

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 μ s pulse, output up to 210 V/315 mA, and with the best-in-class 10 fA resolution and lowest source noise



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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 μ s 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 μ s | Suppresses self-heating effect and has the true characteristics of the devices to improve measurement throughput |
| Fast transient capability: 1.4 V/ μ s 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.

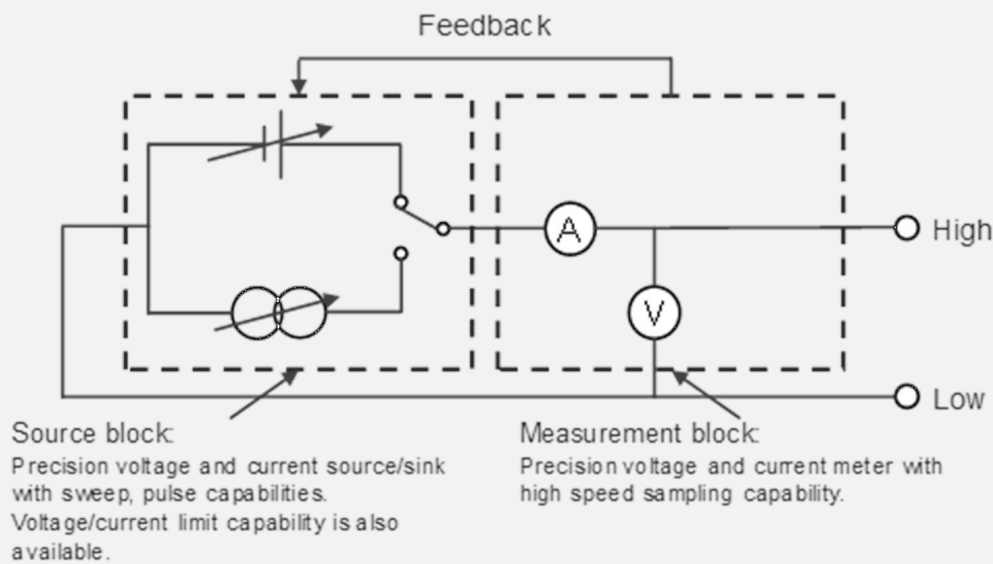


Figure 1. Simplified block diagram of the M9601A

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.

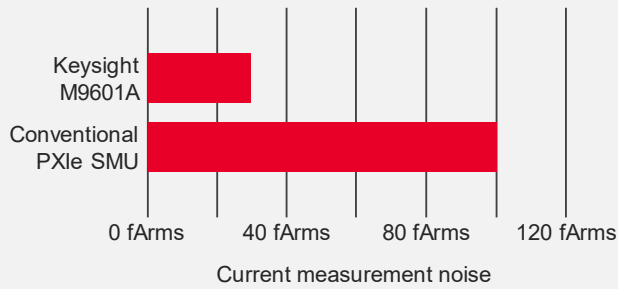


Figure 2. Current measurement noise with 1 PLC (20 ms) aperture time

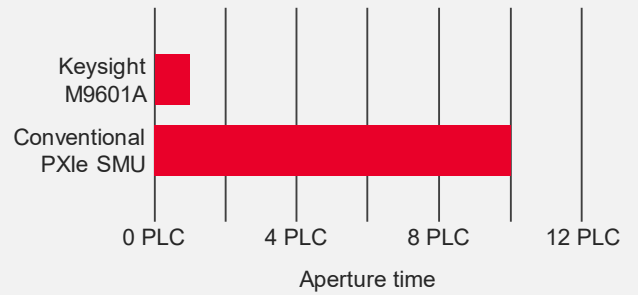


Figure 3. Aperture time required to achieve 30 fArms current measurement noise

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.

