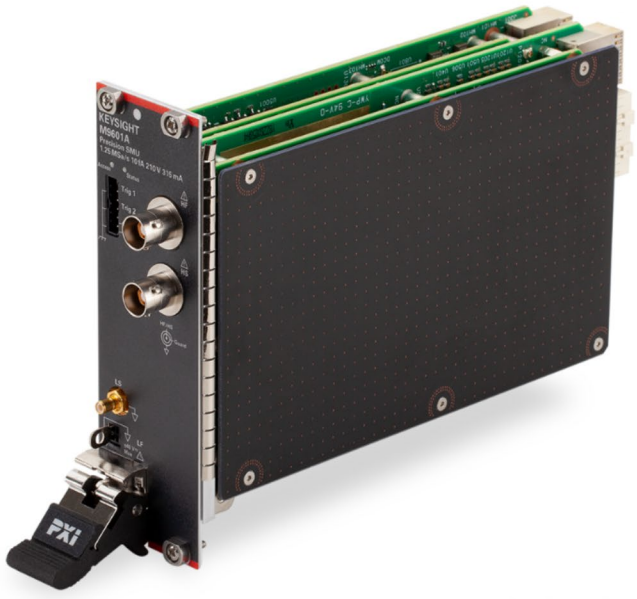
DATA SHEET

M9601A
PXIe Precision Source/Measure Unit
1.25 MSa/s, 10 fA, 210 V, 315 mA

The industry high-performance PXIe SMU enabling faster precise dynamic measurement from DC to 20 µs pulse, output up to 210 V/315 mA, and with the best-in-class 10 fA resolution and lowest source noise



KEYSIGHT TECHNOLOGIES

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Introduction

The Keysight M9601A PXIe precision source/measure unit is a precision source/measure unit (SMU) with the capability to source and measure both voltage and current. It covers currents from 10 fA to 315 mA and voltages from 500 nV to 210 V. It can make precise measurements broadly from DC to pulsed down to 20 µs pulse width with the sampling rate up to 1.25 MSa/s. The M9601A is ideal for a wide variety of current versus voltage (IV) measurement tasks that require both high resolution and accuracy such as the characterization, parametric/reliability tests of semiconductors, active/passive components, and general electronic devices.

Feature	Benefit
Integrated symmetry 4-quadrant sourcing and measuring capabilities	Easily and accurately measures current and voltage using a single module without the need to change any connections manually
Wide voltage and current coverage: ± 210 V, ± 315 mA	Single SMU module covers both voltage and current measurement requirements, allowing for standardization and simplifying inventory and support concerns
Source and measurement resolution down to 10 fA and 500 nV	Makes low-level measurements using a PXIe SMU module
Low current measurement noise: 30 fArms at 1PLC	Reveals more of the true characteristics of the devices with less aperture time, which improves measurement throughput
Narrow pulse capability: 20 µs	Suppresses self-heating effect and has the true characteristics of the devices to improve measurement throughput
Fast transient capability: 1.4 V/µs slew rate at maximum	Captures the actual transient response from the devices and circuits without the influence of the measurement equipment's performance
High-speed sampling measurement: 1.25 MSa/s sampling rate, 1 Mpts memory depth	Captures dynamic behavior and response to the pulsed signal of the devices and circuits in a single measurement

Overview

Integrated source and measurement capabilities simplify challenging IV measurement tasks

The M9601A PXIe SMU integrates different source and measurement capabilities into one PXIe module (please see Figure 1). It can operate as a seamless symmetry 4-quadrant precision voltage/current source, an electrical load, an accurate voltage/current meter, and a pulse generator. Its versatile all-in-one integrated source and measurement capabilities allow it to perform a wide variety of measurements from DC to pulsed without the need to change connections or use additional equipment.

Since SMUs can very accurately measure their current and voltage output, they have many advantages over conventional power supplies. All SMUs have internal feedback loops that provide instantaneous feedback to the sourcing circuitry, which allows the SMU output to remain accurate and stable even if the load conditions change unexpectedly.

SMUs also possess a voltage and current limit (compliance) feature that allows you to set limits to protect devices from damage caused by excessive voltage or current.

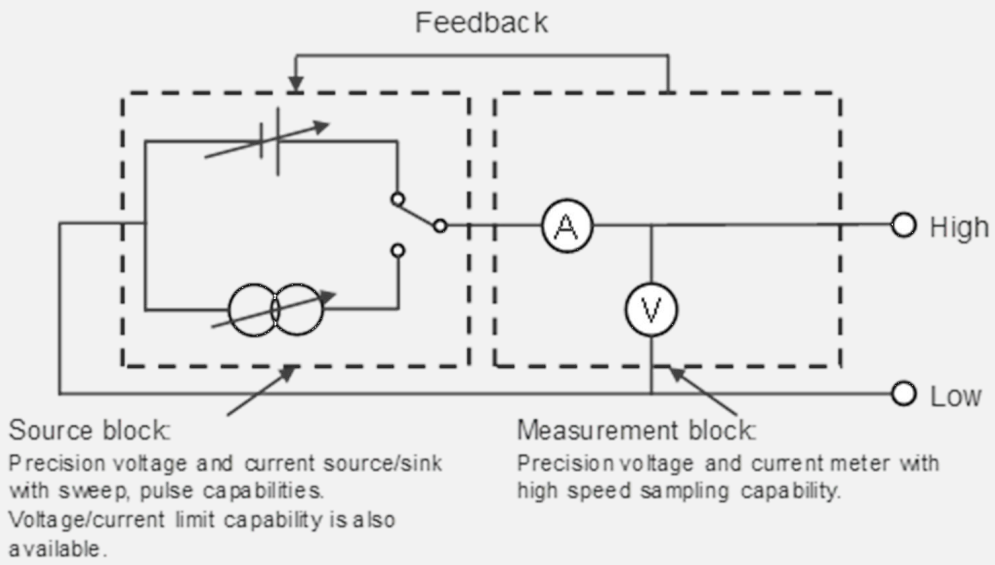


Figure 1. Simplified block diagram of the M9601A

Low current measurement noise performance reduces the measurement time

The low measurement noise performance is important for the low-level measurement as well as the high measurement resolution capability. The long aperture time is commonly used to eliminate the measurement noise, especially for small current measurement, but the measurement time becomes longer accordingly. The Keysight M9601A can achieve 30 fArms noise level with 1 power line cycle (PLC) aperture time (at 50 Hz power line frequency), which is three times lower than the conventional PXIe SMU under the same condition (aperture time) and 10 times faster than the conventional PXIe SMU module to achieve the same level noise (please see Figure 2 and 3). This capability enables you to reveal more of the true characteristics of your devices and shorten the measurement time significantly.

