

# Model 2290-5 5 kV Power Supply

## User's Manual

2290-5-900-01 Rev. A / December 2013



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2290-5-900-01

A Greater Measure of Confidence

**KEITHLEY**  
A Tektronix Company

Model 2290-5  
5 kV Power Supply  
User's Manual

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# Safety precautions

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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 nonhazardous 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 user documentation for complete product specifications.

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

The types of product users are:

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

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

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

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

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

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

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

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

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

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

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

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

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


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


Do not exceed the maximum signal levels of the instruments and accessories, 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 the same type and rating for continued protection against fire hazard.


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

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


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

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

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

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

The  symbol indicates a connection terminal to the equipment frame.

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

The **WARNING** heading in the user documentation explains 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 the user documentation 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., a data acquisition board for installation into a computer) should never require cleaning if handled according to instructions. If the board becomes contaminated and operation is affected, the board should be returned to the factory for proper cleaning/servicing.

Safety precaution revision as of January 2013.

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## Introduction

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## Welcome

Thank you for choosing a Keithley Instruments product. The Model 2290-5 5 kV power supply is designed for use in the laboratory and for test applications. It also has excellent regulation and low output voltage ripple. The digital displays provide accurate readings of voltage and current and also provide for easy, precise setting of output values using digital entry of current and voltage values. Output voltage can be set from the front panel, using a remote analog voltage, or over the standard IEEE-488 interface. Voltage and current analog outputs are also available for remote monitoring and analog control.

## Extended warranty

Additional years of warranty coverage are available on many products. These valuable contracts protect you from unbudgeted service expenses and provide additional years of protection at a fraction of the price of a repair. Extended warranties are available on new and existing products. Contact your local Keithley Instruments representative for details.

## Contact information

If you have any questions after you review the information in this documentation, please contact your local Keithley Instruments representative or call Keithley Instruments corporate headquarters (toll-free inside the U.S. and Canada only) at 1-888-KEITHLEY (1-888-534-8453), or from outside the U.S. at +1-440-248-0400. For worldwide contact numbers, visit the Keithley Instruments website (<http://www.keithley.com>).



## CD-ROM contents

The Series 2290 Power Supply Product Information CD-ROM contains:

**User's Manuals:** Includes information about optional accessories, operation topics, remote operation, performance verification, troubleshooting, and application examples that you can use as starting point to create your own applications.

**LabVIEW™ Driver and IVI Driver software:** Instrument drivers are used to communicate with an instrument and help to control it.

## Organization of manual

**Getting started:** Front and rear panel familiarization, LED displays.

**Safe connection:** Configuration and test setup.

**Basic operations:** Set the voltage source, set the voltage trip limit, and set the current limit.

**Remote operation:** Remote interfaces and commands.

**Status messages:** Description of the Model 2290-5 status messages.

**Errors:** Error numbers with descriptions.

**Typical applications:** Detailed examples of how to use commands to accomplish certain test applications.

**Performance verification:** Environmental conditions, test equipment, and verification procedures.

**Troubleshooting:** Description of commonly encountered issues and information on how to resolve them.

## Features

The key features of the Model 2290-5 include:

- High-voltage operation – Source voltages up to a maximum of 5 kilovolts (kV).
- 25 W power capability – Source currents up to 5 milliamps (mA) at 5 kV.
- Ease of use – Digital displays and the keypad simplify setting the voltage and current parameters.
- Programmable voltage limit – Voltage limit can be preset to ensure safe operation.
- Programmable current limits – Current limit and trip point can be preset to prevent possible equipment damage.
- Output filter – Reduces output ripple and noise.
- Monitor outputs – Provide 0 – 10 V signals that can be used to monitor the high-voltage output and current.
- External voltage control – Allows the high-voltage output value to be controlled with a 0 – 10 V input signal.
- Standard IEEE-488 interface – Allows the instrument to be remotely controlled by a personal computer.
- Safety interlock – Connections to an internal circuit that shuts down the high-voltage output when an external circuit is opened. The external circuit would typically include a limit switch on a test fixture door.

## Unpacking and inspecting

### Inspect for damage

Upon receiving the Model 2290-5, carefully unpack the unit, and inspect for any obvious signs of physical damage that might have occurred during shipment. Notify the shipping agent of any damage immediately.

### Shipment contents

The following items are included with every Model 2290-5 order:

- Model 2290-5 high voltage power supply
- Model 2290-5 product information CD-ROM
- AC line power cord
- Model 2290-5 additional accessories, as ordered

## Optional accessories

The following optional accessories are available for use with the Model 2290-5:

### Connecting cables and connectors

- Model 2290-5-SHV – SHV plug to SHV plug cable; 3.05 meters (10 feet).
- Model 2290-5-MHV – SHV plug to MHV male cable; 3.05 meters (10 feet).
- Model 2290-INT-CABLE – 3-pin interlock connector to unterminated cable; 3.05 meters (10 feet).
- Model 2290-5-SHVBH – SHV male bulkhead connector.

### Rack mount kits

- Model 2290-5-RMK-2 – double rack-mount kit; mounts two power supplies side-by-side.
- Model 2290-5-RMK-1 – single rack-mount kit; mounts a single power supply.
- Model 4299-7 – shelf rack-mount kit; mounts one or two power supplies.

### Protection module

#### Model 2290-PM-200

The protection module is intended for use in applications where a device breakdown or other potential failure could connect the high-voltage output of the Model 2290-5 or Model 2290-10 High Voltage Power Supply to a lower voltage source-measure unit (SMU).

## Front-panel familiarization

The Model 2290-5 front panel is shown below. Descriptions of the controls on the front panel follow the figure.

Figure 1: Model 2290-5 front panel

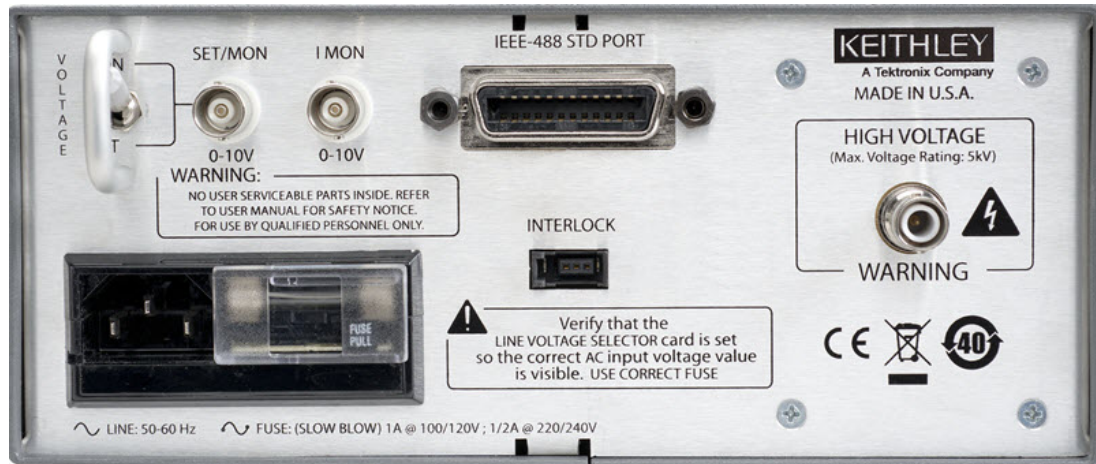


<b>POWER</b> button	Press the <b>POWER</b> button so that it is in the on position to turn the instrument on. Press the <b>POWER</b> button so that it is in the off position to turn it off.
<b>HIGH VOLTAGE</b> enable switch	This is a three position switch. In the <b>OFF/RESET</b> position, the high voltage is off, and all trips are cleared. In this position, the high voltage is locked off and cannot be turned on by computer control. The <b>ON</b> position is a momentary-contact position and turns on the high voltage for manual or rear panel analog control. Note that the switch should be held in the <b>ON</b> position for at least a half second to turn the high voltage on. In the middle position, the high voltage is enabled and can be turned on by commands sent over the IEEE-488 bus. The <b>ON</b> LED above the switch indicates that the high voltage is on; the yellow <b>TRIP</b> LED indicates a trip has occurred.
<b>VOLTS</b> LED display	Displays the output voltage.
Center LED display	Displays the value of the parameter that is entered or adjusted, including <a href="#">Error and status messages</a> that may occur.
<b>mA</b> LED display	Displays the output current.
<b>SELECT, ENTER, CLR</b> (Clear) button	The <b>SELECT</b> button is used to choose which parameter is being displayed in the center display. The <b>ENTER</b> button enters the parameter shown in the center display. The <b>CLR</b> (clear) button erases the value in the center display and recalls the last value that was entered.
Numeric and cursor buttons	All parameters are adjusted using the cursor or numeric buttons.
<b>STATUS</b> indicators	Three LEDs indicate the instrument's status. The <b>LIMIT</b> LED is on when the unit is in current limit. The <b>REM</b> LED is on when the unit is in remote, and the front panel is locked out. The <b>FILTER</b> LED is on when one of the two available output filters is enabled.
<b>RESET</b> button	Reset mode determines how the instrument responds after a voltage or current trip. There are two modes: <b>MAN</b> and <b>AUTO</b> . In <b>MAN</b> (manual) mode the high voltage remains off after a trip and requires that the operator manually turn it back on. In <b>AUTO</b> (automatic) mode the unit waits until the output voltage has fallen to 2% of its full-scale value and then turns the high voltage back on. This feature is useful when dealing with loads that occasionally short circuit, but recover after high voltage has been removed.
<b>FILTER</b> buttons	The output filter, which may be used to reduce output ripple and noise, is controlled with the <b>FILTER</b> , <b>NO FILTER</b> , <b>FILTER 1</b> , and <b>FILTER 2</b> buttons.
<b>GPIB ADDR</b> buttons	The GPIB address buttons set the GPIB primary address.
<b>LOCAL</b> button	The <b>LOCAL</b> button takes the instrument out of remote and restores operation of other front panel controls.
<b>STO</b> and <b>RCL</b> buttons	<b>STO</b> (store) and <b>RCL</b> (recall) allow up to nine complete instrument settings to be saved in nonvolatile memory. <b>RCL 0</b> recalls the default settings.

## Rear-panel familiarization

The Model 2290-5 rear panel is shown below. Descriptions of the controls on the rear panel follow the figure.

**Figure 2: Model 2290-5 rear panel**



Power entry	The power entry module contains the line fuse, the line voltage selection, and includes filtering to block high-frequency noise from entering or exiting the unit. Refer to the <a href="#">Safely connect to instruments</a> topic for instructions on selecting the correct line voltage and fuse.
<b>HIGH VOLTAGE</b> output port	The <b>HIGH VOLTAGE</b> output port is an SHV male port that connects the Model 2290-5 source output to external equipment. SHV-to-SHV and SHV-to-MHV mated high voltage cables are available.
Analog I/O	The <b>SET/MON</b> and <b>I MON</b> BNC jacks provide voltage and current monitor signals, or an external voltage control input and current monitor, depending upon the setting of the <b>VOLTAGE</b> select switch. If the switch is in the <b>MON</b> (monitor) position, the front panel controls the voltage. If the switch is in the <b>SET</b> position, the rear panel analog voltage will control the output voltage. When the <b>VOLTAGE</b> select switch is in the <b>MON</b> (monitor) position, both jacks are 0 to +10 V outputs corresponding to 0 to full scale. For example, if the voltage source output is 2 kV, the <b>SET/MON</b> jack output voltage will be 4 V.
<b>IEEE-488 STD PORT</b>	The 24-pin IEEE-488 (GPIB) port allows computer control of the Model 2290-5.
<b>INTERLOCK</b> port	The contacts of the interlock port allow an external limit switch in the connector path. The circuit must be engaged to allow high-voltage output.

## Line cord

The Model 2290-5 uses a detachable, three-wire power cord for connection to the power source and to a safety earth ground through a grounded AC outlet. Only use the power cord that's provided with your instrument, or an equivalent adequately rated power cord.