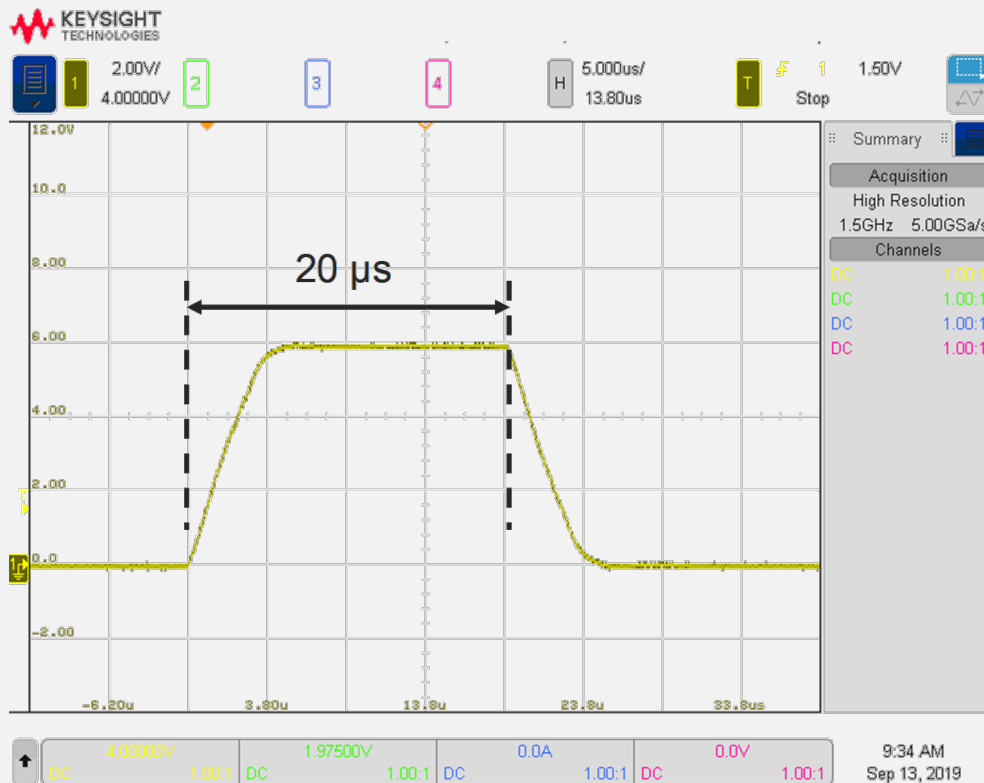


Figure 4. Narrow pulse down to 20 μs enables you to suppress self-heat effect to reveal the true characteristics of the devices

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/ μ s 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.

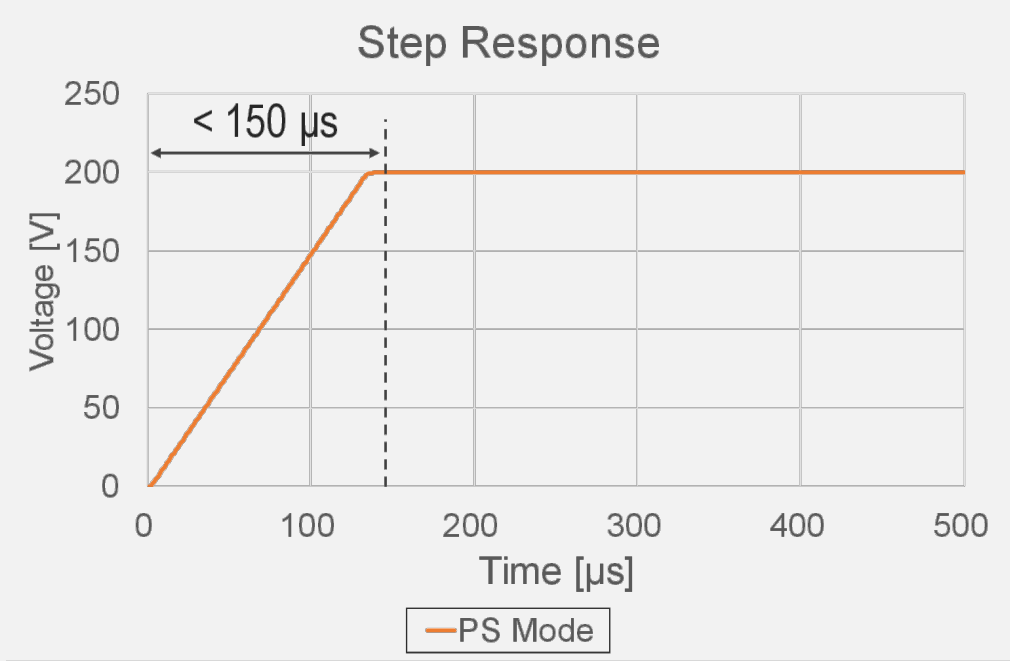


Figure 5. A voltage of 200 V ramped up to within 150 μ s

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.

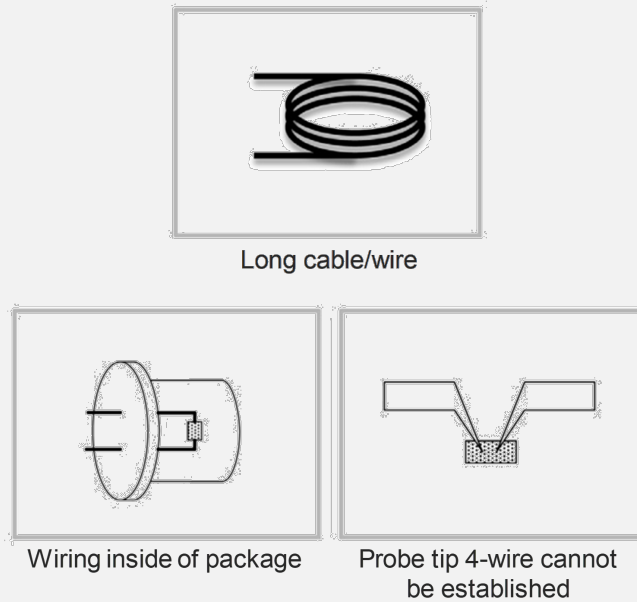


Figure 6. Measurement situations that benefit from Programmable Output Resistance feature

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.