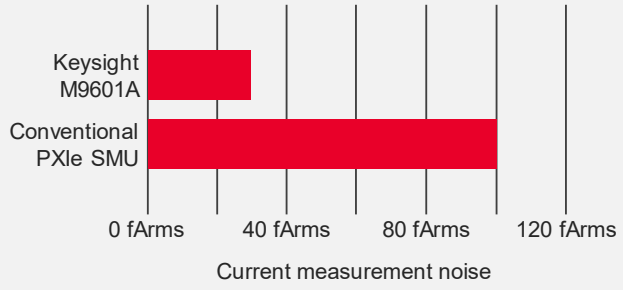


Figure 2. Current measurement noise with 1 PLC (20 ms) aperture time

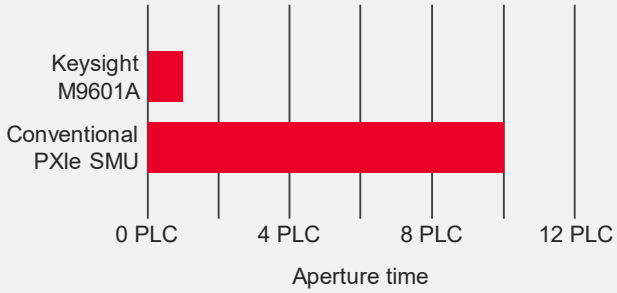


Figure 3. Aperture time required to achieve 30 fArms current measurement noise

Narrow pulse suppresses self-heating effect

The M9601A can make precise measurement broadly from DC to pulsed down to 20 µs pulse width with the sampling rate up to 1.25 MSa/s, which makes the M9601A ideal for a wide variety of current versus voltage (IV) measurement tasks that require both high resolution and accuracy (please see Figure 4). The narrow pulse capability down to 20 µs width enables you to suppress the self-heating effect to reveal the true characteristics of the devices.

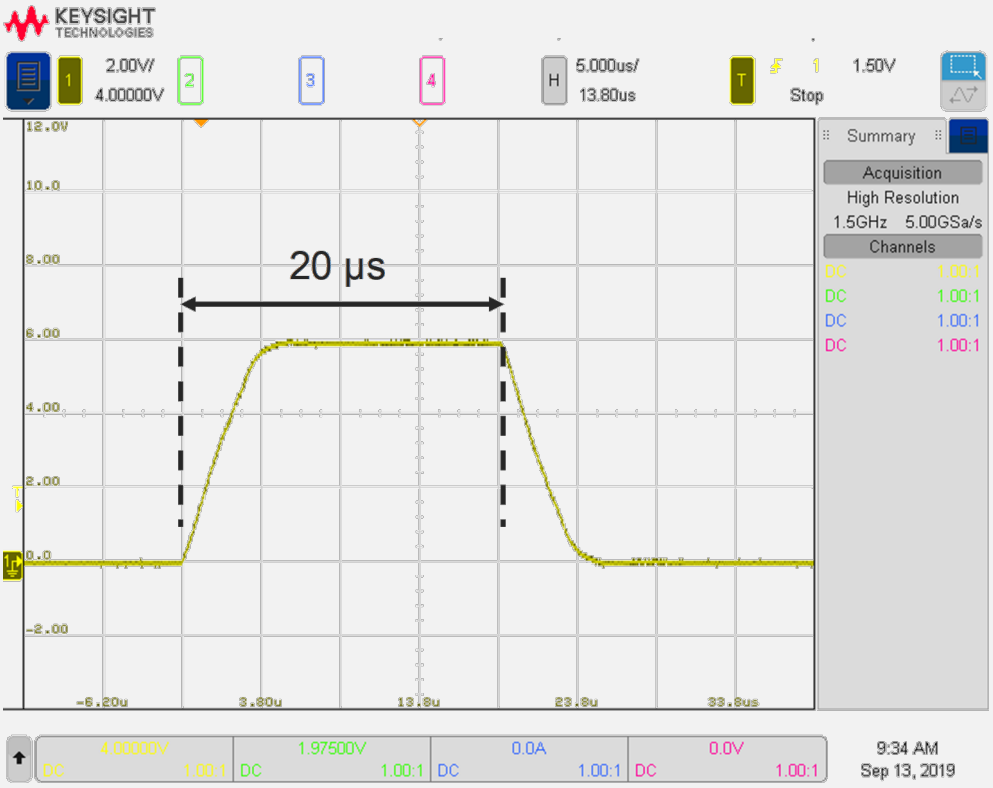


Figure 4. Narrow pulse down to 20 µs enables you to suppress self-heat effect to reveal the true characteristics of the devices

Fast transient captures the actual transient response from the devices and circuits

Commonly, the slew rate of the conventional SMUs varies with the measurement conditions, which affects the measurement results. The M9601A has two operation modes such as standard mode (works the same as a conventional SMU) and the PS mode which enables fast transient with 1.4 V/µs slew rate at maximum (please see Figure 5). The unmatched fast transient capability enables you to capture the actual transient response from the devices and circuits without the influence of the measurement equipment's performance.

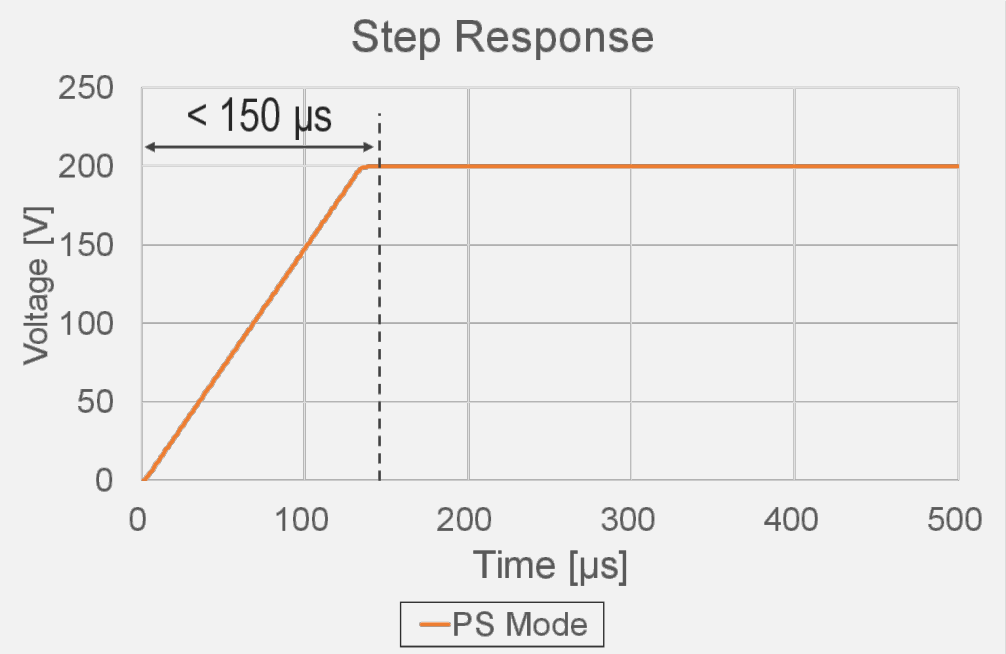


Figure 5. A voltage of 200 V ramped up to within 150 µs

Programmable output resistance function provides flexible measurement capabilities

The M9601A has a programmable output resistance feature that allows you to control the output behavior of the SMU. It allows you to specify an output resistance value (either positive or negative) such that the output will respond exactly as if the specified resistance value were in series (voltage source mode) or in parallel (current source mode) with the source output. It can emulate resistance values over a wide range, and the negative resistance capability is particularly useful for cancelling out unwanted external resistances. For example, you can use the negative resistance feature to eliminate the resistance of long connection wires without the need to use a 4-wire (Kelvin) connection scheme. This is especially useful in situations where a 4-wire measurement is not possible due to packaged device limitations or to the absence of sense pads for probing.