### WARNING

*The exposed metal parts of the instrument are connected to the outlet ground through the line cord to provide protection against electrical shock. Always use an AC outlet that has a properly connected safety ground.*

## Connect to other instruments

The rear panel SET/MON and I MON BNC jack shields are connected to chassis ground and the AC power source ground using the power cord. Do not apply any voltage to the shields. The HIGH VOLTAGE SHV port is also connected to chassis ground and cannot be floated above ground.

### WARNING

*This unit contains hazardous voltages. Be absolutely certain that the high voltage is completely discharged before removing or connecting the high-voltage cable. High-voltage cables can store charge if they are disconnected from the supply while high voltage is turned on, and can cause personal injury or death if not handled properly. Use only connecting cables with a rated working voltage of 5 kV or higher (see the [Optional accessories](#) section for more information).*

*Do not connect the high-voltage output to exposed circuitry. And load connected to the high-voltage output should be enclosed in a metal shield that is connected to safety earth ground using #18 AWG or larger wire.*

*If the instrument is used in a manner not specified by Keithley Instruments, the protection provided by the equipment may be impaired.*

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## Safe configuration and test setup

### In this section:

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## Introduction

The Model 2290-5 can generate hazardous voltages. It is intended for use with a test fixture or in a test system that has safety mechanisms in place to prevent an operator from accessing these voltages.

This section describes how to use the Model 2290-5 to test a device with a custom test fixture or system.

## High voltage safety precautions

Make sure that you read and observe the following high voltage safety precautions before operating the Model 2290-5.

### WARNING

*The Model 2290-5 is capable of sourcing hazardous live high voltages that can cause personal injury or death due to electric shock. This unit should be used only by qualified personnel who recognize the dangers of high voltages.*

*Make certain that the source is turned off and that high voltage is completely discharged before removing the high-voltage cable. High-voltage cables can store charge if they are disconnected from the supply while the high voltage is on. The charge on the cable can cause injury or damage even after the cable is disconnected from the unit.*

*The Model 2290-5 is provided with an interlock circuit that must be engaged to allow high voltage output. The interlock helps facilitate safe operation of the equipment in a test system. Bypassing the interlock could expose the operator to hazardous voltages that could result in personal injury or death.*

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## Safely connect to instruments

### Line voltage selection

There are three versions of the Model 2290-5 to allow operation from a 100, 120, 220, or 240 V nominal AC power source with a line frequency of 50 or 60 Hz. Before connecting the power cord to a power source, verify that the line voltage selector card, located in the rear panel fuse holder, is set for the correct AC line voltage.

The following table indicates the three versions of the Model 2290-5 5 kV power supply and their respective line voltage:

Model	Nominal voltage
2290-5	120 V AC
2290E-5	220/240 V AC
2290J-5	100 V AC

### CAUTION

This instrument may be damaged if operated with the line voltage selector set for the wrong AC line voltage, or if the wrong fuse is installed.

### Line fuse

Verify that the correct line fuse is installed before connecting the line cord as follows:

Model	Line voltage	Fuse type	Keithley fuse part number
2290-5	120 V AC	1 A, 250 V, 3 AG, Slow Blow	FU-10
2290J-5	100 VAC		
2290E-5	220/240 V AC	1/2 A, 250 V, 3 AG, Slow Blow	FU-4

## Interlock circuit

An interlock circuit is provided on the rear panel of the instrument. This circuit must be engaged to allow the Model 2290-5 to produce output voltages. When the safety interlock signal is engaged, all voltage ranges of the instrument are available. However, when the safety interlock signal is disengaged, the output voltage is turned off.

### WARNING

*The Model 2290-5 is provided with an interlock circuit that must be engaged to allow high voltage output. The interlock helps facilitate safe operation of the equipment in a test system. Bypassing the interlock could expose the operator to hazardous voltages that could result in personal injury or death.*



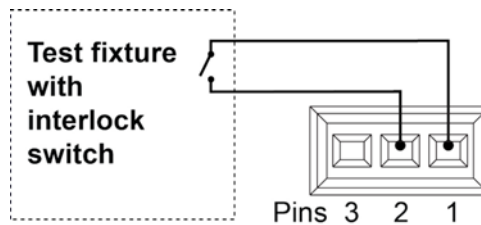
## Connecting the interlock of the Model 2290-5

The interlock pins control the high-voltage supply.

The pin locations and connections are shown in the following figure. The pins are:

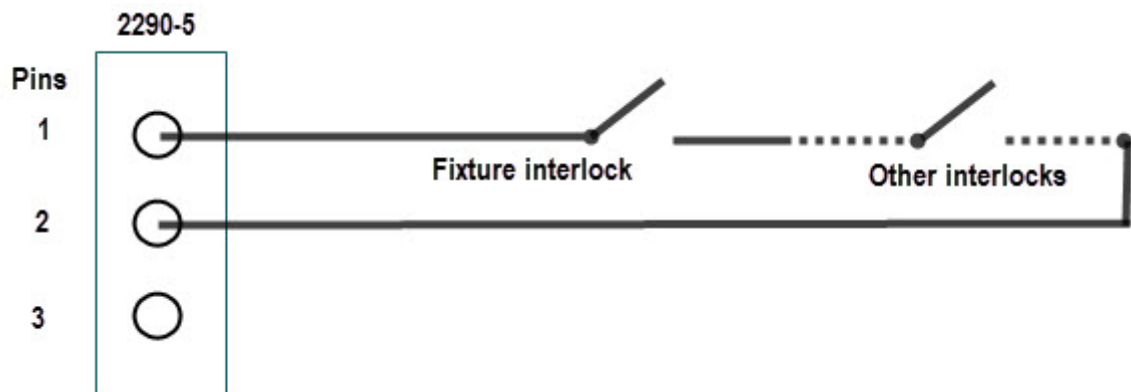
- Pin 3: Chassis ground
- Pin 2: Interlock enable
- Pin 1: +5 V DC out (current limited)

**Figure 3: Model 2290-5 Interlock connector wiring**



The following figure shows how to connect the Model 2290-5 internal 5 V source in order to engage the external interlock (or interlocks) circuits:

**Figure 4: Model 2290-5 Internal 5 kV source**



## Connecting the Model 2290-5 output to a custom test fixture

Keithley Instruments offers several accessories that can help you when building a custom test fixture or system.

You can use a high-voltage SHV bulkhead connector (Model 2290-5-SHVBH) on your test fixture. The following sections show you how to connect a Model 2290-5 to a custom fixture and also how to make connections to the device inside the custom fixture.

### Using SHV coaxial connections

#### **⚠ WARNING**

*If you need to convert from safe high-voltage (SHV) to another connector type, be sure to only adapt SHV connectors to connectors that are rated to the maximum possible voltage in your test setup. If you use adapters that are not rated to the maximum possible voltage in your test setup, electric shock may result.*

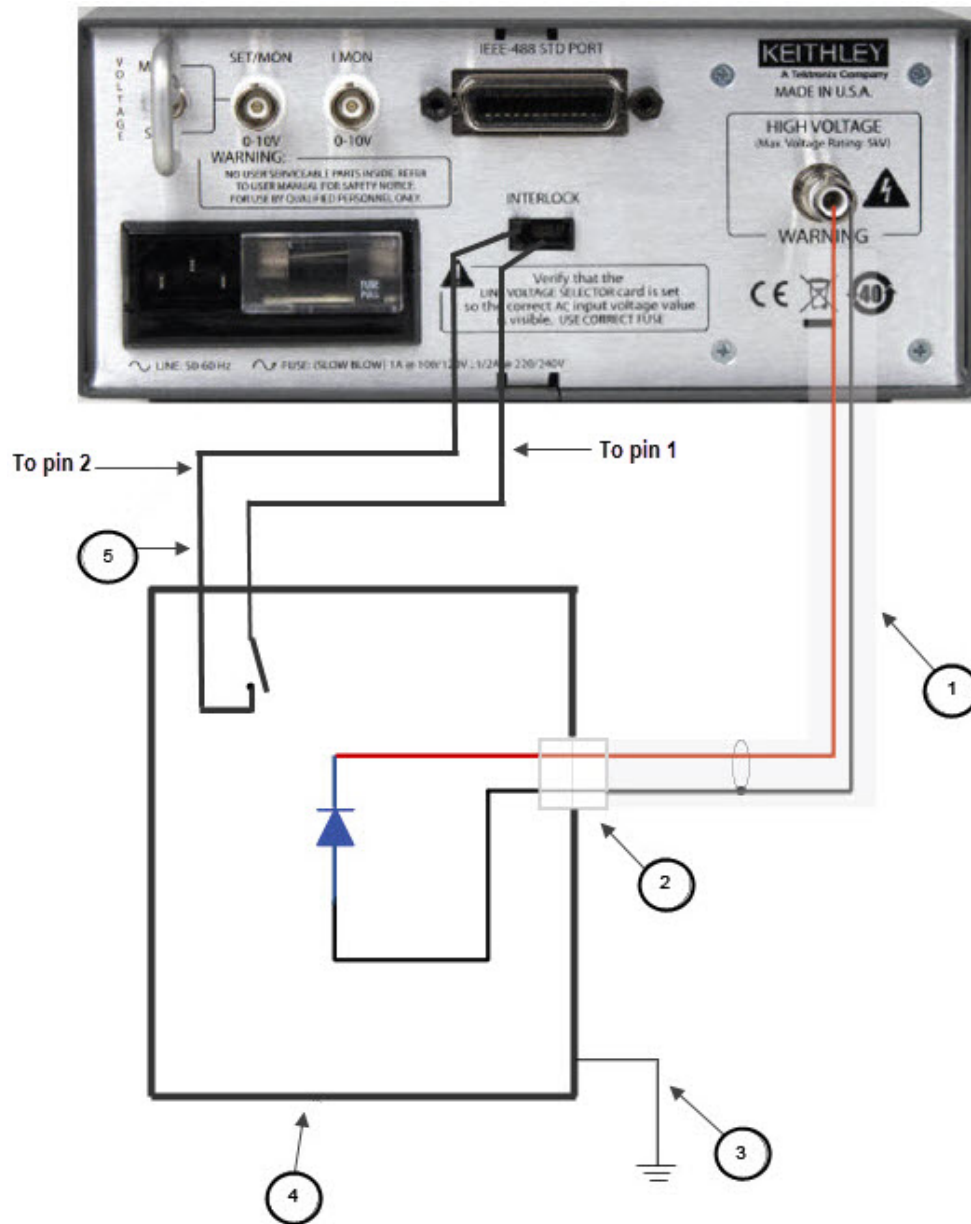
**Device connections**

Equipment used in the next figure:

- 1 high-voltage diode enclosed in a safe test fixture
- 1 Model 2290-5 high-voltage power supply
- 1 Model 2290-5-SHV cable
- 1 Model 2290-5-SHVBH bulkhead connector

The next figure shows a test configuration using the Model 2290-5 power supply with a safe interlock test enclosure circuit:

**Figure 5: Model 2290-5 high-voltage output connections**



Item	Description	Notes
1	Model 2290-5-SHV high-voltage cable	
2	Model 2290-5-SHVBH high-voltage male bulkhead connector	
3	Test fixture protective earth (safety ground)	
4	Test fixture interlocked metal safety enclosure	A safety enclosure with an interlock that has a normally open (NO) switch.
5	Test fixture lid interlock switch connection	Connect pin 1 (+5 V DC out) and pin 2 (interlock).

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## Basic operations

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Analog programming and monitor.....	3-4
Set output voltage .....	3-6
Turn output on.....	3-6
Set voltage limit.....	3-6
Set current limit .....	3-7
Set current trip.....	3-7

## Numeric and cursor buttons

All parameters are adjusted using the cursor or numeric buttons. When using the cursors, the adjusted digit in the center display will flash. When using direct numerical entry, press the number and decimal point buttons until the desired value appears on the center display. Note that the current is specified in mA.