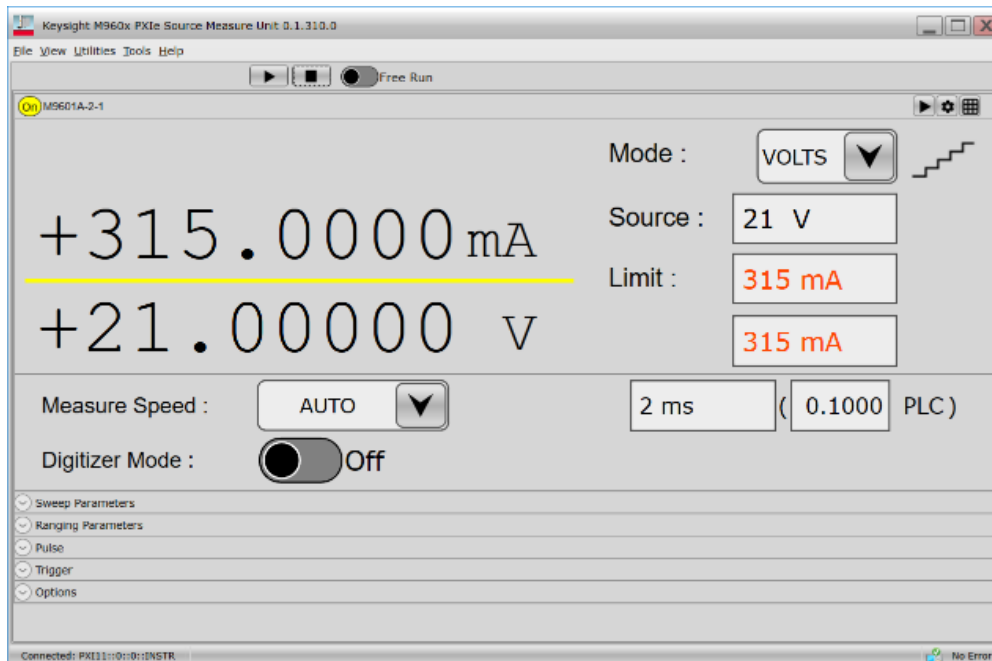


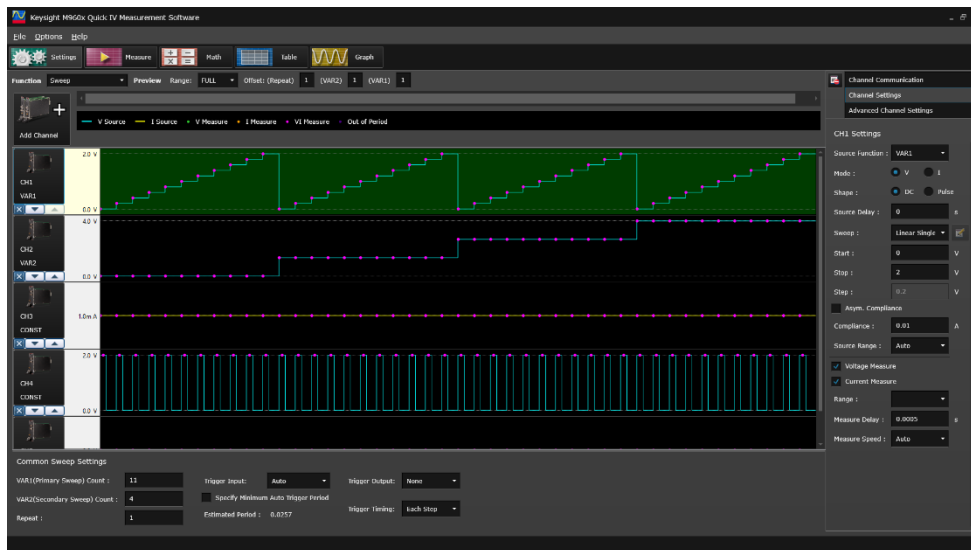
Figure 7. M9601A soft front panel

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.