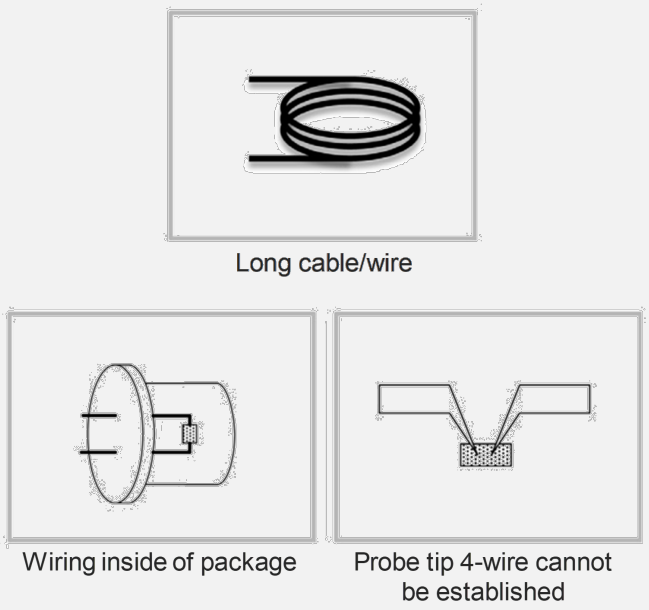


Figure 6. Measurement situations that benefit from Programmable Output Resistance feature

Drivers and soft front panel

The M9601A comes complete with software drivers for Microsoft Windows 7 Professional SP1 or later (32-bit/64-bit), Microsoft Windows 8.1 Professional or later (32-bit/64-bit), Microsoft Windows 10 (32-bit/64-bit). These software drivers work in the most popular test and measurement development environments, including Visual Studio (VB.NET, C#, C/C++), LabVIEW, MATLAB, VEE.

Standard Commands for Programmable Instruments (SCPI) are a popular and easy-to-understand instrument control protocol. The M9601A supports it as well, which will minimize code conversion work from the existing benchtop-based test system.

The soft front panel provides easy to use instrument control (please see Figure 7). Its user-friendly graphical user interface guides developers through module setup so users can quickly configure the SMU.

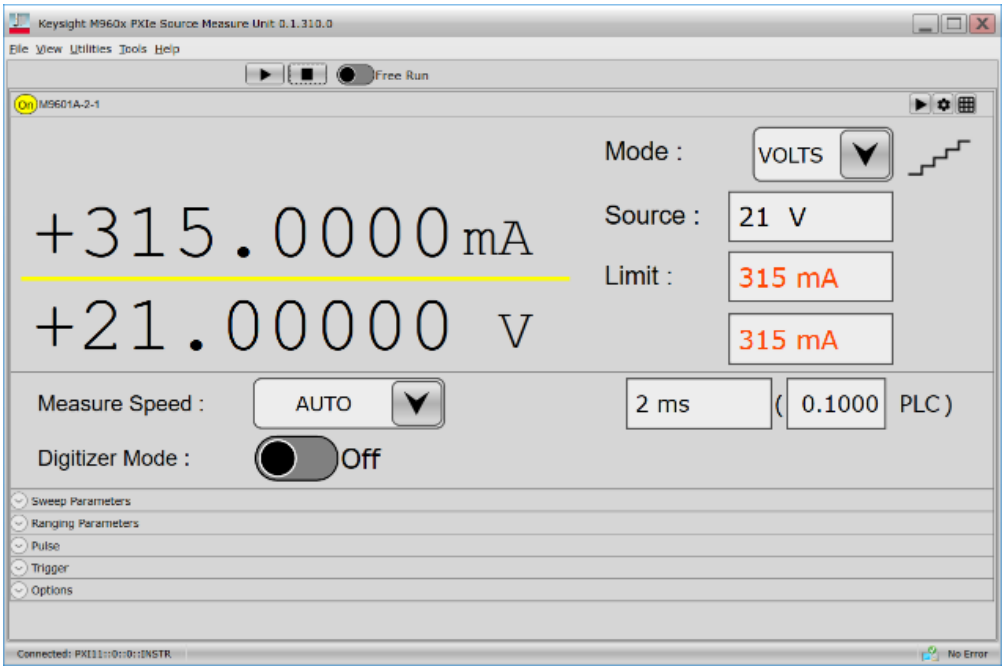


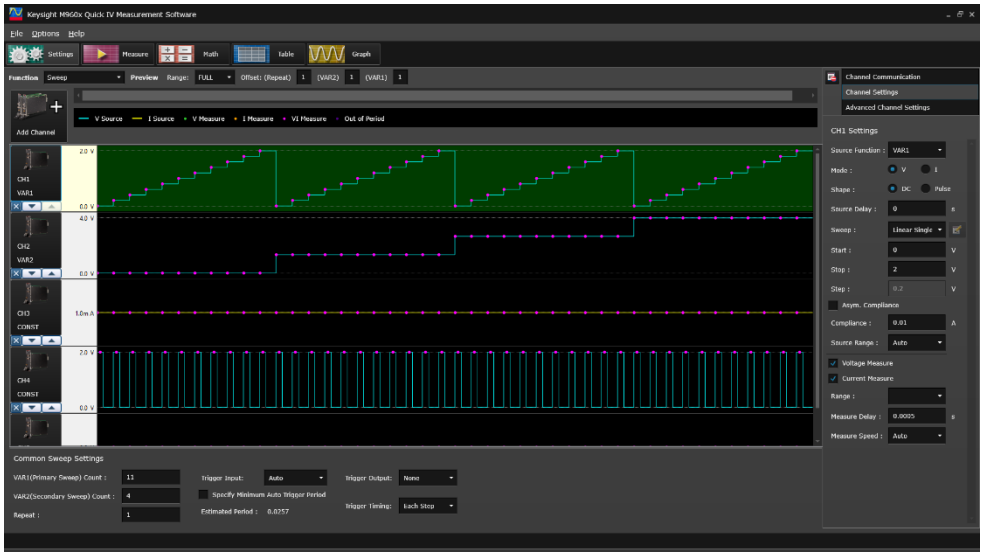
Figure 7. M9601A soft front panel

PX0109A Quick I/V Measurement Software, essential and powerful software tool to control the PXIe Precision SMU