The cursor buttons are used to adjust parameters:

- Up arrow increments the digit
- Down arrow decrements the digit
- Left arrow cursor selects and moves the digit to the left
- Right arrow cursor selects and moves the digit to the right

## Select, Enter, Clear

To adjust a value, press the **SELECT** button until the appropriate LED is lit (for example, the VOLTAGE LEDs SET or LIMIT). While the value is changing, the appropriate LED will flash indicating that the value in the center display is not the present unit setting. If an incorrect value is entered, press **CLR** (clear) to start over. When the desired value is in the center display, press the **ENTER** button to update the unit's actual setting, and the LED will stop flashing.

## Output filter

The Model 2290-5 employs a switchable output filter for low noise performance. If higher slew rate or output power is required, the filter can be disabled. When the filter is enabled, the unit can reach either maximum voltage or maximum current but not both simultaneously. The filter has three possible settings: Filter Disabled (Filter 0); Filter Enabled, High Current (Filter 1); and Filter Enabled, High Voltage (Filter 2).

The output filter determines the voltage and current limits, as well as the ripple and noise performance of the unit. Note that the noise reduction characteristics for the two filters are identical, but other factors such as rise and discharge times virtually depend on the selected filter (see specifications). See the specifications for information on ripple and noise for the different filter settings. The voltage and current limits for the different filter settings are listed in the next table.

Filter mode	Voltage limit	Current limit	Current trip
Filter out (Filter 0)	5000 VDC	5.25 mA	5.25 mA
High Current Filter (Filter 1)	3000 VDC	5.25 mA	5.25 mA
High Voltage Filter (Filter 2)	5000 VDC	3.25 mA	3.25 mA

It is recommended that you turn off the output before changing the filter. If the filter is changed while the high voltage is on, the unit will turn off the high voltage and wait until the voltage has dropped below 100 VDC before switching the filter. This is done to minimize stress on the filter components. During this time, the HIGH VOLTAGE ON switch is disabled. If the filter is changed while the high voltage is off, it will switch immediately.

To display and change the present filter value:

1. Press the **FILTER** button to display the current filter selection in the center display.
2. Press **FILTER 1** or **FILTER 2** at the **FIL** display prompt (the associated FILTER LED will turn on to indicate that the filter is enabled).
3. Enter a new filter value (enter the value), then press the **ENTER** button.
4. To turn off filtering, press **FILTER** then **NO FILTER** followed by **ENTER**.

### NOTE

If an illegal value is entered, the unit will display Err2 (illegal parameter entered). Use the **CLR** button to clear any error messages.

## Store and recall

STO (store) and RCL (recall) allow up to nine complete instrument setups to be saved in nonvolatile memory and later recalled.

To store a setup:

1. Program the various instrument operating modes to be stored.
2. Press the **STO** button.
3. Press a number (**1 to 9**) to select the desired storage location.
4. Press the **ENTER** button to complete the storage process.

To recall a setup:

1. Press the **RCL** button.
2. Press the number button (**1 to 9**) for the configuration to be recalled. (RCL 0 returns the instrument to the factory default setup.)
3. Press the **ENTER** button.

### NOTE

Whenever a setup is recalled, the high voltage is turned off for safety.

If an Err3 (recall error) occurs, the stored setup was lost due to a memory error and must be stored again using the **STO** button.

The factory default setup can be recalled by pressing the **CLR** button while turning on the power or by recalling setup 0 (RCL 0). The default setup is also recalled after a power-on memory error (Err 1). The next table lists the factory default setup.

Mode	Default setting
Output voltage	0 V
Voltage limit	5000 V
Current limit	5.25 mA
Current trip	5.25 mA
Reset mode	MAN
High voltage	OFF
GPIB address	14
Filter	OFF

## Analog programming and monitor

The rear panel VOLTAGE select switch determines whether the output voltage is set from the front panel or from the rear panel SET/MON input. If the switch is in the MON (monitor) position, use the front panel controls. If the switch is in the SET position, use the rear panel analog voltage to control the output voltage.

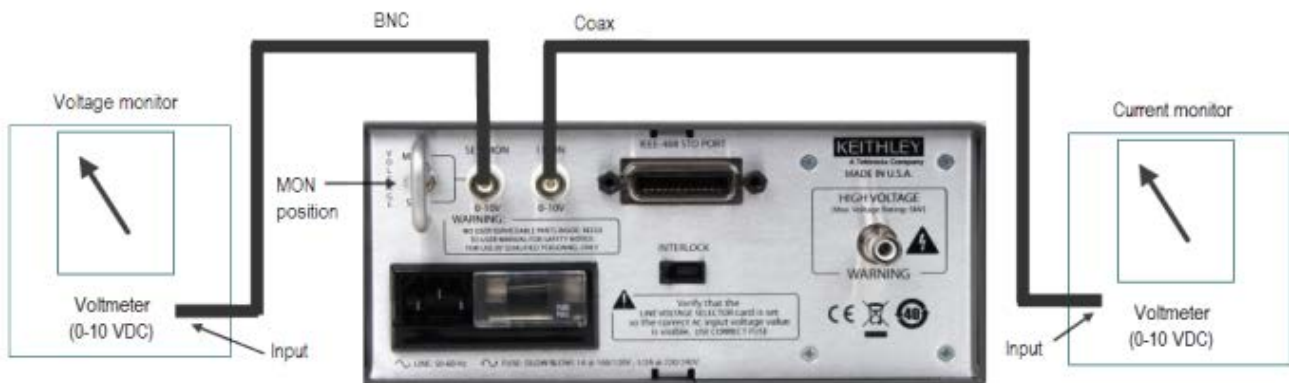
When the VOLTAGE switch is in the SET position, the I MON jack remains an output signal, the SET/MON jack becomes an input signal and sets the high voltage source value over the same range as the control voltage input. For example, a 2 V analog voltage input results in a 1 kV source output voltage. When the switch is in the SET position, the REAR LED on the front panel is lit, indicating that high voltage is under analog control and cannot be adjusted using the front panel buttons. All signals are positive voltages.

The next two figures show examples of analog output connections.

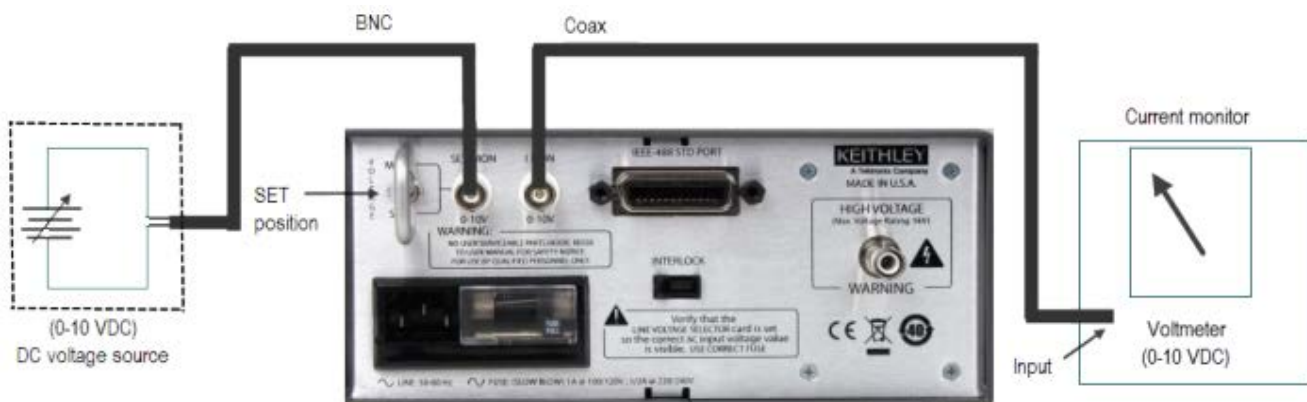
**⚠ WARNING**

*The BNC jack outer shells are connected to chassis ground and cannot be floated.*

**Figure 6: Model 2290-5 voltage and current monitor connections**



**Figure 7: Model 2290-5 Voltage set connections**



When the VOLTAGE switch is in the SET position, the REAR (rear panel) LED is on, and the output voltage is controlled by the rear panel signal and displayed on the center display when in the VOLTAGE SET mode. The voltage limit is still active, and the unit does not allow the rear panel voltage to set the output value above the voltage limit.

**NOTE**

If the VOLTAGE switch position is changed while the high voltage is on, the unit will turn off the high voltage.

Voltage Monitor: When the VOLTAGE switch is in the MON position, the SET/MON jack is a monitor output providing 0 to +10V for 0 to full-scale output. The next table lists the voltage monitor examples.

Output voltage	Analog monitor examples
1 kV	2 V
3.5 kV	7 V
5 kV	10 V
2.5 kV	5 V

Voltage Set: When the switch is in the SET position, this BNC jack becomes an input over the same range. An input of 0 V to +10 V will set the output voltage from 0 V to full scale. The next table summarizes the analog input voltage examples.

Analog input voltage	High voltage output
2 V	1 kV
5 V	2.5 kV
6 V	3 kV
10 V	5 kV

Current Monitor: The I MON jack provides a 0 to +10V signal for 0 to full-scale current output. The next table summarizes the current monitor output examples.

Current output	Current monitor
1 mA	2 V
2.5 mA	5 V
3.5 mA	7 V
5 mA	10 V



## Set output voltage

To manually set the output voltage, with the high voltage on or off (refer to the [Front-panel familiarization](#) graphic for more information):

1. Press the **SELECT** button until the **VOLTAGE SET LED** is on. The present voltage setting will appear on the center display.
2. To change the voltage setting, enter the desired voltage using either the numeric or cursor buttons.
3. After the new value has been entered into the center display, press **ENTER** to update the output voltage.

### NOTE

The VOLTAGE SET LED will flash until **ENTER** or **CLR** is pressed to remind you that the displayed value is not the actual programmed value.

If an Err2 message appears (illegal parameter entered), check the voltage limit to see that it is greater than or equal to the desired set voltage. Use the **CLR** button to clear any error message (see the [Set voltage limit](#) topic for more information).

If the REAR LED is on, the high voltage is programmed from the voltage applied to the analog input on the rear panel. In this mode, the high voltage cannot be programmed from the front panel, and the center display will show the actual output voltage in the VOLTAGE SET mode.

If you want to set the output voltage remotely, refer to [Voltage set](#) (see [VSET\(?\) <n>](#)). To set the output voltage using the rear panel analog input, refer to [Analog programming and monitor](#).

## Turn output on

Once you have set the voltage limit, you must press the HIGH VOLTAGE enable switch (see [Set voltage limit](#) for more information).

### NOTE

The switch should be held in the ON position for at least a half second to turn the high voltage on. If the interlock is open, an `iloc` error message appears on the center display, the voltage will be 0, and the yellow TRIP LED indicates that a trip has occurred (see [Front-panel familiarization](#) for more information).

## Set voltage limit

The voltage limit is a protection feature intended to prevent the output voltage from being set too high or from overshooting because of large load changes. The output voltage cannot be set higher than the voltage limit. In addition, if the output voltage ever exceeds the programmed limit by more than 10% of full scale, the trip point is reached, and the high voltage is disabled. In this case, a VTRP (voltage trip) message appears on the center display.

### NOTE

It is not necessary to clear the trip before turning the high voltage back on. If it is necessary to change a parameter before turning the high voltage back on, pressing **CLR** or placing the high voltage switch in the off position will clear the trip.

Set the voltage limit as follows:

1. Press the **SELECT** button until the **VOLTAGE LIMIT LED** is lit. The present value of the voltage limit is shown on the center display.
2. Change the limit value using either the numeric or cursor buttons.
3. Press **ENTER** to update the actual limit value.

## NOTE

If an Err2 message appears (illegal parameter entered), check to see that the output voltage is less than or equal to the new desired voltage limit.