The screenshot shows the 'Table' view of the Keyight MS66x Quick IV Measurement Software. The table displays numerical measurement results for various parameters over time. The columns include PowerSupply Voltage, PowerSupply Current, VOUT1 Voltage, VOUT1 Current, VOUT2 Voltage, VOUT2 Current, VOUT3 Voltage, VOUT3 Current, VOUT4 Voltage, and VOUT4 Current. The rows represent individual data points, with the first column indicating the time in seconds. The data shows a transient event where the voltage drops from approximately 1.1V to 0.8V and then recovers, with corresponding changes in current.

| Time (s) | PowerSupply Voltage | PowerSupply Current | VOUT1 Voltage | VOUT1 Current | VOUT2 Voltage | VOUT2 Current | VOUT3 Voltage | VOUT3 Current | VOUT4 Voltage | VOUT4 Current |
|----------|---------------------|---------------------|---------------|---------------|----------------|---------------|---------------|----------------|---------------|---------------|
| 1.1 | 7.48535E-06 | 1.15720E+00 | 0.0000E+00 | 0.0000E+00 | 78.5654E-06 | 0.0000E+00 | 66.46049E-017 | 0.0000E+00 | 33.5504E-06 | 1.9598E-09 |
| 1.2 | 2.139E-06 | 6.2222E-00 | 330.0000E-000 | 9.14937E-06 | 472.5226E-012 | 330.0000E-000 | 28.1878E-000 | 122.7576E-012 | 330.0000E-000 | 52.4213E-000 |
| 1.3 | -14.0729E-06 | -920.6516E-09 | 700.0000E-000 | 14.6651E-06 | -403.3750E-013 | 700.0000E-000 | 78.3320E-000 | -499.6811E-013 | 70.0000E-000 | 70.0000E-000 |
| 1.4 | 10.6752E-06 | 10.7979E-00 | 300.0000E-000 | 37.1598E-06 | -93.3820E-012 | 300.0000E-000 | 23.9318E-000 | 806.7622E-012 | 300.0000E-000 | 37.1598E-000 |
| 1.5 | 8.5546E-06 | 6.8221E-00 | 400.0000E-000 | -17.8027E-06 | 508.6096E-012 | 400.0000E-000 | 51.3212E-000 | 1.2104E-000 | 400.0000E-000 | -5.2734E-000 |
| 1.6 | 10.6932E-06 | 186.1379E-09 | 500.0000E-000 | 15.7120E-06 | 1.1520E-000 | 500.0000E-000 | 78.1812E-000 | 1.2978E-000 | 500.0000E-000 | 13.6170E-000 |
| 1.7 | 16.9804E-06 | -20.9328E-09 | 600.0000E-000 | 17.8027E-06 | 1.0348E-000 | 600.0000E-000 | 11.5228E-000 | 1.9412E-000 | 600.0000E-000 | 2.9950E-000 |
| 1.8 | 34.1817E-06 | 7.3887E-00 | 700.0000E-000 | 10.4713E-06 | 947.0663E-012 | 700.0000E-000 | 48.1855E-000 | 2.3155E-000 | 700.0000E-000 | 23.0428E-000 |
| 1.9 | 16.9804E-06 | 30.7402E-09 | 800.0000E-000 | 5.2278E-06 | 70.1526E-012 | 800.0000E-000 | 45.6429E-000 | 0.0000E+000 | 800.0000E-000 | -2.0452E-000 |
| 2.0 | 8.5546E-06 | -15.154E-09 | 900.0000E-000 | 31.4077E-06 | -35.0758E-012 | 900.0000E-000 | 13.6170E-000 | 17.3337E-012 | 900.0000E-000 | 49.2311E-000 |
| 2.1 | -18.0932E-06 | 12.6545E-09 | 1.0000E-003 | 28.8049E-06 | 288.8224E-012 | 1.0000E-003 | 62.8021E-000 | 288.8224E-012 | 1.0000E-003 | 16.7622E-000 |
| 2.2 | 25.6649E-06 | -6.4659E-09 | 1.0000E-003 | 43.9489E-06 | 433.3880E-012 | 1.0000E-003 | 34.5789E-000 | 508.6096E-012 | 1.0000E-003 | 17.8027E-000 |
| 2.3 | -22.4502E-06 | -2.7857E-09 | 1.0000E-003 | 31.4228E-06 | -1.7282E-000 | 1.0000E-003 | 42.9802E-000 | -210.4928E-012 | 1.0000E-003 | 24.0927E-000 |
| 2.4 | 3.208E-06 | 13.0849E-09 | 1.0000E-003 | 50.2608E-06 | 7.2799E-000 | 1.0000E-003 | 49.8320E-000 | -308.3077E-012 | 1.0000E-003 | 9.4371E-000 |
| 2.5 | 7.8102E-06 | -11.5218E-09 | 1.0000E-003 | 22.4228E-06 | 12.0282E-012 | 1.0000E-003 | 22.2222E-000 | 1.8071E-000 | 1.0000E-003 | 12.5023E-000 |
