KEITHLEY
A Tektronix Company

Model 2651A

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High Power System SourceMeter Instrument Specifications

SPECIFICATION CONDITIONS

This document contains specifications and supplemental information for the Model 2651A High Power System SourceMeter™ instrument. Specifications are the standards against which the 2651A is tested. Upon leaving the factory, the 2651A meets these specifications. Supplemental and typical values are nonwarranted, apply at 23 °C, and are provided solely as useful information.

Accuracy specifications are applicable for both normal and high-capacitance modes.

Source and measurement accuracies are specified at the 2651A terminals under these conditions:

- 18 °C to 23 °C, < 70 percent relative humidity
- After two-hour warm-up
- Speed normal (1 NPLC)
- A/D autozero enabled
- Remote sense operation or properly zeroed local operation
- Calibration period: One year

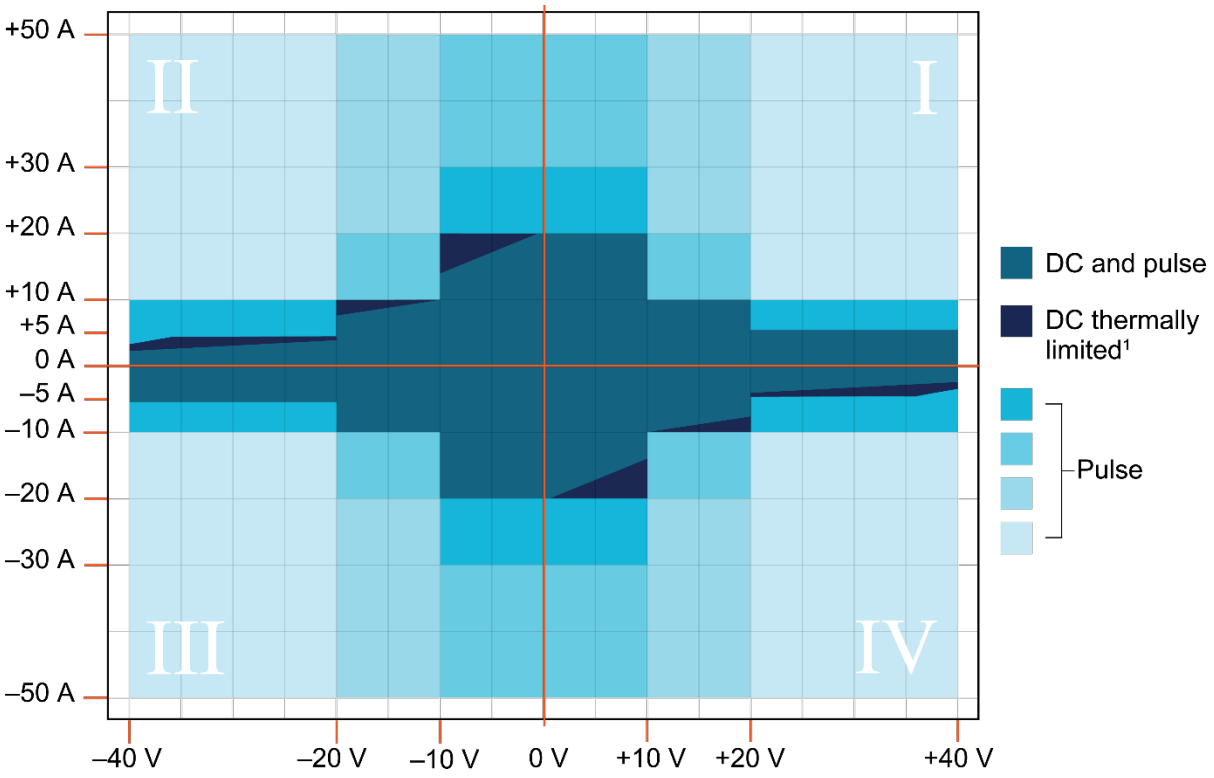
DC POWER SPECIFICATIONS

	Voltage	**Current**
Maximum output power and source/sink limits[1]	202 W maximum ▪ ± 10.1 V at ± 20.0 A ▪ ± 20.2 V at ± 10.0 A ▪ ± 40.4 V at ± 5.0 A[2] ▪ Four-quadrant source or sink operation	202 W maximum ▪ ± 5.05 A at ± 40 V[2] ▪ ± 10.1 A at ± 20 V ▪ ± 20.2 A at ± 10 V ▪ Four-quadrant source or sink operation

[1] Full power source operation regardless of load to 30 °C ambient. Above 30 °C or power sink operation, refer to “Operating boundaries” in the *Model 2651A Reference Manual* for additional power derating information and guaranteed thermal cutoffs. Typical thermal cutoffs are shown in the following table.