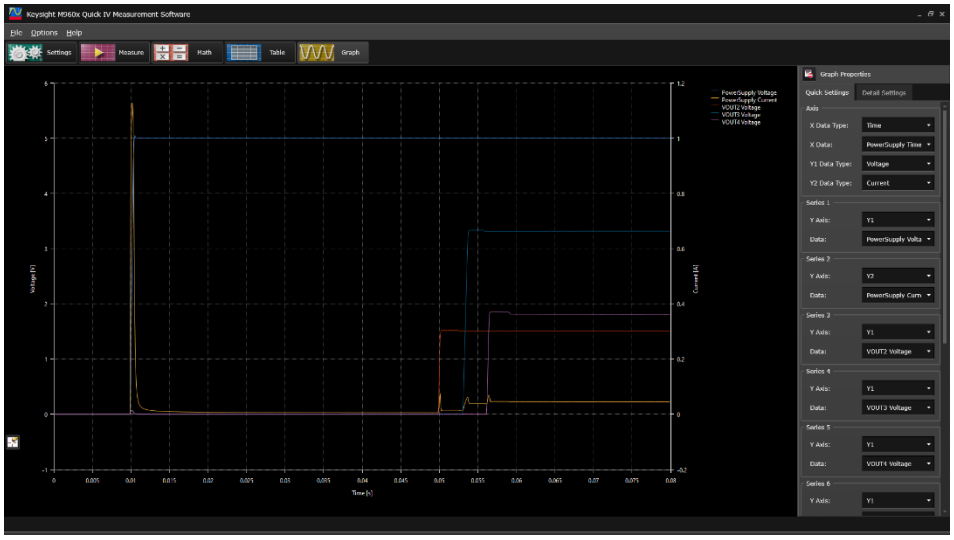
The Keysight PX0109A Quick I/V Measurement Software for PXIe Precision SMU has powerful measurement capabilities to control the M9601A, M9602A, M9603A, M9614A and M9615A. It supports a variety of functions such as a sweep measurement, a sampling measurement, graphical display functions and the ability to save test results into CSV files, which makes it easy to quickly setup and perform current-voltage (IV) measurements and to display the measurement data in tables and graphs without the need to program. It is licensed based and the licenses are sold as node-locked, floating, transportable and USB portable.

The PX0109A Quick I/V also allows you to control up to ten SMU channels so that you can measure devices or circuits requiring more than two SMU channels for characterization, verification, or test. In addition, the PX0109A Quick I/V has the capability to make not only primary sweep measurements but also measurements where a second terminal is swept, making it easy to generate a variety of IV curves.

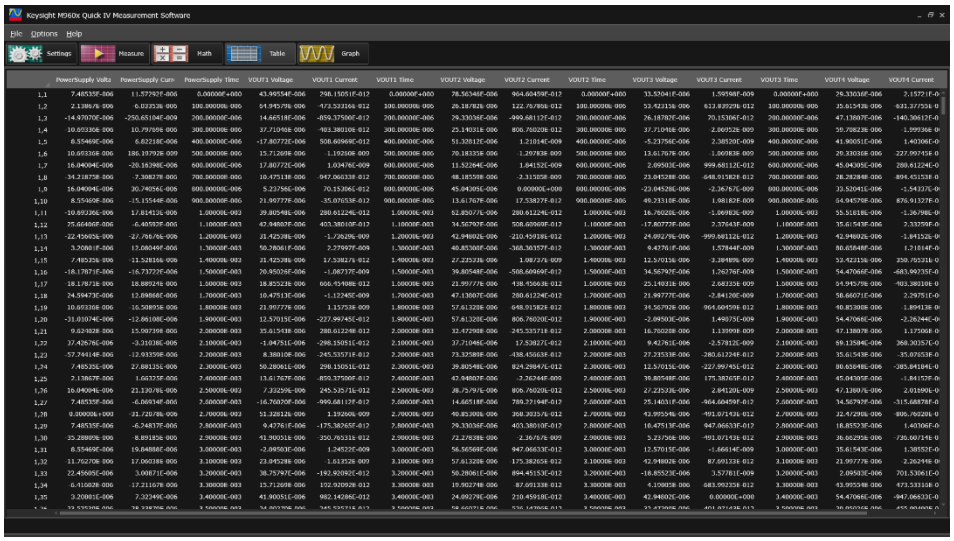
The setup menu allows you to specify and preview the settings on up to ten SMU channels before you perform a measurement, giving you the flexibility and ease of setting up the SMU channels.



The built-in graph function supports both basic and advanced features (such as the family of curves shown here).



Numerical measurement results can be viewed in a table format, and this data can easily be copied into Excel for further analysis.



For free 30-day trials, visit: www.keysight.com/find/px0109a

Specifications

Specification conditions

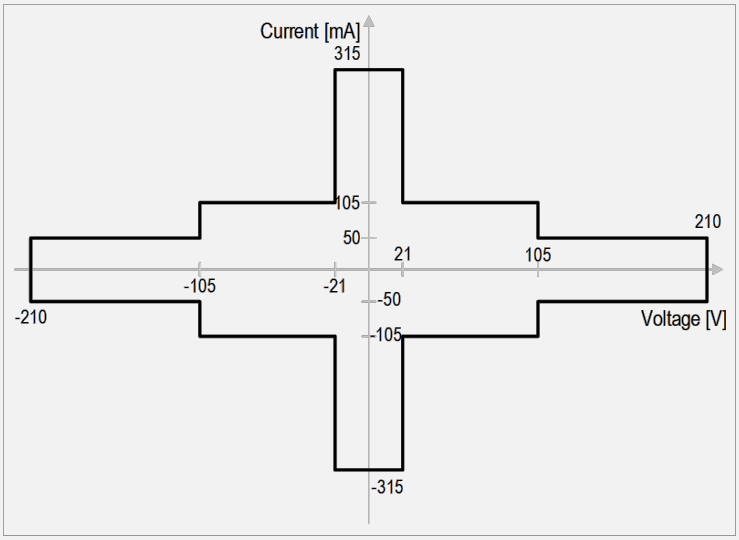
The measurement and programming accuracy are specified at the front panel connector terminals. Accuracy is specified under the following conditions.