| 2.6 | -16.1787E-06 | -16.7327E-06 | 1.0000E-003 | 20.8508E-06 | -1.0877E-000 | 1.0000E-003 | 36.8508E-000 | -508.6096E-012 | 1.0000E-003 | 34.5789E-000 |
| 2.7 | 18.1873E-06 | 18.8927E-09 | 1.0000E-003 | 18.8522E-06 | 608.4598E-012 | 1.0000E-003 | 21.9977E-000 | 438.4508E-012 | 1.0000E-003 | 2.6822E-000 |
| 2.8 | 24.5847E-06 | 12.8886E-09 | 1.0000E-003 | 18.4973E-06 | -1.1228E-000 | 1.0000E-003 | 47.1380E-000 | 280.8124E-012 | 1.0000E-003 | 21.9977E-000 |
| 2.9 | 18.6932E-06 | 16.5895E-09 | 1.0000E-003 | 21.4927E-06 | 1.1373E-000 | 1.0000E-003 | 57.6122E-000 | 648.9324E-012 | 1.0000E-003 | 14.5070E-000 |
| 3.0 | -11.0304E-06 | -12.8618E-09 | 1.0000E-003 | 12.5735E-06 | -227.9485E-012 | 1.0000E-003 | 57.6122E-000 | 806.7622E-012 | 1.0000E-003 | -2.0950E-000 |
| 3.1 | 9.4292E-06 | 15.0078E-09 | 2.0000E-003 | 35.6133E-06 | 288.6122E-012 | 2.0000E-003 | 32.4728E-000 | 245.3371E-012 | 2.0000E-003 | 16.7622E-000 |
| 3.2 | 37.4829E-06 | -2.0102E-09 | 2.0000E-003 | 1.9451E-06 | -298.5501E-012 | 2.0000E-003 | 37.7104E-000 | 12.5302E-012 | 2.0000E-003 | 9.4292E-000 |
| 3.3 | -57.744E-06 | -12.9359E-09 | 2.0000E-003 | 8.3835E-06 | -245.5551E-012 | 2.0000E-003 | 71.5258E-000 | -48.4563E-012 | 2.0000E-003 | 27.2735E-000 |
| 3.4 | 7.4853E-06 | 2.7812E-09 | 2.0000E-003 | 58.2804E-06 | 298.1503E-012 | 2.0000E-003 | 39.8058E-000 | 824.2987E-012 | 2.0000E-003 | 12.5735E-000 |
| 3.5 | 2.1386E-06 | 1.6337E-09 | 3.0000E-003 | 13.6170E-06 | 409.3750E-012 | 3.0000E-003 | 42.6480E-000 | -3.2624E-000 | 3.0000E-003 | 36.8508E-000 |
| 3.6 | 16.9804E-06 | 21.2120E-09 | 2.0000E-003 | 7.2324E-06 | 243.5231E-012 | 2.0000E-003 | 26.2570E-000 | 806.7622E-012 | 2.0000E-003 | 21.2222E-000 |
| 3.7 | 7.4853E-06 | -6.0658E-09 | 2.0000E-003 | -16.7650E-06 | -902.6811E-012 | 2.0000E-003 | 14.6651E-000 | 789.3714E-012 | 2.0000E-003 | 251.4051E-000 |
| 3.8 | 0.0000E+000 | -21.7278E-09 | 2.0000E-003 | 51.2822E-06 | 1.19200E+000 | 2.0000E-003 | 40.8200E-000 | 308.3077E-012 | 2.0000E-003 | 492.0713E-012 |
| 3.9 | 7.4853E-06 | -6.2487E-09 | 2.0000E-003 | 9.4276E-06 | -175.3855E-012 | 2.0000E-003 | 24.3335E-000 | 433.3880E-012 | 2.0000E-003 | 16.4791E-000 |
| 4.0 | 22.2000E-06 | 9.8102E-09 | 2.0000E-003 | 41.9023E-06 | 250.9221E-012 | 2.0000E-003 | 72.1870E-000 | 1.2670E-000 | 2.0000E-003 | 2.2222E-000 |
| 4.1 | 8.5546E-06 | 19.6488E-09 | 3.0000E-003 | -2.8959E-06 | 1.8452E+000 | 3.0000E-003 | 56.5688E-000 | 947.0663E-012 | 3.0000E-003 | 12.5735E-000 |
| 4.2 | 11.7627E-06 | 17.0602E-09 | 3.0000E-003 | 23.9528E-06 | 1.6123E+000 | 3.0000E-003 | 57.6122E-000 | 175.3855E-012 | 3.0000E-003 | 42.9802E-000 |
| 4.3 | 22.4502E-06 | 3.0881E-09 | 3.0000E-003 | 38.7570E-06 | -182.4080E-012 | 3.0000E-003 | 58.3886E-000 | 894.4513E-012 | 3.0000E-003 | -18.8522E-000 |
| 4.4 | 6.0100E-06 | -11.2117E-09 | 3.0000E-003 | 15.7228E-06 | 172.0703E-012 | 3.0000E-003 | 19.8027E-000 | 87.0318E-012 | 3.0000E-003 | 6.0100E-000 |
| 4.5 | 2.2080E-06 | 7.2378E-09 | 3.0000E-003 | 41.9023E-06 | 992.1486E-012 | 3.0000E-003 | 24.9927E-000 | 218.4998E-012 | 3.0000E-003 | 42.9802E-000 |
| 4.6 | 33.5358E-06 | 78.3398E-09 | 3.0000E-003 | 345.5571E-013 | 3.0000E-003 | 88.6670E-000 | 372.4788E-012 | 372.4788E-012 | 3.0000E-003 | 403.0718E-013 |

