	Set pulse width (seconds): 50e-6 to 12e-3.	110e-6		
:WIDTh?	Query pulse width.			
:SDELay <NRf>	Set source delay (seconds): 16e-6 to 11.966e-3.	16e-6		
:SDELay?	Query source delay.			
:COUNT <NRf>	Set number of Pulse Delta readings to perform: 1 to 65636 or INFinity.	INF		
:COUNT?	Query Pulse Delta count.			
:RANGing <NRf>	Select fixed pulse source range: BEST or FIXed.	BEST		
:RANGing?	Query fixed pulse source range.			
:INTerval <NRf>	Set interval (in PLCs) for each pulse cycle: 5 to 999999.	5		
:INTerval?	Query interval.			
:SWEep	Pulse Delta Sweep output:			
[:STATe] 	Enable or disable Sweep output mode.	OFF		
[:STATe]?	Query state of Sweep output mode.			
:LMEasure <NRf>	Set number of low measurement per cycle: 1 or 2.	2		
:LMEasure?	Query number of low measurements.			
:ARM	Arm Pulse Delta.			
:ARM?	Query arm. 1 = Pulse Delta armed, 0 = not armed.			

Table 14-6 (cont.)

Source command summary

Command	Description	Default	Sec	SCPI
:DCONductance	Differential Conductance operation:			
:NVPresent?	Query connection to 2182/2182A: 1 = yes, 0 = no.			
:NVZero?	Query V-zero value acquired from 2182/2182A.			
:STARt <NRf>	Set start value (amps): -105e-3 to 105e-3.	-10e-6		
:STARt?	Query start value.			
:STEP <NRf>	Set step size (amps): 0 to 105e-3.	1e-6		
:STEP?	Query step size.			
:STOP <NRf>	Set stop value (amps): -105e-3 to 105e-3.	+10e-6		
:STOP?	Query stop value.			
:DELTa <NRf>	Set delta value (amps): 0 to 105e-3.	1e-6		
:DELTa?	Query delta value.			
:DELay <NRf>	Set delay (seconds): 1e-3 to 9999.999.	2e-3		
:DELay?	Query delay.			
:CABort 	Enable to abort test on compliance: ON or OFF	OFF		
:CABort?	Query compliance sweep abort state.			
:ARM	Arm Differential Conductance.			
:ARM?	Query arm. 1 = armed, 0 = not armed.			
:WAVE	Wave function operation:			7
:FUNCtion <name>	Select wave function: SINusoid, SQUare, RAMP or ARBArbitraryX (where X = 0 to 4).	SIN		
:FUNCtion?	Query selected wave function.			
:DCYCle <NRf>	Set duty cycle (in %): 0 to 100.	50		
:DCYCle?	Query duty cycle.			
:AMPLitude <NRf>	Set amplitude (amps peak): 2e-12 to 105e-3.	1e-3		
:AMPLitude?	Query amplitude.			
:FREQuency <NRf>	Set frequency (Hz): 1e-3 to 1e5.	1e3		
:FREQuency?	Query frequency.			
:OFFSet <NRf>	Set offset (amps): -105e-3 to 105e-3.	0		
:OFFSet?	Query offset.			
:PMARK	Phase marker:			
[:LEVel] <NRf>	Set marker phase (in degrees): 0 to 360.	180		
[:LEVel]?	Query marker phase level.			
:OLINe <NRf>	Set phase marker trigger line: 1 to 6.	3		
:OLINe?	Query phase marker trigger line.			
:STATe 	Enable or disable phase marker.	OFF		
:STATe?	Query state (on or off) of phase marker.			

Table 14-6 (cont.)

Source command summary

Command	Description	Default	Sec	SCPI
:ARbitrary	Arbitrary waveforms:		7	
:DATA <NRf> [,<NRf>, ...<NRf>]	Define arbitrary data points: -1 to +1 (100 points maximum).			
:DATA?	Query the points in the arbitrary waveform.			
:APPend <NRf> [,<NRf>, ...<NRf>]	Append arbitrary data points: -1 to +1 (100 points max. per instance of command).			
:POINTS?	Query number of points in the waveform.			
:COPY <NRf>	Copy arbitrary points to NVRAM: 1 to 4.			
:RANGing <name>	Select source ranging mode: BEST or FIXed.	BEST		
:RANGing?	Query selected range mode.			
:DURation	Waveform duration:			
:TIME <NRf>	Set waveform time duration (seconds): 100e-9 to 999999.999 or INFinity.	INFinity		
:TIME?	Query waveform time duration.			
:CYCLe <NRf>	Set waveform duration in cycles: 1e-3 to 99999999900 or INFinity.	INFinity		
:CYCLe?	Query waveform duration in cycles.			
:ARM	Arm waveform function.			
:INITiate	Start waveform output.			
:ABORT	Abort waveform output.			
:EXTRig	Waveform external trigger commands: *			
[:ENABLE] 	Enables/disables mode to externally trigger the waveform generator: = ON or OFF.	OFF		
[:ENABLE]?	Query if external waveform trigger is enabled.			
:ILINe <NRf>	Specify trigger link input trigger line: <NRf> = 0 (none) or 1 to 6.	0		
:ILINe?	Query trigger link line.			
:IGNore 	Sets whether or not to restart waveform upon retriggering: = ON or OFF.	OFF		
:IGNore?	Query retrigger mode.			
:IVALue <NRf>	Sets inactive value to output before/after waveform: <NRf> = -1 to +1.	0.00		
:IVALue?	Query inactive value.			

* Available with firmware revision A03 and later.

Table 14-7
Status command summary

Command	Description	Default	Sec	SCPI
STATUs	Commands status registers:	Note 1	11	✓
:MEASurement	Measurement event registers:			
[:]EVENT[?]	Read the event register.	Note 2		
:ENABLE <NDN> or <NRf>	Program the enable register.	Note 3		
:ENABLE?	Read the enable register.			
:CONDITION?	Read the condition register.			
:OPERation	Operation event registers:			✓
[:]EVENT[?]	Read the event register.	Note 2		✓
:ENABLE <NDN> or <NRf>	Program the enable register.	Note 3		✓
:ENABLE?	Read the enable register.			✓
:CONDITION?	Read the condition register.			✓
:QUEstionable	Questionable event registers:			✓
[:]EVENT[?]	Read the event register.	Note 2		✓
:ENABLE <NDN> or <NRf>	Program the enable register.	Note 3		✓
:ENABLE?	Read the enable register.			✓
:CONDITION?	Read the condition register.			✓
:PRESet	Return status registers to default states.			✓
:QUEue	Read error queue:			✓
[:]NEXT[?]	Read the most recent error message.	Note 4		✓
:ENABLE <list>	Specify error and status messages for error queue: -999 to +999.	Note 5		✓
:ENABLE?	Read the enabled messages.			✓
:DISable <list>	Specify error and status messages not to be placed in error queue: -999 to +999.			✓
:DISable?	Read the disabled messages.			✓
:CLEar	Clears all messages from error queue.			
Parameters:				
<NDN>	= #Bxx...x	Binary format (each x = 1 or 0)		
	= #Hx	Hexadecimal format (x = 0 to FFFF)		
	= #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 empties 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 14-8
System command summary

Command	Description	Default	Sec	SCPI
:SYSTem				
:COMMunicate	Communication interfaces:		5	
:SElect <name>	Select interface: SERial, GPIB or ETHernet.		10	
:GPIB	GPIB interface:			
:ADDRess <NRf>	Set primary address: 0 to 30.			
:ADDRess?	Query primary address.			
:SERial	RS-232 interface:			
:CONTrol	Handshaking:			
:RTS <name>	Select handshaking: IBFull, RFR, or OFF.			
:RTS?	Query handshaking.			
:PACE <name>	Set flow control: XON or OFF			
:PACE?	Query flow control.			
:TERMinator <name>	Set output terminator: CR, LF, CRLF, or LFCR.			
:TERMinator?	Query output terminator.			
:BAUD <n>	Set baud rate: 300, 600, 1200, 2400, 4800, 9600, 19.2k, 38.4k, 57.6k, or 115.2k.			
:BAUD?	Query baud rate.			
:SEND <data>	Send data via RS-232.			
:ENTER?	Reads data from serial port.			
:LOCal	RS-232 only – Take 622x out of remote.			
:REMote	RS-232 only – Put 622x in remote.			
:RWLock 	RS-232 only – Enable or disable local lockout.			
:RWLock?	RS-232 only – Query state of local lockout.			
:ETHernet	Ethernet interface (6221 only):			
:ADDRess <string>	Set IP address: "n.n.n.n".			
:ADDRess?	Query IP address.			
:MASK <string>	Set subnet mask: "n.n.n.n".			
:MASK?	Query subnet mask.			
:GATEway <string>	Set Ethernet gateway: "n.n.n.n".			
:GATEway?	Query Ethernet gateway.			
:DHCP 	Enable or disable DHCP.			
:DHCP?	Query state (on or off) of DHCP.			
:SAVE	Saves Ethernet setting changes.			
:KEY <n>	Simulate key press. See "SYSTem key-press codes," on page 13-9.		13	

Table 14-8 (cont.)
System command summary

Command	Description	Default	Sec	SCPI
:KEY?	Query last pressed key.			
:KCLick 	Enable or disable key-click.	ON	1	
:KCLick?	Query state of key-click.			
:BEEPer	Beeper:			
:STATE 	Enable or disable beeper.	ON	1	
:STATE?	Query state of beeper.			
:PRES't	Return 622x to PRESET default setup.		1	
:POSetup <name>	Select power-on setup: RST, PRESet, SAV0, SAV1, SAV2, SAV3, or SAV4.		1	
:POSetup?	Query power-on setup.			
:ERRor?	Query the latest error code and message.		11	
:CLEar	Clears error code and message from Error Queue.		11	
:TStamp	System timestamp:		13	
:RESET	Reset timestamp to zero seconds.			
:RNUMBER	System reading number:		13	
:RESET	Reset reading number to zero.			
:VERSion?	Query revision level of SCPI standard.			
:ABOard	Analog board:		1	
:SNUMber?	Query serial number of analog board.			
:REVision?	Query revision level of analog board.			
:DBOard	Digital board:		1	
:SNUMber?	Query serial number of digital board.			
:REVision?	Query revision level of digital board.			
:PASSword	Password:		10	
:ENABLE 	Enable or disable the use of password.			
:ENABLE?	Query state of password usage.			
:CDISable <string>	Disables protected commands. <string> = "password".			
[:CENable] <string>	Enables protected commands. <string> = "password".			
:STATE?	Query state of password: Returns "0" if password protected commands are disabled. Returns "1" if enabled.			
:NEW <string>	Set new password. <string> = "password".			

Table 14-9

Trace command summary

Command	Description	Default	Sec	SCPI
TRACe	Commands to control buffer:	Note 1	6	✓
:CLEar	Clear readings from buffer.			
:FREE?	Query memory bytes available in buffer.			
:POINts <n>	Specify buffer size (number of readings to store): 1 to 65536.	Note 2		✓
:ACTual?	Query number readings stored in the buffer.			
:POINts?	Query buffer size.			✓
:NOTify <NRf>	Specify number of stored readings that will set the Trace Notify bit (B6) of the measurement event register. Must be less than the TRACe:POINts value: 1 to (TRACe:POIN -1).	Note 3		
:NOTify?	Query trace notify value.			
:FEED <name>	Select source (feed) for buffer readings: SENS1, CALC1, or NONE,	CALC1		✓
:CONTrol <name>	Set buffer control: NEXT or NEVer	NEV		✓
:CONTrol?	Query buffer control.			✓
:FEED?	Query buffer feed.			✓
:TSTamp	Timestamp for buffer readings:			
:FORMat <name>	Select timestamp format: ABSolute or DELTa	ABS		
:FORMat?	Query timestamp format.			
:DATA?	Request all readings in buffer.			✓
:TYPE?	Query type of readings stored in buffer: Returns NONE, DELT, DCON, or PULS.			
:SElected? <start>, <count>	Request list of stored readings: Requires a starting value and the number of readings (count).			

Notes:

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 14-10
Trigger command summary

Command*	Description	Default	Sec	SCPI
INITiate [:IMMEDIATE]	Trigger initiation: Initiate one trigger cycle.	OFF	8	
ABORt	Reset trigger system.		8	
ARM [:SEQUENCE[1]] [:LAYER[1]]	Arm layer commands:		8	
:SOURce <name>	Select event detector: IMMEDIATE, TIMER, BUS, TLINK, BSTEST, PSTEST, NSTEST, or MANUAL.			
:SOURce?	Query selected event detector.			
:SIGNal	Bypass ARM control source.			
:TIMER <n>	Set timer interval (seconds): 0 to 99999.99. 1msec resolution.	0.1		
:TIMER?	Query timer interval.			
[:TCONFIGURE]				
:DIRection <name>	Control ARM source bypass: SOURce or ACCEPTor.	ACC		
:DIRection?	Query ARM source bypass.			
[:ASYNchronous]				
:ILINE <NRf>	Set ARM input signal line: 1 to 6.	1		
:ILINE?	Query ARM input signal line.			
:OLINE <NRf>	Set ARM output signal line: 1 to 6.	2		
:OLINE?	Query ARM output signal line.			
:OUTPUT <name>	Enable/disable ARM output trigger: TENTER, TEXIT or NONE.	NONE		
:OUTPUT?	Query ARM output trigger.			
TRIGger	Trigger layer commands:		8	
[:SEQUENCE[1]]				
:SOURce <name>	Select event detector: IMMEDIATE or TLINK.	IMM		
:SOURce?	Query selected event detector.			
:SIGNal	Bypass TRIG control source.			
[:TCONFIGURE]				
:DIRection <name>	Control TRIG source bypass: SOURce or ACCEPTor.	ACC		
:DIRection?	Query TRIG source bypass.			
[:ASYNchronous]				
:ILINE <NRf>	Set TRIG input signal line: 1 to 6.	1		

* Arm layer commands control entire sweep. Trigger Layer commands control individual sweep steps.

Table 14-10 (cont.)

Trigger command summary

Command*	Description	Default	Sec	SCPI
:ILINe?	Query TRIG input signal line.			
:OLINe <NRf>	Set TRIG output signal line: 1 to 6.	2		
:OLINe?	Query TRIG output signal line.			
:OUTPut <name>	Enable/disable TRIG output trigger: SOURce[1], DELay, or NONE.	NONE		
:OUTPut?	Query TRIG output trigger.			

* Arm layer commands control entire sweep. Trigger Layer commands control individual sweep steps.

Table 14-11

Units command summary

Command	Description	Default	Sec	SCPI
UNIT	Commands to set reading units for Delta, Pulse Delta, and Differential Conductance:		5	
[:VOLT]	Volts readings are sent from 2182/2182A to 622x.			
[:DC] <name>	Specify reading units*: V, OHMS, W, or SIEMens.	V		
[:DC]?	Query reading units.			
:POWER	Power reading type for Pulse Delta (6221):			
[:TYPE] <name>	Set power units reading type: PEAK or AVERage.	AVER		
[:TYPE]?	Query power units reading type.			

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

15

KI-220 Language

Section 15 topics

[Introduction, page 15-2](#)

Introduction

The Model 622x can be used to emulate the Keithley Model 220 current source by using the KI-220 language mode with GPIB remote operation. When using the KI-220 language mode, Device-Dependent Commands (DDCs) used by the Model 220 are also used to control the Model 622x. The DDC emulation commands used by the Model 622x are listed and explained in [Table 15-1](#).

The KI-220 language mode is set from the COMMUNICATIONS SETUP menu and is selected using the following key-press sequence:

*Press **COMM > Select GPIB > Set the address (0-30) > Select KI-220 language***
Details on selecting the KI-220 language are provided in [Section 10](#).

Table 15-1
DDC emulation commands

Mode	Command	Description	Note
Display	D0 - D3	These display commands are accepted but do not do anything since the Model 622x can display all information at once.	Note 3
Function	F0 F1	Put current source in standby. Turn output on.	
Prefix	G0 G1 G2 G3 G4 G5	Location with Prefix Location without Prefix Location with Prefix Location without Prefix Full Buffer with Prefix Full Buffer without Prefix	
Self-Test	J0	This digital self-test command has no effect on the Model 622x.	Note 2
EO1	K0 K1	Send EOI Send no EOI	
SRQ	M0 M1 M2 M4 M8 M16	SRQ disabled IDDC, IDDC, No Remote Over Voltage Limit End of Buffer End of Dwell Time (Delay) Input Port Change	
Program	P0 P1 P2	Single Continuous Step	Notes 12, 14

Table 15-1 (cont.)
DDC emulation commands

Range	R0 R1 R2 R3 R4 R5 R6 R7 R8 R9	Auto 1nA 10nA 100nA 1µA 10µA 100µA 1mA 10mA 100mA	
Trigger	T0 T1 T2 T3 T4 T5 T6 T7	Start on Talk Stop on Talk Start on GET Stop on GET Start on X Stop on X Start on External Trigger Stop on External Trigger	
Terminator	Y0 Y1 Y2 Y3 Y4	CR LF LF CR CR LF None	Note 11
Inputs	I V W B L	Current Source Voltage Limit Dwell Time Buffer Address Memory Location	Note 8 Note 5 Notes 7, 10
I/O Port	O (0-15)	Set Output Control Bits	Note 1
Status	U0 U1	Send Status Word Send I/O Port Status	
Digital Self-Test	J0	Not Supported	
Execute	X	Execute other DDCs	

Notes:

The following notes explain the operational differences between the Models 622x and Model 220. Some notes provide additional information for the commands listed in [Table 15-1](#).