Temperature	23 °C ± 5 °C (double for 5 °C to 18 °C, and 28 °C to 40 °C unless noted otherwise)
Humidity	20% to 60% RH (double for 60% to 70% unless noted otherwise)
Warm-up time	40 minutes
Self-calibration	Performed within the last 24 hours
	Ambient temperature changes less than ± 5 °C after self-calibration execution
Calibration period	One year
Aperture time	1 PLC1 (100 nA to 300 mA ranges, voltage ranges)
	10 PLC (1 nA and 10 nA ranges)
Terminal connection	Kelvin connection

1. Power line cycle.

Maximum voltage and current

Maximum voltage	Maximum current	Maximum power
± 21 V	± 315 mA	6.6 W
± 105 V	± 105 mA	11 W
± 210 V	± 50 mA	10.5 W



Source/measurement specifications and characteristics

Voltage source/measurement specifications

Range	Programming and measurement		Source noise (peak to peak) 0.1 Hz to 10 Hz [1]	Max current
	Resolution	Accuracy (% of reading + offset)		
± 0.5 V	0.5 µV	± (0.015% + 120 µV)	≤ 4 µV	± 315 mA
± 2 V	2 µV	± (0.015% + 140 µV)	≤ 5 µV	± 315 mA
± 6 V	6 µV	± (0.015% + 250 µV)	≤ 5 µV	± 315 mA
± 20 V	20 µV	± (0.015% + 900 µV)	≤ 15 µV	± 315 mA
± 40 V	40 µV	± (0.015% + 1 mV)	≤ 30 µV	[2]
± 100 V	100 µV	± (0.015% + 2.5 mV)	≤ 60 µV	[2]
± 200 V	200 µV	± (0.015% + 2.8 mV)	≤ 100 µV	± 50 mA (100 mA or less ranges)

1. Supplemental characteristics, 0 V sourced, 10 mA or less ranges.
2. ± 315 mA (-21 V ≤ V_o ≤ 21V), ± 105 mA (V_o < -21 V, V_o > 21 V).

Current source/measurement specifications

Range	Programming and measurement		Source noise (peak to peak) 0.1 Hz to 10 Hz [1]	Max voltage
	Resolution	Accuracy (% of reading + offset)		
± 1 nA	10 fA	± (0.1% + 1.5 pA + 1 fA x V_o) [2]	≤ 200 fA	± 210 V
± 10 nA	10 fA	± (0.1% + 3 pA + 10 fA x V_o) [2]	≤ 200 fA	± 210 V
± 100 nA	100 fA	± (0.05% + 20 pA)	≤ 2 pA	± 210 V
± 1 µA	1 pA	± (0.05% + 100 pA)	≤ 2 pA	± 210 V
± 10 µA	10 pA	± (0.04% + 2 nA)	≤ 80 pA	± 210 V
± 100 µA	100 pA	± (0.03% + 3 nA)	≤ 90 pA	± 210 V
± 1 mA	1 nA	± (0.03% + 60 nA)	≤ 8 nA	± 210 V
± 10 mA	10 nA	± (0.03% + 200 nA)	≤ 10 nA	± 210 V
± 100 mA	100 nA	± (0.04% + 6 µA)	≤ 200 nA	[3]
± 300 mA	300 nA	± (0.04% + 20 µA)	≤ 1 µA	± 21 V (100 V or less ranges)

1. Supplemental characteristics, 0 A sourced.
2. Aperture time: 10 PLC.
3. ± 210 V (-50 mA ≤ I_o ≤ 50 mA), ± 105 V (I_o < -50 mA, I_o > 50 mA).

Source supplemental characteristics

Max output power and source/sink limits	11 W
	± 21 V at ± 315 mA, ± 105 V at ± 105 mA, ± 210 V at ± 50 mA, four quadrant source or sink operation
Current compliance setting accuracy	Accuracy is same as current source; minimum value is
	1% of range (100 nA to 300 mA ranges)
	1 nA (1 nA, 10 nA ranges)
Voltage compliance setting accuracy	Accuracy is same as voltage source; minimum value is
	1% of range (6 V to 200 V ranges)
	50 mV (500 mV, 2 V ranges)
Over range	105% of voltage source range for all voltage ranges
	105% of current source range for 300 mA range
	115% of current source range for ranges other than 300 mA range
Over-temperature protection	Output turns off then resets at over temperature sensed internally.
Voltage output settling time	< 45 µs (500 mV to 40 V ranges, open load)
	< 100 µs (100 V range, 100 kΩ load)
	< 200 µs (200 V range, 100 kΩ load)
	Time required to reach within 0.1% of final value at described load condition; step is 10% to 90% range with 10 mA compliance, filter auto settings
Slew rate	1.4 V/µs (PS mode with 50 mA compliance)
	1 V/µs (Standard mode with 10 mA compliance)
	Step is 0 V to 200 V at open load condition
Current output settling time	< 18 ms (1 nA, 10 nA ranges, 50 MΩ load)
	< 1.2 ms (100 nA, 1 µA ranges, 500 kΩ load)
	< 400 µs (10 µA, 100 µA ranges, 5 kΩ load)
	< 70 µs (1 mA range, 50 Ω load)
	< 40 µs (10 mA range, 50 Ω load)
	< 40 µs (100 mA range, 500 mΩ load)
	< 40 µs (300 mA range, 100 mΩ load)
	Time required to reach within 0.1% [1] of final value at described load condition; step is 10% to 90% range with 6 V compliance, filter auto settings
V source noise (BW = 20 MHz)	< 3 mVrms, < 25 mVp-p, 20 V range, 0 V sourced (10 mA or less ranges)
	< 6 mVrms, < 40 mVp-p, 20 V range, 0 V sourced (100 mA, 300 mA ranges)
V source noise (BW = 200 MHz)	< 5 mVrms, < 50 mVp-p, 20 V range, 0 V sourced
Voltage range switching transient noise	< 250 mV, 100 kΩ load, 20 MHz bandwidth
Current range switching transient noise	< 70 mV, 100 kΩ load, 20 MHz bandwidth, V source mode, 20 V range

1. 0.3% for 100 mA, 300 mA ranges.

Programmable output resistance [1]

In its default state the M9601A behaves like either an ideal voltage source with a negligibly small source resistance or an ideal current source with a huge source resistance. The programmable output resistance feature allows you to specify a particular output resistance.