Specifications

Specification conditions

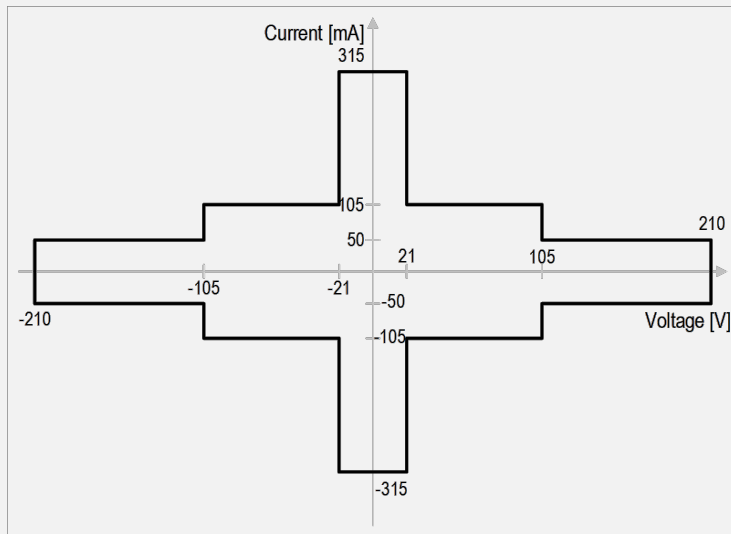
The measurement and programming accuracy are specified at the front panel connector terminals. Accuracy is specified under the following conditions.

| | |
|---------------------|--|
| 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 × V _o) ² | ≤ 200 fA | ± 210 V |
| ± 10 nA | 10 fA | ± (0.1% + 3 pA + 10 fA × 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 μ s (500 mV to 40 V ranges, open load) |
| | < 100 μ s (100 V range, 100 k Ω load) |
| | < 200 μ s (200 V range, 100 k Ω 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/ μ s (PS mode with 50 mA compliance) |
| | 1 V/ μ s (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 M Ω load) |
| | < 1.2 ms (100 nA, 1 μ A ranges, 500 k Ω load) |
| | < 400 μ s (10 μ A, 100 μ A ranges, 5 k Ω load) |
| | < 70 μ s (1 mA range, 50 Ω load) |
| | < 40 μ s (10 mA range, 50 Ω load) |
| | < 40 μ s (100 mA range, 500 m Ω load) |
| | < 40 μ s (300 mA range, 100 m Ω 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 k Ω load, 20 MHz bandwidth |
| Current range switching transient noise | < 70 mV, 100 k Ω 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 | - $(\text{Load Resistance}/2) \leq R_s \leq \text{Load Resistance}$, for resistive load |
| | $R_s \leq 2 \text{ k}\Omega$ at 1 mA, 10 mA, 100 mA, and 300 mA ranges, $\leq 40 \text{ k}\Omega$ at 10 μA and 100 μA ranges, $\leq 200 \text{ k}\Omega$ at 1 μA range, or $\leq 100 \text{ k}\Omega$ at other ranges. |
| | Rs can be limited by capacitive load |
| Shunt resistance (Rsh) at current source | $\text{Load Resistance} \leq R_{sh} \leq 2 \text{ G}\Omega$, for resistive load |
| | $R_{sh} \geq 100 \text{ k}\Omega$ at 1 nA and 10 nA range, $\geq 10 \text{ k}\Omega$ at 100 nA and 1 μA range, $\geq 1 \text{ k}\Omega$ at 10 μA and 100 μA range, or $\geq 200\Omega$ 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 μ s to 1 s |
| Minimum pulse width programming resolution | 0.2 μ s |
| Pulse width programming accuracy | 0.5 % \pm 2 μ s |
| Pulse period programming accuracy | 0.5 % \pm 4 μ s |
| Pulse width definition | The time from 10% leading to 90% trailing edge (Figure 8) |

