Tektronix®

2182A Nanovoltmeter

DATASHEET

The two-channel 2182A Nanovoltmeter is optimized for making stable, low noise voltage measurements and for characterizing low resistance materials and devices reliably and repeatably. It provides higher measurement speed and significantly better noise performance than alternative low voltage measurement solutions.

The 2182A represents the next step forward in Keithley nanovoltmeter technology, replacing the original 2182 and offering enhanced capabilities including pulse capability, lower measurement noise, faster current reversals, and a simplified delta mode for making resistance measurements in combination with a reversing current source, such as the 6220 or 6221.

Key Features

- Make low noise measurements at high speeds, typically just 15 nV p-p noise at 1s response time, 40–50 nV p-p noise at 60 ms
- Delta mode coordinates measurements with a reversing current source at up to 24 Hz with 30 nV p-p noise (typical) for one reading. Averages multiple readings for greater noise reduction
- Synchronization to line provides 110 dB NMRR and minimizes the effect of AC common-mode currents
- Dual channels support measuring voltage, temperature, or the ratio of an unknown resistance to a reference resistor
- Built-in thermocouple linearization and cold junction compensation

Flexible, Effective Speed/Noise Trade-offs

The 2182A makes it easy to choose the best speed/filter combination for a particular application's response time and noise level requirements. The ability to select from a wide range of response times allows optimizing speed/noise trade-offs. Low noise levels are assured over a wide range of useful response times, e.g., 15 nV p-p noise at 1 s and 40–50 nV p-p noise at 60 ms are typical. **Figure 1** illustrates the 2182A's noise performance.

Figure 1. Compare the 2182A's DC noise performance with a nanovolt/micro-ohmmeter's. All the data shown was taken at 10 readings per second with a low thermal short applied to the input.

Reliable Results

Power line noise can compromise measurement accuracy significantly at the nanovolt level. The 2182A reduces this interference by synchronizing its measurement cycle to line, which minimizes variations due to readings that begin at different phases of the line cycle. The result is exceptionally high immunity to line interference with little or no shielding and filtering required.

Optimized for Use with 6220/6221 Current Sources

Device test and characterization for today's very small and power-efficient electronics requires sourcing low current levels, which demands the use of a precision, low current source. Lower stimulus currents produce lower—and harder to measure—voltages across the devices. Linking the 2182A Nanovoltmeter with a 6220 or 6221 Current Source makes it possible to address both of these challenges in one easy-to-use configuration.

When connected, the 2182A and 6220 or 6221 can be operated like a single instrument. Their simple connections eliminate the isolation and noise current problems that plague other solutions. The 2182A/622X combination allows making delta mode and differential conductance measurements faster and with less noise than the original 2182 design allowed. The 2182A will also work together with the 6221 to make pulse-mode measurements.

The 2182A/622X combination is ideal for a variety of applications, including resistance measurements, pulsed I-V measurements, and differential conductance measurements, providing significant advantages over earlier solutions like lock-in amplifiers or AC resistance bridges. The 2182A/622X combination is also well suited for many nanotechnology applications because it can measure resistance without dissipating much power into the device under test (DUT), which would otherwise invalidate results or even destroy the DUT.

An Easy-to-Use Delta Mode

Keithley originally created the delta mode method for measuring voltage and resistance for the 2182 and a triggerable external current source, such as the 2400 SourceMeter® SMU instrument. Basically, the delta mode automatically triggers the current source to alternate the signal polarity, and then triggers a nanovoltmeter reading