1. The Model 622x does not have four digital input lines but instead only has two.
2. The J command for digital self-test is not supported. J0 will be accepted but has no effect. The U0 response string will correctly indicate a '1' in the J position after a J0 command is sent, and the next query of U0 will correctly change the '1' in that position back to zero.
3. The D commands are accepted but do not have any effect. The two-line display of the 622x can accommodate all the information at once, so there is no need to change display modes.
4. Delta, Pulse Delta, and Differential Conductance cannot be run if the language is set to the KI-220 mode.
5. The V command for setting compliance accepts any valid floating-point number between 0.1 and 105. The Model 220 only accepts integers between 1 and 105.
6. The KI-220 language can only be used with the GPIB. It is not available when RS-232 or Ethernet communication is selected.
7. The KI-220 language is a bus-only operation with significantly different front panel operation from the Model 220. The B command (buffer location) will be accepted and returned properly in queries, but it has no effect on the display. You can use the CONFIG > SWP > CUSTOM > ADJUST POINTS menu to adjust sweep point locations. The front panel will display the memory location selected by the L command (see note 10 below).
8. Unlike the Model 220, which truncates the last digit of the 4-1/2 digit I value to either zero or five, the 622x gives you a full four and a half digits. The last digit can take on any value, 0-9.
9. The Model 220 does not have a Local key and allows you to make front panel entries at any time, even when in Remote. The Model 622x does NOT emulate that behavior; you'll need to press Local to get out of Remote before front panel key presses will be accepted on the 622x.
10. To properly emulate the Model 220, the display will show a Mem:xxx indicator in the lower right corner of the display while in the KI-220 language mode. This Mem value cannot be accessed from the front panel (recall that KI-220 mode is bus-only) but is the Memory Location as defined by the L command. The Model 220 is basically a collection of memory locations that can be sequenced through (like a list sweep) or stepped one at a time.
11. The Y command options are supported but have changed some from the original Model 220 due to differences in the parser functions. Not supported is the Y <ascii> option that allows any valid ASCII character to be used as the terminator.

Terminators are selected using Y<n>, where n = 0-4. The default terminator is <CR LF>, which is Y0 in this notation. For the U0 query string, the Model 622x will return a ‘:’ in the Y position for the default terminator (like the Model 220 does). Otherwise we will return the digit 1-4 will be returned for the other choices.

12. When a sweep is halted on the Model 220 (by pressing the Start/Stop key), the output remains on and the source remains at the last memory value it was at when the sweep is stopped. Stopping a sweep on the Model 622x (with the EXIT key) resets you to the first memory location and turns the output off. Note that in the KI-220 mode with the Program Command set to Continuous or Single (P1 or P0), the Model 622x TRIG key will behave like the Model 220 Start/Stop key (e.g., one push starts the sweep, the next pauses, etc.).
13. The Model 220 has only a single external trigger line available. In the KI-220 language mode, only TLINK line #1 will function as the external trigger input. To avoid confusion and the possibility of getting into undesirable states, the entire CONFIG > TRIG menu will be locked out in the KI-220 mode. The trigger output pulse will always be issued on TLINK line #2, and it will be issued at the end of the Dwell time (Delay time). Unlike Model 622x operation, the trigger output pulse cannot be disabled in KI-220 mode.
14. Changing Model 622x trigger modes by sending the P command will always reset the memory location back to 1. The Model 220 leaves it where it was.

16

Performance Verification

Section 16 topics

Introduction, page 16-2

Test requirements, page 16-3

Environmental conditions, page 16-3

Warm-up period, page 16-3

Line power, page 16-3

Recommended test equipment, page 16-4

Test equipment connections, page 16-4

Calculating test limits, page 16-4

Example limit calculation, page 16-4

Restoring factory defaults, page 16-5

Test summary and considerations, page 16-5

Test summary, page 16-5

Test considerations, page 16-5

Verification procedures, page 16-6

DC current output accuracy, page 16-6

Compliance accuracy, page 16-8

Waveform function accuracy, page 16-9

Amplitude flatness, page 16-9

Frequency accuracy, page 16-10

Introduction

WARNING **The information in this section is intended only for qualified service personnel. Do not attempt these procedures unless you are qualified to do so.**

Information is provided in this section to offer recommendations to the owner of the Model 622x to perform test procedures to the extent that is required by their quality system in the event that they have elected not to return the instrument to Keithley for routine verification/calibration. Any verification procedure for this instrument should account for measurement uncertainties that arise from test equipment tolerances.

Before proceeding, the laboratory should characterize the components used with the testing process in order to correct for test equipment tolerance and to estimate measurement uncertainty appropriately.

NOTE **The test procedures in this section provide a relatively low-cost method of verifying instrument performance. The techniques used for these tests should be adequate for most users. However, in some cases, measurement uncertainty may not be sufficient for those with more stringent requirements. If necessary, contact your Keithley representative or the factory for information on more comprehensive procedures to verify Model 622x performance.**

Test requirements

Be sure that you perform the verification tests:

- Under the proper environmental conditions.
- After the specified warm-up period.
- Using the correct line voltage.
- Using the proper test equipment.
- Using the specified reading limits.

Environmental conditions

Conduct the procedures in a test environment that has:

- An ambient temperature of 18° to 28°C (65° to 82°F).
- A relative humidity of less than 70% unless otherwise noted.

Warm-up period

Allow the Model 622x to warm up for at least one hour before conducting the procedures.

If the instrument has been subjected to temperature extremes (those outside the ranges stated above), allow additional time for the instrument's internal temperature to stabilize. Allow one extra hour to stabilize a unit that is 10°C (18°F) outside the specified temperature range.

Also, allow the test equipment to warm up for the minimum time specified by the manufacturer.

Line power

The Model 622x requires a line voltage of 100V to 240V and a line frequency of 50Hz to 60Hz.

Recommended test equipment

Table 16-1 summarizes recommended test equipment specifications as well as typical suitable models. Ideally, test equipment uncertainty should be at least four times better than equivalent Model 6220 or 6221 specifications. However, the equipment listed for the 2nA and 20nA ranges does not quite meet that requirement.

Table 16-1
Recommended test equipment

Description	Key specifications	Manufacturer/model
Digital Multimeter	Measure 200nA to 100mA DC, $\pm 100\text{ppm}$ ¹ Measure 10V and 100V DC, $\pm 100\text{ppm}$ ¹ Measure 100mA AC @ 1kHz and 100kHz ²	Agilent 3458A
Picoammeter ¹	Measure 2nA and 20nA DC, $\pm 2000\text{ppm}$	Keithley 6487
Frequency Counter ²	Measure 1kHz sine wave within $\pm 25\text{ppm}$	Any suitable
Test Resistor ²	50Ω, 1/2W composition	Any suitable

1. Equipment used to test output current and compliance accuracy of both 6220 and 6221.
2. Equipment used to test wave functions of 6221 only.

Test equipment connections

For the sake of clarity, only actual signal lines are shown in test equipment connection drawings in this section. To ensure measurement integrity, be sure to use appropriate triax cables or (where appropriate) coax cables for all connections.

Calculating test limits

The test limits stated in this section have been calculated using only the Model 622x one-year accuracy specifications, and they do not include test equipment uncertainty. If a particular measurement falls slightly outside the allowable range, recalculate the new limits based on both Model 622x specifications and pertinent calibration equipment specifications.

Example limit calculation

The following is an example of how test limits have been calculated. Assume you are testing the 20mA range using a 20mA output current. Using $\pm(0.05\% + 10\mu\text{A})$ accuracy, the calculated limits are:

$$\begin{aligned} \text{Output current limits} &= 20\text{mA} \pm [20\text{mA}(0.05\%) + 10\mu\text{A}] \\ \text{Output current limits} &= 19.980 \text{ to } 20.020\text{mA} \end{aligned}$$

Restoring factory defaults

Before performing each procedure, restore the instrument to its factory defaults as follows:

1. Press **SETUP**.
2. Select **PRESET**, then restore the factory default conditions by pressing **ENTER**.

Test summary and considerations

Test summary

Model 622x test procedures include:

- DC current output amplitude accuracy (Model 6220 and 6221), [page 16-6](#)
- Compliance accuracy (Model 6220 and 6221), [page 16-8](#)
- Waveform function amplitude and frequency accuracy (Model 6221 only), [page 16-9](#)

Test considerations

When performing the procedures:

- Be sure to restore factory defaults as outlined above.
- Make sure that the test equipment is properly warmed up and connected to the correct Model 622x connector.
- Be sure that a shorting connector is connected to the INTERLOCK connector, or you will not be able to turn on the output for testing. See Section 2 for details on the interlock.
- Make sure the test equipment and Model 622x settings are correct.

Verification procedures

DC current output accuracy

Follow these steps in order to test Model 6220/6221 DC output current accuracy:

1. With the power off, connect the digital multimeter (DMM) to the Model 6220/6221 OUTPUT jack, as shown in [Figure 16-1](#). Also connect the shorting connector to the INTERLOCK connector (see Section 2 for interlock connections).
2. Turn on the Model 6220/6221 and DMM, and allow them to warm up for one hour before proceeding. Set the DMM to the DC current function, and enable auto range.
3. Set the Model 6220/6221 output current to 100.000mA, and turn on the output. (See Section 3 for details on setting output current and range.)
4. Verify that the output current limits are within the range shown in [Table 16-2, page 16-7](#).
5. Repeat steps 3 and 4 for all ranges listed in [Table 16-2](#). For the 2nA and 20nA ranges, change the test connections as shown in [Figure 16-2](#) to the picoammeter input jack.
6. After testing all ranges, first turn off the output, then disconnect the test equipment.

Figure 16-1

Connections for DC current output accuracy (200nA to 100mA ranges)

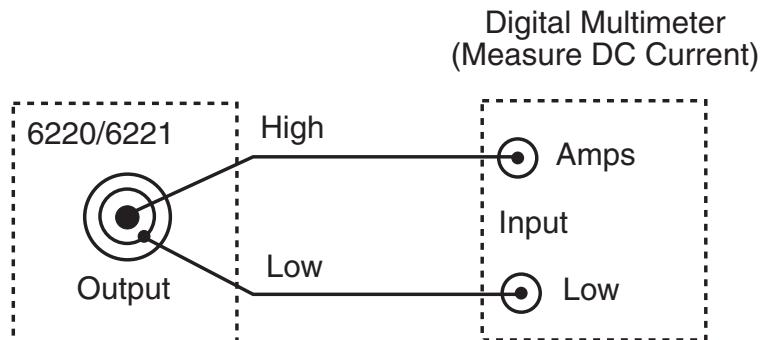


Figure 16-2
Connections for DC current output accuracy (2nA and 20nA ranges)

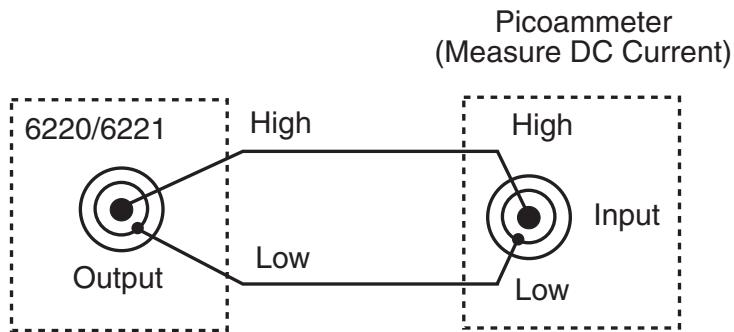


Table 16-2
DC current output limits

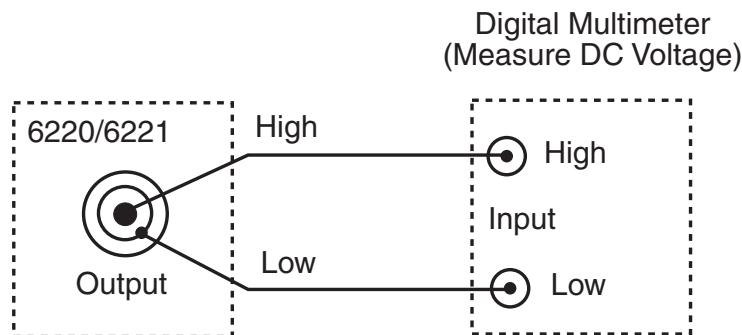
Range	Output current	Output current limits (1 year, 18° to 28°C)
100mA	100.000mA	99.850 to 100.150mA
20mA	20.000mA	19.980 to 20.020mA
2mA	2.0000mA	1.9980 to 2.0020mA
200µA	200.00µA	199.80 to 200.20µA
20µA	20.000µA	19.980 to 20.020µA
2µA	2.0000µA	1.9970 to 2.0030µA
200nA	200.00nA	199.30 to 200.70nA
20nA	20.000nA	19.930 to 20.070nA
2nA	2.0000nA	1.9900 to 2.0100nA

Compliance accuracy

Follow these steps in order to test Model 6220/6221 compliance accuracy:

1. With the power off, connect the digital multimeter (DMM) to the Model 6220/6221 OUTPUT jack, as shown in [Figure 16-3](#). Also connect the shorting connector to the INTERLOCK connector (see Section 2 for interlock connections).
2. Turn on the Model 6220/6221 and DMM, and allow them to warm up for one hour before proceeding. Set the DMM to the DC volts function, and enable auto range.
3. Set the Model 6220/6221 current output to 10mA and the compliance to 10.000V, and turn on the output. (See Section 3 for details on setting the output current, compliance, and range.)
4. Verify that the DMM reading is within the following range: 9.97 to 10.03V.
5. Set the Model 6220/6221 compliance to 100.00V.
6. Verify that the DMM reading is within the following range: 99.8 to 100.2V.
7. Repeat steps 3 through 6 for a current output of -10mA. DMM readings will be negative, but they should be within the same range of magnitude as in steps 4 and 6.
8. After testing, first turn off the output, then disconnect the test equipment.

Figure 16-3
Connections for compliance accuracy



Waveform function accuracy

The following tests apply only to the Model 6221.

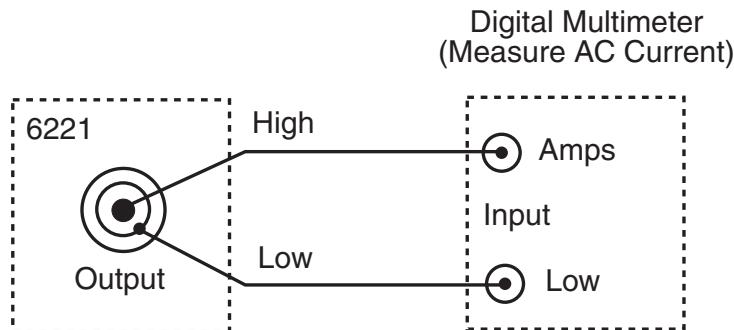
Amplitude flatness

NOTE Digital Multimeter (DMM) input impedance variations may affect the accuracy of amplitude flatness measurements.

1. With the power off, connect the DMM to the Model 6221 OUTPUT jack, as shown in [Figure 16-4](#). Also connect the shorting connector to the INTER-LOCK connector (see Section 2 for interlock connections).
2. Turn on the Model 6221 and test equipment, and allow them to warm up for one hour before proceeding. Select the AC current function on the DMM, and enable auto range.
3. Select the Model 6221 sine wave function by pressing the WAVE key.
4. Set the Model 6221 amplitude (AMPL) and frequency (FREQ) to 100mA at 1kHz, and turn on the output.
5. Note the DMM reading at 1kHz. If your DMM has a dB reference function, set the present reading to 0dB.
6. Set the Model 6221 frequency to 100kHz.
7. Verify that the 100kHz DMM reading is within $\pm 1\text{dB}$ of the reading in step 5. If your DMM does not have a dB function, you can calculate the variation as follows: $\text{dB} = \pm 20 \log(I_1/I_2)$, where I_1 is the higher of the two readings.
8. After testing, first turn off the output, then disconnect the test equipment.

Figure 16-4

Connections for waveform function amplitude flatness

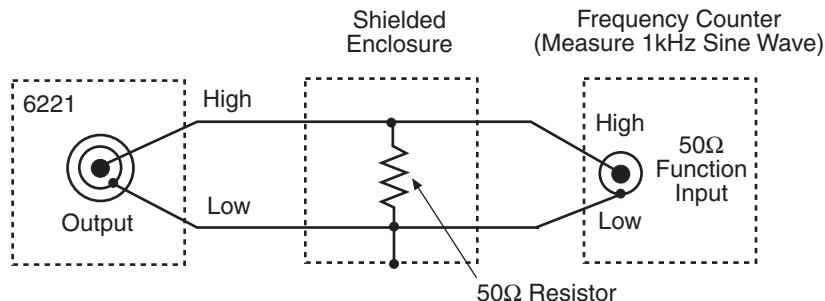


Frequency accuracy

1. With the power off, connect the frequency counter to the Model 6221 OUTPUT jack, as shown in [Figure 16-5](#). Also connect the shorting connector to the INTERLOCK connector (see Section 2 for interlock connections).
2. Turn on the Model 6221 and test equipment, and allow them to warm up for one hour before proceeding.
3. Select the sine wave function by pressing the WAVE key.
4. Set the Model 6221 amplitude (AMPL) to 20mA on the 20mA range, and set the frequency (FREQ) to 1kHz. Turn on the output.
5. Verify that the counter frequency reading is between 0.9999kHz and 1.0001kHz.
6. After testing, first turn off the output, then disconnect the test equipment.

Figure 16-5

Connections for waveform function frequency accuracy



Note: If the frequency counter has a 50Ω input impedance, the 50Ω resistor should not be necessary.