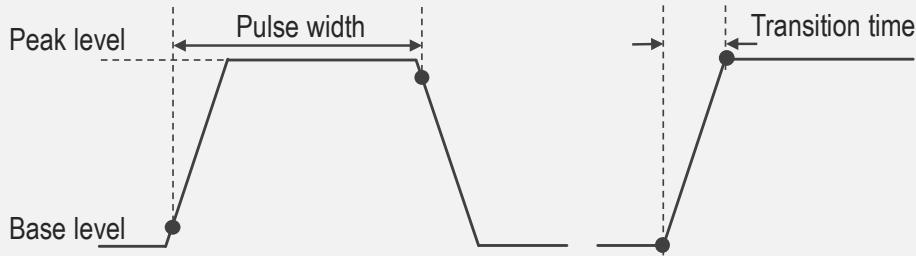


Figure 8. Definition of the pulse parameters and the transition time

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 k Ω | 0.1% | 2.5 ms |
| 200 V | 50 mA | PS | 100 k Ω | 0.1% | 140 μ s |
| 300 mA | 6 V | Standard | 100 m Ω | 0.3% | 40 μ s |

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)

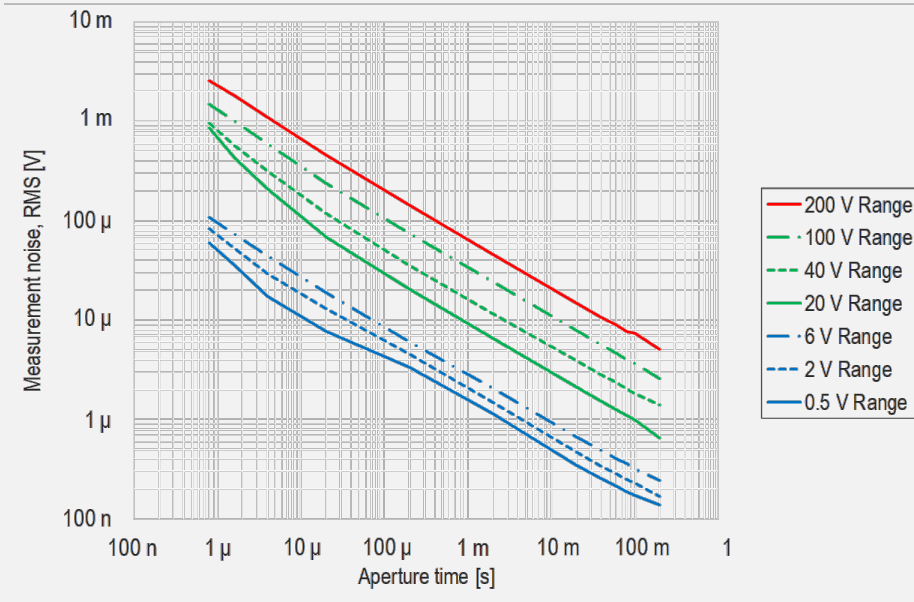


Figure 9. Voltage measurement noise vs. measurement aperture time

Current measurement noise (observed data)

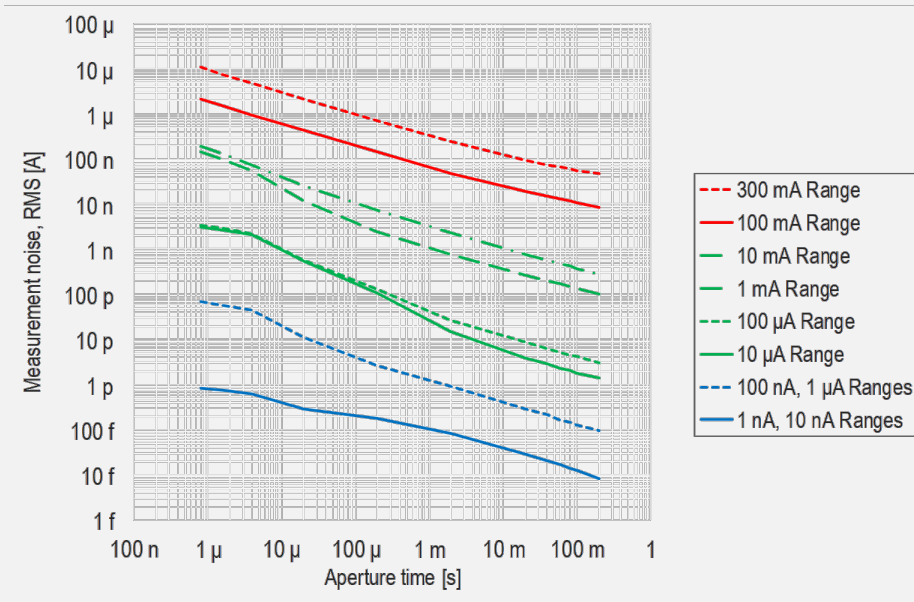


Figure 10. Current measurement noise vs. measurement aperture time

Measurement noise – no load (observed data)