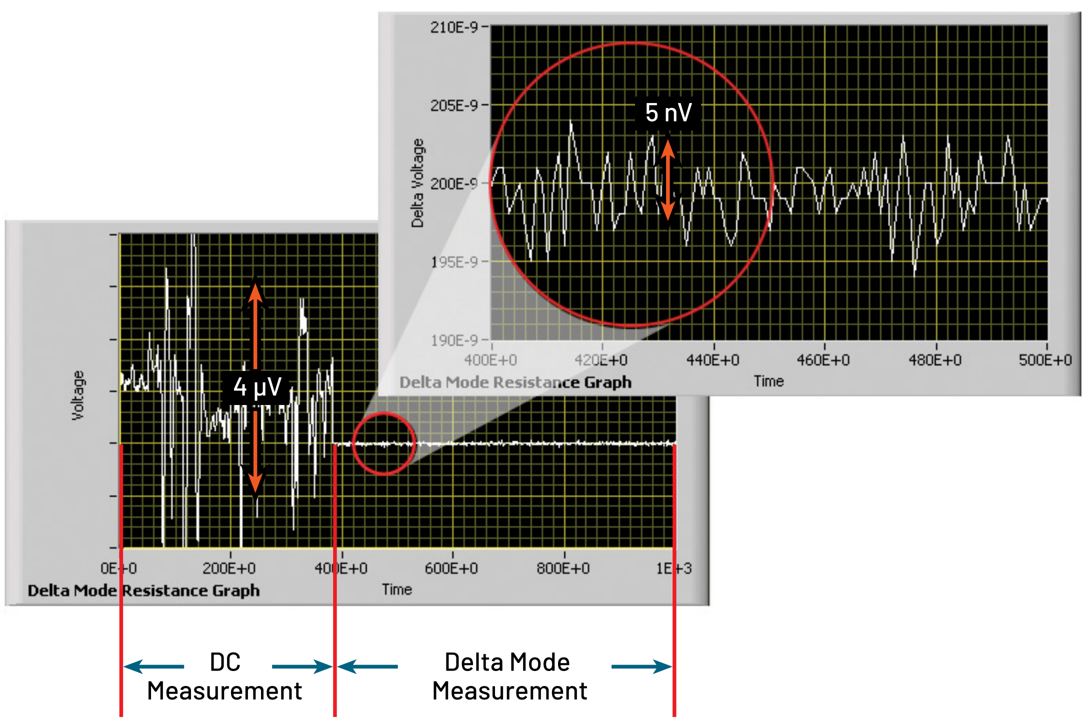

Figure 2. Results from a 2182A/6220 using the delta mode to measure a 10 mΩ resistor with a 20 µA test current. The free 6220/6221 instrument control example start-up software used here can be downloaded from www.keithley.com.

at each polarity. This current reversal technique cancels out any constant thermoelectric offsets, so the results reflect the true value of the voltage being measured. The improved delta mode for the 2182A and the 622X current sources uses the same basic technique, but the way in which it's implemented has been simplified dramatically. The new technique can cancel thermoelectric offsets that drift over time (not just static offsets), produces results in half the time of the original technique, and allows the current source to control and configure the 2182A. Two key presses are all that's required to set up the measurement. The improved cancellation and higher reading rates reduce measurement noise to as little as 1 nV.

Differential Conductance Measurements

Characterizing non-linear tunneling devices and low temperature devices often requires measuring differential conductance (the derivative of a device's I-V curve). When used with a 622X current source, the 2182A is the industry's fastest, most complete solution for differential conductance measurements, providing 10× the speed and significantly lower noise than other instrumentation options. There's no need to average the results of multiple sweeps, because data can be obtained in a single measurement pass, reducing test time and minimizing the potential for measurement error.

Pulsed Testing with the 6221

When measuring small devices, introducing even tiny amounts of heat to the DUT can raise its temperature, skewing test results or even destroying the device. When used with the 2182A, the 6221's pulse capability minimizes the amount of power dissipated into a DUT. The 2182A/6221 combination synchronizes the pulse and measurement. A measurement can begin as soon as 16 μs after the 6221 applies the pulse. The entire pulse, including a complete nanovolt measurement, can be as short as 50 μs.

In the delta, differential conductance, and pulse modes, The 2182A produces virtually no transient currents, so it's ideal for characterizing devices that can be easily disrupted by current spikes (see **Figure 4**).