Mode	Constant Resistance
Series resistance (Rs) at voltage source	- (Load Resistance/2) ≤ Rs ≤ Load Resistance, for resistive load
	Rs ≤ 2 kΩ at 1 mA,10 mA,100 mA, and 300 mA ranges, ≤ 40 kΩ at 10 µA and 100 µA ranges, ≤ 200 kΩ at 1 µA range, or ≤ 100 kΩ at other ranges.
	Rs can be limited by capacitive load
Shunt resistance (Rsh) at current source	Load Resistance ≤ Rsh ≤ 2 GΩ, for resistive load
	Rsh ≥ 100 kΩ at 1 nA and 10 nA range, ≥ 10 kΩ at 100 nA and 1 µA range, ≥ 1 kΩ at 10 µA and 100 µA range, or ≥ 200Ω at other ranges.
	Rsh can be limited by capacitive load

1. Programmable output resistance is only available for DC output and for the firmware rev. 4.2 or later.

Pulse source supplemental characteristics

Programmable pulse width	20 µs to 1 s
Minimum pulse width programming resolution	0.2 µs
Pulse width programming accuracy	0.5 % ± 2 µs
Pulse period programming accuracy	0.5 % ± 4 µs
Pulse width definition	The time from 10% leading to 90% trailing edge (Figure 8)

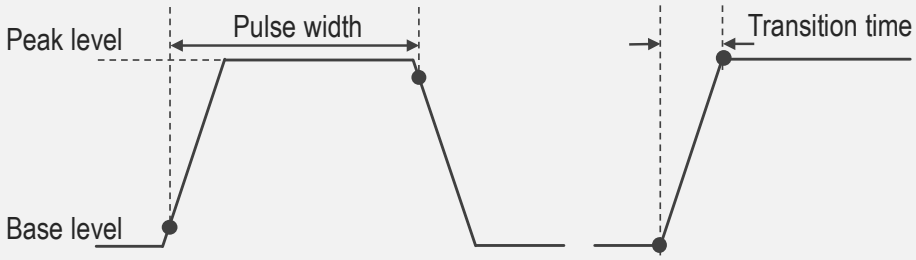


Figure 8. Definition of the pulse parameters and the transition time

Transition time at the given voltage, current and settling conditions (observed data)

Source value	Limit value	Operation mode	Load	Source settling band (% of range)	Transition time
200 V	50 mA	Standard	100 kΩ	0.1%	2.5 ms
200 V	50 mA	PS	100 kΩ	0.1%	140 µs
300 mA	6 V	Standard	100 mΩ	0.3%	40 µs

Transition time definition: The time from “Source settling band” to “100% - Source settling band” leading edges (Figure 8).

Measurement supplemental characteristics

Over range	105% of voltage measurement range for 200 V range
	110% of voltage measurement range for ranges other than 200 V range
	105% of current measurement range for 300 mA range
	115% of current measurement range for ranges other than 300 mA range

Voltage measurement noise (observed data)

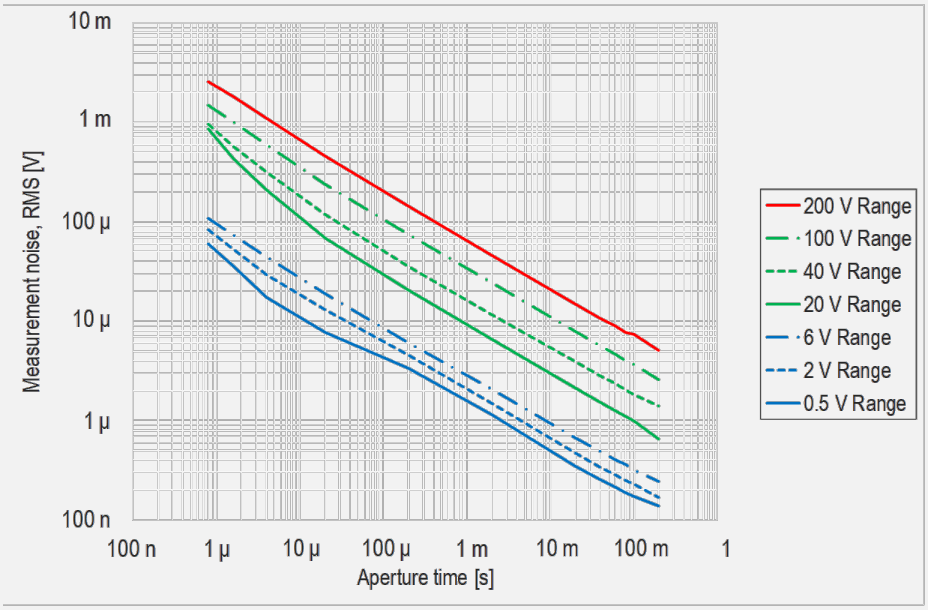


Figure 9. Voltage measurement noise vs. measurement aperture time

Current measurement noise (observed data)

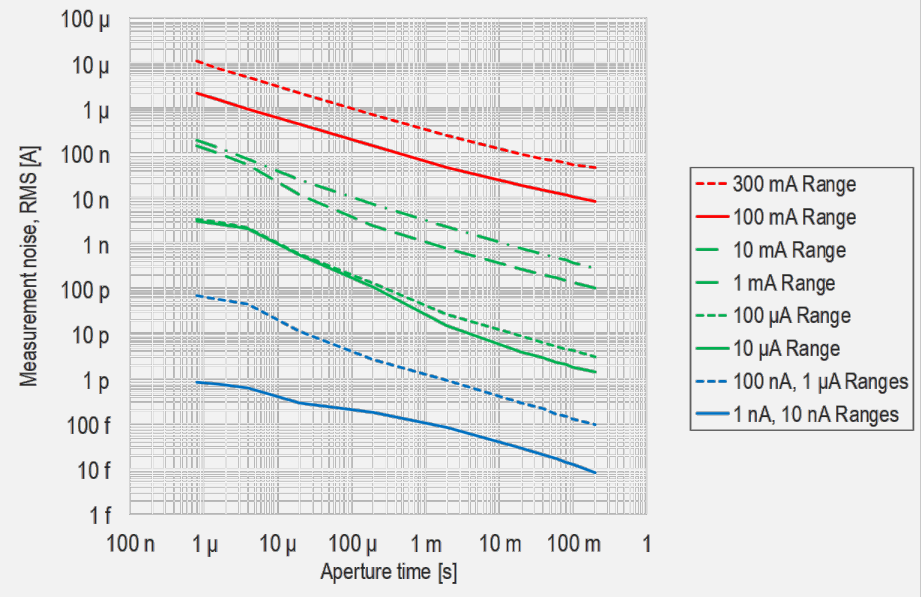


Figure 10. Current measurement noise vs. measurement aperture time

Measurement noise – no load (observed data)