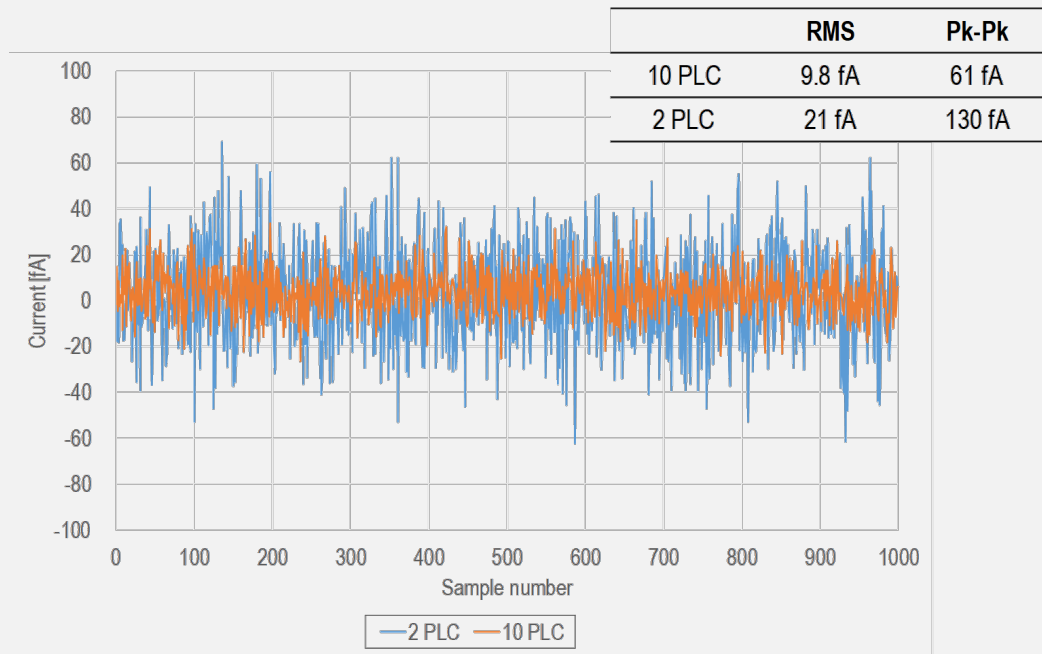


Figure 11. Measurement noise, 10 nA range, no load, 0 V, triax cable (3 m)

Measurement noise – 1 GΩ load (observed data)

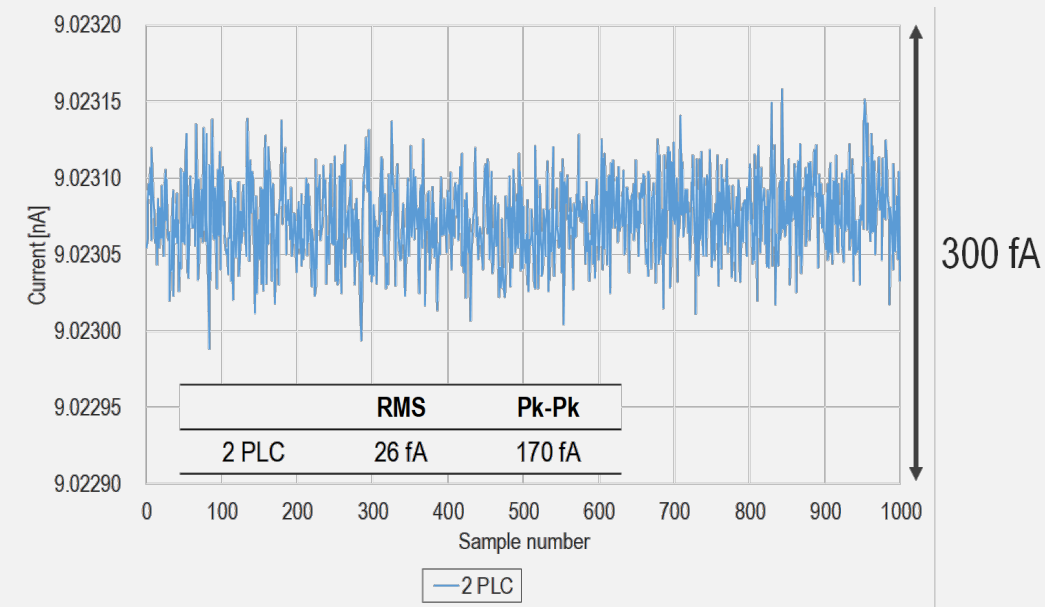


Figure 12. Measurement noise, 10 nA range, 1 GΩ load, 9 V, triax cable (3 m)

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)

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