Applications

Research

- Determining the transition temperature of superconductive materials
- I-V characterization of a material at a specific temperature
- Calorimetry
- Differential thermometry
- Superconductivity
- Nanomaterials

Metrology

- Intercomparisons of standard cells
- Null meter for resistance bridge measurements

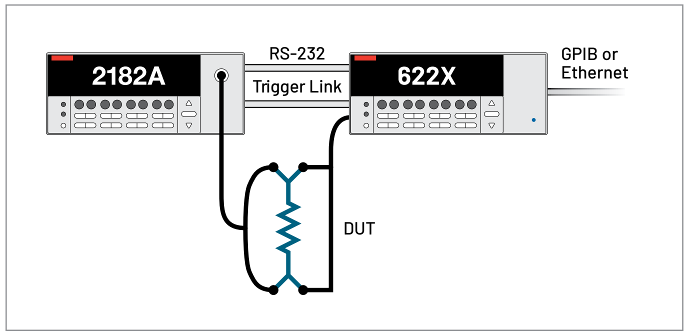

Figure 3. It's simple to connect the 2182A to the 6220 or 6221 to make a variety of measurements. The instrument control example start-up software available for the 622X current sources includes a step-by-step guide to setting up the instrumentation and making proper connections.

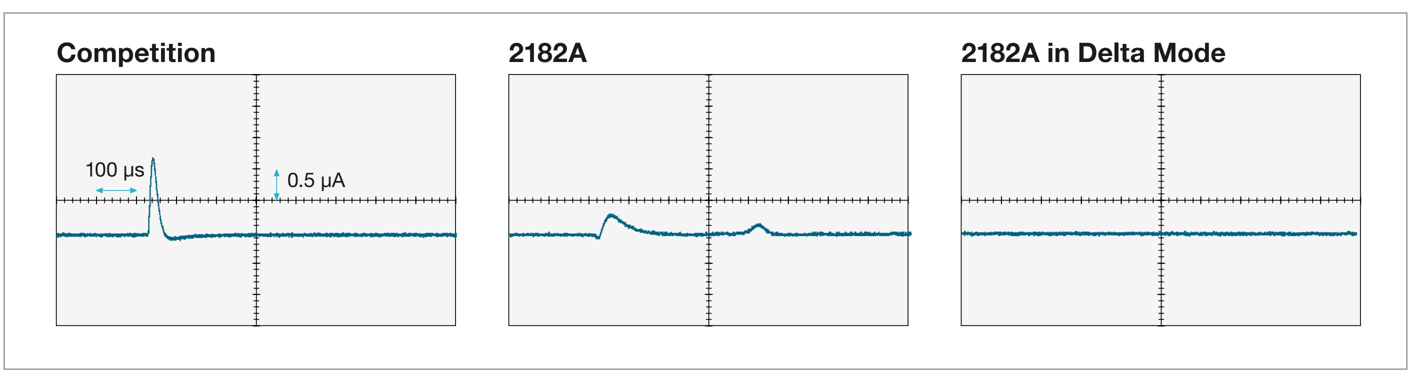

Figure 4. The 2182A produces the lowest transient currents of any nanovoltmeter available.

Three Ways to Measure Nanovolts

DC nanovoltmeters. DC nanovoltmeters and sensitive DMMs both provide low noise DC voltage measurements by using long integration times and highly filtered readings to minimize the bandwidth near DC. Unfortunately, this approach has limitations, particularly the fact that thermal voltages develop in the sample and connections vary, so long integration times don't improve measurement precision. With a noise specification of just 6 nV p-p, the 2182A is the lowest noise digital nanovoltmeter available.

AC technique. The limitations of the long integration and filtered readings technique have led many people to use an AC technique for measuring low resistances and voltages. In this method, an AC excitation is applied to the sample and the voltage is detected synchronously at the same frequency and an optimum phase. While this technique removes the varying DC component, in many experiments at high frequencies, users can experience problems related to phase shifts caused by spurious capacitance or the L/R time constant. At low frequencies, as the AC frequency is reduced to minimize phase shifts, amplifier noise increases.