Maximum output power	**Voltage**	**Current**
Quadrant II	–10 V at 13 A –20 V at 7.7 A –40 V at 3.3 A	4.3 A at –20 V 10 A at –10 V 20 A at –1.3 V
Quadrant IV	10 V at –13 A 20 V at –7.7 A 40 V at –3.3 A	–4.3 A at 20 V –10 A at 10 V –20 A at 1.3 V

[2] Quadrants 2 and 4 in the power envelope are trimmed at 36 V and 4.5 A.



Refer to Pulse characteristics for pulsing details, such as duty cycle and pulse width.

VOLTAGE ACCURACY SPECIFICATIONS[3, 4]

Range	Source		Measure		
	Programming resolution	Accuracy ± (% reading + volts)	Display resolution	Integrating ADC accuracy[5] ± (% reading + volts)	High-speed ADC accuracy[6] ± (% reading + volts)
100 mV	5 µV	0.02% + 500 µV	100 nV	0.02% + 300 µV	0.05% + 600 µV
1 V	50 µV	0.02% + 500 µV	1 µV	0.02% + 300 µV	0.05% + 600 µV
10 V	500 µV	0.02% + 5 mV	10 µV	0.02% + 3 mV	0.05% + 8 mV
20 V	500 µV	0.02% + 5 mV	10 µV	0.02% + 5 mV	0.05% + 8 mV
40 V	500 µV	0.02% + 12 mV	10 µV	0.02% + 12 mV	0.05% + 15 mV

[3] Add 50 µV to source accuracy specifications per volt of HI lead drop.
[4] For temperatures 0 °C to 18 °C and 28 °C to 50 °C, accuracy is degraded by ± (0.15 × accuracy specification)/°C. High-capacitance mode accuracy is applicable at 23 °C ± 5 °C only.
[5] Derate accuracy specification for NPLC setting < 1 by increasing error term. Add appropriate typical percent of range term for resistive loads using the table below.

NPLC setting	100 mV range	1 V to 40 V ranges	100 nA range	1 µA to 100 mA ranges	1 A to 20 A ranges
0.1	0.01%	0.01%	0.01%	0.01%	0.01%
0.01	0.08%	0.07%	0.1%	0.05%	0.1%
0.001	0.8%	0.6%	1%	0.5%	1.8%

[6] 18-bit ADC. Average of 1000 samples taken at 100 µs intervals.

CURRENT ACCURACY SPECIFICATIONS[7]