17 Calibration

Section 17 topics

Introduction, page 17-2

Calibration requirements, page 17-3

Environmental conditions, page 17-3

Warm-up period, page 17-3

Line power, page 17-3

Recommended calibration equipment, page 17-4

Calibration equipment connections, page 17-4

Restoring factory defaults, page 17-4

Calibration summary and considerations, page 17-5

Calibration summary, page 17-5

Calibration considerations, page 17-5

Calibration procedures, page 17-5

Front panel calibration, page 17-5

Using the calibration menu, page 17-5

Front panel calibration procedure, page 17-6

Remote calibration, page 17-14

SCPI commands — calibration, page 17-20

Calibration dates, count, and password, page 17-24

Viewing calibration dates and count, page 17-24

Changing the calibration password, page 17-24

Introduction

WARNING **The information in this section is intended only for qualified service personnel. Do not attempt these procedures unless you are qualified to do so.**

Information is provided in this section to offer recommendations to the owner of the Model 622x to calibrate the instrument to the extent that is required by their quality system in the event that they have elected not to return the instrument to Keithley for routine calibration. Any calibration procedure for this instrument should account for measurement uncertainties that arise from test equipment tolerances.

Before proceeding, the laboratory should characterize the components used with the testing process in order to correct for test equipment tolerance and to estimate calibration uncertainty appropriately.

NOTE

The test procedures in this section provide a relatively low-cost method of calibrating the instrument. The techniques used for these tests should be adequate for most users. However, in some cases, calibration uncertainty may not be sufficient for those with more stringent requirements. If necessary, contact your Keithley representative or the factory for information on more comprehensive procedures to calibrate the Model 622x.

Calibration requirements

Be sure that you perform calibration:

- Under the proper environmental conditions.
- After the specified warm-up period.
- Using the correct line voltage.
- Using the proper test equipment.
- Using the specified reading limits.

Environmental conditions

Conduct the calibration procedures in a test environment that has:

- An ambient temperature of 18° to 28°C (65° to 82°F).
- A relative humidity of less than 70% unless otherwise noted.

Warm-up period

Allow the Model 622x to warm up for at least one hour before performing calibration.

If the instrument has been subjected to temperature extremes (those outside the ranges stated above), allow additional time for the instrument's internal temperature to stabilize. Allow one extra hour to stabilize a unit that is 10°C (18°F) outside the specified temperature range.

Also, allow the test equipment to warm up for the minimum time specified by the manufacturer.

Line power

The Model 622x requires a line voltage of 100V to 240V and a line frequency of 50Hz to 60Hz.

Recommended calibration equipment

Table 17-1 summarizes recommended calibration equipment specifications and typical models. Ideally, equipment uncertainty should be at least four times better than equivalent Model 6220/6221 specifications. However, the equipment listed for the 2nA and 20nA ranges does not quite meet that requirement. For optimum calibration to factory specifications, it is recommended that the Model 622x be returned to the factory for calibration.

Table 17-1
Recommended calibration equipment

Description	Key specifications	Manufacturer/model
Digital Multimeter	Measure 200nA to 100mA DC, $\pm 100\text{ppm}$ Measure $\pm 25\text{mV}$, $\pm 0.1\text{V}$, $\pm 20\text{V}$, $\pm 21\text{V}$ and $\pm 100\text{V}$ DC, $\pm 100\text{ppm}$	Agilent 3458A
Picoammeter	Measure 2nA and 20nA DC, $\pm 2000\text{ppm}$	Keithley 6487

Calibration equipment connections

For the sake of clarity, only actual signal lines are shown in equipment connection drawings in this section. To ensure calibration integrity, be sure to use appropriate triax cables or (where appropriate) coax cables for all signal connections.

Restoring factory defaults

Before performing the calibration procedures, restore the instrument to its factory defaults as follows:

1. Press **SETUP**.
2. Select **RESET**, then restore the factory default conditions by pressing **ENTER**.

Calibration summary and considerations

Calibration summary

Model 622x calibration procedures include:

- Front panel calibration, [page 17-5](#)
- Remote calibration, [page 17-14](#)

Calibration considerations

When performing the procedures:

- Be sure to restore factory defaults as outlined above.
- Make sure that the test equipment is properly warmed up and connected to the correct Model 622x connector.
- Be sure that a shorting connector is connected to the INTERLOCK connector, or you will not be able to turn on the output for calibration. See Section 2 for details on the interlock.
- Make sure the test equipment and Model 622x calibration settings are correct.

Calibration procedures

Front panel calibration

Using the calibration menu

[Table 17-2](#) summarizes the main calibration menu. To enter the menu, press the MENU key, select CAL, then press ENTER. Note that the calibration menus for the Models 6220 and 6221 are almost identical except that the Model 6221 menu has a WAVE calibration selection to calibrate the waveform generator while the Model 6220 does not.

Table 17-2
Calibration menu

Menu selection	Description
UNLOCK	Unlock calibration using PASSWORD: Default password = 006220 or 006221
EXECUTE SOURCE COMPLIANCE GUARD WAVE	Execute calibration steps: Calibrate current source for each range. Calibrate voltage compliance. Calibrate guard circuit. Calibrate 6221 waveform generator.
VIEW-DATES	View next calibration and last calibration dates.
SAVE	Save calibration constants and dates.
LOCK	Lock out calibration.
CHANGE-PASSWORD	Change calibration password.

Front panel calibration procedure

Step 1: Prepare for calibration

1. With the power off, connect the DMM to the Model 6220/6221 OUTPUT jack, as shown in [Figure 17-1](#). Also connect the shorting connector to the INTERLOCK connector (see Section 2 for interlock connections).
2. Turn on the Model 6220/6221 and calibration equipment, and allow them to warm up for one hour before proceeding
3. Unlock calibration as follows:
 - a. Press the MENU key, select CAL, and press ENTER. The main calibration menu will be displayed.
 - b. Select UNLOCK, and press ENTER. The instrument will display the following:
PASSWORD:
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
 - c. Enter the password at the prompt. The default Model 6220 password is 006220, and the default Model 6221 password is 006221.
 - d. Press ENTER to unlock calibration.

Step 2: Calibrate current source

1. Select the DMM DC current function with auto range enabled.
2. From normal display, select the Model 6220/6221 100mA current source range. (See Section 3 for details on setting current source range.)
3. Press the MENU key, select CAL, and press ENTER.
4. From the main calibration menu, select EXECUTE, and press ENTER. The instrument will display:
CALIBRATION
SOURCE COMPLIANCE GUARD WAVE *(WAVE displayed only for 6221)*
5. Select SOURCE, then press ENTER. The unit will display:
I-CAL
Press ENTER to Output +100.00mA
6. Press ENTER to output the positive full-range current value for the presently selected range. The instrument will prompt as follows:
DMM RDG=+100.0000mA
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
7. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value.
8. Press ENTER. The display will prompt:
I-CAL
Press ENTER to Output +000.00mA
9. Press ENTER to output the zero value for the present range. The following prompt will be displayed:
DMM RDG=+000.0000mA
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
10. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value.
11. Press ENTER. The display will prompt:
I-CAL
Press ENTER to Output -100.00mA
12. Press ENTER to output the negative full range value for the present range. The following prompt will be displayed:
DMM RDG=-100.0000mA
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
13. Note the DMM reading, adjust the Model 6220/6221 display to agree with that value, then press ENTER to complete calibration for the present range.
14. Repeat steps 2 through 13 above for each current range (see [Table 17-3, page 17-8](#)). For the 2nA and 20nA ranges, connect the Model 6220/6221 to the picoammeter input, and use the picoammeter reading at the DMM reading prompt ([Figure 17-2](#)).

15. For the Model 6221 only:
 - a. Disconnect the DMM from the Model 6221 OUTPUT jack.
 - b. From the main calibration menu, select WAVE, then press ENTER to perform calibration of the Model 6221 waveform generator.

Figure 17-1

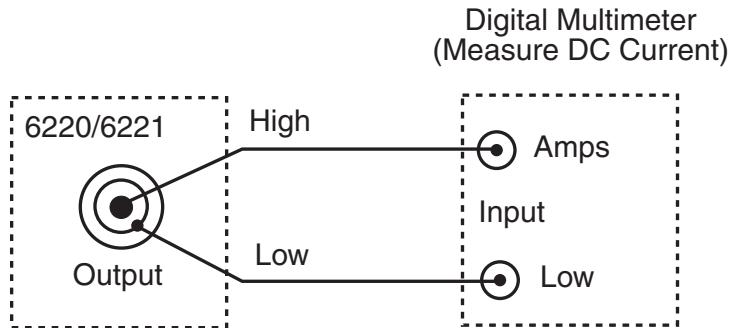
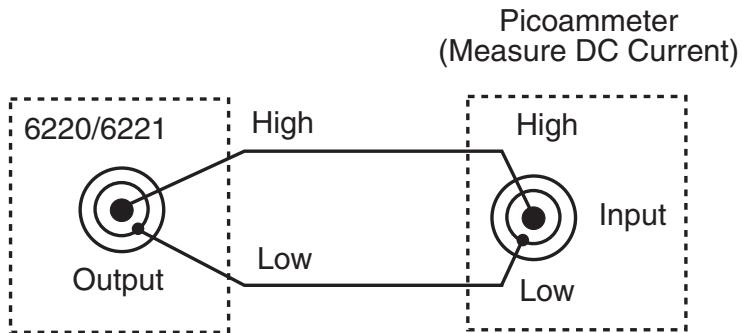
Connections for current source calibration (200nA to 100mA ranges)

Table 17-3

Front panel current calibration summary

Range	Current values
100mA	100mA, 0mA, -100mA
20mA	20mA, 0mA, -20mA
2mA	2mA, 0mA, -2mA
200µA	200µA, 0µA, -200µA
20µA	20µA, 0µA, -20µA
2µA	2µA, 0µA, -2µA
200nA	200nA, 0nA, -200nA
20nA	20nA, 0nA, -20nA
2nA	2nA, 0nA, -2nA

Figure 17-2
Connections for current source calibration (2nA and 20nA ranges)



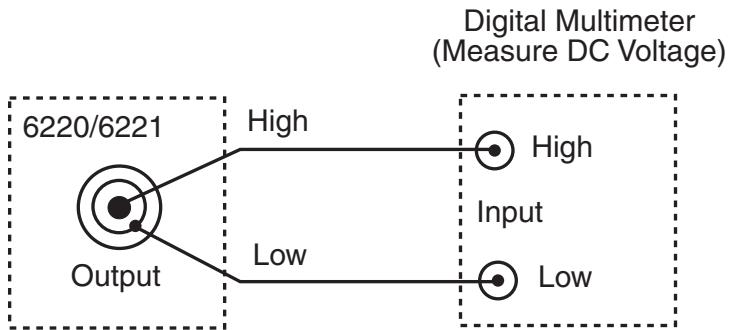
Step 3: Calibrate compliance

1. Connect the digital multimeter (DMM) to the Model 6220/6221 as shown in [Figure 17-3](#) and select the DMM DC volts function with auto range enabled.
2. From the main calibration menu, select EXECUTE, and press ENTER. The unit will display:
CALIBRATION
SOURCE COMPLIANCE GUARD WAVE (*WAVE displayed only for 6221*)
3. Select COMPLIANCE, then press ENTER. The unit will display:
20V COMPLIANCE CAL
Press ENTER to Output +2.0000mA
4. Press ENTER to output +2mA for 20V compliance calibration. The instrument will prompt as follows:
DMM RDG=+020.0000V
Use ◀, ▶, ▲, ▼, ENTER, or EXIT
5. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value.
6. Press ENTER. The display will prompt:
.1V COMPLIANCE CAL
Press ENTER to Output +2.0000mA
7. Press ENTER to output +2mA for 0.1V compliance calibration. The instrument will prompt as follows:
DMM RDG=+0.100000V
Use ◀, ▶, ▲, ▼, ENTER, or EXIT
8. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value.

9. Press ENTER. The display will prompt:
-20V COMPLIANCE CAL
Press ENTER to Output -2.0000mA
10. Press ENTER to output -2mA for -20V compliance calibration. The instrument will prompt as follows:
DMM RDG=-020.0000V
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
11. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value.
12. Press ENTER. The display will prompt:
.1V COMPLIANCE CAL
Press ENTER to Output -2.0000mA
13. Press ENTER to output -2mA for -0.1V compliance calibration. The instrument will prompt as follows:
DMM RDG=-0.100000V
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
14. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value.
15. Press ENTER. The display will prompt:
100V COMPLIANCE CAL
Press ENTER to Output +2.0000mA
16. Press ENTER to output +2mA for 100V compliance calibration. The instrument will prompt as follows:
DMM RDG=+100.0000V
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
17. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value.
18. Press ENTER. The display will prompt:
21V COMPLIANCE CAL
Press ENTER to Output +2.0000mA
19. Press ENTER to output +2mA for 21V compliance calibration. The instrument will prompt as follows:
DMM RDG=+21.00000V
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
20. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value.
21. Press ENTER. The display will prompt:
-100V COMPLIANCE CAL
Press ENTER to Output -2.0000mA

22. Press ENTER to output -2mA for -100V compliance calibration. The instrument will prompt as follows:
DMM RDG=-100.0000V
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
23. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value.
24. Press ENTER. The display will prompt:
-21V COMPLIANCE CAL
Press ENTER to Output -2.0000mA
25. Press ENTER to output -2mA for -21V compliance calibration. The instrument will prompt as follows:
DMM RDG=-21.00000V
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
26. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value.
27. Press ENTER to complete compliance calibration.

Figure 17-3
Connections for compliance calibration

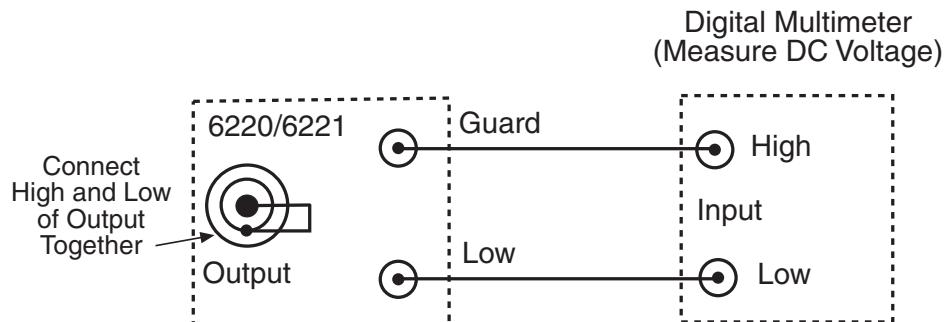


Step 4: Calibrate guard circuit

1. Connect the digital multimeter (DMM) to the Model 6220/6221 GUARD and LO jacks as shown in [Figure 17-4](#). Be sure to connect the HI and LO terminals of the Model 6220/6221 OUTPUT jack together as shown. Select the DMM DC voltage function with auto range enabled.
2. From the main calibration menu, select EXECUTE, and press ENTER. The unit will display:
CALIBRATION
SOURCE COMPLIANCE GUARD WAVE (*WAVE displayed only for 6221*)

3. Select GUARD, then press ENTER. The unit will display:
POSITIVE GUARD CAL
Press ENTER to Output +020.00uA
4. Press ENTER to output $+20\mu\text{A}$ for positive guard calibration. The instrument will prompt as follows:
DMM RDG= $+22.00000\text{mV}$
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
5. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value.
6. Press ENTER. The display will prompt:
NEGATIVE GUARD CAL
Press ENTER to Output $-020.00\mu\text{A}$
7. Press ENTER to output $-20\mu\text{A}$ for negative guard calibration. The instrument will prompt as follows:
DMM RDG= -22.00000mV
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
8. Note the DMM reading, then adjust the Model 6220/6221 display to agree with that value, and then press ENTER.

Figure 17-4

Connections for guard calibration

Step 5: Enter dates and save calibration constants

1. From the main calibration menu, select SAVE, and press ENTER. The unit will display:
CAL DATE=06/01/2004
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
2. Enter the present date as the calibration date, then press ENTER. The unit displays:
NEXT CAL=06/01/2005
Use \blacktriangleleft , \triangleright , \blacktriangleup , \blacktriangledown , ENTER, or EXIT
3. Enter the calibration date, and press ENTER. The unit displays:
CALIBRATION COMPLETE
ENTER to save; EXIT to abort
4. Select ENTER to save calibration constants, or press EXIT to abort calibration without saving constants, then press ENTER. If calibration was successful, the display will prompt:
CALIBRATION SUCCESS
Press ENTER or EXIT to continue
5. Press ENTER or EXIT to complete saving calibration constants and dates.

Step 6: Lock out calibration

From the main calibration menu, select LOCK, and press ENTER to lock out calibration.

Remote calibration

Follow the steps below to calibrate the Model 6220/6221 remotely. See “[SCPI commands — calibration](#),” on page 17-20 for complete command details.

NOTE Be sure to allow enough time for each command to complete before going on to the next step. You can use the *OPC command (Section 12) and SRQ and status structure bits (Section 11) to determine when a step has been completed.

Step 1: Prepare for calibration

1. With the power off, connect the digital multimeter (DMM) to the Model 6220/6221 OUTPUT jack, as shown in [Figure 17-1](#). Also connect the shorting connector to the INTERLOCK connector (see Section 2 for interlock connections).
2. Turn on the Model 6220/6221 and calibration equipment, and allow them to warm up for one hour before proceeding.
3. Send these commands to restore defaults, unlock calibration, and turn on the output:

*RST	‘ Restore defaults.
CAL:PROT:CODE ‘K1006220’	‘ Unlock cal. (6220 default shown; ‘ use K1006221 as 6221 default.)
OUTP ON	‘ Turn on output.

Step 2: Calibrate current source

1. Select the DMM DC current function with auto range enabled.
2. Send these commands in order to calibrate the 100mA current source range using the <DMM_Reading> parameter (actual digital multimeter reading) for each step:

SOUR:CURR:RANG 0.1	‘ Select 100mA range.
SOUR:CURR 0.1	‘ Output 100mA.
CAL:PROT:SOUR <DMM_Reading>	‘ Calibrate +100mA using reading.
SOUR:CURR 0	‘ Output 0mA.
CAL:PROT:SOUR <DMM_Reading>	‘ Calibrate 0mA using reading.
SOUR:CURR -0.1	‘ Output -100mA.
CAL:PROT:SOUR <DMM_Reading>	‘ Calibrate -100mA using reading.