The current reversal method. The 2182A is optimized for the current reversal method, which combines the advantages of both earlier approaches. In this technique, the DC test current is reversed, then the difference in voltage due to the difference in current is determined. Typically, this measurement is performed at a few hertz (a frequency just high enough for the current to be reversed before the thermal voltages can change). The 2182A's low noise performance at measurement times of a few hundred milliseconds to a few seconds means that the reversal period can be set quite small in comparison with the thermal time constant of the sample and the connections, effectively reducing the impact of thermal voltages.

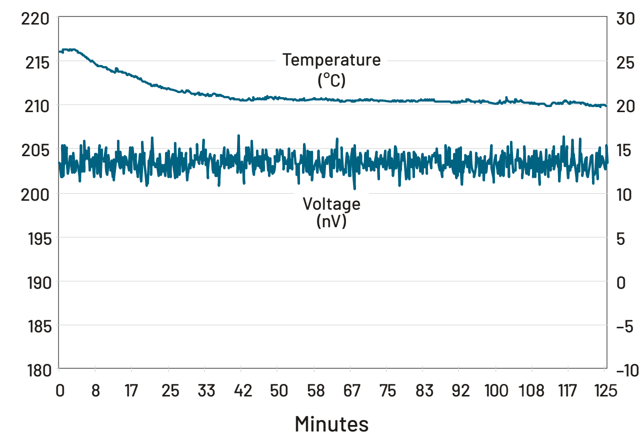

Figure 5. The 2182A's delta mode provides extremely stable results, even in the presence of large ambient temperature changes. In this challenging example, the 200 nV signal results from a 20 µA current sourced by a 6221 through a 10 mΩ test resistor.

Metrology Applications

The 2182A combines the accuracy of a digital multimeter with low noise at high speeds for high-precision metrology applications. Its low noise, high signal observation time, fast measurement rates, and 2 ppm accuracy provide the most cost-effective meter available today for applications such as intercomparison of voltage standards and direct measurements of resistance standards.

Nanotechnology Applications

The 2182A combined with the 622X current source or Series 2400 SourceMeter® SMU instrument is a highly accurate and repeatable solution for measuring resistances on carbon nanotube based materials and silicon nanowires.

Research Applications

The 2182A's 1nV sensitivity, thermoelectric EMF cancellation, direct display of "true" voltage, ability to perform calculations, and high measurement speed makes it ideal for determining the characteristics of materials such as metals, low resistance filled plastics, and high and low temperature superconductors.

Optional Accessory: 2187-4 Low Thermal Test Lead Kit

The standard cabling provided with the 2182A Nanovoltmeter and 622X Current Sources provides everything normally needed to connect the instruments to each other and to the DUT. The 2187-4 Low Thermal Test Lead Kit is required when the cabling provided may not be sufficient for specific applications, such as when the DUT has special connection requirements. The kit includes an input cable with banana terminations, banana extensions, sprung-hook clips, alligator clips, needle probes, and spade lugs to accommodate virtually any DUT. The 2187-4 is also helpful when the DUT has roughly 1 GΩ impedance or higher. In this case, measuring with the 2182A directly across the DUT will lead to loading errors. The 2187-4 Low Thermal Test Lead Kit provides a banana cable and banana jack extender to allow the 2182A to connect easily to the 622X's low impedance guard output, so the 2182A can measure the DUT voltage indirectly. This same configuration also removes the 2182A's input capacitance from the DUT, so it improves device response time, which may be critical for pulsed measurements.