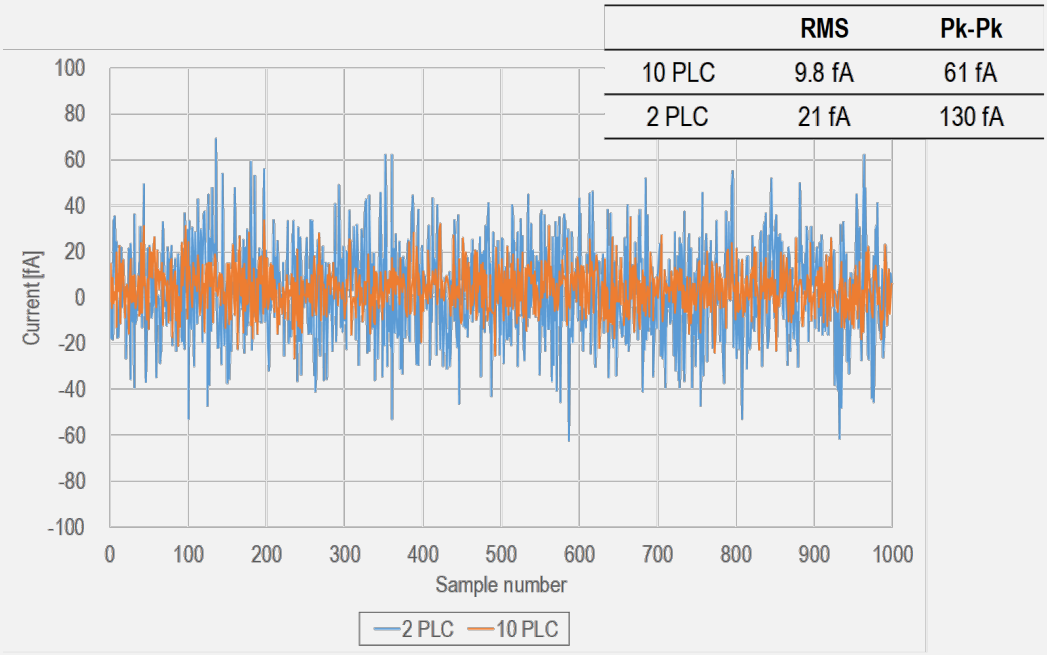


Figure 11. Measurement noise, 10 nA range, no load, 0 V, triax cable (3 m)

Measurement noise – 1 GΩ load (observed data)

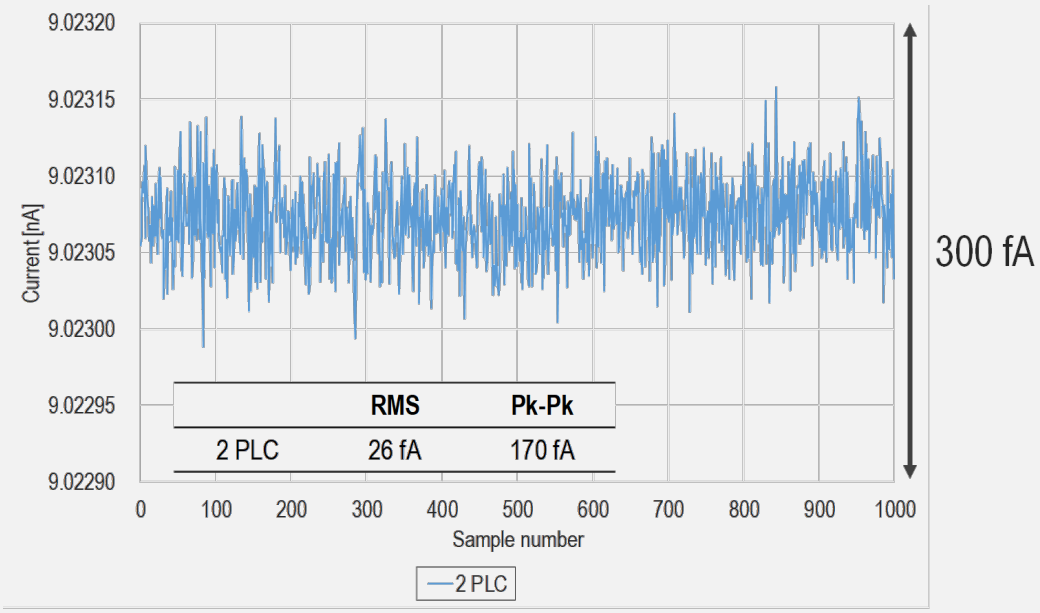


Figure 12. Measurement noise, 10 nA range, 1 GΩ load, 9 V, triax cable (3 m)

Measurement and timing characteristics

Available sampling rates		(1.25 MSa/s)/N where N=1, 2, 3, …, 2^{24}
Sample rate accuracy		Frequency accuracy is inherited from PXIe_CLK100
Maximum source update rate		250 kSa/s
Input trigger to	Source/sense trigger delay	≤ 5 µs
	Source/sense trigger jitter	≤ 4 µs

Other Supplemental Characteristics

Timer		
Timestamp	Timer value automatically saved when each measurement is triggered	
Trigger timing resolution	4 µs to 100 ms	
Clock source	PXIe_CLK100	
Arm/trigger delay	0 µs to 100,000 s	
Arm/trigger interval	4 µs to 100,000 s	
Arm/trigger event	1 to 1,000,000 (count)	
Input triggers		
Sources (PXI trigger lines 0 to 7, external trigger 0 and 1)	Polarity	Configurable
	Minimum pulse width	200 ns, nominal
Output triggers		
Destinations (PXI trigger lines 0 to 7, external trigger 0 and 1)	Polarity	Configurable
	Pulse width	Configurable between 200 ns and 12.8 µs, nominal
Output characteristics		
Sensing modes	2-wire or 4-wire (remote-sensing) connections	
Low terminal connection	Chassis grounded or floating	
Output connectors	Triaxial jack for high force and high sense	
	SMB jack for low sense	
Maximum guard offset voltage	< 2 mV	
Remote sense operation range	Max voltage between high force and high sense = 1 V	
	Max voltage between low force and low sense = 1 V	
Voltage source output resistance	< 0.3 Ω (non-kelvin)	
Current source output resistance	≥ 10 TΩ (1 nA range)	
Maximum allowable cable resistance	Sense: 10 Ω	
	Force: 10 Ω (I_o ≤ 100 mA), 3 Ω (I_o > 100 mA)	
Maximum load capacitance	100 µF (100 mA to 300 mA ranges, ESR ≥ 25 mΩ)	
Guard output impedance	610 Ω (nominal)	
Maximum DC floating voltage	± 40 V between low force and chassis	

Environmental Specifications

Environment	For use in indoor facilities
Operating	5 °C to 40 °C, 15% to 70% RH, non-condensing
Storage	-20 °C to 60 °C, 5% to 90% RH, non-condensing
Altitude	Operating: 0 m to 2000 m; storage: 0 to 4600 m
Power consumption	+ 3.3 V ± 5%, 1.5 A
	+ 12 V ± 5%, 3.5 A
EMC	IEC61326-1/EN61326-1, IEC61326-2-1/EN61326-2-1, CISPR 11/EN55011 Group 1 Class A, ICES-001, AS/NZS CISPR11, KN61000-6-1, KN11
Safety	IEC61010-1/EN61010-1, IEC61010-2-030/EN61010-2-030, CAN/CSA-C22.2 No. 61010-1, CAN/CSA-C22.2 No. 61010-2-030
Compliance and Certifications	CE, cCSAus, C-Tick, KC
Warm-up	40 minutes
Dimensions	3U, 2-slot PXIe module
	Height 40.1 mm x depth 131 mm x width 210 mm
Weight	0.55 kg