3. Repeat step 2 for each range, as listed in [Table 17-4, page 17-16](#), noting the following:
 - Be sure to set the correct range using the RANG command.
 - Each range is calibrated with three values, +FS (positive full scale), 0, and -FS (negative full scale) in that order. Use the SOUR:CURR command as shown to set the output current value for each step.
 - For the 2nA and 20nA ranges, use the picoammeter with connections shown in [Figure 17-2](#). Substitute the picoammeter reading for the DMM reading in the command listings. Be sure to turn the output off (send OUTP OFF) before changing connections, then turn the output back on (OUTP ON) before completing calibration.
4. For the Model 6221 only:
 - a. Disconnect the DMM from the Model 6221 OUTPUT jack.
 - b. Send this command to calibrate the waveform generator:

CAL : PROT : WAVE : STEP1 ' Calibrate waveform generator

Table 17-4
Remote current calibration summary

Range	Currents	Commands*
100mA	100mA 0mA -100mA	OUTP ON SOUR:CURR:RANG 0.1 SOUR:CURR 0.1 CAL:PROT:SOUR <+FS_DMM_Reading> SOUR:CURR 0 CAL:PROT:SOUR <0_DMM_Reading> SOUR:CURR -0.1 CAL:PROT:SOUR <-FS_DMM_Reading>
20mA	20mA 0mA -20mA	SOUR:CURR:RANG 2e-2 SOUR:CURR 2e-2 CAL:PROT:SOUR <+FS_DMM_Reading> SOUR:CURR 0 CAL:PROT:SOUR <0_DMM_Reading> SOUR:CURR -2e-2 CAL:PROT:SOUR <-FS_DMM_Reading>
2mA	2mA 0mA -2mA	SOUR:CURR:RANG 2e-3 SOUR:CURR 2e-3 CAL:PROT:SOUR <+FS_DMM_Reading> SOUR:CURR 0 CAL:PROT:SOUR <0_DMM_Reading> SOUR:CURR -2e-3 CAL:PROT:SOUR <-FS_DMM_Reading>
200µA	200µA 0µA -200µA	SOUR:CURR:RANG 2e-4 SOUR:CURR 2e-4 CAL:PROT:SOUR <+FS_DMM_Reading> SOUR:CURR 0 CAL:PROT:SOUR <0_DMM_Reading> SOUR:CURR -2e-4 CAL:PROT:SOUR <-FS_DMM_Reading>
20µA	20µA 0µA -20µA	SOUR:CURR:RANG 2e-5 SOUR:CURR 2e-5 CAL:PROT:SOUR <+FS_DMM_Reading> SOUR:CURR 0 CAL:PROT:SOUR <0_DMM_Reading> SOUR:CURR -2e-5 CAL:PROT:SOUR <-FS_DMM_Reading>

* Use DMM ([Figure 17-1](#)) for 100mA-200nA ranges.

* Use picoammeter ([Figure 17-2](#)) for 20nA and 2nA ranges.

Table 17-4 (cont.)
Remote current calibration summary

Range	Currents	Commands*
2µA	2µA 0µA -2µA	SOUR:CURR:RANG 2e-6 SOUR:CURR 2e-6 CAL:PROT:SOUR <+FS_DMM_Reading> SOUR:CURR 0 CAL:PROT:SOUR <0_DMM_Reading> SOUR:CURR -2e-6 CAL:PROT:SOUR <-FS_DMM_Reading>
200nA	200nA 0nA -200nA	SOUR:CURR:RANG 2e-7 SOUR:CURR 2e-7 CAL:PROT:SOUR <+FS_DMM_Reading> SOUR:CURR 0 CAL:PROT:SOUR <0_DMM_Reading> SOUR:CURR -2e-7 CAL:PROT:SOUR <-FS_DMM_Reading> OUTP OFF
20nA	20nA 0nA -20nA	OUTP ON SOUR:CURR:RANG 2e-8 SOUR:CURR 2e-8 CAL:PROT:SOUR <+FS_DMM_Reading> SOUR:CURR 0 CAL:PROT:SOUR <0_DMM_Reading> SOUR:CURR -2e-8 CAL:PROT:SOUR <-FS_DMM_Reading>
2nA	2nA 0nA -2nA	SOUR:CURR:RANG 2e-9 SOUR:CURR 2e-9 CAL:PROT:SOUR <+FS_DMM_Reading> SOUR:CURR 0 CAL:PROT:SOUR <0_DMM_Reading> SOUR:CURR -2e-9 CAL:PROT:SOUR <-FS_DMM_Reading> OUTP OFF

* Use DMM ([Figure 17-1](#)) for 100mA-200nA ranges.

* Use picoammeter ([Figure 17-2](#)) for 20nA and 2nA ranges.

Step 3: Calibrate compliance

1. Connect the digital multimeter (DMM) to the Model 6220/6221 OUTPUT jack, as shown in [Figure 17-3](#). Set the DMM to measure DC voltage with auto range enabled.
2. Send these commands in order to calibrate compliance using the <DMM_Reading> parameter (actual digital multimeter reading) for each step:

OUTP ON	‘ Turn on output.
SOUR:CURR:RANG 2e-3	‘ Select 2mA range.
SOUR:CURR 2e-3	‘ Output +2mA for cal.
SOUR:CURR:COMP 20	‘ Set compliance to +20V
CAL:PROT:SENS <DMM_Reading>	‘ Calibrate +20V using reading.
SOUR:CURR:COMP 0.1	‘ Set compliance to +0.1V
CAL:PROT:SENS <DMM_Reading>	‘ Calibrate +0.1V using reading.
SOUR:CURR -2e-3	‘ Output -2mA for cal.
SOUR:CURR:COMP 20	‘ Set compliance to -20V
CAL:PROT:SENS <DMM_Reading>	‘ Calibrate -20V using reading.
SOUR:CURR:COMP 0.1	‘ Set compliance to -0.1V
CAL:PROT:SENS <DMM_Reading>	‘ Calibrate -0.1V using reading.
SOUR:CURR 2e-3	‘ Output +2mA for cal.
SOUR:CURR:COMP 100	‘ Set compliance to +100V
CAL:PROT:SENS <DMM_Reading>	‘ Calibrate +100V using reading.
SOUR:CURR:COMP 21	‘ Set compliance to +21V
CAL:PROT:SENS <DMM_Reading>	‘ Calibrate +21V using reading.
SOUR:CURR -2e-3	‘ Output -2mA for cal.
SOUR:CURR:COMP 100	‘ Set compliance to -100V
CAL:PROT:SENS <DMM_Reading>	‘ Calibrate -100V using reading.
SOUR:CURR:COMP 21	‘ Set compliance to -21V
CAL:PROT:SENS <DMM_Reading>	‘ Calibrate -21V using reading.
OUTP OFF	‘ Turn off output.

Step 4: Calibrate guard circuit

1. Connect the digital multimeter to the Model 6220/6221 GUARD and LO jacks as shown in [Figure 17-4](#). Be sure to connect the HI and LO terminals of the Model 6220/6221 OUTPUT jack together as shown. Select the DMM DC voltage function with auto range enabled.
2. Send these commands in order to calibrate the guard circuit using the <DMM_Reading> parameter (actual digital multimeter reading) for each step:

SOUR:CURR:RANG 2e-4	' Set current range to 200 μ A.
SOUR:CURR 2e-5	' Set current source to 20 μ A.
OUTP ON	' Turn on output.
CAL:PROT:GUAR:STEP1:INIT	' Set up for step 1 guard cal.
CAL:PROT:GUAR:STEP1 <DMM_Reading>	' Cal step 1 with reading.
CAL:PROT:GUAR:STEP2:INIT	' Set up for step 2 guard cal.
CAL:PROT:GUAR:STEP2 <DMM_Reading>	' Cal step 2 with reading.
OUTP OFF	' Turn off output.

Step 5: Send dates, save calibration, and lock output calibration

Send these command to send dates, save calibration constants and dates, and then finally lock out calibration:

CAL:PROT:DATE 2004,05,15	' Send cal date (5/15/2004).
CAL:PROT:NDUE 2005,05,15	' Send cal due date (5/15/2005).
CAL:PROT:SAVE	' Save cal constants and dates.
CAL:PROT:LOCK	' Lock out calibration.

SCPI commands — calibration

Commands for calibration are listed in [Table 17-5](#). Additional information for each command is provided in added notes and several tables that follow.

Table 17-5
Calibration commands

Command	Description
CALibration:PROTected:CODE "<string>"	Enters calibration code/password. ¹ <string> = 8-character password 6220 default: KI006220 6221 default: KI006221
CALibration:PROTected:LOCK	Locks out calibration. ²
CALibration:PROTected:SAVE	Saves all cal data to non-volatile memory. ³
CALibration:PROTected:DATE <yyyy,mm,dd>	Saves last calibration date. ⁴
CALibration:PROTected:NDUE <yyyy,mm,dd>	Saves next calibration date. ⁴
CALibration:PROTected:COUNT?	Queries number of times unit was calibrated. ⁵
CALibration:PROTected:SOURce <NRf>	Calibrates active current source range. ⁶
CALibration:PROTected:SENSe <NRf>	Calibrates compliance voltage. ⁷
CALibration:PROTected:GUARD:STEP1 <NRf>	Voltage reading for guard calibration step 1. ⁸
CALibration:PROTected:GUARD:STEP1:INIT	Sets up unit for step 1 of guard calibration. ⁸
CALibration:PROTected:GUARD:STEP2 <NRf>	Voltage reading for guard calibration step 2. ⁸
CALibration:PROTected:GUARD:STEP2:INIT	Sets up unit for step 2 of guard calibration. ⁸
CALibration:PROTected:WAVE:STEP1	Calibrates 6221 waveform generator. ⁹

1. CAL:PROT:CODE "<string>" ‘ Enter password

This command sends the calibration password/code to unlock calibration. The code is an eight-character string that must be enclosed in single or double quotes. The Model 6220 default code is KI006220; the default Model 6221 code is KI006221. You can change the code once calibration is unlocked by sending a different code with this command. However, if you change the first two characters to something other than “KI”, you will not be able to unlock calibration from the front panel.
2. CAL:PROT:LOCK ‘ Lock out calibration

This command locks out calibration. Note that the CAL:PROT:LOCK? query will return a 1 if calibration is locked; 0 otherwise.

3. CAL:PROT:SAVE ' Save calibration
This command saves all calibration constants and dates in non-volatile memory. Calibration data will *not* be saved if: 1) Calibration was not unlocked with :CODE command; 2) Invalid data exists (For example, cal step failed or was aborted); or 3) Incomplete number of cal steps were performed (For example, omitting a negative full-scale step).
4. CAL:PROT:DATE <yyyy,mm,dd> ' Send last cal date
CAL:PROT:NDUE <yyyy,mm,dd> ' Send next cal date
These commands send the last calibration date and next calibration due date. The query forms of these commands will return the year, month, and day delimited by commas, for example: 2004,12,22.
5. CAL:PROT:COUN? ' Query calibration count
This query requests the number of times the unit was calibrated. The count variable will be incremented by 1 each time the Model 6220/6221 is calibrated.
6. CAL:PROT:SOUR <NRf> ' Calibrate active source range
This command calibrates the active current source range from DMM reading values. Note that this command is sent three times: positive full-scale, 0, and negative full-scale. See the complete procedure in "[Step 2: Calibrate current source,](#)" on page 17-14. [Table 17-6, page 17-22](#) summarizes allowed ranges for each parameter. Note that Parameter steps for each range may be performed in any order, but all three parameter steps for each range must be completed.
7. CAL:PROT:SENS <NRf> ' Calibrate voltage compliance
This command calibrates the voltage compliance from a number DMM reading values. See the complete procedure in "[Step 3: Calibrate compliance,](#)" on page 17-18. [Table 17-7, page 17-22](#) summarizes allowed ranges for each parameter.
8. CAL:PROT:GUAR:STEP1 <NRf> ' Calibrate guard step 1
CAL:PROT:GUAR:STEP2 <NRf> ' Calibrate guard step 2
CAL:PROT:GUAR:STEP1:INIT ' Set up unit for guard cal step 1
CAL:PROT:GUAR:STEP2:INIT ' Set up unit for guard cal step 2
These commands calibrate the Model 6220/6221 guard circuit. The INIT commands set up the unit for guard cal steps, while the STEP commands use a DMM reading taken during the calibration procedure. See the complete procedure in "[Step 4: Calibrate guard circuit,](#)" on page 17-19. [Table 17-8, page 17-23](#) summarizes allowed ranges for each parameter.
9. CAL:PROT:WAVE:STEP1 ' Calibrate 6221 waveform generator
This command calibrates the Model 6221 waveform generator. This is an internal self-calibration and requires no user inputs or external DMM readings. This step should be run immediately after the SOURce calibration of the current ranges.

Table 17-6
CAL:PROT:SOUR command parameter ranges

Source range	First parameter (+FS)	Second parameter (0)	Third parameter (-FS)
2nA	+1.8e-9 to +2.2e-9	-2e-11 to +2e-11	-1.8e-9 to -2.2e-9
20nA	+18e-9 to +22e-9	-2e-10 to +2e-10	-18e-9 to -22e-9
200nA	+180e-9 to +220e-9	-2e-9 to +2e-9	-180e-9 to -220e-9
2μA	+1.8e-6 to +2.2e-6	-2e-8 to +2e-8	-1.8e-6 to -2.2e-6
20μA	+18e-6 to +22e-6	-2e-7 to +2e-7	-18e-6 to -22e-6
200μA	+180e-6 to +220e-6	-2e-6 to +2e-6	-180e-6 to -220e-6
2mA	+1.8e-3 to +2.2e-3	-2e-5 to +2e-5	-1.8e-3 to -2.2e-3
20mA	+18e-3 to +22e-3	-2e-4 to +2e-4	-18e-3 to -22e-3
100mA	+90e-3 to +110e-3	-1e-3 to +1e-3	-90e-3 to -110e-3

NOTE: Parameter steps for each range may be performed in any order, but all three parameter steps for each range must be completed.

Table 17-7
CAL:PROT:SENS command parameter ranges

Sense range	First parameter	Second parameter	Third parameter	Fourth parameter
20V	+18.0 to +22.0 (full scale + curr.)	-1.05 to +1.05 (.1V at + curr.)	-18.0 to -22.0 (full scale at -curr.)	-1.05 to +1.05 (.1V at -curr.)
100V	+90 to +110 (full scale + curr.)	+18.9 to +23.1 (21V at pos. curr.)	-90 to -110 (full scale at -curr.)	-18.9 to -23.1 (21V at neg. curr.)

Notes:

1. Parameter steps for each range may be performed in any order, but all four parameter steps for each range must be completed.
2. There are two internal voltage compliance ranges (20V + 100V), but externally it appears as if there is only one (100V) range. The calibration for this range must be performed on the 2mA source range. All four 20V steps must be completed before any of the 100V steps.

Table 17-8
CAL:PROT:GUAR command parameter ranges

Step	Parameter
STEP1	0.00 to +50.0e-3
STEP2	-50.0e-3 to 0.0

NOTE: Step1 and Step 2 may be performed in any order, but both must be completed, and each step must be initialized with INIT before being run.

Table 17-9
Calibration errors

Number	Description
+500	"Date of calibration not set"
+501	"Next date of calibration not set"
+502	"Calibration data invalid"
+503	"DAC calibration overflow"
+504	"DAC calibration underflow"
+505	"Source offset data invalid"
+506	"Source gain data invalid"
+507	"Sense offset data invalid"
+508	"Sense gain data invalid"
+509	"Not permitted with cal locked"
+510	"Not permitted with cal un-locked"

Calibration dates, count, and password

Viewing calibration dates and count

Front panel calibration dates and count

To view last calibration date, calibration due date, and count:

1. Press the MENU key.
2. Select CAL, and press ENTER. The main calibration menu will be displayed.
3. Select VIEW-DATES, and press ENTER. The instrument will display the next calibration date, last calibration date, and the calibration count. For example:
NEXT CAL: 05/15/2005
Last cal: 05/15/2004 Count: 0001

Remote calibration dates and count

To view calibration dates and count via remote, send these queries:

CAL : PROT : DATE?	' Query last cal date.
CAL : PROT : NDUE?	' Query next cal date.
CAL : PROT : COUN?	' Query cal count.

For the dates, the instrument will return a string of characters with the year, day, and month delimited by commas.

Changing the calibration password

To change the calibration password, first unlock calibration using the present password, then enter or send the new password.

Front panel password

To change the password:

1. Press the MENU key.
2. Select CAL, and press ENTER. The main calibration menu will be displayed.
3. Select UNLOCK, then press ENTER. Enter the present password at the prompt, then press ENTER to unlock calibration.

4. From the main calibration menu, select CHANGE-PASSWORD, and press ENTER. The instrument will display:
NEW PWD: 006220
Use **◀**, **▶**, **▲**, **▼**, ENTER, or EXIT
5. Enter the new password, then press ENTER.
6. Use the LOCK selection to lock out calibration when finished.

Remote password

To change the password via remote, send these queries, first with the old password, then the new password:

CAL:PROT:CODE 'KI006220'	' Unlock cal with present password.
CAL:PROT:CODE 'KI_CAL'	' Send new password.
CAL:PROT:LOCK	' Lock out password.

Note that you will not be able to unlock calibration from the front panel if you change the first two characters to something other than "KI".