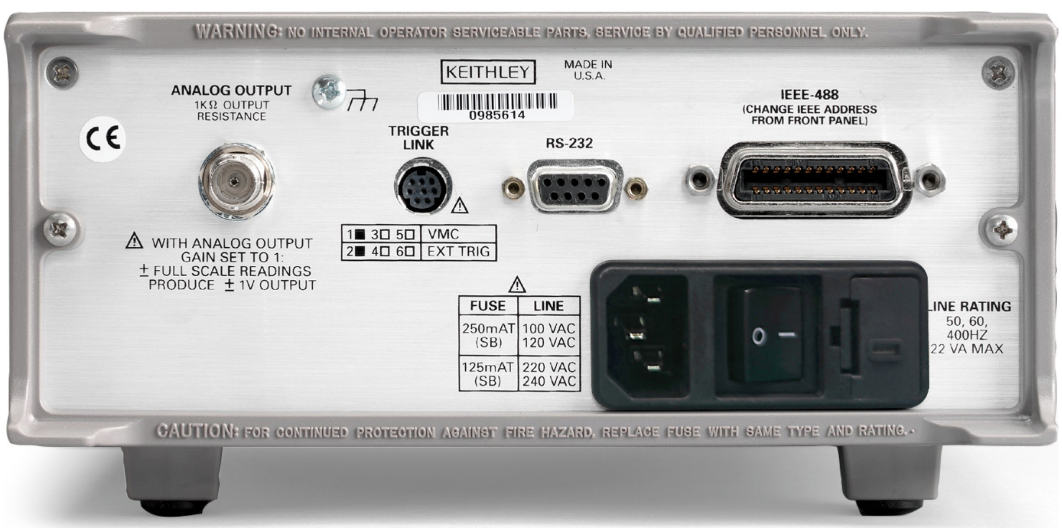

Figure 7. 2182A rear panel.

Specifications

Volts Specifications (20% over range)

Conditions 1 PLC with 10 reading digital filter or 5 PLC with 2 reading digital filter.

	Range	Resolution	Input Resistance	Accuracy: ±(ppm of reading + ppm of range) (ppm = parts per million) (e.g., 10ppm = 0.001%)				Temperature Coefficient 0°–18°C & 28°–50°C
				24 Hour[1] T_{CAL} ±1°C	90 Day T_{CAL} ±5°C	1 Year T_{CAL} ±5°C	2 Year T_{CAL} ±5°C	
Channel 1	10.000000 mV[2, 3, 4]	1 nV	>10 GΩ	20 + 4	40 + 4	50 + 4	60 + 4	(1 + 0.5)/°C
	100.00000 mV	10 nV	>10 GΩ	10 + 3	25 + 3	30 + 4	40 + 5	(1 + 0.2)/°C
	1.0000000 V	100 nV	>10 GΩ	7 + 2	18 + 2	25 + 2	32 + 3	(1 + 0.1)/°C
	10.000000 V	1 µV	>10 GΩ	2 + 15	18 + 2	25 + 2	32 + 3	(1 + 0.1)/°C
	100.00000 V 4	10 µV	10 MΩ ±1%	10 + 3	25 + 3	35 + 4	52 + 5	(1 + 0.5)/°C
Channel 2[6, 9]	100.00000 mV	10 nV	>10 GΩ	10 + 6	25 + 6	30 + 7	40 + 7	(1 + 1)/°C
	1.0000000 V	100 nV	>10 GΩ	7 + 2	18 + 2	25 + 2	32 + 3	(1 + 0.5)/°C
	10.000000 V	1 µV	>10 GΩ	2 + 15	18 + 2	25 + 2	32 + 3	(1 + 0.5)/°C

Channel 1/Channel 2 Ratio

For input signals ≥1% of the range, Ratio Accuracy =

$$\frac{\text{Channel 1 Reading + Chanel 1 Accuracy}}{\text{Channel 2 Reading – Channel 2 Accuracy}} - \frac{\text{Channel 1 Reading}}{\text{Channel 2 Reading}}$$

Delta (hardware-triggered coordination with Series 24XX, Series 26XXA, or Series 622X current sources for low noise R measurement)

Accuracy = accuracy of selected Channel 1 range plus accuracy of I source range.