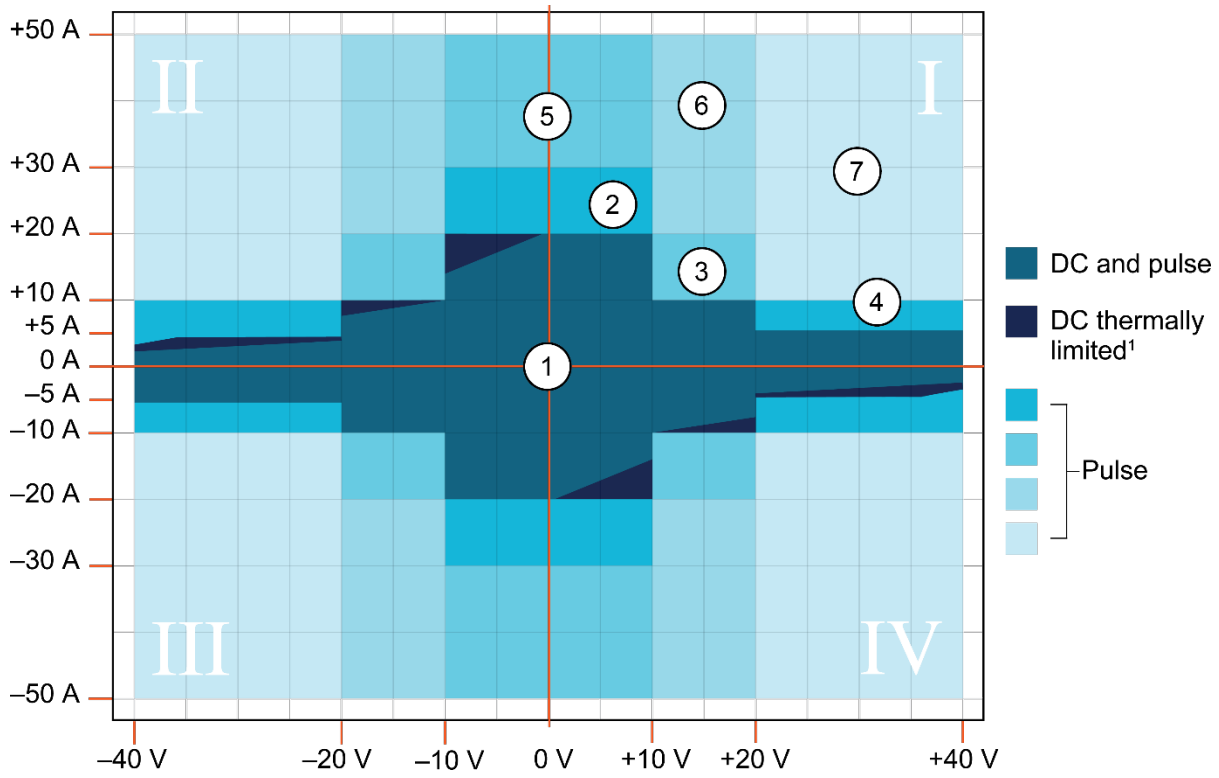
Range	Source		Measure		
	Programming resolution	**Accuracy** ± (% reading + volts)	**Display resolution**	**Integrating ADC accuracy[5]** ± (% reading + amperes)	**High-speed ADC accuracy[6]** ± (% reading + amperes)
100 nA	2 pA	0.1% + 500 pA	100 fA	0.08% + 500 pA	0.08% + 800 pA
1 µA	20 pA	0.1% + 2 nA	1 pA	0.08% + 2 nA	0.08% + 4 nA
10 µA	200 pA	0.1% +10 nA	10 pA	0.08% + 8 nA	0.08% +10 nA
100 µA	2 nA	0.03% + 60 nA	100 pA	0.02% + 25 nA	0.05% + 60 nA
1 mA	20 nA	0.03% +300 nA	1 nA	0.02% +200 nA	0.05% + 500 nA
10 mA	200 nA	0.03% + 8 µA	10 nA	0.02% + 2.5 µA	0.05% + 10 µA
100 mA	2 µA	0.03% + 30 µA	100 nA	0.02% + 20 µA	0.05% + 50 µA
1 A	200 µA	0.08% + 3.5 mA	1 µA	0.05% + 3 mA	0.05% + 5 mA
5 A	200 µA	0.08% + 3.5 mA	1 µA	0.05% + 3 mA	0.05% + 5 mA
10 A	500 µA	0.15% + 6 mA	10 µA	0.12% + 6 mA	0.12% + 12 mA
20 A	500 µA	0.15% + 8 mA	10 µA	0.08% + 8 mA	0.08% + 15 mA
50 A[8]	2 mA	0.15% + 80 mA	10 µA	0.05% + 50 mA[9]	0.05% + 90 mA[10]

SUPPLEMENTAL CHARACTERISTICS

The following specifications are supplemental characteristics that provide additional information about instrument functions and performance. These characteristics are not guaranteed specifications; they describe the typical performance of the 2651A.

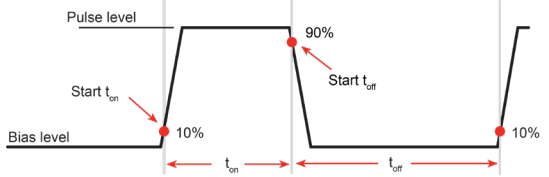
[7] At temperatures 0 °C to 18 °C and 28 °C to 50 °C; 100 nA to 10 µA accuracy is degraded by ± (0.35 × accuracy specification)/°C. 100 µA to 50 A accuracy is degraded by ± (0.15 × accuracy specification)/°C. High-capacitance mode accuracy is applicable at 23 °C ± 5 °C only.
[8] 50 A range is accessible only in pulse mode.
[9] 50 A range accuracy measurements are made at 0.008 NPLC.
[10] Average of 100 samples taken at 1 µs intervals.