A

Specifications

6220 Programmable Current Source

SOURCE SPECIFICATIONS

Range (+5% over range)	Accuracy (1 Year) 23°C±5°C ±(%rdg. + amps)	Programming Resolution	Temperature Coefficient/°C 0°-18°C & 28°-50°C	Typical Noise (peak-peak) /RMS ^{3,4,5} 0.1Hz-10Hz	Settling Time ^{1,2} (1% of final value)
2nA	0.4% + 2pA	100fA	0.02% + 200fA	400/80fA	100μs
20nA	0.3% + 10pA	1pA	0.02% + 200fA	4/0.8pA	100μs
200nA	0.3% + 100pA	10pA	0.02% + 2pA	20/4pA	100μs
2μA	0.1% + 1nA	100pA	0.01% + 20pA	200/40pA	100μs
20μA	0.05% + 10nA	1nA	0.005% + 200pA	2/0.4nA	100μs
200μA	0.05% + 100nA	10nA	0.005% + 2nA	20/4nA	100μs
2mA	0.05% + 1μA	100nA	0.005% + 20nA	200/40nA	100μs
20mA	0.05% + 10μA	1μA	0.005% + 200nA	2/0.4μA	100μs
100mA	0.1% + 50μA	10μA	0.01% + 2μA	10/2μA	100μs

ADDITIONAL SOURCE SPECIFICATIONS

OUTPUT RESISTANCE: $>10^{14}\Omega$. (2nA/20nA range)

OUTPUT CAPACITANCE: $<10\text{pF}$, $<100\text{pF}$ Filter ON. (2nA/20nA range)

LOAD IMPEDANCE: Stable into $100\mu\text{H}$ 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 $1\text{G}\Omega$ (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 $2\text{V} / I_{\text{fullscale}}$ 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 $<100\Omega$.

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

COMMON MODE VOLTAGE: 250V rms, DC to 60Hz.

COMMON MODE ISOLATION: >10⁹Ω, <2nF.

SOURCE OUTPUT MODES: Fixed DC level, Memory List.

REMOTE INTERFACE:

IEEE-488 and RS-232C.

SCPI (Standard Commands for Programmable Instruments)

DDC (command language compatible with Keithley Model 220)

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
(33V@500mA, diode clamped).

OUTPUT CONNECTIONS:

- Teflon insulated 3-lug triax connector for output.
- Banana Safety Jack for GUARD, OUTPUT LO
- Screw Terminal for CHASSIS
- DB-9 connector for EXTERNAL TRIGGER INPUT, OUTPUT, and DIGITAL I/O
- 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°-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.

EMC: Conforms to European Union Directive 89/336/EEC, EN
61326-1.

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 213mm 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: Model 237-ALG-2 Triaxial Test
Lead (6.6ft), Trigger Link cable, RS-232 (Null Modem) cable,
Interlock terminal block, User's Manual, CD Manual, LabVIEW
Drivers.

6221 AC and DC Current Source

SOURCE SPECIFICATIONS

Range (+5% over range)	Accuracy (1 Year) $23^{\circ}\text{C} \pm 5^{\circ}\text{C}$ $\pm(\%\text{rdg.} +$ $\text{amps})$	Programming Resolution	Temperature Coefficient/ $^{\circ}\text{C}$ $0^{\circ}\text{--}18^{\circ}\text{C} \& 28^{\circ}\text{--}$ 50°C	Typical Noise (peak-peak) $/\text{RMS}^{3,5}$ $0.1\text{Hz}\text{--}10\text{Hz}$	Typical Noise (peak-peak) $/\text{RMS}^{3,4,5}$ $10\text{Hz}\text{--}(BW)$	Output Response Bandwidth (BW) into Short	Settling Time ^{1,2} (1% of final value)	
							Output Resp. Fast (Typical ⁵)	Output Resp. Slow (Max)
2nA	0.4% + 2pA	100fA	0.02% + 200fA	400/80fA	250/50pA	10kHz	90μs	100μs
20nA	0.3% + 10pA	1pA	0.02% + 200fA	4/0.8pA	250/50pA	10kHz	90μs	100μs
200nA	0.3% + 100pA	10pA	0.02% + 2pA	20/4pA	2.5/0.5nA	100kHz	30μs	100μs
2μA	0.1% + 1nA	100pA	0.01% + 20pA	200/40pA	25/5.0nA	1MHz	4μs	100μs
20μA	0.05% + 10nA	1nA	0.005% + 200pA	2/0.4nA	500/100nA	1MHz	2μs	100μs
200μA	0.05% + 100nA	10nA	0.005% + 2nA	20/4nA	1.0/0.2μA	1MHz	2μs	100μs
2mA	0.05% + 1μA	100nA	0.005% + 20nA	200/40nA	5.0/1μA	1MHz	2μs	100μs
20mA	0.05% + 10μA	1μA	0.005% + 200nA	2/0.4μA	20/4.0μA	1MHz	2μs	100μs
100mA	0.1% + 50μA	10μA	0.01% + 2μA	10/2μA	100/20μA	1MHz	3μs	100μs

ADDITIONAL SOURCE SPECIFICATIONS

OUTPUT RESISTANCE: $>10^{14}\Omega$. (2nA/20nA range)

OUTPUT CAPACITANCE: $<10\text{pF}$, $<100\text{pF}$ Filter ON. (2nA/20nA range)

LOAD IMPEDANCE: Stable into $10\mu\text{H}$ typical, $100\mu\text{H}$ 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% + 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: $\pm 1\text{mV}$ 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

- Settling times are specified into a resistive load, with a maximum resistance equal to $2\text{V} / I_{\text{fullscale}}$ of range. See manual for other load conditions.
- Settling times to 0.1% of final value are typically <2x of 1% settling times.
- Noise current into $<100\Omega$.
- RMS Noise 10Hz-20MHz (2nA – 20mA Range) Less than 1mVRms, 5mVp-p (into 50Ω load).
- 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 ACCURACY⁴: ±100 ppm (1 Year)

AMPLITUDE: 2pA to 210mA peak-peak into loads up to $10^{12}\Omega$.

AMPLITUDE ACCURACY (<10kHz):²

Magnitude: 1% rdg + 0.2% rng

Offset: 0.2% rdg + 0.2% rng

SINE WAVE CHARACTERISTICS:

Frequency Range: 1mHz to 100kHz.²

Amplitude Flatness: Less than 1dB up to 100kHz.⁴

SQUARE WAVE CHARACTERISTICS:

Frequency Range: 1mHz to 100kHz.²

Overshoot: <2.5%⁴

Variable Duty Cycle: ^{1,3} Settable to 1μs min. pulse duration, 0.01% programming resolution.

Jitter (RMS): 100ns + 0.1% of period.⁴

RAMP WAVE CHARACTERISTICS:

Frequency Range: 1mHz to 100kHz.²

Linearity: <0.1% of peak output up to 10kHz.⁴

ARBITRARY WAVE CHARACTERISTICS:

Frequency Range: 1mHz to 100kHz.²

Waveform Length: 2 to 64K points.

Amplitude Resolution: 16 bits (including sign).⁵

Sample Rate: 10 MSPS.⁵

Jitter (RMS): 100ns + 0.1% of period.⁴

Maximum User Waveforms: 4.

PROGRAMMING TIME (Typical):⁶

Waveform/Amplitude/Frequency Change: 1ms

ARB Transfer Times:

(External transfer time over Bus)

	16K	64K
LAN	0.750s	3.000s
GPIB	1.250s	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 50μs to 12ms, 1pA to 100mA.

Repetition interval 83.3ms 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/1fullscale 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: 250Vrms, DC to 60Hz.

COMMON MODE ISOLATION: > $10^9\Omega$, <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 Tx), 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 (33V@500mA, diode clamped).

OUTPUT CONNECTIONS:

- Teflon insulated 3-lug triax connector for output.
- Banana Safety Jack for GUARD, OUTPUT LO
- Screw Terminal for CHASSIS
- DB-9 connector for EXTERNAL TRIGGER INPUT, OUTPUT, and DIGITAL I/O
- 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°-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.

EMC: Conforms to European Union Directive 89/336/EEC, EN 61326-1.

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 213mm 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: Model 237-ALG-2 Triaxial Test Lead (6.6ft), Trigger Link cable, RS-232 (Null Modem) cable, Interlock terminal block, User's Manual, CD Manual, LabVIEW Drivers.

B

Error and Status Messages

Appendix B topics

[Introduction](#), page B-2

Introduction

Coded error and status messages are reported for error/status events that may occur. The coded error and status messages are listed in [Table B-1](#). Error/status codes with a negative (-) number are reserved by SCPI. Positive (+) numbered codes are instrument-dependent.

The code and message is displayed briefly on the Model 622x when the error/status event occurs. The code and message is also place in the Error Queue. The following commands are used to read the Error Queue:

`SYStem:ERRor?`

`STATus:QUEue?`

When a queue command is sent, the latest error/status event is returned and is then cleared from the queue. Details on the “[Error queue](#)” are provided on [page 11-20](#).

When an error or status event occurs, a corresponding bit in a status register will set. The status registers include the Standard Event Register, Measurement Event Register, Operation Event Register and the Questionable Event Register. [Table B-1](#) also lists the register bit that is set by the error/status event. The status structure is covered in [Section 11](#).

NOTE

Error/status events +950 through +962 pertain to the KI-220 Language, which is covered in [Section 15](#). The status registers that are affected by the listed error/status events are explained in the Model 220, 230 Programming Manual available for download at www.keithley.com.

Table B-1
Status and error messages

Code	Description	Status Model		
		Register	Bit	Reference
-430	Query DEADLOCKED	Standard	B2	page 11-11
-420	Query INTERMINATED	Standard	B2	page 11-11
-410	Query INTERRUPTED	Standard	B2	page 11-11
-363	Input buffer overrun	Standard	B3	page 11-11
-350	Queue overflow	Standard	B3	page 11-11
-314	Save/recall memory lost	Standard	B3	page 11-11
-260	Expression error	Standard	B4	page 11-11
-241	Hardware missing	Standard	B4	page 11-11
-230	Data corrupt or stale	Standard	B4	page 11-11
-225	Out of memory	Standard	B4	page 11-11
-224	Illegal parameter value	Standard	B4	page 11-11

Table B-1 (cont.)
Status and error messages

Code	Description	Status Model		
		Register	Bit	Reference
-223	Too much data	Standard	B4	page 11-11
-222	Parameter data out of range	Standard	B4	page 11-11
-221	Settings conflict	Standard	B4	page 11-11
-220	Parameter error	Standard	B4	page 11-11
-213	Init ignored	Standard	B4	page 11-11
-211	Trigger ignored	Standard	B4	page 11-11
-210	Trigger error	Standard	B4	page 11-11
-203	Command protected	Standard	B4	page 11-11
-200	Execution error	Standard	B4	page 11-11
-171	Invalid expression	Standard	B5	page 11-11
-170	Expression error	Standard	B5	page 11-11
-161	Invalid block data	Standard	B5	page 11-11
-160	Block data error	Standard	B5	page 11-11
-154	String too long	Standard	B5	page 11-11
-151	Invalid string data	Standard	B5	page 11-11
-150	String data error	Standard	B5	page 11-11
-148	Character data not allowed	Standard	B5	page 11-11
-144	Character data too long	Standard	B5	page 11-11
-141	Invalid character data	Standard	B5	page 11-11
-140	Character data error	Standard	B5	page 11-11
-124	Too many digits	Standard	B5	page 11-11
-123	Exponent too large	Standard	B5	page 11-11
-121	Invalid character in number	Standard	B5	page 11-11
-120	Numeric data error	Standard	B5	page 11-11
-113	Undefined header	Standard	B5	page 11-11
-112	Program mnemonic too long	Standard	B5	page 11-11
-111	Header separator error	Standard	B5	page 11-11
-110	Command header error	Standard	B5	page 11-11
-109	Missing parameter	Standard	B5	page 11-11
-108	Parameter not allowed	Standard	B5	page 11-11
-105	GET not allowed	Standard	B5	page 11-11
-104	Data type error	Standard	B5	page 11-11
-102	Syntax error	Standard	B5	page 11-11
-101	Invalid character	Standard	B5	page 11-11
-100	Command error	Standard	B5	page 11-11

Table B-1 (cont.)
Status and error messages

Code	Description	Status Model		
		Register	Bit	Reference
+000	No error			
+101	*OPC Operation complete	Standard	B0	page 11-11
+111	Output Interlock Asserted	Measurement	B1	page 11-14
+112	Temperature limit exceeded	Measurement	B2	page 11-14
+114	Source in compliance	Measurement	B3	page 11-14
+121	Device calibrating	Operation	B0	page 11-12
+122	Sweep done	Operation	B1	page 11-12
+123	Sweep aborted	Operation	B2	page 11-12
+124	Device sweeping	Operation	B3	page 11-12
+125	Wave started	Operation	B4	page 11-12
+126	Wave stopped	Operation	B7	page 11-12
+171	Waiting in trigger layer	Operation	B5	page 11-12
+172	Waiting in arm layer	Operation	B6	page 11-12
+174	Re-entering the idle layer	Operation	B10	page 11-12
+180	Filter settled	Operation	B8	page 11-12
+301	Reading overflow	Measurement	B0	page 11-14
+306	Reading available event	Measurement	B5	page 11-14
+307	Buffer user-selectable event (Trace Notify)	Measurement	B6	page 11-14
+308	Buffer available	Measurement	B7	page 11-14
+309	Buffer half full	Measurement	B8	page 11-14
+310	Buffer full	Measurement	B9	page 11-14
+312	Buffer one quarter full	Measurement	B12	page 11-14
+313	Buffer three quarters full	Measurement	B13	page 11-14
+401	Not allowed with sweep armed	Standard	B4	page 11-11
+402	Output blocked by interlock	Standard	B4	page 11-11
+403	Not allowed with output on	Standard	B4	page 11-11
+404	Not allowed with wave armed	Standard	B4	page 11-11
+405	Amplitude changed to fit range	Standard	B4	page 11-11
+406	Offset changed to fit range	Standard	B4	page 11-11
+407	Wave ampl+offset range error	Standard	B4	page 11-11
+408	Diff. Conductance truncated	Standard	B4	page 11-11
+409	Pulse width or sdelay error	Standard	B4	page 11-11
+410	Model 2182A required	Standard	B4	page 11-11
+411	Diff. Conductance step error	Standard	B4	page 11-11
+412	Diff. Conductance upranged	Standard	B4	page 11-11

Table B-1 (cont.)
Status and error messages

Code	Description	Status Model		
		Register	Bit	Reference
+413	Not allowed with mode armed	Standard	B4	page 11-11
+414	Src delay >= 55µs recommended	Standard	B4	page 11-11
+415	Src delay >= 500µs recommended	Standard	B4	page 11-11
+416	Step size too small	Standard	B4	page 11-11
+417	Output exceeds range limit	Standard	B4	page 11-11
+418	Not allowed with Pulse armed	Standard	B4	page 11-11
+419	Trigger link cable not connected	Standard	B4	page 11-11
+420	Log sweep zero adjusted	Standard	B4	page 11-11
+500	Date of calibration not set	Standard	B3	page 11-11
+501	Next date of calibration not set	Standard	B3	page 11-11
+502	Calibration data invalid	Standard	B3	page 11-11
+503	DAC calibration overflow	Standard	B3	page 11-11
+504	DAC calibration underflow	Standard	B3	page 11-11
+505	Source offset data invalid	Standard	B3	page 11-11
+506	Source gain data invalid	Standard	B3	page 11-11
+507	Sense offset data invalid	Standard	B3	page 11-11
+508	Sense gain data invalid	Standard	B3	page 11-11
+509	Not permitted with cal locked	Standard	B3	page 11-11
+510	Not permitted with cal un-locked	Standard	B3	page 11-11
+511	GPIB address lost	Standard	B3	page 11-11
+512	Power-on state lost	Standard	B3	page 11-11
+513	Guard offset data invalid	Standard	B3	page 11-11
+514	DC calibration data lost	Standard	B3	page 11-11
+515	Calibration dates lost	Standard	B3	page 11-11
+516	Not allowed when in compliance	Standard	B3	page 11-11
+517	Not allowed unless in compliance	Standard	B3	page 11-11
+518	Must cal lower four points first	Standard	B3	page 11-11
+522	GPIB Comm language lost error	Standard	B3	page 11-11
+523	ARB Wave Data Lost Error	Standard	B3	page 11-11
+524	ARB Wave Data Empty Error	Standard	B3	page 11-11
+525	Cannot save ARB0 as user setup	Standard	B3	page 11-11
+526	Wave offset data invalid	Standard	B3	page 11-11
+527	Wave gain data invalid	Standard	B3	page 11-11
+528	Cannot save CUSTOM sweep setup	Standard	B3	page 11-11
+550	Uninitialized Ethernet Module (6221 only)	Standard	B3	page 11-11
+551	Ethernet Module Swapped (6221 only)	Standard	B3	page 11-11

Table B-1 (cont.)
Status and error messages

Code	Description	Status Model		
		Register	Bit	Reference
+552	Invalid Password (6221 only)	Standard	B3	page 11-11
+557	Cannot change with DHCP ON (6221 only)	Standard	B3	page 11-11
+558	A/D timeout (6221 only)	Standard	B3	page 11-11
+610	Questionable Calibration	Questionable	B8	page 11-16
+611	Questionable Power Measurement	Questionable	B4	page 11-16
+700	Not allowed in DDC (KI-220) mode	Standard	B3	page 11-11
+800	RS-232 Framing Error detected	Operation	B11	page 11-12
+802	RS-232 Overrun detected	Operation	B11	page 11-12
+803	RS-232 Break detected	Operation	B11	page 11-12
+805	Invalid system comm setting	Operation	B11	page 11-12
+808	RS-232 INVALID FORMAT ERR	Operation	B11	page 11-12
+809	Not allowed with RS-232	Operation	B11	page 11-12
+900	Internal System Error	Standard	B3	page 11-11
KI-220 language (DDC status model):				See above Note
+954	DDC mode IDDC Error	U1 Status	B12	—
+955	DDC mode IDDCO Error	U1 Status	B11	—
+957	DDC No Remote Error	U1 Status	B9	—
+958	DDC V-Limit	Status Byte	B0	—
+959	DDC End of Buffer event	Status Byte	B1	—
+960	DDC End of Dwell Time	Status Byte	B2	—
+961	DDC Input Port Change event	U1 Status	B3	—

C

IEEE-488 Bus Overview

Appendix topics

[Introduction](#), page C-2

[Bus description](#), page C-3

[Bus lines](#), page C-4

 Data lines, page C-5

 Bus management lines, page C-5

 Handshake lines, page C-5

[Bus commands](#), page C-6

 Uniline commands, page C-9

 Universal multiline commands, page C-9

 Addressed multiline commands, page C-10

 Address commands, page C-10

 Unaddress commands, page C-11

 Common commands, page C-11

 SCPI commands, page C-11

 Command codes, page C-12

 Typical command sequences, page C-12

 IEEE command groups, page C-14

[Interface function codes](#), page C-15

Introduction

The IEEE-488 bus is a communication system between two or more electronic devices. A device can be either an instrument or a computer. When a computer is used on the bus, it serves as a supervisor of the communication exchange between all the devices and is known as the controller. Supervision by the controller consists of determining which device will talk and which device will listen. As a talker, a device will output information; as a listener, a device will receive information. To simplify the task of keeping track of the devices, a unique address number is assigned to each.