## Set current limit

The power supply output current is clamped at the current limit. If the current limit is reached, the output voltage may not equal its programmed value. When the unit is current limited, the STATUS LIMIT LED is on.

Set the current limit as follows:

1. Press the **SELECT** button until the mA **LIMIT LED** is on. The present value of the current limit is shown on the center display.
2. Change the limit value using either the numeric or cursor buttons.
3. Press **ENTER** to update the actual limit value.

## Set current trip

The current trip shuts off the high voltage when the output current exceeds the trip value. The current trip value is set in the same manner as the voltage and current limits. After a current trip occurs, the ITRP (current trip) message will appear on the middle display. Current trips are cleared in the same fashion as voltage trips.

Set the current trip as follows:

1. Press the **SELECT** button until the mA **TRIP LED** is on. The present value of the current trip is displayed in the center window.
2. Change the limit value using either the numeric or cursor buttons.
3. Press **ENTER** to update the actual trip value.

---

## Remote operation

### In this section:

---

Introduction .....	4-1
Command syntax .....	4-3
Remote commands .....	4-4

## Introduction

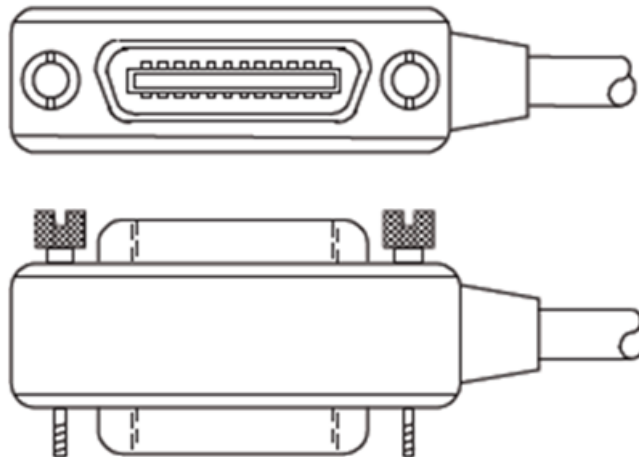
This section contains detailed information on remotely programming the Model 2290-5 over the IEEE-488 (GPIB) interface. Any computer that supports the IEEE-488 bus may be used to program the instrument. The Model 2290-5 supports the IEEE-488.1 (1978) interface standard, as well as the required common commands of the IEEE-488.2 (1987) standard.

The cabling distance between the controller and instrument hub with GPIB is limited to 9 meters (30 feet). In a system connected with GPIB, you can have 15 instruments attached to each controller.

## Connect GPIB cables to your instrument

To connect an instrument to the GPIB, use a cable equipped with standard GPIB connectors, as shown below.

**Figure 8: GPIB Connector**

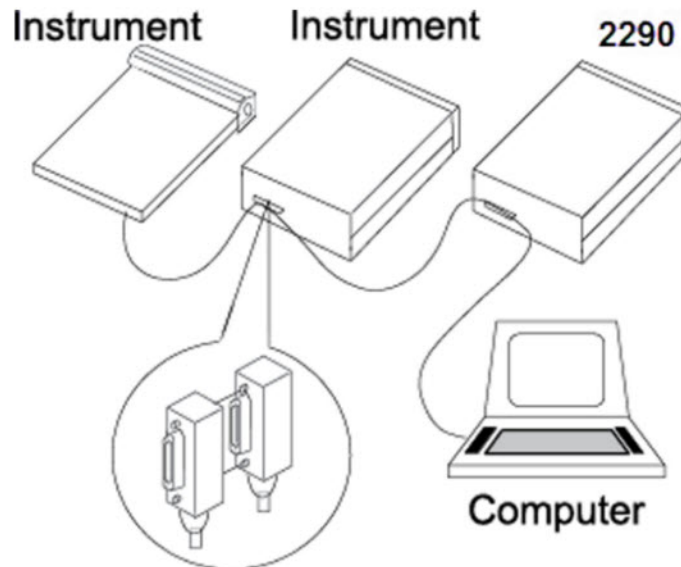


To make a parallel connection to the instrument, stack the connectors. Each connector has two screws to ensure that connections remain secure. The figure below shows a typical connection diagram for a test system with multiple instrument .

### ⚠ CAUTION

To avoid possible mechanical damage, stack no more than three connectors on any one instrument. To minimize interference caused by electromagnetic radiation, use only shielded GPIB cables. Contact Keithley Instruments for shielded cables.

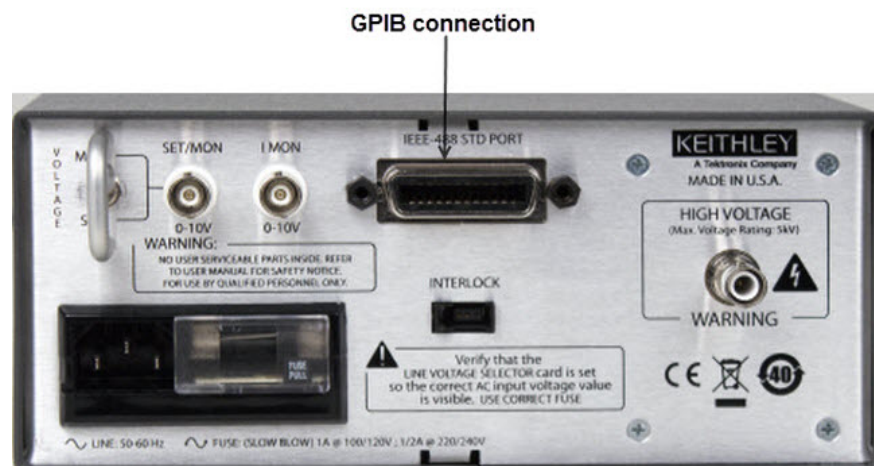
**Figure 9: Model 2290-10 GPIB example connections**



**To connect the instrument to the GPIB:**

1. Align the cable connector with the port on the rear panel. The location of the port is shown in the following figure.
2. Attach the connector. Tighten the screws securely but do not overtighten them.

**Figure 10: Model 2290-5 rear panel GPIB location**



3. Connect any additional connectors from other instruments, as required for your application.
4. Ensure the other end of the cable is properly connected to the controller.

## Set the GPIB address

Before attempting to communicate with the Model 2290-5 over the IEEE-488 interface, make sure the instrument's primary address is set correctly. To enter the GPIB address mode, press both **GPIB ADDR** buttons simultaneously and then increment or decrement the address as required using the up and down arrow buttons. The allowable primary address range is from 0 to 30. Be sure to avoid address conflicts with other instruments on the bus, including the controller.

## Bus connections

With the power off, connect the Model 2290-5 GPIB connector to the computer IEEE-488 interface. Shielded GPIB cables such as the Keithley Model 7007 are recommended.

## Command syntax

Commands sent to the Model 2290-5 use ASCII characters. Commands may be in either upper or lower case and may contain any number of embedded space characters.

A command to the Model 2290-5 must be followed by a command terminator. The terminator is a linefeed (<LF>) or EOI. No command processing occurs until a command terminator is received. Commands beginning with an asterisk (\*) are IEEE-488.2 defined common commands.

## Multiple commands

Multiple commands may be sent on one command line by separating them with semicolons (;). When several commands are included on the same line, the entire line is parsed and executed before any other device action proceeds. This method allows command synchronization using the synchronization command (\*WAI).

## Command buffer

The Model 2290-5 has a 256-character input buffer and processes commands in the order received. Therefore, it is not necessary to wait between commands. If the buffer becomes full, the Model 2290-5 will hold off bus handshaking until commands are processed. Similarly, the unit has a 256-character output buffer to store output data until the host computer is ready for reception. If the output buffer becomes full, it is cleared, and an appropriate error is reported.

## Command queries

The present value of a particular parameter may be determined by querying the Model 2290-5 for its value. A query is formed by appending a question mark (?) to the command and omitting the desired parameter from the command. If multiple queries are sent on one command line (separated by semicolons), responses will be returned in a single line with the individual responses separated by semicolons. The default response terminator is a linefeed (<LF>) plus EOI. All commands return integer results except as noted in individual command descriptions.

## Command examples

Command	Description
VSET 1.0E3	Sets the voltage to 1000 V.
VSET?	Queries the voltage setting.
*IDN?	Queries the device identification.
VSET 100.0;VSET?	Sets the voltage to 100 V and queries the voltage.

## Remote commands

The following Model 2290-5 commands are divided by the type of command: Output control, Setting control, Interface control, and Status reporting. Note that multiple parameters are separated by commas. Commands with queries are followed by a question mark in parentheses (?). Commands that have only a query include a "?". Commands that cannot be queried have no question mark. Brackets [ ] indicate the parameter is optional. An asterisk (\*) preceding the command indicates IEEE-488.2 common commands.

### NOTE

Parentheses shown in command descriptions indicate only that a query form is available. Do not include parentheses in commands.

## Output control commands

### HVOF

The `HVOF` command turns off the high voltage output.

### HVON

The `HVON` command turns on the high voltage provided that the front panel HIGH VOLTAGE switch is not in the OFF position. If the switch is in the OFF position, the high voltage is left off, and an execution error is reported. This command also automatically clears any voltage or current trips.

### NOTE

An Err6 (syntax error over GPIB) may appear when sending this command. To avoid this situation, insert a `*WAI` (wait command) before `HVON`. The command string `*WAI ; HVON` is valid.

### IOUT?

The `IOUT?` query returns the value of the actual output current. This value is the same as that shown on the front panel mA display.

### NOTE

As with the front panel display, this value takes about one second to stabilize after a change in current.

## VOUT?

---

The `VOUT?` query returns the actual output voltage. This value is the same as that shown on the front panel VOLTS display. The value returned is a floating-point number and includes the positive sign of the output voltage.

### NOTE

As with the front panel voltage display, this value takes about one second to stabilize after a change in voltage.

## Setting control commands

### \*RCL <n>

---

The `*RCL` (Recall) command recalls stored configuration setting <n>, where <n> ranges from 0 to 9. Setting 0 recalls the default settings. If the stored setting is corrupted, an error is returned.

**Example:**                      `*RCL 0`                      Recall default setting

### \*SAV <n>

---

The `*SAV` (Save) command stores the present instrument setup as setting <n>, where <n> ranges from 1 to 9.

**Example:**                      `*SAV 3`                      Save setting #3

### ILIM(?) <n>

---

The `ILIM` command sets the value of the current limit to <n>, where <n> is a floating-point value in amperes. The `ILIM?` query returns the current limit setting.

**Example:**                      `ILIM 1E-3`                      Set 1 mA current limit

Default value: 5.25 mA

### ITRP(?) <n>

---

The `ITRP` command sets the value of the current trip to <n>, where <n> is a floating-point value in amperes. The `ITRP?` query returns the current trip setting.

**Example:**                      `ITRP 1E-3`                      Set 1mA trip current

Default value: 5.25 mA

---

**SMOD?**

---

The `SMOD?` query returns the `VSET` setting mode. A returned value of 0 indicates that the voltage value is controlled by the front panel or bus setting, while the value 1 indicates that the output is controlled by the rear panel SET/MON voltage control input. Note that the setting mode may only be changed by setting the rear panel VOLTAGE switch.

---

**TCLR**

---

The `TCLR` command clears any voltage or current trips.

---

**TMOD(?) <n>**

---

The `TMOD` command sets the trip reset mode. The value `<n> = 0` sets manual trip reset, while the value `<n> = 1` sets the trip reset mode to automatic.

---

**VLIM(?) <n>**

---

The `VLIM` command sets the value of the voltage limit to `<n>`, where `<n>` is in volts. The `VLIM?` query returns the present limit setting. As with front panel control, the `VLIM` value must be greater than or equal to the `VSET` value, or an execution error will occur.