Delta Measurement Noise with 6220 or 6221

Typical 3 nVrms/$\sqrt{\text{Hz}}$ (10 mV range)[20]. 1 Hz achieved with 1 PLC, delay = 1ms, RPT filter = 23 (20 if 50 Hz).

Pulse-Mode (with 6221) Line synchronized voltage measurements within current pulses from 50 µs to 12 ms, pulse repetition rate up to 12 Hz.

Pulse Measurement Noise

Typical rms noise, R_{DUT}<10 Ω:*

$$V_{RMS} + \frac{C}{\text{meas\_time} * \sqrt{\text{pulse\_avg\_count}}}$$

where meas_time (seconds) = pulse width – pulse_meas_delay in 33 µs increments.

The constant C varies by range as follows:
10 mV Range: 0.16 nV*s. **100 mV Range:** 0.60 nV*s. **1 V Range:** 2.2 nV*s. **10 V Range:** 18 nV*s.

*meas_time(sec) = pulsewidth – source_delay in 33 µs increments.

DC Noise Performance (DC noise expressed in volts peak-to-peak)

Response time = time required for reading to be settled within noise levels from a stepped input, 60 Hz operation.

	Response Time	NPLC, Filter	Range					NMRR[7]	CMRR[8]
			10 mV	100 mV	1 V	10 V	100 V		
Channel 1	25.0 s	5, 75	6 nV	20 nV	75 nV	750 nV	75 µV	110 dB	140 dB
	4.0 s	5, 10	15 nV	50 nV	150 nV	1.5 µV	75 µV	100 dB	140 dB
	1.0 s	1, 18	25 nV	175 nV	600 nV	2.5 µV	100 µV	95 dB	140 dB
	667 ms	1, 10 or 5, 2	35 nV	250 nV	650 nV	3.3 µV	150 µV	90 dB	140 dB
	60 ms	1, Off	70 nV	300 nV	700 nV	6.6 µV	300 µV	60 dB	140 dB
Channel 2[6, 9]	25.0 s	5, 75	—	150 nV	200 nV	750 nV	—	110 dB	140 dB
	4.0 s	5, 10	—	150 nV	200 nV	1.5 µV	—	100 dB	140 dB
	1.0 s	1, 10 or 5, 2	—	175 nV	400 nV	2.5 µV	—	90 dB	140 dB
	85 ms	1, Off	—	425 nV	1 µV	9.5 µV	—	60 dB	140 dB

Voltage Noise vs. Source Resistance[10]

DC noise expressed in volts peak-to-peak.

Analog Filter	Digital Filter	Source Resistance	Noise
0 Ω	6 nV	Off	100
100 Ω	8 nV	Off	100
1 kΩ	15 nV	Off	100
10 kΩ	35 nV	Off	100
100 kΩ	100 nV	On	100
1 MΩ	350 nV	On	100

Temperature (Thermocouples)[11]

Displayed in °C, °F, or K. Accuracy based on ITS-90, exclusive of thermocouple errors.

Type	Range	Resolution	Accuracy 90 Day/1 Year 23° ±5°C Relative to Simulated Reference Junction
J	–200 to +760°C	0.001 °C	±0.2 °C
K	–200 to +1372°C	0.001 °C	±0.2 °C
N	–200 to +1300°C	0.001 °C	±0.2 °C
T	–200 to +400°C	0.001 °C	±0.2 °C
E	–200 to +1000°C	0.001 °C	±0.2 °C
R	0 to +1768°C	0.1 °C	±0.2 °C
S	0 to +1768°C	0.1 °C	±0.2 °C
B	+350 to +1820°C	0.1 °C	±0.2 °C

Operating Characteristics[12, 13]