On the bus, only one device can talk at a time and is addressed to talk by the controller. The device that is talking is known as the active talker. The devices that need to listen to the talker are addressed to listen by the controller. Each listener is then referred to as an active listener. Devices that do not need to listen are instructed to unlisten. The reason for the unlisten instruction is to optimize the speed of bus information transfer since the task of listening takes up bus time.

Through the use of control lines, a handshake sequence takes place in the transfer process of information from a talker to a listener. This handshake sequence helps ensure the credibility of the information transfer. The basic handshake sequence between an active controller (talker) and a listener is as follows:

1. The listener indicates that it is ready to listen.
2. The talker places the byte of data on the bus and indicates that the data is available to the listener.
3. The listener, aware that the data is available, accepts the data and then indicates that the data has been accepted.
4. The talker, aware that the data has been accepted, stops sending data and indicates that data is not being sent.
5. The listener, aware that there is no data on the bus, indicates that it is ready for the next byte of data.

Bus description

The IEEE-488 bus, which is also referred to as the GPIB (General Purpose Interface Bus), was designed as a parallel transfer medium to optimize data transfer without using an excessive number of bus lines. In keeping with this goal, the bus has only eight data lines that are used for both data and with most commands. Five bus management lines and three handshake lines round out the complement of bus signal lines.

A typical setup for controlled operation is shown in [Figure C-1](#). Generally, a system will contain one controller and a number of other instruments to which the commands are given. Device operation is categorized into three operators: controller, talker, and listener. The controller controls the instruments on the bus. The talker sends data while a listener receives data. Depending on the type of instrument, any particular device can be a talker only, a listener only, or both a talker and listener.

There are two categories of controllers: system controller and basic controller. Both are able to control other instruments, but only the system controller has the absolute authority in the system. In a system with more than one controller, only one controller may be active at any given time. Certain protocol is used to pass control from one controller to another.

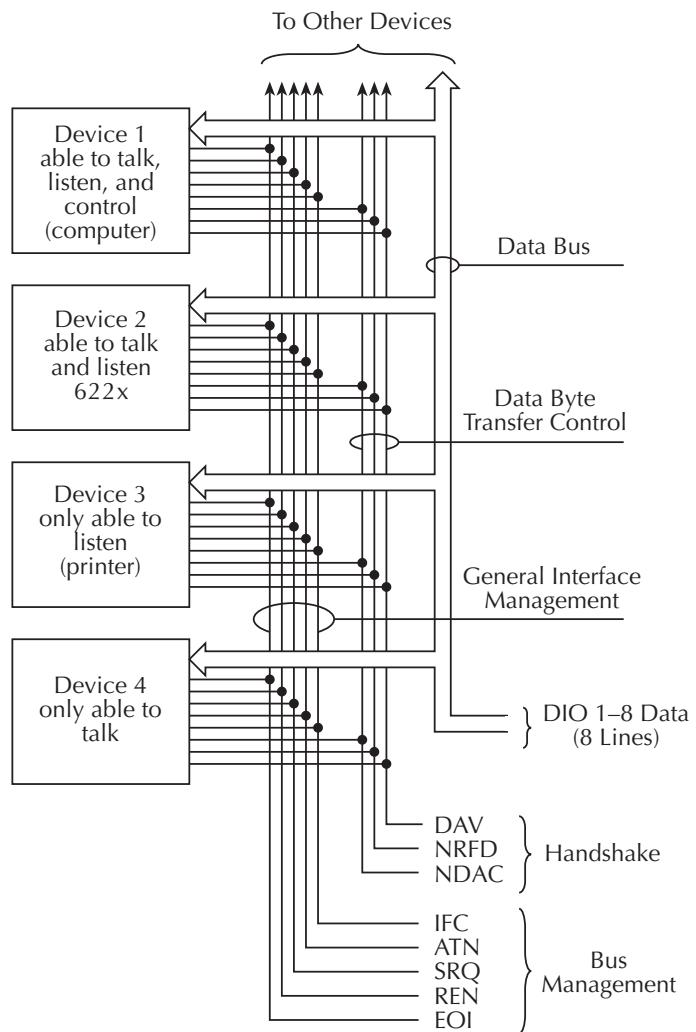
The IEEE-488 bus is limited to 15 devices, including the controller. Thus, any number of talkers and listeners up to that limit may be present on the bus at one time. Although several devices may be commanded to listen simultaneously, the bus can have only one active talker or communications would be scrambled.

A device is placed in the talk or listen state by sending an appropriate talk or listen command. These talk and listen commands are derived from an instrument's primary address. The primary address may have any value between 0 and 31, and is generally set by rear panel DIP switches or programmed in from the front panel of the instrument. The actual listen address value sent out over the bus is obtained by ORing the primary address with \$20. For example, if the primary address is \$12, the actual listen address is \$32 ($\$32 = \$12 + \20). In a similar manner, the talk address is obtained by ORing the primary address with \$40. With the present example, the talk address derived from a primary address of \$12 would be \$52 ($\$52 = \$12 + \$40$).

The IEEE-488 standards also include another addressing mode called secondary addressing. Secondary addresses lie in the range of \$60-\$7F. Note, however, that many devices, including the Model 622x, do not use secondary addressing.

Once a device is addressed to talk or listen, the appropriate bus transactions take place. For example, if the instrument is addressed to talk, it places its data string on the bus one byte at a time. The controller reads the information and the appropriate software can be used to direct the information to the desired location.

Figure C-1
IEEE-488 bus configuration



Bus lines

The signal lines on the IEEE-488 bus are grouped into three different categories: data lines, management lines, and handshake lines. The data lines handle bus data and commands, while the management and handshake lines ensure that proper data transfer and operation takes place. Each bus line is active low, with approximately zero volts representing a logic 1 (true). The following paragraphs describe the operation of these lines.

Data lines

The IEEE-488 bus uses eight data lines that transfer data one byte at a time. DIO1 (Data Input/Output) through DIO8 (Data Input/Output) are the eight data lines used to transmit both data and multiline commands and are bi-directional. The data lines operate with low true logic.

Bus management lines

The five bus management lines help to ensure proper interface control and management. These lines are used to send the uniline commands.

ATN (Attention) — The ATN state determines how information on the data bus is to be interpreted.

IFC (Interface Clear) — The IFC line controls clearing of instruments from the bus.

REN (Remote Enable) — The REN line is used to place the instrument on the bus in the remote mode.

EOI (End or Identify) — The EOI line is used to mark the end of a multi-byte data transfer sequence.

SRQ (Service Request) — The SRQ line is used by devices when they require service from the controller.

Handshake lines

The bus handshake lines operate in an interlocked sequence. This method ensures reliable data transmission regardless of the transfer rate. Generally, data transfer will occur at a rate determined by the slowest active device on the bus.

One of the three handshake lines is controlled by the source (the talker sending information), while the remaining two lines are controlled by accepting devices (the listener or listeners receiving the information). The three handshake lines are:

DAV (DATA VALID) — The source controls the state of the DAV line to indicate to any listening devices whether or not data bus information is valid.

NRFD (Not Ready For Data) — The acceptor controls the state of NRFD. It is used to signal to the transmitting device to hold off the byte transfer sequence until the accepting device is ready.

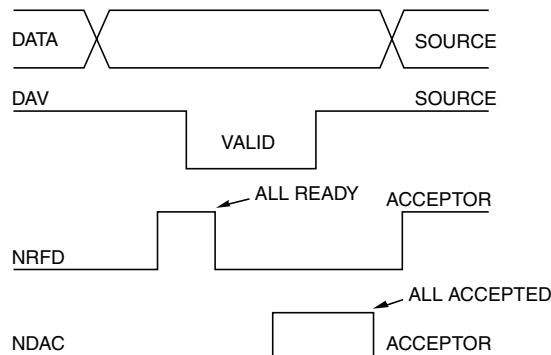
NDAC (Not Data Accepted) — NDAC is also controlled by the accepting device. The state of NDAC tells the source whether or not the device has accepted the data byte.

The complete handshake sequence for one data byte is shown in [Figure C-2](#). Once data is placed on the data lines, the source checks to see that NRFD is high, indicating that all active devices are ready. At the same time, NDAC should be low from the previous byte transfer. If these conditions are not met, the source must wait until NDAC and NRFD have the correct status. If the source is a controller, NRFD and NDAC must be stable for at least 100ns after ATN is set true. Because of the possibility of a bus hang up, many controllers have time-out routines that display messages in case the transfer sequence stops for any reason.

Once all NDAC and NRFD are properly set, the source sets DAV low, indicating to accepting devices that the byte on the data lines is now valid. NRFD will then go low, and NDAC will go high once all devices have accepted the data. Each device will release NDAC at its own rate, but NDAC will not be released to go high until all devices have accepted the data byte.

The previous sequence is used to transfer both data, talk, and listen addresses, as well as multiline commands. The state of the ATN line determines whether the data bus contains data, addresses, or commands as described in the following paragraphs.

**Figure C-2
IEEE-488 handshake sequence**



Bus commands

The instrument may be given a number of special bus commands through the IEEE-488 interface. The following paragraphs briefly describe the purpose of the bus commands which are grouped into the following three categories.

1. **Uniline commands** — Sent by setting the associated bus lines true. For example, to assert REN (Remote Enable), the REN line would be set low (true).

2. **Multiline commands** — General bus commands which are sent over the data lines with the ATN line true (low).
3. **Common commands** — Commands that are common to all devices on the bus; sent with ATN high (false).
4. **SCPI commands** — Commands that are particular to each device on the bus; sent with ATN (false).

These bus commands and their general purpose are summarized in [Table C-1](#).

Table C-1
IEEE-488 bus command summary

Command type	Command	State of ATN line	Comments
Uniline	REN (Remote Enable)	X	Set up devices for remote operation.
	EOI	X	Marks end of transmission.
	IFC (Interface Clear)	X	Clears interface.
	ATN (Attention)	Low	Defines data bus contents.
	SRQ	X	Controlled by external device.
Multiline Universal	LLO (Local Lockout)	Low	Locks out local operation.
	DCL (Device Clear)	Low	Returns device to default conditions.
	SPE (Serial Enable)	Low	Enables serial polling.
	SPD (Serial Poll Disable)	Low	Disables serial polling.
Addressed	SDC (Selective Device Clear)	Low	Returns unit to default conditions.
	GTL (Go To Local)	Low	Returns device to local.
Unaddressed	UNL (Unlisten)	Low	Removes all listeners from the bus.
	UNT (Untalk)	Low	Removes any talkers from the bus.
Common	—	High	Programs IEEE-488.2 compatible instruments for common operations.
SCPI	—	High	Programs SCPI compatible instruments for particular operations.

Table C-2
Command codes

Note: D₀ = D₁₀₁ and T₀ = D₁₀₁ (PARALLEL POLL CONFIGURE) PPU (PARALLEL POLL UNCONFIGURE), and T₀ = D₁₀₈; X = Don't Care.

Note: $D_0 \equiv D|_{U_1} \dots D|_{U_7} \equiv D|_{U8}; \lambda \equiv D|_{\text{full}} \text{ case.}$

Uniline commands

ATN, IFC, and REN are asserted only by the controller. SRQ is asserted by an external device. EOI may be asserted either by the controller or other devices depending on the direction of data transfer. The following is a description of each command. Each command is sent by setting the corresponding bus line true.

REN (Remote Enable) — REN is sent to set up instruments on the bus for remote operation. When REN is true, devices will be removed from the local mode. Depending on device configuration, all front panel controls, except the LOCAL button (if the device is so equipped), may be locked out when REN is true. Generally, REN should be sent before attempting to program instruments over the bus.

EOI (End or Identify) — EOI is used to positively identify the last byte in a multi-byte transfer sequence, thus allowing data words of various lengths to be transmitted easily.

IFC (Interface Clear) — IFC is used to clear the interface and return all devices to the talker and listener idle states.

ATN (Attention) — The controller sends ATN while transmitting addresses or multiline commands.

SRQ (Service Request) — SRQ is asserted by a device when it requires service from a controller.

Universal multiline commands

Universal commands are those multiline commands that require no addressing. All devices equipped to implement such commands will do so simultaneously when the commands are transmitted. As with all multiline commands, these commands are transmitted with ATN true.

LLO (Local Lockout) — LLO is sent to the instrument to lock out the LOCAL key and all their front panel controls.

DCL (Device Clear) — DCL is used to return instruments to some default state. Instruments usually return to their power-up conditions.

SPE (Serial Poll Enable) — SPE is the first step in the serial polling sequence which is used to determine which device has requested service.

SPD (Serial Poll Disable) — SPD is used by the controller to remove all devices on the bus from the serial poll mode and is generally the last command in the serial polling sequence.

Addressed multiline commands

Addressed commands are multiline commands that must be preceded by the device listen address before that instrument will respond to the command in question. Note that only the addressed device will respond to these commands. Both the commands and the address preceding it are sent with ATN true.

SDC (Selective Device Clear) — The SDC command performs essentially the same function as the DCL command except that only the addressed device responds. Generally, instruments return to their power-up default conditions when responding to the SDC command.

GTL (Go To Local) — The GTL command is used to remove instruments from the remote mode. With some instruments, GTL also unlocks front panel controls if they were previously locked out with the LLO command.

GET (Group Execute Trigger) — The GET command is used to trigger devices to perform a specific action that depends on device configuration (for example, take a reading). Although GET is an addressed command, many devices respond to GET without addressing.

Address commands

Addressed commands include two primary command groups and a secondary address group. ATN is true when these commands are asserted. The commands include:

LAG (Listen Address Group) — These listen commands are derived from an instrument's primary address and are used to address devices to listen. The actual command byte is obtained by ORing the primary address with \$20.

TAG (Talk Address Group) — The talk commands are derived from the primary address by ORing the address with \$40. Talk commands are used to address devices to talk.

SCG (Secondary Command Group) — Commands in this group provide additional addressing capabilities. Many devices (including the Model 622x) do not use these commands.

Unaddress commands

The two unaddress commands are used by the controller to remove any talkers or listeners from the bus. ATN is true when these commands are asserted.

UNL (Unlisten) — Listeners are placed in the listener idle state by the UNL command.

UNT (Untalk) — Any previously commanded talkers will be placed in the talker idle state by the UNT command.

Common commands

Common commands are commands that are common to all devices on the bus. These commands are designated and defined by the IEEE-488.2 standard.

Generally, these commands are sent as one or more ASCII characters that tell the device to perform a common operation, such as reset. The IEEE-488 bus treats these commands as data in that ATN is false when the commands are transmitted.

SCPI commands

SCPI commands are commands that are particular to each device on the bus. These commands are designated by the instrument manufacturer and are based on the instrument model defined by the Standard Commands for Programmable Instruments (SCPI) Consortium's SCPI standard.

Generally, these commands are sent as one or more ASCII characters that tell the device to perform a particular operation, such as setting a range or closing a relay. The IEEE-488 bus treats these commands as data in that ATN is false when the commands are transmitted.

Command codes

Command codes for the various commands that use the data lines are summarized in [Table C-2](#). Hexadecimal and the decimal values for the various commands are listed in [Table C-3](#).

**Table C-3
Hexadecimal and decimal command codes**

Command	Hex value	Decimal value
GTL	01	1
SDC	04	4
GET	08	8
LLO	11	17
DCL	14	20
SPE	18	24
SPD	19	25
LAG	20-3F	32-63
TAG	40-5F	64-95
SCG	60-7F	96-127
UNL	3F	63
UNT	5F	95

Typical command sequences

For the various multiline commands, a specific bus sequence must take place to properly send the command. In particular, the correct listen address must be sent to the instrument before it will respond to addressed commands. [Table C-4](#) lists a typical bus sequence for sending the addressed multiline commands. In this instance, the SDC command is being sent to the instrument. UNL is generally sent as part of the sequence to ensure that no other active listeners are present.

Note that ATN is true for both the listen command and the SDC command byte itself.

Table C-4
Typical bus sequence

Step	Com- mand	ATN state	Data bus		
			ASCII	Hex	Decimal
1	UNL	Set low	?	3F	63
2	LAG*	Stays low	.	2C	44
3	SDC	Stays low	EOT	04	4
4		Returns high			

*Assumes primary address = 12.

Table C-5 gives a typical common command sequence. In this instance, ATN is true while the instrument is being addressed, but it is set high while sending the common command string.