**Example:**                      `VLIM 500`                      Set 500 V voltage limit

Default value: 5000 V

---

**VSET(?) <n>**

---

The `VSET` command sets the voltage output level to `<n>`. If rear panel control is enabled, an error is returned. The value `<n>` is in volts. The `VSET?` query returns the current `VSET` value. As with front panel control, the `VSET` value must be less than or equal to the `VLIM` value, or an execution error will occur.

**Example:**                      `VSET 2500`                      Set output to 2.5 kV

Default value: 0 V



## FILT(?) <n>

---

The `FILT` command controls the output filter, which is useful for reducing output ripple and noise. When `<n> = 0` the output filter is disabled, while `<n> = 1` and `<n> = 2` enable Filter 1 and Filter 2, respectively. The `FILT?` query returns the state of the filter.

**Example:**                      `FILT 1`                      Enable Filter 1

Default value: 0

### NOTE

When the filter is changed, the high voltage is turned off. The unit does not actually change the filter until the high voltage has dropped below 100 VDC. If the high voltage is turned on remotely while the filter is in the process of changing, an error will result. So if the commands `FILT 1;HVON` are sent, an Err7 (illegal GPIB command) will appear. To avoid this situation, insert a `*WAI` (wait command) between the two. The command string `FILT 1; *WAI;HVON` is valid.

For more information about the output filter, see the [Output filter](#) topic.

## Interface control commands

### \*RST

---

The `*RST` (Reset) common command resets the Model 2290-5 to its default configuration. This command performs the same function as holding down the front panel **CLR** button at power-on.

### \*IDN?

---

The `*IDN?` (Identification) common query returns the Model 2290-5 device configuration. The response string is in the format:

KEITHLEY INSTRUMENTS INC., MODEL 2290-5, <serial\_number>, <version\_number>

Where:

2290-5 is the model number.

serial\_number is the serial number of the particular unit.

version\_number is the 3-digit firmware version level.

### \*WAI

---

The `*WAI` common command is a synchronization command that halts further command processing until all present commands are complete. For example, the commands `FILT 1; *WAI;HVON` will change the output filter setting, wait until the operation is complete, and turn the high voltage back on.

## Status reporting commands

The following commands control various status reporting aspects.

### \*CLS

---

The `*CLS` (Clear Status) common command clears all status registers.

**\*ESE(?) <n>**

---

The \*ESE common command sets the Standard Event Status Enable Register. The parameter <n> is the decimal value that programs the enable register.

**Example:**                    \*ESE 12                    Set bits 2 and 3

**\*ESR? [<n>]**

---

The \*ESR? common query reads the value of the Standard Event Status Register. If the parameter <n> is present, the value of bit <n> is returned. Reading this register without specifying <n> will clear the register, but reading bit <n> will clear only bit <n>. The range of <n> is 0 to 7.

**Example:**                    ESR? 2                    Request and clear bit 2

**\*PSC(?) <n>**

---

The \*PSC (Power-on Status Clear) common command sets the value of the power-on status clear bit. If <n> = 1, the power-on status clear bit is set, and all status registers and enable registers are cleared on power-up. If <n> = 0, the bit is cleared, and the status enable registers maintain their values at power-down. This feature allows the generation of a service request at power-up.

**Example:**                    \*PSC 1                    Set power-on status clear bit

**\*SRE(?) <n>**

---

The \*SRE (Service Request Enable) common command sets the value of the Service Request Enable Register. The parameter <n> is the decimal value representing the register bits to be set.

**Example:**                    \*SRE 3                    Set bits 0 and 1

**\*STB? [<n>]**

---

The \*STB? (Status Byte) common query reads the value of the Status Byte Register. If the parameter <n> is included, the value of bit <n> is returned. Reading this register has no effect on its value; it only represents the summary of the other status registers. The range of <n> is 0 to 7.

**Example:**                    \*STB? 1                    Request bit 1 status

# Status messages

**In this section:**

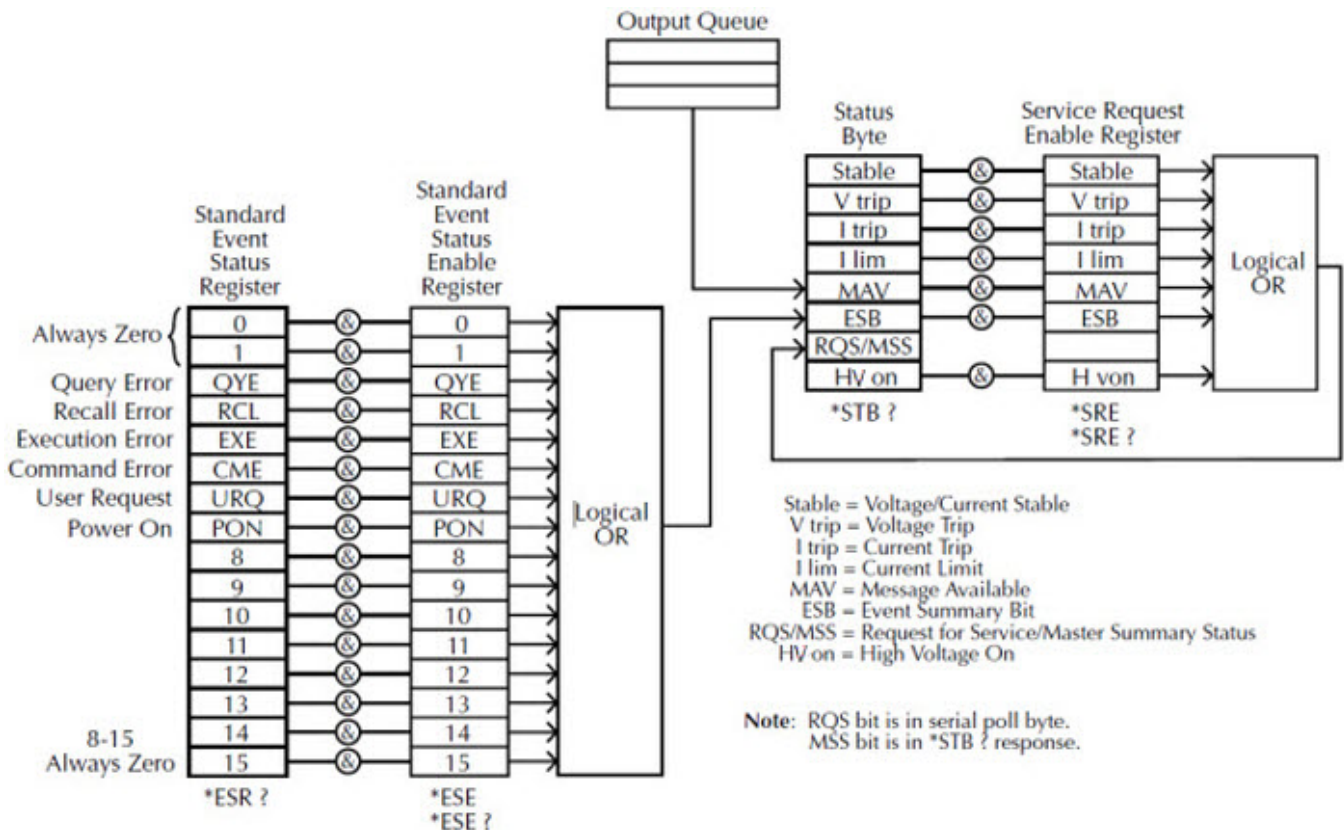
Status reporting..... 5-1

## Status reporting

The Model 2290-5 reports on its status with two registers: the Status Byte Register and the Standard Event Status Register. The overall configuration of these registers is shown in the next figure. Note that bits 0, 1, and 8 through 15 of both the Standard Event Status Register and Standard Event Status Enable Register are not used in the Model 2290-5 and are always set to zero.

On power-up, the 2290-5 will either clear all of its status enable registers or maintain them in the state they were in during power-down. The action taken is controlled by the \*PSC command and allows events such as SRQ on power-up to be generated if desired.

**Figure 11: Model 2290-5 Status model**



## Status byte register

The next table summarizes bits in the Status Byte, which may be read with the \*STB? query or with the serial polling sequence. The Model 2290-5 will generate a service request (SRQ) whenever one of these bits is set and the corresponding bit in the Service Request Enable Register is set, except for bit 6, the RQS/MSS bit. (Use the \*SRE command and the decimal bit value in the table to set Service Request Enable Register bits.) Note that any given status condition will produce only one SRQ even if that condition is never cleared.

**Table: Status byte**

Bit	Decimal value	Name	Description
0	1	Stable	Indicates that the VSET or ILIM value is stable. The function depends on whether the Model 2290-5 is in current limit or constant voltage mode.
1	2	<sup>1</sup> V trip	Indicates that a voltage trip has occurred.
2	4	<sup>1</sup> I trip	Indicates that a current trip has occurred.
3	8	<sup>1</sup> I lim	Indicates that a current limit condition has occurred.
4	16	MAV	Indicates message available in the GPIB output queue.
5	32	ESB	Indicates that an unmasked bit in the Standard Event Status Register has been set.
6	64	<sup>2</sup> RQS/MSS	Request for Service/Master Summary Status.
7	128	HV on	Indicates that the high voltage is on.
Note: SRQ may be enabled for corresponding condition by sending *SRE with decimal value of bit (except bit 6). For example, *SRE 4 enables SRQ on current trip.			
<sup>1</sup> The V trip, I trip, and I lim bits are latched bits. They are set on the occurrence of the appropriate event and will remain set until either the status byte is read or the *CLS command is sent. Latching allows you to detect if a trip or limit condition has ever occurred.			
<sup>2</sup> Request for Service bit in serial poll byte. Master Summary Status bit in *STB? response.			

## Standard event status register

The next table summarizes the bits in the Standard Event Status Register, which can be read using the \*ESR? query. This status register is defined by the IEEE-488.2 standard and is used primarily to report errors in commands received over the GPIB. When the bits in this register are latched, they stay latched and are cleared by reading them, or by sending the \*CLS command. If a bit in the Standard Event Status Register is latched and the corresponding bit in the Standard Event Status Enable Register (programmed with \*ESE) is also latched, the ESB bit in the Status Byte Register is latched.

**Table: Standard event status register**

Bit	Decimal value	Name	Description
0	1	Unused	
1	2	Unused	
2	4	Query Error	Set by an output queue overflow.
3	8	Recall Error	Set if a stored configuration setting is corrupt.
4	16	Execution	Set by an out-of-range parameter, or non-completion of a command due to a condition such as an overload.
5	32	Command Error	Set by a command syntax error or unrecognized command.
6	64	URQ	Set by any button press.
7	128	PON	Set by power-on.
Note: Set ESB bit in Status Byte Register by sending *ESE command with desired condition. For example, *ESE 16 sets ESB on execution error.			

**In this section:**

Error and status messages ..... 6-1

**Error and status messages****Table: Error messages**

The next table shows the error numbers that you will see on the center display. These errors also set corresponding bits of the Standard Event Status Register.

Note that the **CLR** button clears any errors.

<b>Error number</b>	<b>Description</b>	<b>Comments</b>
Err1	Memory Error	Power-on memory error of the last setup. Default setup is recalled.
Err2	Illegal Parameter Entered	Parameter entered is out of range.
Err3	Stored Value Recall Error	The stored setup (from STO and RCL) was lost.
Err4	Illegal Storage Address	STO 0 is reserved for default settings.
Err5	No GPIB Interface	GPIB interface not detected, and the GPIB address cannot be set.
Err6	Syntax error over GPIB	Invalid command. Err6 indicates the command had an error in syntax or was unrecognizable. A syntax error could be a misspelling of a command. This error will set the Command Error bit (bit 5) of the Standard Event Status Register.
Err7	Illegal parameter sent over GPIB	Parameter programmed is out of range. Err7 indicates a parameter was set out of range, or a command could not be completed because of an overload. This error will set the Execution Error bit (bit 4) of the Standard Event Status Register.
Err8	GPIB Output queue full	Output buffer overflowed. Err8 indicates the output queue overflowed and was cleared. This error could be caused by querying the unit repeatedly and not reading out all of the characters, or by a problem at the GPIB controller (the unit that's requesting and receiving the data). This error will set the Query Error bit (bit 2) of the Standard Event Status Register.