60 Hz (50 Hz) operation.

Function	Digits	Readings/s	PLCs
DCV Channel 1, Channel 2, Thermocouple	7.5	3 (2)	5
	7.5[16, 18]	6 (4)	5
	6.5[17, 18]	18 (15)	1
	6.5[17, 18, 19]	45 (36)	1
	5.5[16, 18]	80 (72)	0.1
	4.5[15, 16, 18]	115 (105)	0.01
Channel 1/Channel 2 (Ratio), Delta with 24XX, Scan	7.5	1.5 (1.3)	5
	7.5[16, 18]	2.3 (2.1)	5
	6.5[17]	8.5 (7.5)	1
	6.5[17, 19]	20 (16)	1
	5.5[16]	30 (29)	0.1
	4.5[16]	41 (40)	0.01
Delta with 622X	6.5	47 (40.0)[21]	1

System Speeds [12, 14]

Range Change Time: [13]	<40 ms	(<50 ms).
Function Change Time: [13]	<45 ms	(<55 ms).
Autorange Time: [13]	<60 ms	(<70 ms).
ASCII Reading to RS-232 (19.2K Baud)	40/s	(40/s).
Max. Internal Trigger Rate [15]	120/s	(120/s).
Max. External Trigger Rate [15]	120/s	(120/s).

Measurement Characteristics

A/D Linearity	±(0.8 ppm of reading + 0.5 ppm of range).
Front Autozero Off Error	**10 mV–10 V:** Add ±(8 ppm of range + 500 μV) for <10 minutes and ±1°C. NOTE: Offset voltage error does not apply for Delta Mode.
Autozero Off Error	**10 mV:** Add ±(8 ppm of range + 100 nV) for <10 minutes and ±1°C. **100 mV–100 V:** Add ±(8 ppm of range + 10 μV) for <10 minutes and ±1°C. NOTE: Offset voltage error does not apply for Delta Mode.
Input Impedance	**10 mV–10 V:** >10 GΩ, in parallel with <1.5 nF (Front Filter ON). **10 mV–10 V:** >10 GΩ, in parallel with <0.5 nF (Front Filter OFF). **100 V:** 10MΩ ±1%.
DC Input Bias Current	<60 pA DC at 23°C, –10 V to 5 V. <120 pA @ 23°C, 5 V to 10 V.
Common Mode Current	<50 nA p-p at 50 Hz or 60 Hz.
Input Protection	150 V peak to any terminal. 70 V peak Channel 1 LO to Channel 2 LO.
Channel Isolation	>10 GΩ.
Earth Isolation	350 V peak, >10 GΩ and <150 pF any terminal to earth. Add 35 pF/ft with 2107 Low Thermal Input Cable.

Analog Output

Maximum Output	±1.2 V.
Accuracy	±(0.1% of output + 1 mV).
Output Resistance	1 kΩ ±5%.
Gain	Adjustable from 10–9 to 106. With gain set to 1, a full range input will produce a 1V output.
Output REL	Selects the value of input that represents 0V at output. The reference value can be either programmed value or the value of the previous input.

Triggering and Memory

Window Filter Sensitivity	0.01%, 0.1%, 1%, 10%, or full scale of range (none).
Reading Hold Sensitivity	0.01%, 0.1%, 1%, or 10% of reading.
Trigger Delay	0 to 99 hours (1ms step size).
External Trigger Delay	2 ms + <1 ms jitter with auto zero off, trigger delay = 0.
Memory Size	1024 readings.

Math Functions

Rel, Min/Max/Average/Std Dev/Peak-to-Peak (of stored reading), Limit Test, %, and mX+b with user-defined units displayed.

Remote Interface

	Keithley 182 emulation.
	GPIB (IEEE-488.2) and RS-232C.
	SCPI (Standard Commands for Programmable Instruments).