PULSE CHARACTERISTICS



Pulse region characteristics	Pulse region characteristics			
	Region	**Region maximums**	**Maximum pulse width[11]**	**Maximum duty cycle[12]**
	1	5 A at 40 V	DC, no limit	100%
	1	10 A at 20 V	DC, no limit	100%
	1	20 A at 10 V	DC, no limit	100%
	2	30 A at 10 V	1 ms	50%
	3	20 A at 20 V	1.5 ms	40%
	4	10 A at 40 V	1.5 ms	40%
	5	50 A at 10 V	1 ms	35%
	6	50 A at 20 V	330 µs	10%
	7	50 A at 40 V	300 µs	1%

[11] Times measured from the start of the pulse to the start off-time; see figure below.



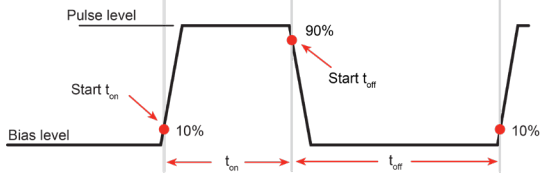
[12] Thermally limited in sink mode (quadrants 2 and 4) and ambient temperatures above 30 °C. See power equations in the *Model 2651A Reference Manual* for more information.

CAUTION

Carefully consider and configure the appropriate output-off state and source and compliance levels before connecting the 2651A to a device that can deliver energy. Failure to consider the output-off state and source and compliance levels may result in damage to the instrument or to the device under test.

Current and voltage range expansion	Two 2651A instruments can be combined in series or parallel to expand the operating ranges and power performance for some applications. Refer to tek.com/keithley for the necessary application notes.		
Minimum programmable pulse width[13]	100 µs Note: Minimum pulse width for settled source at a given I/V output and load can be longer than 100 µs		
Pulse width programming resolution	1 µs		
Pulse width programming accuracy[13]	± 5 µs		
Pulse width jitter	2 µs		
Pulse rise time	**Current range**	**R_{LOAD}**	**Rise time**
	50 A	0.05 Ω	26 µs
	50 A	0.2 Ω	57 µs
	50 A	0.4 Ω	85 µs
	20 A	0.5 Ω	95 µs
	50 A	0.8 Ω	130 µs
	20 A	1 Ω	180 µs
	10 A	2 Ω	330 µs
	5 A	8.2 Ω	400 µs

[13] Times measured from the start of pulse to the start off-time; see figure below.