**Table: Summarizes status messages**

The next table summarizes the status messages. Note that the message indicated in the next table is seen on the center display.

Message	Description
VTRP	Voltage trip (voltage limit exceeded)
ITRP	Current trip (current limit exceeded)
PTRP	Primary trip (power transformer primary current limit exceeded)

---

## Typical applications

### In this section:

---

Introduction .....	7-1
Program example 1 .....	7-1
Program example 2 .....	7-4

## Introduction

This section is broken into two examples:

**Example 1** demonstrates how to generate a basic linear voltage sweep with the Model 2290-5 to reverse bias a high voltage diode and make leakage current measurements at each point of the sweep.

**Example 2** demonstrates basic interaction of the Model 2290-5 high voltage power supply with a Model 263xB System SourceMeter. The Model 2290-5 is used to generate a basic linear voltage sweep across the diode and the Model 263xB is used to make a leakage current measurement on the diode.

## Program example 1

### Linear voltage sweep and current measurements with Model 2990-5

Equipment needed:

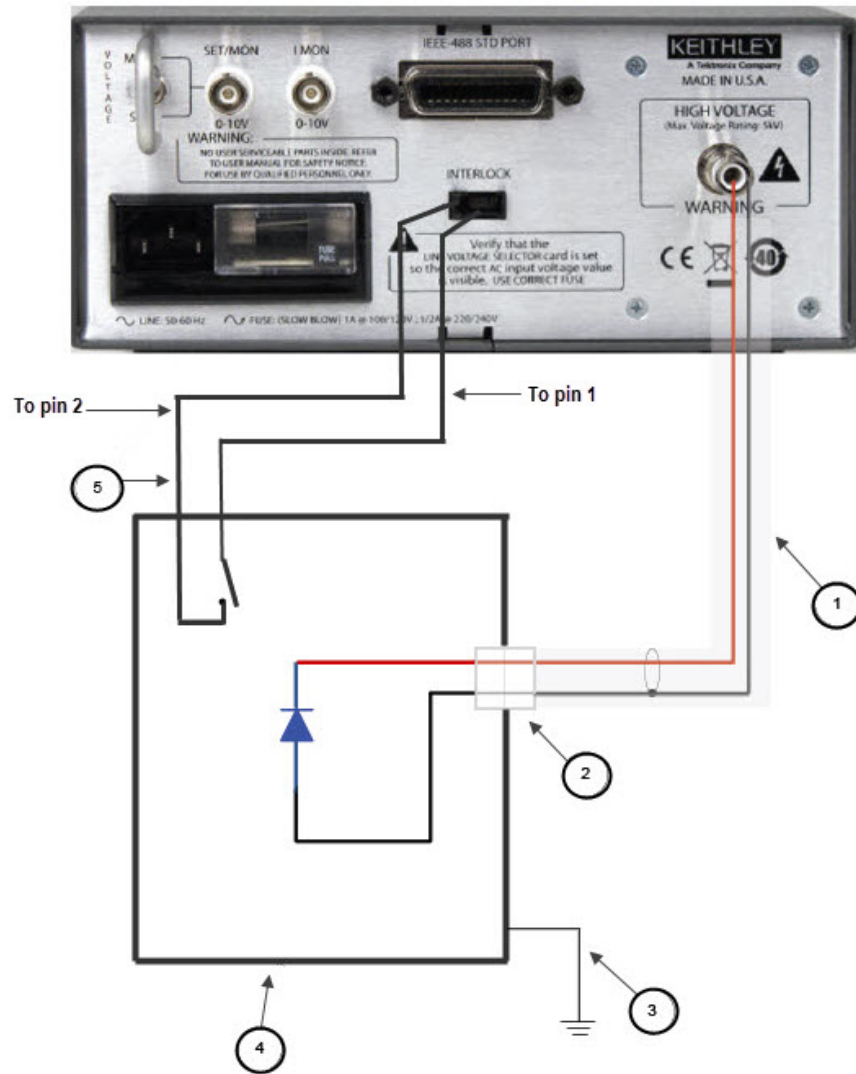
- 1 high-voltage diode enclosed in a safe test fixture
- 1 Model 2290-5 high voltage power supply
- 1 GPIB cable to connect the Model 2290-5 to a computer with a GPIB interface
- Appropriate cabling to connect the Model 2290-5 to the test fixture



Device connections:

The Model 2290-5 is a unipolar power supply. Therefore, the diode should be connected so that it can be reverse-biased, which means that the cathode should be connected to the HI output terminal of the Model 2290-5.

**Figure 12: Model 2290-5 reverse-biased diode**



Item	Description	Notes
1	Model 2290-5-SHV high-voltage cable	
2	Model 2290-5-SHVBH high-voltage male bulkhead connector	
3	Test fixture protective earth (safety ground)	
4	Interlocked metal safety enclosure	A safety enclosure with an interlock that has a normally open (NO) switch.
5	Test fixture interlock switch connection	Connect pin 1 (+5 V DC out) and pin 2 (interlock)

## Example program code

The following code was created and tested using the Python programming language using the pyVISA module. To learn more about Python, go to [www.python.org](http://www.python.org).

### NOTE

The example python program code below can be copied and pasted for your testing purposes, however, the code must match to include the indents of specific lines.

```
# Import pyVISA and time modules into the Python environment
import visa
import time

# Open a VISA session with the 2290 at GPIB address 14
ki2290 = visa.instrument("GPIB::14")

# Reset and clear the status of the 2290
ki2290.write("*RST")
ki2290.write("*CLS")
ki2290.write("*RCL 0")

# Define sweep variables for the programmed output voltage and
# measured current readings
voltage = 0
currReading = ""
currRdgList = []

# Turn on the output of the 2290
time.sleep(1)
ki2290.write("HVON")

# Perform a sweep from 0 to 3000V and make current measurements
# at each point of the sweep
for n in range(0,11):
    ki2290.write("VSET " + str(voltage))
    time.sleep(2) # Allow new voltage level to stabilize
    currReading = ki2290.ask("IOUT?")
    currRdgList.append(currReading)
    voltage = voltage + 300

# Set the voltage of the 2290 to 0V and turn off its output
ki2290.write("VSET 0")
ki2290.write("HVOF")

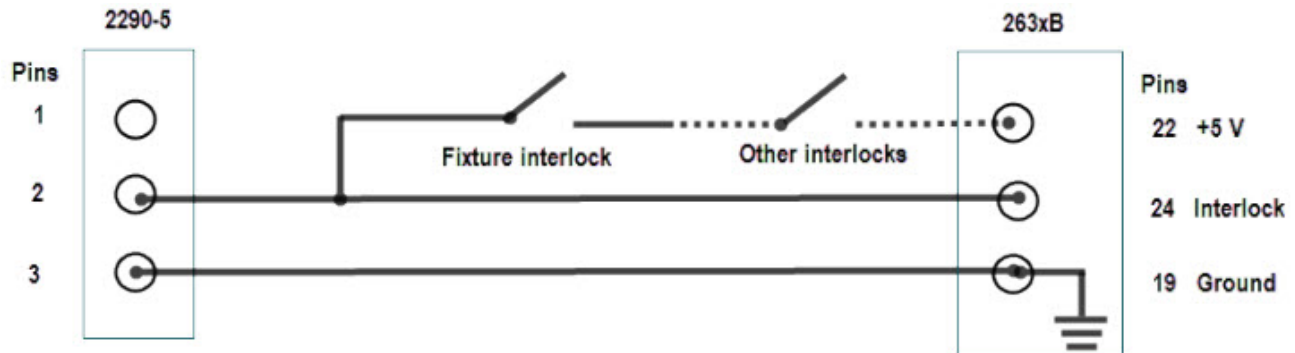
# Print the current measurements
print "Current Measurements: ", currRdgList
```

## Program example 2

### Linear voltage sweep with Model 2290-5 and current measurements with Model 263xB

The next figure shows how to connect the interlock circuits of the Model 2290-5 and Keithley Model 263xB SourceMeter instrument with the normally-open switch of the test fixture:

**Figure 13: Interfacing the interlocks of the Model 2290-10 and the Model 263xB SourceMeter Instrument to the test fixture**



The output of the Model 2290-5 can only be turned on when the interlock is engaged. The interlock is engaged when the interlock pin is pulled high through a switch to more than +3 V. The interlock is disengaged when the signal applied is less than +1.2 V.

The interlock is intended for use through a normally open switch, which may be installed on the lid of a test fixture, on the enclosure of a semiconductor prober or device handler, or on the door (or doors) of a test equipment rack.

In the next example, the reverse-bias sweep across the diode is performed like program example 1. However, the Model 263xB System SourceMeter is used to obtain more accurate leakage current measurements on the diode. This example may also be easily applied to measuring the drain leakage current of a MOSFET, or collector leakage current of a BJT or IGBT.

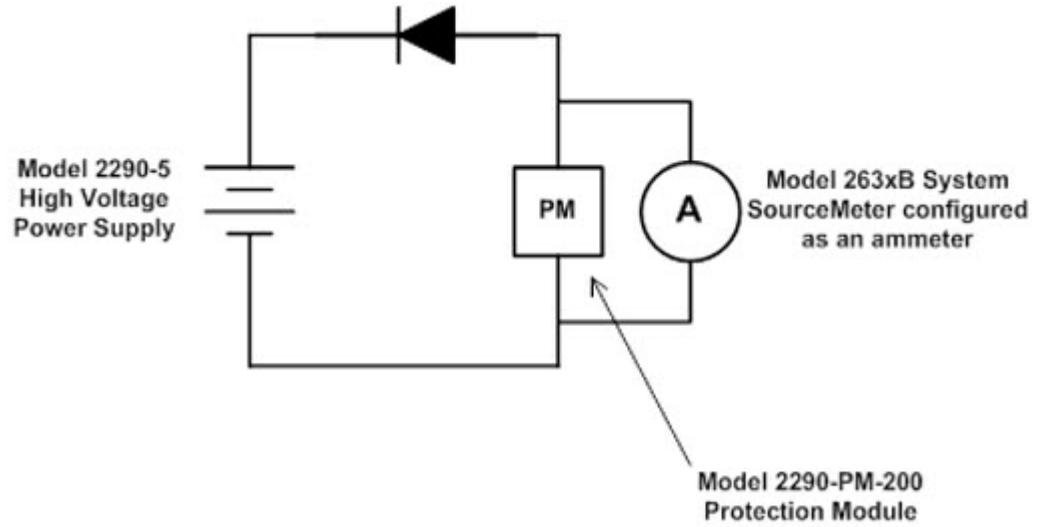
#### Equipment Needed:

- 1 high-voltage diode enclosed in a safe test fixture
- 1 Model 2290-5 high voltage power supply
- 1 Model 263xB system SourceMeter
- 2 Model 2290-5-SHV cables
- 2 Model 2290-5-SHVBH bulkhead connectors
- 1 Model 2290-PM-200 protection module
- 2 Model 7078-TRX cables to connect the Model 263xB to the protection module
- 2 GPIB cables to connect the Model 2290-5 and the Model 263xB to a computer with a GPIB interface

Device connections:

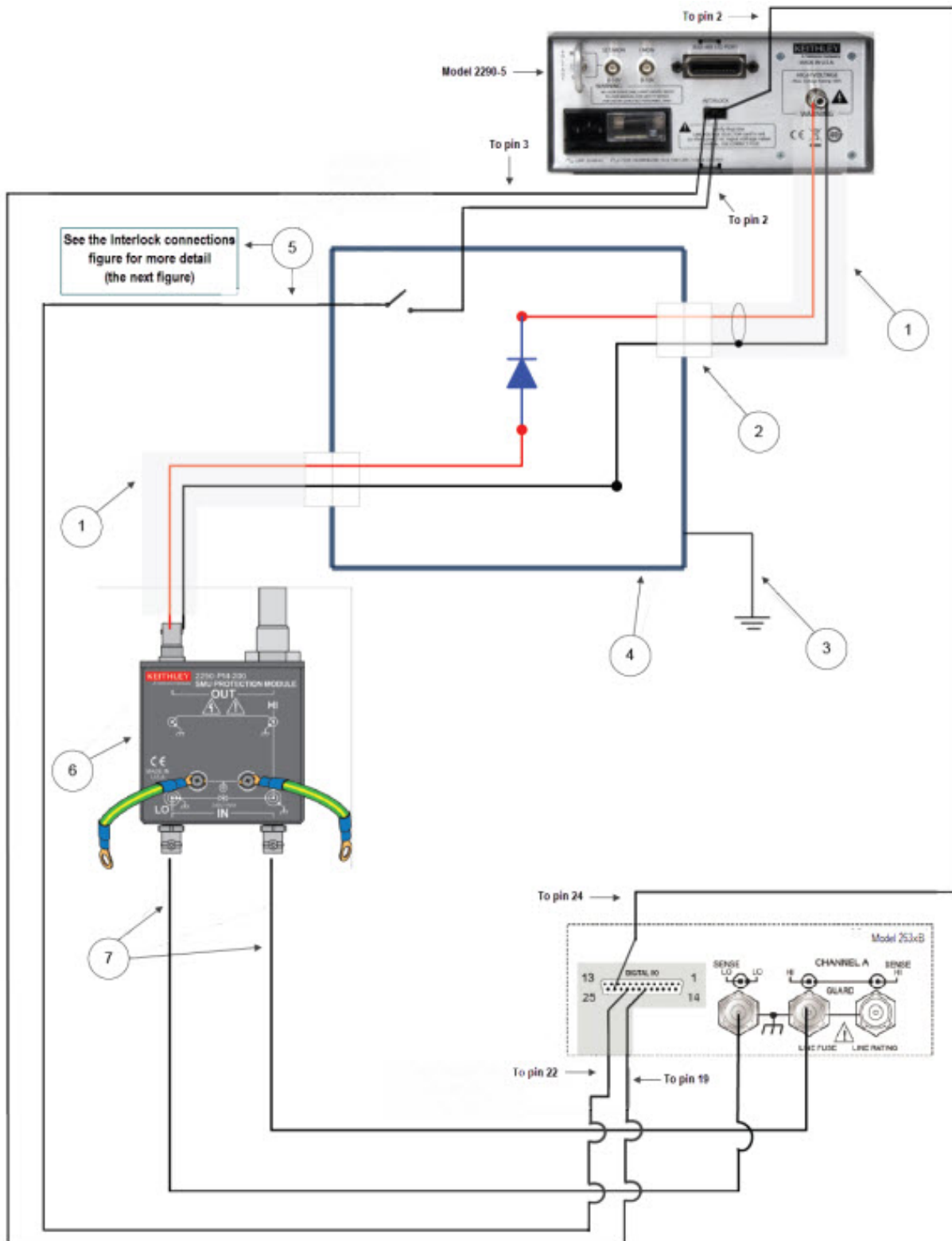
In the next figure is a simple circuit schematic of the test performed in this example:

**Figure 14: Model 2290-5 reverse-biased diode with SourceMeter**



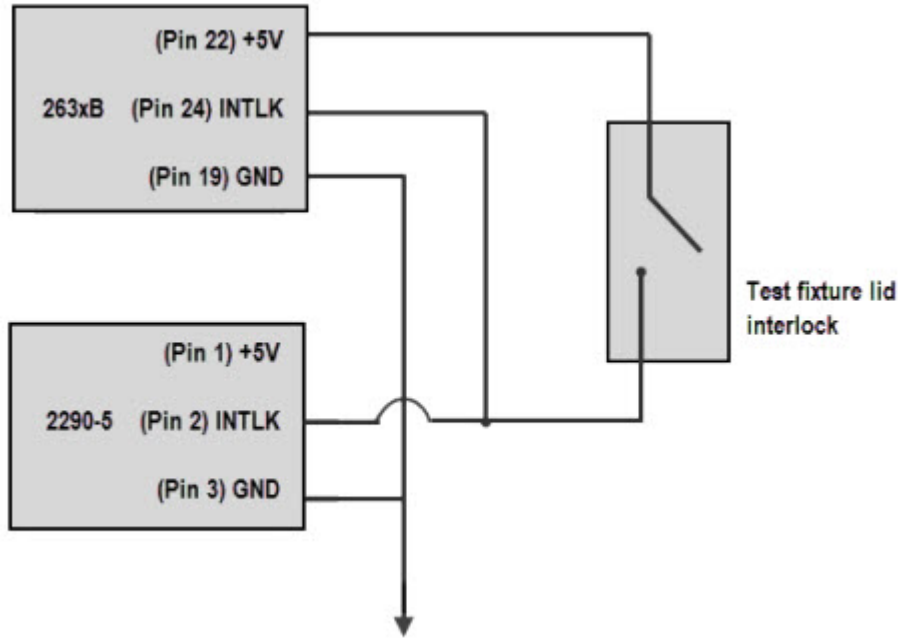
The next figures detail how these connections should be made in a safe test enclosure.

**Figure 15: Model 2290-5 reverse-biased diode connections with SourceMeter**



The following figure indicates pin connections for the lid interlock connections to Models 2290-5 and 263xB.

**Figure 16: Model 2290-5 reverse-biased diode interlock connections**



Item	Description	Notes
1	Model 2290-5-SHV high-voltage cable	
2	Model 2290-5-SHVBH high-voltage male bulkhead connector	
3	Test fixture protective earth (safety ground)	
4	Interlocked metal safety enclosure	A safety enclosure with an interlock that has a normally-open (NO) switch.
5	Test fixture interlock switch connection	For 2290-5 connect pin 2 (interlock) and pin 3 (ground) , and 263xB connect pin 22 (+5 V DC out), pin 24 (interlock), pin 19 (ground).
6	Model 2290-PM-200 high voltage SMU Protection Module	
7	Model 7078-TRX cables	Connect the Protection Module to the Model 263xB SMU.

## Example program code

The following code was created and tested using the Python programming language using the pyVISA module. To learn more about Python, go to [www.python.org](http://www.python.org).

### NOTE

The example python program code below can be copied and pasted for your testing purposes, however, the code must match yours to include the indents and spacing between lines.

```
# Import pyVISA and time modules into the Python environment
import visa
import time

# Open a VISA session with the 2290 at GPIB address 14
# and 263xB at GPIB address 26
ki2290 = visa.instrument("GPIB::14")
ki263x = visa.instrument("GPIB::26")

# Reset and clear the status of the 263xB
ki263x.write("reset()")
ki263x.write("*CLS")

# Reset and clear any errors of the 2290
ki2290.write("*RST")
ki2290.write("*CLS")
ki2290.write("*RCL 0")

# Configure the 263xB as an ammeter, set the current limit
# and current measurement range
ki263x.write("smua.source.rangev = 0.2")
ki263x.write("smua.source.levelv = 0")
ki263x.write("smua.source.limiti = 1e-3")
ki263x.write("smua.measure.rangei = 100e-6")

# Configure the display of the 263xB and turn on the output
ki263x.write("display.screen = display.SMUA")
ki263x.write("display.smua.measure.func = display.MEASURE_DCAMPS")
ki263x.write("smua.source.output = smua.OUTPUT_ON")

# Define sweep variables for the programmed output voltage
# and measured current readings
voltage = 0
currReading = ""
currRdgList = []

# Turn on the output of the 2290
time.sleep(1)
ki2290.write("HVON")

# Perform a sweep from 0 to 3000V and make current measurements
# at each point of the sweep
for n in range(0,11):
    ki2290.write("VSET " + str(voltage))
    time.sleep(2) # Allow new voltage level to stabilize
    currReading = ki263x.ask("print(smua.measure.i())")
```

```
time.sleep(1) # Allow measurement to be taken
currRdgList.append(currReading)
voltage = voltage + 300

# Set the voltage of the 2290 to 0V and turn off its output
ki2290.write("VSET 0")
ki2290.write("HVOF")

# Turn off the output of the Model 263xB
ki263x.write("smua.source.output = smua.OUTPUT_OFF")

# Print the current measurements
print "Current Measurements: ", currRdgList
```



---

## Performance verification

### In this section:

---

Introduction .....	8-1
Environmental conditions .....	8-1
Warm-up period .....	8-1
Recommended test equipment .....	8-2
Verification procedures .....	8-2

## Introduction

This section contains procedures to verify that the Model 2290-5 meets or exceeds its stated performance specifications for DC voltage accuracy, DC current accuracy, load regulation, and output voltage ripple. These procedures do not adjust your instrument. If your instrument fails any of the performance verification tests, you should contact Keithley Instruments service.

### WARNING

*The procedures in this section are intended to be used by qualified service personnel only. Many of these procedures may expose you to hazardous voltages that could result in personal injury or death. Do not perform these procedures unless you are qualified to do so. Use extreme caution when working with hazardous voltages.*

## Environmental conditions

All verification procedures should be performed at an ambient temperature of 18°C to 28°C, and at a relative humidity of 70% or less, unless otherwise noted.

## Warm-up period

The Model 2290-5 should be turned on and allowed to warm up for at least one hour before performing the verification procedures. The test equipment should also be allowed to warm up for the time period recommended by the manufacturer.

## Recommended test equipment

The next table summarizes the recommended test equipment for the verification procedures.

Table: Recommended verification test equipment

Equipment	Specifications	Manufacturer and model
1000:1 high-voltage divider	0.01% DC accuracy	Ohm-Labs, Inc. (formerly Julie Research) KV-10R
DC/AC multimeter	0.002% DC accuracy, 10 G $\Omega$ DC input impedance	Keithley Model 2000
4.99 k $\Omega$ load resistor	1%, 1 W	Any appropriate resistor manufacturer
1 M $\Omega$ load resistor	5 kV, 25 W	

## Verification procedures

The verification procedures are explained in detail in the following paragraphs. Refer to the [Recommended test equipment](#) table and the respective diagrams for test equipment and connections. Note that each procedure is performed both with the output filter off and with Filter 1 enabled. Since the Model 2290-5 specifications are the same for both Filter 1 and Filter 2, only the Filter 1 configuration requires testing.

### WARNING

*The following procedures use high voltage. Use extreme care to avoid electrical shock that could result in personal injury or death. Do not touch any exposed circuitry while the high voltage is enabled.*

*High voltage cables can store a charge even when disconnected from the unit. Always turn off the high voltage and make sure all cables and circuitry are completely discharged before connecting or disconnecting cables or other circuitry.*

## DC voltage accuracy

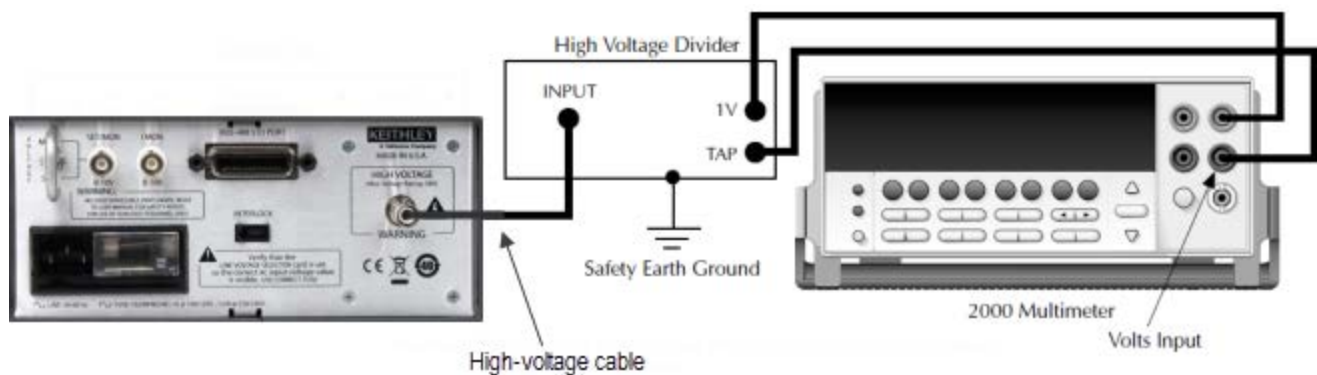
Use the following steps to measure the accuracy of the DC output voltage.