Table C-5
Typical addressed command sequence

Step	Com- mand	ATN state	Data bus		
			ASCII	Hex	Decimal
1	UNL	Set low	?	3F	63
2	LAG*	Stays low	.	2C	44
3	Data	Set high	*	2A	42
4	Data	Stays high	R	52	82
5	Data	Stays high	S	53	83
6	Data	Stays high	T	54	84

*Assumes primary address = 12.

IEEE command groups

Command groups supported by the Model 622x are listed in [Table C-6](#). Common commands and SCPI commands are not included in this list.

Table C-6
IEEE command groups

HANDSHAKE COMMAND GROUP	
	NDAC = NOT DATA ACCEPTED NRFD = NOT READY FOR DATA DAV = DATA VALID
UNIVERSAL COMMAND GROUP	
	ATN = ATTENTION DCL = DEVICE CLEAR IFC = INTERFACE CLEAR REN = REMOTE ENABLE SPD = SERIAL POLL DISABLE SPE = SERIAL POLL ENABLE
ADDRESS COMMAND GROUP	
LISTEN	LAG = LISTEN ADDRESS GROUP MLA = MY LISTEN ADDRESS UNL = UNLISTEN
TALK	TAG = TALK ADDRESS GROUP MTA = MY TALK ADDRESS UNT = UNTALK OTA = OTHER TALK ADDRESS
ADDRESSED COMMAND GROUP	
	ACG = ADDRESSED COMMAND GROUP GTL = GO TO LOCAL SDC = SELECTIVE DEVICE CLEAR
STATUS COMMAND GROUP	
	RQS = REQUEST SERVICE SRQ = SERIAL POLL REQUEST STB = STATUS BYTE EOI = END OF IDENTIFY

Interface function codes

The interface function codes, which are part of the IEEE-488 standards, define an instrument's ability to support various interface functions and should not be confused with programming commands found elsewhere in this manual. The interface function codes for the Model 622x are listed in [Table C-7](#).

Table C-7
Model 622x interface function codes

Code	Interface function
SH1	Source Handshake capability
AH1	Acceptor Handshake capability
T5	Talker (basic talker, talk-only, serial poll, unaddressed to talk on LAG)
L4	
SR1	Listener (basic listener, unaddressed to listen on TAG)
RL1	Service Request capability
PP0	Remote/Local capability
DC1	No Parallel Poll capability
DT1	Device Clear capability
C0	Device Trigger capability
E1	No Controller capability
TE0	Open collector bus drivers
LE0	No Extended Talker capability No Extended Listener capability

The codes define Model 622x capabilities as follows:

SH (Source Handshake Function) — SH1 defines the ability of the instrument to initiate the transfer of message/data over the data bus.

AH (Acceptor Handshake Function) — AH1 defines the ability of the instrument to guarantee proper reception of message/data transmitted over the data bus.

T (Talker Function) — The ability of the instrument to send data over the bus to other devices is provided by the T function. Instrument talker capabilities (T5) exist only after the instrument has been addressed to talk.

L (Listener Function) — The ability for the instrument to receive device-dependent data over the bus from other devices is provided by the L function. Listener capabilities (L4) of the instrument exist only after it has been addressed to listen.

SR (Service Request Function) — SR1 defines the ability of the instrument to request service from the controller.

RL (Remote-Local Function) — RL1 defines the ability of the instrument to be placed in the remote or local modes.

E (Bus Driver Type) — The instrument has open-collector bus drivers (E1).

TE (Extended Talker Function) — The instrument does not have extended talker capabilities (TE0).

LE (Extended Listener Function) — The instrument does not have extended listener capabilities (LE0).

D IEEE-488 and SCPI Conformance Information

Appendix topics

[Introduction](#), page D-2

Introduction

The IEEE-488.2 standard requires specific information about how the Model 622x implements the standard. Paragraph 4.9 of the IEEE-488.2 standard (Standard 488.2-1987) lists the documentation requirements. [Table D-1](#) provides a summary of the requirements and provides the information or references the manual for that information.

[Table D-2](#) lists the coupled command used by the Model 622x.

The Model 622x complies with SCPI version 1996.0. The tables in [Section 14](#) list the SCPI confirmed commands and the non-SCPI commands implemented by the Model 622x.

**Table D-1
IEEE-488 documentation requirements**

	Requirements	Description or Reference
(1)	IEEE-488 Interface Function Codes.	See Appendix C .
(2)	Behavior of 622x when the address is set outside the range 0-30.	Cannot enter an invalid address.
(3)	Behavior of 622x when valid address is entered.	Address changes and bus resets.
(4)	Power-On Setup Conditions.	Determine by :SYST:POS (Section 14).
(5)	Message Exchange Options: (a) Input buffer size. (b) Queries that return more than one response message unit. (c) Queries that generate a response when parsed. (d) Queries that generate a response when read. (e) Coupled commands.	2048 bytes. None. All queries (Common Commands and SCPI). None. See Table D-2
(6)	Functional elements required for SCPI commands.	Contained in SCPI command subsystems tables (see Section 14).
(7)	Buffer size limitations for block data.	Block display message buffer size is 40 characters max (top line display is 20 characters, bottom line is 32 characters).
(8)	Syntax restrictions.	See Programming Syntax in Section 10 .
(9)	Response syntax for every query command.	See Programming Syntax in Section 10 .
(10)	Device-to-device message transfer that does not follow rules of the standard.	None.
(11)	Block data response size.	See Display Subsystem in Section 13 .
(12)	Common Commands implemented by 622x.	See Common Commands in Section 12 .

Table D-1 (cont.)

IEEE-488 documentation requirements

	Requirements	Description or Reference
(13)	Calibration query information.	Section 17 .
(14)	Trigger macro for *DDT.	Not applicable.
(15)	Macro information.	Not applicable.
(16)	Response to *IDN (identification).	See Common Commands in Section 12 .
(17)	Storage area for *PUD and *PUD?	Not applicable.
(18)	Resource description for *RDT and *RDT?	Not applicable.
(19)	Effects of *RST, *RCL, and *SAV.	See Common Commands in Section 12 .
(20)	*TST information.	See Common Commands in Section 12 .
(21)	Status register structure.	See Status Structure in Section 11
(22)	Sequential or overlapped commands.	All are sequential except :INIT which is overlapped.
(23)	Operation complete messages.	*OPC, *OPC?, and *WAI; see Common Commands in Section 12 .

Table D-2

Coupled commands

Sending	Changes	To
SOUR:DELT:HIGH <value>	SOUR:DELT:LOW <value>	:HIGH <value>

E Applications

Appendix topics

- Calibration source, page E-2
- Resistivity measurements, page E-3
- Diode characterization, page E-4
- Transistor characterization, page E-5
- External user-supplied filter, page E-7
- Compliance overshoot prevention, page E-11

Calibration source

The Model 622x, with its high accuracy, can be used as a current calibration source. The custom (list) 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.

For example, assume calibration of a picoammeter requires the following current levels to be sourced in this order:

0nA, -1nA, +1nA, -10nA, +10nA, -100nA, +100nA, -1mA, +1mA

The nine point custom sweep is configured as follows:

P00000 = 0nA
P00001 = -1nA
P00002 = +1nA
P00003 = -10nA
P00004 = +10nA
P00005 = -100nA
P00006 = +100nA
P00007 = -1mA
P00008 = +1mA

For a manually controlled calibration system, the **TRIG** key of the Model 622x can be used to control the current source output. Each press of the **TRIG** key will output the next sweep point.

For an automated calibration system, the program can control the current source output using **GET** or ***TRG** commands. Each time a **GET** or ***TRG** command is received by the Model 622x, the next sweep point will be output.

If the device to be calibrated supports external triggering, the Trigger Link can be used to control triggering between the two instruments. While sourcing the first sweep point level, the Model 622x outputs a trigger to the external device triggering it to perform the calibration. When the external device is finished with the calibration, it will send a trigger to the Model 622x triggering it to output the next sweep point. This back and forth triggering between the two instruments will continue until all nine calibration points are completed.

Details on “Custom Sweep” are provided in [Section 4](#), and details on “Triggering” are provided in [Section 8](#).

Resistivity measurements

Certain semiconductor materials such as silicon have high resistivities. The measurement of their resistivity can be a difficult measurement. To aid in the measurement, special probes of a hard metal such as tungsten are used. Because contact resistance is so high, a four point probe is usually employed. The outer two contacts supply a constant current, and the inner two contacts measure the voltage drop across a portion of the sample. With the geometry of the probe and wafer known, resistivity can then be calculated.

The current source used must be stable and accurate. The Model 622x is ideal for this application. The accurate and stable current along with compliance voltage can be easily programmed before making the voltage measurement.

The electrometer requires a high impedance to overcome lead resistance problems. The Keithley Model 6514 Electrometer has the high input impedance ($>200T\Omega$ in parallel with $20pF$) required to make the measurement accurately. A simple test system to measure resistivity is shown in [Figure E-1](#).

For most wafers the resistivity is calculated from: $P = ktV/I$

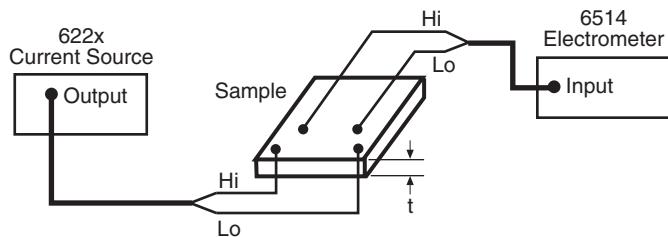
Where: k is a constant based on the geometry of the wafer and probe.

t is the sample thickness.

V is the measured voltage.

I is the current in the sample.

Figure E-1
Resistivity measurement test system



Diode characterization

With the Model 622x, it is possible to plot I-V (current-voltage) characteristics of a diode over several decades. A simple test system for diode characterization is shown in [Figure E-2](#).

The Model 6514, with its high input resistance ($>200\text{T}\Omega$ in parallel with 20pF), will allow the voltage measurement to be made accurately. [Figure E-3](#) shows several examples of diodes whose curves have been plotted using the test system shown in [Figure E-2](#).

NOTE

A standard DMM cannot be used to accurately measure the voltage across the diode because its much lower input resistance would cause loading error. However, a standard DMM can be used to make the voltage measurement at the banana jack GUARD terminal of the Model 622x (see “[Banana Jack Guard](#),” on page 2-12).

Figure E-2
Diode characterization test system

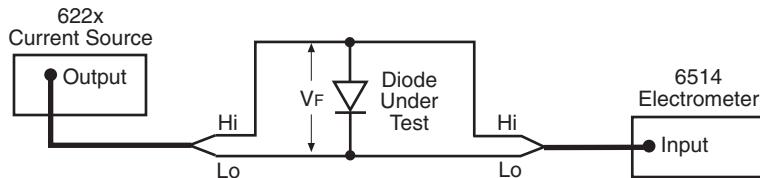
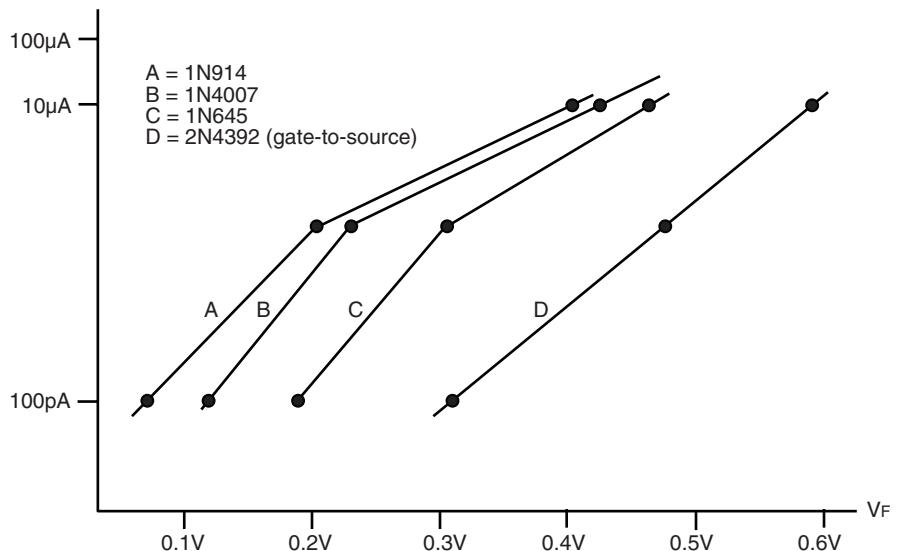


Figure E-3
Diode curves



Transistor characterization

The Model 622x can be used with a Keithley 24xx SourceMeter to characterize a device's electrical DC parameters. Such a test system for a BJT is shown in Figure E-4.

The Model 622x current source can be configured to sweep a number of base currents for the test. The Model 24xx SourceMeter is configured to sweep voltage and measure current. External triggering (Trigger Link) is used between the two instruments to synchronize the testing process.

When the test is started, the Model 622x will output the first base current and send a trigger pulse to the SourceMeter to start its operations. The SourceMeter will run the voltage sweep and measure current at each sweep point. After the sweep is complete, the SourceMeter sends a trigger to the Model 622x to output the next base current. This back and forth triggering between the two instruments will continue until all the collector I-V curves at the different base current levels are acquired.

Figure E-4
BJT characterization test system

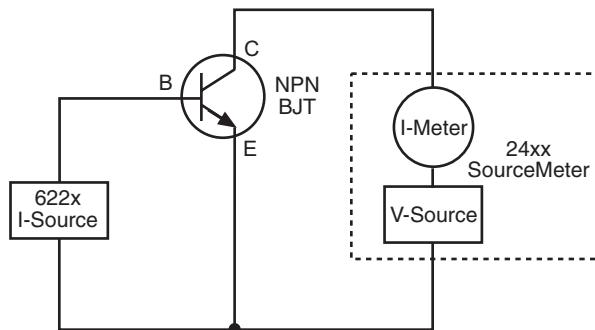
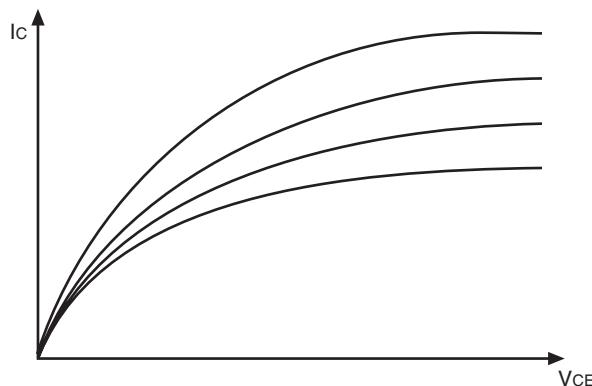


Figure E-5 shows an example of I-V curves acquired for four base current levels. I_C is the measured collector current, and V_{CE} is the voltage at each sweep point. Details on “Sweep” are provided in [Section 4](#), and details on Triggering are provided in [Section 8](#).

The same information for the Model 24xx SourceMeter is provided in the Model 2400 Series User’s Manual, which is available for download at www.keithley.com.

Figure E-5
BJT collector family curves



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. This high frequency noise can drive the user's DUT (Device Under Test) in the 1MHz to 20MHz range and higher.

The filter circuitry is to be wired into a metal box that has two triax connectors mounted on it for input and output. An example of such a filter box is shown [Figure E-6](#). The input of the filter box is connected to the output of the Model 622x, and the output of the filter box is connected to the DUT.

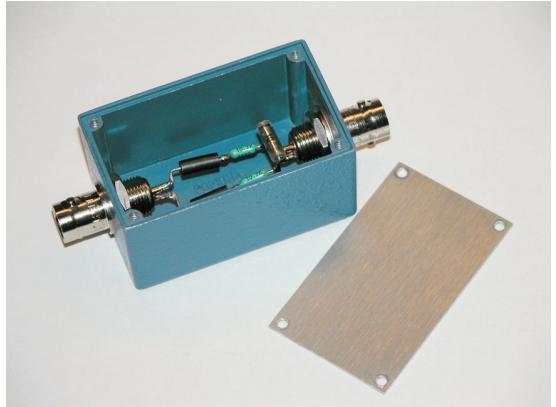
Figure E-6

Example filter box

A) Exterior view of filter box



B) Interior view of filter box (filter circuit wired in)



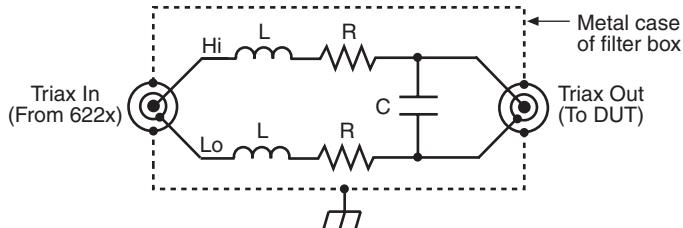
Typical filter circuits

The basic passive components for a filter circuit are capacitors, inductors, resistors, and ferrites. A ferrite inductor exhibits higher resistance at higher noise frequencies.

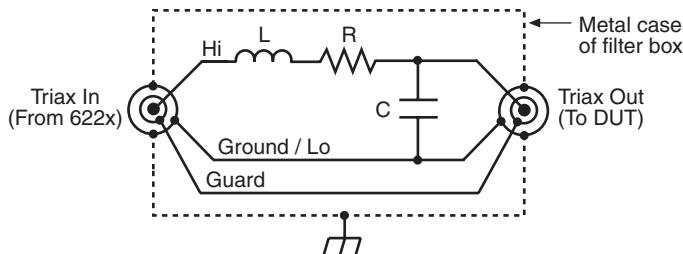
Figure E-7A shows a typical filter circuit when using the Model 622x with output low connected to the inner shield of the triax connector. Figure E-7B shows a typical filter circuit when using the Model 622x with Cable Guard connected to the inner shield of the triax connector. Cable Guard is routed through the test box to the DUT.