Notes

1. Relative to calibration accuracy.
2. With Analog Filter on, add 20 ppm of reading to listed specification.
3. When properly zeroed using REL function. If REL is not used, add 100 nV to the range accuracy.
4. Specifications include the use of ACAL function. If ACAL is not used, add 9 ppm of reading/°C from Tcal to the listed specification. Tcal is the internal temperature stored during ACAL.
5. For 5 PLC with 2-reading Digital Filter. Use ±(4ppm of reading + 2 ppm of range) for 1PLC with 10-reading Digital Filter.
6. Channel 2 must be referenced to Channel 1. Channel 2 HI must not exceed 125% (referenced to Channel 1 LO) of Channel 2 range selected.
7. For Lsync On, line frequency ±0.1%. If Lsync Off, use 60 dB.
8. For 1 kΩ unbalance in LO lead. AC CMRR is 70 dB.
9. For Low Q mode On, add the following to DC noise and range accuracy at stated response time: 200 nV p-p @ 25 s, 500 nV p-p @ 4.0 s, 1.2 µV p-p @ 1 s, and 5 µV p-p @ 85 ms.
10. After 2.5 hour warm-up, ±1°C, 5 PLC, 2 minute observation time, Channel 1 10 mV range only.
11. For Channel 1 or Channel 2, add 0.3°C for external reference junction. Add 2°C for internal reference junction.
12. Speeds are for 60 Hz (50 Hz) operation using factory defaults operating conditions (*RST). Autorange Off, Display Off, Trigger Delay = 0, Analog Output off.
13. Speeds include measurements and binary data transfer out the GPIB. Analog Filter On, 4 readings/s max.
14. Auto Zero Off, NPLC = 0.01.
15. 10 mV range, 80 readings/s max.
16. Sample count = 1024, Auto Zero Off.
17. For Lsync On, reduce reading rate by 15%.
18. For Channel 2 Low Q mode Off, reduce reading rate by 30%.
19. Front Auto Zero off, Auto Zero off.
20. Applies to measurements of room temperature resistances <10 Ω, Isource range ≤20 µA.
21. Display off, delay 1ms.

General

Power Supply	100 V / 120 V / 220 V / 240 V.
Line Frequency	50 Hz, 60 Hz, and 400 Hz, automatically sensed at power-up.
Power Consumption	22 VA.
Magnetic Field Density	10 mV range 4.0 s response noise tested to 500 gauss.
Operating Environment	Specified for 0° to 50°C. Specified to 80% RH at 35°C.
Storage Environment	–40° to 70°C.
EMC	Complies with European Union Directive 89/336/EEC (CE marking requirement), FCC part 15 class B, CISPR 11, IEC 801-2, IEC-801-3, IEC 801-4.
Safety	Complies with European Union Directive 73/23/EEC (low voltage directive); meets EN61010-1 safety standard. Installation category I.
Vibration	MIL-T-28800E Type III, Class 5.
Warm-Up	2.5 hours to rated accuracy.
Dimensions	Rack Mounting: 89 mm high × 213 mm wide × 370 mm deep (3.5 in × 8.375 in × 14.563 in). Bench Configuration (with handles and feet): 104 mm high × 238 mm wide × 370 mm deep (4.125 in × 9.375 in ×14.563 in).
Shipping Weight	5 kg (11 lbs).

Ordering Information

2182A	Nanovoltmeter

Supplied Accessories

2107-4	Low Thermal Input Cable with spade lugs, 1.2 m (4 ft).
	User manual, service manual, contact cleaner, line cord, alligator clips.

Available Accessories

4288-1	Single Fixed Rack Mount Kit
4288-2	Dual Fixed Rack Mount Kit
7007-1	Shielded GPIB Cable, 1 m (3.2 ft)
8501-1	Trigger Link Cable, 1 m (3.2 ft)
8503	Trigger Link Cable to 2 male BNC connectors
KPCI-488LPA	IEEE-488 Interface/Controller for the PCI Bus
KUSB-488B	IEEE-488 USB-to-GPIB Interface Adapter

Available Services

2182A-3Y-EW	1-year factory warranty extended to 3 years from date of shipment
C/2182A-3Y-ISO	3 (ISO-17025 accredited) calibrations within 3 years of purchase*
	* Not available in all countries

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