Source/Measurement Capabilities

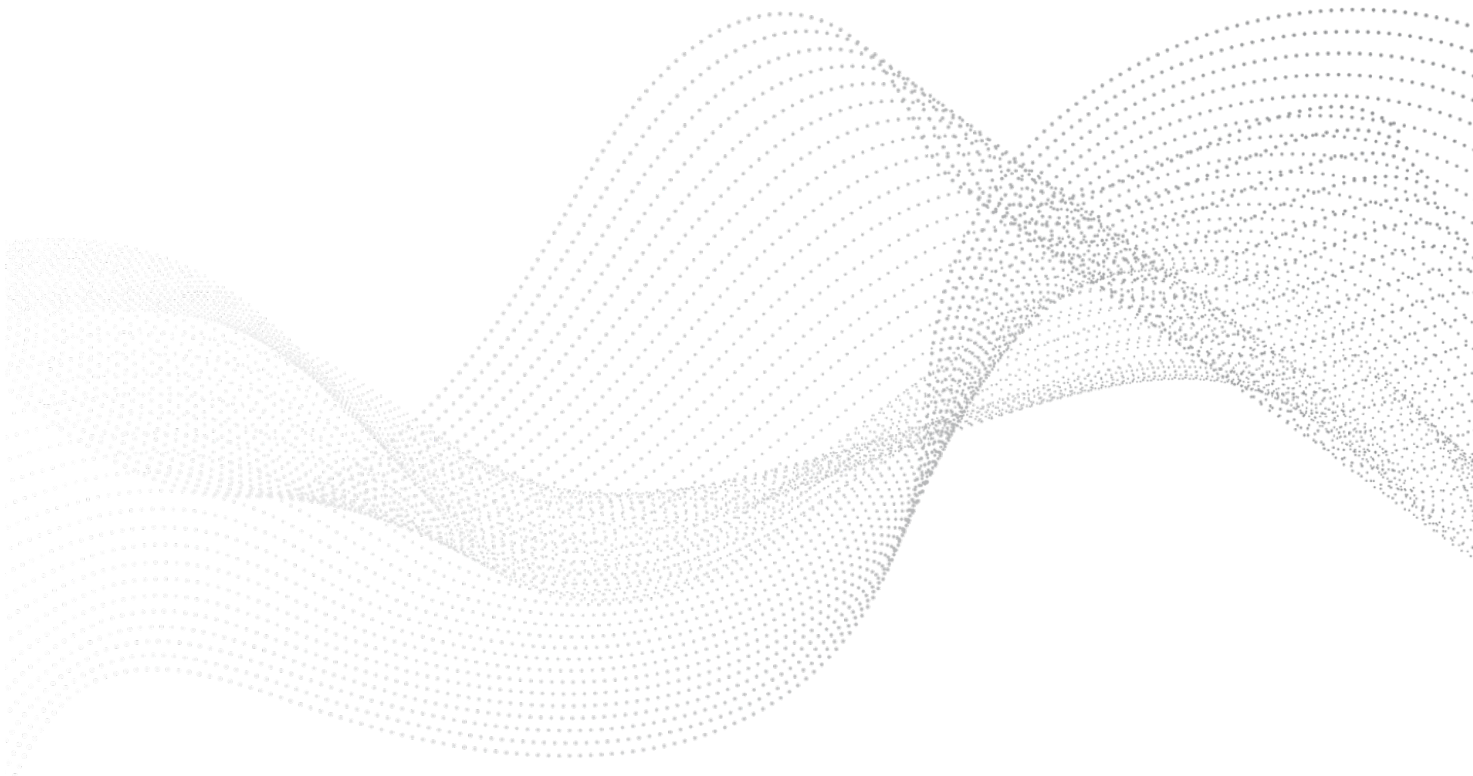
Sweep measurement	
Number of steps	1 to 1,000,000
Sweep mode	Linear or list
Sweep direction	Single or double
Type	DC or pulse
Min programmable value to create list sweep waveform	4 µs
Digitizing/sampling measurement	
Max sampling rate	1.25 MSa/s
Data buffers	
Max buffer size	1,000,000 points
Program, software, and drivers	
Programming	SCPI (Rev 4.0 or later)
Supported operating systems	Microsoft Windows 7 Professional SP1 or later (32-bit/64-bit)
	Microsoft Windows 8.1 Professional or later (32-bit/64-bit)
	Microsoft Windows 10 (32-bit/64-bit)
Standard compliant drivers	IVI-C, IVI.Net, LabVIEW
Supported application development environment (ADE)	Visual Studio (VB.NET, C#, C/C++), LabVIEW, MATLAB, VEE
.NET Framework	Microsoft .NET Framework 4.5.2 or later
Keysight IO libraries	Keysight IO Libraries Suite 2019 or later

System and Installation Requirements for PX0109A

Computer operating system	
Operating system	Windows 10 (64-bit) Pro, Windows 10 (64-bit) Enterprise
Supporting language	English (US)
.NET Framework	Microsoft .NET, Framework 4.7.1
IO Libraries	Keysight IO Libraries Suite 2019 or later
PathWave License Manager	2.4.1 or later
Interfaces	PXIe

Furnished Accessories

Furnished accessories
Short bar, connector-terminal block 2.5 mm 6-terminal, certificate of calibration (without test data), quick startup poster



Ordering Information

Model number	
M9601A	PXIe precision source/measure unit, 1.25 MSa/s, 10 fA, 210 V, 315 mA
Options	
1A7	Calibration + uncertainties + guardbanding (not accredited)
A6J	ANSI Z540-1-1994 calibration
UK6	Commercial calibration certificate with test data
Accessories	
PX0101A-001	BNC to ferrule terminal cable, 1.5 m
PX0101A-002	BNC to ferrule terminal cable, 3 m
PX0102A-001	Low noise triaxial cable, 1.5 m
PX0102A-002	Low noise triaxial cable, 3 m
PX0103A-001	Triaxial to SMB cable, 1.5 m
PX0103A-002	Triaxial to SMB cable, 3 m

Software		
Product	**License Type**	**License term (36 months Subscription) License & support**
PX0109A	Node-locked (fixed)	R-X45-001-Y
	Transportable	R-X45-004-Y
	USB Portable[1]	R-X45-005-Y
	Floating (single site)	R-X45-002-Y
	Floating (single region)	R-X45-006-Y

1. USB portable license requires a certified USB dongle (available for additional purchase. Keysight part number PX0100-D10)

Learn more at: www.keysight.com

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