Figure E-7
Filter circuit examples

A) Output Lo on inner shield



B) Guard on inner shield



Filter circuit considerations

The filter can be tailored around the specific DUT impedance levels and speed response requirements. Almost any range of resistance (R) and capacitance (C) can be used as long as the corresponding voltage drops are within the dynamic range of the Model 622x.

Care should be taken when using inductors (L), since there are maximum limitations of inductance that the Model 622x can tolerate (<10 μ H preferably). Because of this limitation, it is best to use ferrite inductors that do not exhibit as much phase shift for the same increase in impedance as regular inductors.

The flexibility of adding a wide range of resistor and capacitor values, in addition to the ferrite, provides a wide range of options to aid in the overall reduction of noise.

High current applications

For higher current applications, resistors may not be the best choice, and a single capacitor may suffice. This capacitance will interact with the load impedance (assuming a resistance of R) and provide the following single pole low pass filter response:

$$F_{3\text{db}} = 1/(2\pi RC)$$

Again, the only real limitation is the maximum settling time response that can be tolerated, which in this case would be approximately five RC time constants:

$$ST = \sim 5RC$$

Where: R is in Ohms, C is in Farads, and ST is the settling time (in seconds) to approximately 1% of the final settled value.

For additional higher frequency attenuation of noise, a ferrite can be inserted in the Hi and Lo sides that will act as a resistor at the higher noise frequencies to attenuate the noise spikes in the 1MHz and higher range.

Low current applications

For the other extreme where high DUT impedances are used along with the nA current ranges, the capacitance will have a large effect on settling time. Therefore, capacitance in the filter circuit should be in the 10pF to 1nF range to achieve a response time that is tolerable.

In this case, minimizing the capacitance is desired. To help improve the filtering capability, the series resistors in the Hi and/or Lo sides will help reduce the overall noise coming out of the 622x. These can be sized as large as needed and can be tolerated up to the point of the maximum voltage drop that is desired.

For example, when sourcing 2nA, two $1\text{M}\Omega$ resistors (one in the Hi side and one in the Lo side) would contribute only 4mV of additional drop ($2\text{nA} \times 2\text{M}\Omega = 4\text{mV}$). Two $1\text{G}\Omega$ resistors would add only 4V of additional drop. The Model 622x will still accurately drive the programmed current through the DUT.

The only difference required is that the voltage compliance would need to be set to a higher value to accommodate the additional voltage drops. However, keep in mind that in an open-load condition, the voltage on the DUT test leads will rise to the higher set compliance voltage.

The flexibility of adding a wide range of resistor and capacitor values, in addition to the ferrite, provides a wide range of options for a DUT and settling time requirements, to aid in the overall reduction of noise.

Suggested filter circuit components

Filter test box – Pomona Electronics manufactures several different connection boxes suitable for the filter enclosure. The examples in this application use the Model 2417 enclosure. Another alternative enclosure that comes with two BNC (Coax) connectors is the Model 3231. This could be used for non-guarded configurations where high impedances are not used. Use the Keithley Model 7078-TRX-GND triax to BNC adapter to use this enclosure with the Model 622x.

Triax connectors – Keithley Model 7078-TRX-TBC bulkhead triax connectors can be used with the 2417 enclosure. Of course, any suitable panel mount triax connectors could be used.

Ferrite inductors – Fair-Rite Products Corp. manufactures a wide range of products suitable for this application. One specific part number used is Fair-Rite Part Number 2743001112. This device has an impedance of about 40Ω at 20MHz, making it suitable for higher current applications when using the mA ranges of the Model 622x.

Resistors – Any suitable metal film resistor capable of handling the power needed for the specific application will work well. A specific device that works well for this application is the Vishay/Dale Model CMF55 series of resistors.

Capacitor – The capacitor is probably the most critical component since it shunts the output of the current source. It must have extremely low leakage when sourcing pA level currents. For reasonable time response, it should also have low dielectric absorption. A specific device that works well for this application is the Vishay/BC components KP46x series of polypropylene capacitors.

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. This compliance voltage “glitch” will settle to the expected output voltage within the settling time specification for the selected range. This voltage “glitch” will typically not overheat a DUT, but a few microseconds of overshoot could be enough to damage a voltage sensitive DUT.

Overshoot is due to the current source overshooting its desired value. If the source does not go into voltage compliance, the overshoot will decay in <1μs and will typically not adversely affect your test or damage the DUT.

Calculating overshoot

The overshoot that typically occurs is <1V, with worse case being a maximum of 2V. The overshoot that will actually occur depends on the change in output current relative to the full-scale current of the presently selected source range.

The following calculations for overshoot are approximations. It is assumed that the unit is not in compliance at the beginning of the step, but then enters compliance after the step occurs. In the calculations, the 2V term represents the maximum overshoot that can occur.

$$\text{Overshoot} = (\text{Current Step} / \text{Current Range}) \times 2\text{V}$$

For example, on the 2mA range, a 2mA step change is 100% of range and will result in 2V overshoot:

$$\begin{aligned}\text{Overshoot} &= (2\text{mA} / 2\text{mA}) \times 2\text{V} \\ &= 2\text{V}\end{aligned}$$

On the same range (2mA), a step change of 0.2mA only results in an overshoot of 200mV:

$$\begin{aligned}\text{Overshoot} &= (0.2\text{mA} / 2\text{mA}) \times 2\text{V} \\ &= 0.1 \times 2\text{V} \\ &= 200\text{mV}\end{aligned}$$

A small current step size lessens the chance of driving the source into compliance. Small current steps are typically used for slow sweeps and the waveform function. The larger step sizes are typically used for fast sweeps and the delta tests. The delta tests generate square waves (or pulses), which have a fast rising edge.

Effect of compliance setpoint on settling times

If the compliance voltage is set to close to the expected load voltage (load current times load resistance), then the settling time of the step response will increase from the specified level. In order to reduce this side effect, the compliance voltage needs to be set >2V higher than the expected load voltage.

For example, if a zero to 20mA step is sourced into a 100W load, the resulting voltage would be a 0 to 2V step that would settle within 2 μ s, assuming the compliance setpoint is >4V. However, if the compliance setpoint is set to 2.5V, the settling time could be expected to increase by several microseconds.

Preventing compliance overshoot

There are three options that can be considered to prevent or minimize compliance overshoot:

- Set compliance 2V above the operating voltage.
- Use small current step changes.
- Shunt the output with a capacitor.

Set compliance 2V above operating voltage

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.

Use small current step changes

As explained in “[Calculating overshoot](#)”, a small current step change in relation to the selected source range results in smaller overshoot. If you limit the step size to 1% of the current range, the maximum overshoot will typically only be 20mV.

Shunt output with a capacitor

With little or no output capacitance, the output voltage of the Model 6221 can rise at a rate of 5V/ μ s. This fast slew rate (dv/dt) is a primary cause of the overshoot. Once the overshoot reaches the compliance setpoint, it takes approximately 1 μ s for the compliance circuit to respond. This allows the output voltage to overshoot (up to ~2V) before the compliance circuit can pull it down to its normal operating level.

Slowing down the slew rate by adding a capacitor across the output will allow the compliance circuit to respond fast enough to clamp the output voltage without any significant overshoot into the compliance region.

The slew rate (dv/dt) is calculated as follows:

$$dv/dt = I / C$$

Where: I is the output current

C is capacitance placed across the output

For example, assume the output current is 100 μ A and a 1nF capacitor is placed across the output. The slew rate is calculated as follows:

$$\begin{aligned} dv/dt &= I / C \\ &= 100\mu A / 1nF \\ &= 0.1V/\mu s \end{aligned}$$

This much slower slew rate (0.1V/ μ s versus 5V/ μ s with no capacitor) will allow the compliance circuit to respond quickly enough to clamp the overshoot.

Always use the smallest possible capacitor that will meet your needs. Using a capacitor that is too large may slow down the slew rate to an unacceptable level.

CAUTION A capacitor is an energy storage device. If the output is shorted, a large current spike could be delivered to the load.

Index

Symbols

*RST default setup 1-25

A

Accessories 1-5
Adapters 1-5
Address commands C-10
Addressed multiline commands C-10
Analog filter 3-5
Applications
 Calibration source E-2
 Diode characterization E-4
 Resistivity measurements E-3
 Transistor characterization E-5
Arming process 5-11
ASCII data format 13-5
Average voltage 13-8
Averaging filter 6-1
 Commands 6-8
 Filter count 6-2
 Filter window 6-5
 Moving filter 6-3
 Repeating filter 6-4
 Setup and control 6-8

B

Banana jack Guard 2-8, 2-12
 Connections 2-19
Baud rate 10-25
Beeper 1-16
Buffer 6-11
 Buffer data elements 6-12
 Buffer size 6-12
 Buffer statistics 6-12
 Buffer timestamp 6-13
 Commands 6-16
 Recalling readings 6-14
 Storing readings 6-14
Bus command summary C-7
Bus configuration C-4
Bus description C-3
Byte order 13-8

C

Cable capacitance 2-9
Cable Guard 2-8
 Connections 2-17
Capabilities 1-2
Carrying case 1-6
Case sensitivity 10-14
Cleaning test fixtures 2-23
Clearing registers and queues 11-4
Command
 execution rules 10-17
 path rules 10-16
 words 10-12
Command codes C-12
Command groups C-14
Common commands 12-2, C-11
Communications
 Model 2182/2182A 5-10
 Model 622x 5-11
Communications test 5-12
Compliance 3-3
Compliance overshoot 3-3
Condition registers 11-17
CONFIG/LOCAL key 10-24
Connections
 DUT 5-8
 Ethernet 10-31
 System 5-6
Connections to DUT 2-15
Connectors
 Digital I/O 1-11
 Ethernet 1-11
 Guard 1-12
 IEEE-488 1-11, 10-31
 Interlock 1-12
 LO 1-12
 Output 1-11
 Power module 1-12
 RS-232 1-11
 Trigger Link 1-12
Contact information 1-3
Control sources 8-5
Controlling 9-7
Cooling vents 1-12
Custom sweep 4-6

D

Data and stop bits 10-25
Data elements 13-7
Data flow 5-13, 5-14
Data lines C-5
DCL (device clear) 10-23
DDC emulation commands 15-2
DDC language 10-3
Default settings 1-24, 1-26
Delta 5-2, 5-20
 Arming process 5-24
 Configuration 5-24
 Measurement technique 5-21
 Measurement units 5-23
 Operation 5-27
 Setup commands 5-30
 Triggering sequence 5-25
Differential Conductance 5-2, 5-51
 Arming process 5-56
 Average Voltage 5-54
 Calculations 5-53
 Configuration 5-55
 Measurement process 5-51
 Measurement units 5-54
 Operation 5-59
 Power 5-54
 Setup commands 5-64
 Triggering sequence 5-58
Digital 9-5, 9-6
Disabling front panel 1-17
Display commands 13-2
DUT test connections
 Guarding 5-8

E

Editing 1-20
 Compliance 1-20
 Source 1-20
Enable registers 11-5
Error and status messages 1-24, 10-24
Error codes (delta) 5-18
Error messages B-2
Error queue 11-20
Ethernet
 Connections 10-31
 Settings 10-33
 Standards 10-29
 Status LEDs 10-32
Ethernet (6221) 5-7
Ethernet systems 10-29
Event detectors 8-5
Event registers 11-18

F

Features 1-2
Floating connections 2-19
Floating the current source 2-13
Flow control, RS-232 (signal handshaking) 10-26
Frequency variable resistor (FVR) 2-3
Front panel GPIB operation 10-24
Front panel summaries 1-7
Functionality verification
 Calculating limits 16-4, 17-4
 Environmental conditions 16-3, 17-3
 Line power setting 16-3, 17-3
 Recommended test equipment 16-4, 17-4
 Test considerations 16-5, 17-5
 Warm-up period 16-3, 17-3
Fuse replacement 1-15

G

General IEEE-488 bus commands 10-22
GET (group execute trigger) 10-23
Getting Started 4-1, 7-1, 8-1, 9-1, 10-1, 16-1, 17-1
GPIB adapter 1-6
GPIB cables 1-5
GPIB interface 10-2, 10-4
GPIB status indicators 10-24
Ground points 2-3
GTL (go to local) 10-23
GUARD banana jack 2-3
Guarded mounting plate 2-11
Guarding 5-10
Guards 2-8, 2-16

H

Handshake lines C-5
Handshake sequence C-6
Heat sink 1-12

I

Idle and initiate 8-4
IEEE-488 5-7
 Connector 10-19, 10-31
IEEE-488 bus overview C-1
IEEE-488 documentation requirements D-2
IEEE-754 double precision format 13-6
IEEE-754 single precision format 13-5
IFC (interface clear) 10-22
Input cables 1-5
Inspection 1-4

-
- I**
- Interface
 - available 10-2
 - configuration 10-3
 - selection 10-3
 - Interface function codes C-15
 - Interface selection 1-22
 - Ethernet 1-23
 - GPIB and language 1-23
 - RS-232 1-23
 - Interlock 2-4, 2-21
 - Internal sweep table 5-12
 - Isolated LAN system using two NICs 10-30
- K**
- Keypress 1-17
 - Key-press codes 13-10, 13-11
 - Keys
 - Function 1-9
 - Operation 1-9
 - Output control 1-10
 - Range 1-10
 - Special 1-9
 - KI-220 Language 15-1
- L**
- Languages 10-3
 - Leakage current 2-10
 - Line frequency 1-14
 - Line power connection 1-14
 - Linear staircase sweep 4-4
 - LLO (local lockout) 10-23
 - LO banana jack 2-3
 - Logarithmic staircase sweep 4-5
 - Long-form and short-form versions 10-14
- M**
- Math
 - Commands 6-10
 - $mX+b$ and mX/b 6-9
 - Measure action 8-6
 - Measurement event status 11-14
 - Measurement units 5-16
 - Menu navigation 1-20
 - Menus 1-18
 - CONFIG 1-18
 - Direct access 1-19
 - Multiple command messages 10-16
 - Multiple response messages 10-18
- N**
- NAND 9-8
 - Network Interface Card 10-30
- O**
- Operating boundaries 3-4
 - Operation event status 11-12
 - Optional command words 1-29
 - Output configurations 2-5
 - Output connectors 2-2
 - Output power 3-3
 - Output queue 11-20
 - Output response 3-5
 - Output triggers 8-7
- P**
- Password 1-22, 10-6
 - Phone number 1-3
 - Power module 1-12
 - Power switch 1-9
 - Power-on setup 1-25, 1-26
 - Power-up 1-14
 - Sequence 1-15
 - PRESet default setup 1-25
 - Primary address 10-21
 - Program Message Terminator (PMT) 10-17
 - Program messages 10-15
 - Pulse Delta 5-2, 5-32
 - Arming process 5-42
 - Configuration 5-39
 - Duty Cycle 5-39
 - Fixed output 5-36
 - Measurement units 5-34
 - Operation 5-44
 - Pulse Delta process 5-32
 - Setup commands 5-49
 - Sweep output 5-37
 - Triggering sequence 5-43
- Q**
- Query commands 1-29, 10-14
 - Questionable event status 11-16
 - Queues 11-20

R

Rack mount kits 1-6
Read commands 5-14, 5-15
 Buffer 5-16
 Compliance test result 5-15
 Post-math 5-15
 Pre-math 5-15
Rear panel summaries 1-7
Reference manual 1-7
REN (remote enable) 10-22
Response 10-17
 Message Terminator (RMT) 10-18
Response speed (6221) 3-6
Restoring setups 1-25
RJ-45 connector 10-32
Rotary knob 1-10
RS-232 5-7
 connections 10-27
RS-232 cable 1-6
RS-232 interface 10-2, 10-5, 10-25
RS-232 settings 10-25

S

Safety symbols and terms 1-3
SCPI commands 14-1, C-11
SCPI Conformance Information D-1
SCPI language 10-3
SCPI programming 1-29
SDC (selective device clear) 10-23
Sending a response message 10-17
Sending and receiving data, RS-232 10-25
Serial communications 5-5
Serial polling and SRQ 11-9
Service request enable register 11-8
Setting 9-8
Settling time 3-7
Shielding 2-16
 Noise shield 2-17
 Safety shield 2-17
Short-form rules 10-14
Single command messages 10-15
Sink 9-6
Sink operation 3-3
Source 9-8
Source and compliance editing 3-9
Source output commands 3-15
Source preset 1-17, 3-12
Source ranges 3-2
Sourcing current 3-13
SPE, SPD (serial polling) 10-23, 11-9
SRQ 11-7

Standard event status 11-11

Status byte
 and service request (SRQ) 11-7
Status byte register 11-7
Status messages B-2
Status registers 11-10
 Bit descriptions 11-10
 Condition 11-17
 Enable 11-5
 Event 11-18
 Measurement 11-14
 Operation 11-12
 Questionable 11-16
 Reading 11-6
 Service request enable 11-8
 Standard 11-11

Sweep
 Customized 4-6
 Linear staircase 4-4
 Logarithmic staircase 4-5
System connections
 PC control 5-7
 Stand-alone system 5-6

T

Terminator 10-25
Test fixture 2-20
Test systems
 PC control 5-5
 Stand-alone 5-4
Timestamp 13-7
Triax cable 2-15
 Cable Guard 2-9
Triax connector 2-2
 Inner shield 2-7
 Output low 2-7
Trigger Link 5-7
Trigger link adapter 1-6
Trigger link cables 1-6

U

Unaddress commands C-11
Uniline commands C-9
Units 13-7
Universal multiline commands C-9
Unpacking 1-4
User setups 1-24, 1-25
Using common commands and SCPI commands
 in the same message 10-17

W

- Warranty information [1-3](#)
- Waveform triggering [7-10](#)
 - Front panel control [7-11](#)
 - Inactive value [7-12](#)
 - Programming [7-26](#)
 - Remote control [7-11](#)
 - Retriggering behavior [7-12](#)
 - Using [7-12](#), [7-20](#)

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