1. With the power off, connect the Model 2290-5 HIGH VOLTAGE output connector to the high voltage divider, and connect the multimeter to the 1V output tap of the divider (see next figure).

### **⚠ WARNING**

*Turn off high voltage and allow ample time for the voltage to discharge before changing any connections. Also, make sure that you connect the divider chassis to safety earth ground using #18 AWG or larger wire.*

**Figure 17: Model 2290-5 Connections for DC voltage accuracy tests**



2. Turn on the power, and set the Model 2290-5 to its default conditions. (Press **RCL, 0**, and then **ENTER**.)
3. Select the multimeter DCV function, and enable autoranging.
4. With the high voltage turned off, allow the multimeter reading to settle to 0V, and then enable the REL mode to null any residual offset voltage.
5. Turn on the Model 2290-5 high-voltage output. Set the Model 2290-5 output voltage to each value as indicated in the DC voltage accuracy summary table, and verify that the reading parameters are within stated limits. For each setting:
  - Set the output voltage as indicated in the table.
  - Wait at least 10 seconds for the output to settle.
  - Make sure that the Model 2290-5 VOLTS display reading is within stated limits.
  - Verify that the multimeter reading is within required limits.
6. Turn off the high voltage, and allow the voltage to discharge.
7. Repeat the procedure with Filter 1 enabled for voltages up to 3000V. Be sure to test both with positive and negative output polarity.

**Table: Filters off DC voltage accuracy**

Output volts	Volts display limits		Multimeter voltage reading limits	
500	495	505	0.4975	0.5026
1000	995	1005	0.9974	1.0026
1500	1495	1505	1.4974	1.5027
2000	1995	2005	1.9973	2.0027
2500	2495	2505	2.4973	2.5028
3000	2995	3005	2.9972	3.0028
3500	3495	3505	3.4972	3.5029
4000	3995	4005	3.9971	4.0029
4500	4495	4505	4.4971	4.5030
5000	4995	5005	4.9970	5.0030

**Table: Filter 1 enabled DC voltage accuracy**

Output volts	Volts display limits		Multimeter voltage reading limits	
500	493	507	0.4950	0.5051
1000	993	1007	0.9949	1.0051
1500	1493	1507	1.4949	1.5052
2000	1993	2007	1.9948	2.0052
2500	2493	2507	2.4948	2.5053
3000	2993	3007	2.9947	3.0053

## DC current limit accuracy

The DC current accuracy test measures the accuracy of the output current limit and the mA (current) display.

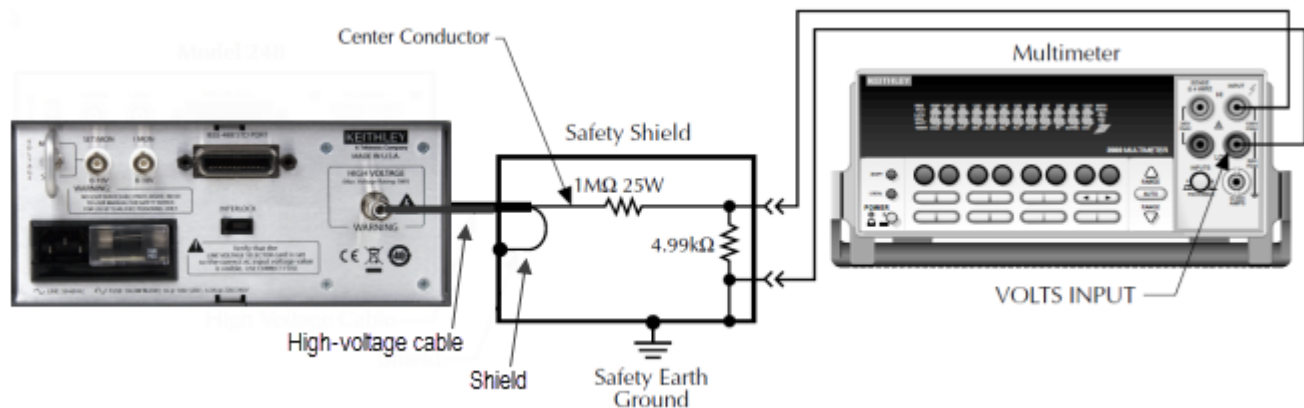
1. Using the ohms function of the multimeter, measure and record the value of the 4.99 kΩ resistor.
2. With the power off, connect the 4.99 kΩ resistor, the 1 MΩ load resistor, and the multimeter to the Model 2290-5 HIGH VOLTAGE output connector, as shown in the next figure. Note that the multimeter is connected across the 4.99 kΩ resistor.

### **⚠ WARNING**

*Turn off high voltage and allow ample time for the voltage to discharge before changing any connections.*

*For safety purposes, the resistors must be mounted within a safety shield connected to safety earth ground using #18 AWG or larger wire. Be sure to connect the 4.99 kΩ resistor to the low (chassis side) of the Model 2290-5 output. Otherwise, the multimeter will be floated 5 kV above earth ground, which could result in instrument damage or risk of electric shock.*

Figure 18: Model 2290-5 Connections for DC current accuracy tests



3. Turn on the power, and recall the Model 2290-5 default conditions. (Press **RCL, 0**, and then **ENTER**.)
4. Select the multimeter DCV function, and enable autoranging.
5. With the high voltage off, allow the multimeter reading to settle and then enable REL to null any residual offset voltage.
6. Set the Model 2290-5 output voltage to 5000V, and set the current limit to 5mA. Turn the high voltage on.
7. Note the DMM reading, and then calculate the current as follows:  $I = V/R$ , where V is the multimeter voltage reading, and R is the actual value of the 4.99 k $\Omega$  resistor measured in step 1.
8. Verify that the current computed in step 7 is within the limits as shown in the table (see [Table: DC current accuracy summary](#)) of the programmed current limit value. Also, make sure that the front panel mA display reading is within the limits shown in the table.
9. Repeat steps 6 through 8 for the remaining currents listed in the next table. For each value:
  - Program the current limit to the correct value.
  - Measure and record the multimeter voltage reading.
  - Compute the current from the voltage and resistance.
  - Verify the computed and display current values are within required limits.
10. Turn off the high voltage, and allow the voltage to discharge.
11. Enable Filter 1, and then repeat the entire procedure with a 3000V output voltage.

**Table: DC current accuracy summary**

Current limit setting	Multimeter voltage <sup>1</sup>	Calculated current <sup>2</sup>	Allowable current range Filters off		Allowable current range Filter 1 and 2 on	
			Lower limit	Upper limit	Lower limit	Upper limit
500 $\mu$ A	V	$\mu$ A	497 $\mu$ A	503 $\mu$ A	495 $\mu$ A	505 $\mu$ A
1 mA	V	$\mu$ A	0.997 mA	1.003 mA	0.995 mA	1.005 mA
1.5 mA	V	$\mu$ A	1.497 mA	1.503 mA	1.495 mA	1.505 mA
2 mA	V	$\mu$ A	1.997 mA	2.003 mA	1.995 mA	2.005 mA
2.5 mA	V	$\mu$ A	2.497 mA	2.503 mA	2.495 mA	2.505 mA
3 mA	V	$\mu$ A	2.997 mA	3.003 mA	2.995 mA	3.005 mA
3.5 mA	V	$\mu$ A	3.497 mA	3.5003 mA	3.495 mA	3.505 mA
4 mA	V	$\mu$ A	3.997 mA	4.003 mA	3.995 mA	4.005 mA
4.5 mA	V	$\mu$ A	4.497 mA	4.503 mA	4.495 mA	4.505 mA
5 mA	V	$\mu$ A	4.997 mA	5.003 mA	4.995 mA	5.006 mA

<sup>1</sup>Voltage across 4.99 k $\Omega$  resistor measured by multimeter.

<sup>2</sup>Calculated as follows:  $I = V/R$ , where V= multimeter voltage reading and R= measured resistor value.

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## Troubleshooting

### In this section:

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### Stuck buttons

If the center display is filled with a number (such as 4444) or one particular message (such as Err2), and the front panel buttons are unresponsive, check to see if a button is stuck. If so, gently tap the stuck button back to the center of its hole to free it.

### Line power

Always make certain that the power entry module is set for the correct line voltage and that the correct fuse is installed. The selected line voltage can be seen through the window on the power entry module. Verify that the line cord is plugged completely into the power entry module and that the front panel power switch is on.

### Repeated trips

**Voltage Trips** — This problem may occur if the load changes too rapidly, causing the voltage to overshoot. Try raising the voltage limit.

**Current Trips** — Disconnect the load, and note if the unit still trips. If the unit operates with no load, the load may be causing the problem. If the unit still trips with the load disconnected, the unit may be damaged. Contact the factory for further information.

**Primary Trip (PTRP)** — If repeated PTRPs occur, the power supply may be damaged. Contact the factory for further information.

#### NOTE

A PTRP message will occur if the line current exceeds 5.3 A. This feature is included to protect the instrument. The PTRP level is not user programmable and may be cleared in the same manner as the voltage and current trips.

## Incorrect rear-panel output voltage

If the output voltage is not correct, check the REAR LED and rear panel VOLTAGE Switch to verify the unit is in the SET mode. Also, check that the voltage limit is higher than the desired voltage.

## Front-panel test

This test verifies that all segment drivers are functional. Hold down the **ENTER** button while turning on the unit to run the front panel test. After power is turned on, one segment of one numerical digit should be on. Press the up arrow button to step through all eight digit segments of the present digit and the following digit. When the up arrow button is pressed again, all segments and one of the single LEDs should be on. Repeatedly press the up arrow button to cycle through all single LEDs.

The buttons can then be tested by pressing each button and observing the button code on the display. The codes increase from top to bottom and left to right. After this test, turn the power off and then back on to restart the instrument.

## Power-on reset

If the instrument turns on with unusual combinations of LEDs on, garbled displays, or is unresponsive to the front panel buttons, the memory contents may have been corrupted, causing the instrument to lock up. To remedy the situation, turn the unit off and hold down the **CLR** button while turning the power back on. Doing so causes the unit to initialize the memory and load the default setup.

## No high voltage

If the Model 2290-5 does not enable the high voltage, check to make sure that the HIGH VOLTAGE LED is on. If the HIGH VOLTAGE LED is OFF, check the following:

1. Make certain that you hold down the high voltage button for at least one-half second. This button requires a fairly long button press to avoid turning on the high voltage accidentally.
2. Check the voltage limit and current trip levels to verify that they are sufficiently high for the expected output values.

If the HIGH VOLTAGE LED is ON, but the output voltage is zero or lower than expected, check the following:

1. The LIMIT LED is on. If so, the current limit value could be too low, or the load could be drawing excessive current.
2. The voltage limit is as large as or larger than the desired output voltage.
3. The REAR LED is on. If so, the high voltage is being programmed by the analog voltage applied to the SET/MON input on the rear panel and not by the front panel. Make sure that the rear panel VOLTAGE switch is in the desired position.
4. The Interlock is not engaged.



## Service

For repair and instrument adjustment services, contact your local Keithley Instruments representative. For worldwide contact numbers, visit the Keithley Instruments website (<http://www.keithley.com>).

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