ADDITIONAL SOURCE CHARACTERISTICS

<table>
<tr><td>Noise
10 Hz to 20 MHz</td><td>< 100 mV peak-peak, < 30 mV_{RMS}
▪ 10 V range with a 20 A limit</td></tr>
<tr><td>Noise
0.1 Hz to 10 Hz</td><td>Voltage:
▪ 0.1% of range for 100 mV range
▪ 0.05% of range for ranges > 100 mV range
Current:
▪ 0.05% of range</td></tr>
<tr><td>Overshoot</td><td>Voltage:
▪ < ± (0.1% + 10 mV)
▪ Step size = 10% to 90% of range, resistive load, maximum current limit/compliance
Current:
▪ < ± (0.1% + 10 mV)
▪ Step size = 10% to 90% of range, resistive load
▪ See Current source output settling time for additional test conditions</td></tr>
<tr><td>Transient response time</td><td>10 V and 20 V ranges: < 70 µs for the output to recover to within 0.1% for a 10% to 90% step change in load
40 V range: < 110 µs for the output to recover to within 0.1% for a 10% to 90% step change in load</td></tr>
<tr><td>Range change overshoot</td><td>Voltage:
▪ < 300 mV + 0.1% of larger range (for < 20 V ranges)
▪ < 400 mV + 0.1% of larger range (for ≥ 20 V ranges)
▪ Overshoot into a 100 kΩ load, 20 MHz bandwidth
Current:
▪ < 5% of larger range + 360 mV/R_{LOAD} (for > 10 µA ranges)
▪ $I_{OUT} \times R_{LOAD} = 1$ V</td></tr>
<tr><td>Current source output settling time</td><td>Time required to reach within 0.1% of final value after source level command is processed on a fixed range
Values below for $I_{OUT} \times R_{LOAD}$
<table>
<tr><th>Current range</th><th>R_{LOAD}</th><th>Settling time</th></tr>
<tr><td>20 A</td><td>0.5 Ω</td><td>< 195 µs</td></tr>
<tr><td>10 A</td><td>1.5 Ω</td><td>< 540 µs</td></tr>
<tr><td>5 A</td><td>5 Ω</td><td>< 560 µs</td></tr>
<tr><td>1 A</td><td>1 Ω</td><td>< 80 µs</td></tr>
<tr><td>100 mA</td><td>10 Ω</td><td>< 80 µs</td></tr>
<tr><td>10 mA</td><td>100 Ω</td><td>< 210 µs</td></tr>
<tr><td>1 mA</td><td>1 kΩ</td><td>< 300 µs</td></tr>
<tr><td>100 µA</td><td>10 kΩ</td><td>< 500 µs</td></tr>
<tr><td>10 µA</td><td>100 kΩ</td><td>< 15 ms</td></tr>
<tr><td>1 µA</td><td>1 MΩ</td><td>< 35 ms</td></tr>
<tr><td>100 nA</td><td>10 MΩ</td><td>< 110 ms</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td>Voltage source output settling time</td><td colspan="2">Time required to reach within 0.1% of final value after source level command is processed on a fixed range[14]<table><tr><th>Range</th><th>Settling time</th></tr><tr><td>1 V</td><td>< 70 µs</td></tr><tr><td>10 V</td><td>< 160 µs</td></tr><tr><td>20 V</td><td>< 190 µs</td></tr><tr><td>40 V</td><td>< 175 µs</td></tr></table></td></tr>
<tr><td>Guard offset voltage</td><td colspan="2">< 4 mV
Current < 10 mA</td></tr>
<tr><td>Remote sense operating range[15]</td><td colspan="2">Maximum voltage between HI and SENSE HI = 3 V
Maximum voltage between LO and SENSE LO = 3 V</td></tr>
<tr><td>Maximum impedance per source lead</td><td colspan="2">Maximum impedance limited by 3 V drop by remote sense operating range
Maximum resistance = 3 V / source current value (amperes)
(maximum of 1 Ω per source lead)
3 V = L di/dt</td></tr>
<tr><td>Voltage output headroom</td><td colspan="2">5 A range
Maximum output voltage = 48.5 V – (total voltage drop across source leads)
10 A range
Maximum output voltage = 24.5 V – (total voltage drop across source leads)
20 A range
Maximum output voltage = 15.9 V – (total voltage drop across source leads)</td></tr>
<tr><td>Overtemperature protection</td><td colspan="2">Internally sensed temperature overload puts unit in standby mode</td></tr>
<tr><td>Limit/compliance</td><td colspan="2">Bipolar limit (compliance) set with single value
Voltage:[16]
Minimum value is 10 mV; accuracy is the same as voltage source
Current:[17]
Minimum value is 10 nA; accuracy is the same as current source</td></tr>
</table>

[14] With measure and compliance set to the maximum current for the specified voltage range.
[15] Add 50 µV to source accuracy specifications per volt of HI lead drop.
[16] For sink mode operation (quadrants II and IV), add 0.6 percent of limit range to the corresponding voltage source accuracy specifications. For 100 mV range, add an additional 60 mV of uncertainty. Specifications apply with sink mode enabled.
[17] For sink mode operation (quadrants II and IV), add 0.6 percent of limit range to the corresponding current limit accuracy specifications. Specifications apply with sink mode enabled.

ADDITIONAL METER CHARACTERISTICS

Contact check characteristics[18]	**Speed**	**Maximum measurement time to memory for 60 Hz (50 Hz)**	**Accuracy (1 year) 23 °C ± 5 °C ± (% reading + ohms)**
	Fast	1.1 ms (1.2 ms)	5% + 15 Ω
	Medium	4.1 ms (5 ms)	5% + 5 Ω
	Slow	36 ms (42 ms)	5% + 3 Ω

Maximum load impedance	**Normal mode** 10 nF 3 µH	**High-capacitance mode** 50 µF 3 µH
Common mode voltage	250 V dc	
Common mode isolation	> 1 GΩ < 4500 pF	
Measure input impedance	> 10 GΩ	
Sense high input impedance	> 10 GΩ	
Maximum sense lead resistance	1 kΩ for rated accuracy	
Overrange	101% of source range 102% of measure range	

HIGH-CAPACITANCE MODE CHARACTERISTICS[19, 20]

Accuracy characteristics[21]	Accuracy characteristics are applicable in both normal and high-capacitance modes	
Voltage source output settling time	Time required to reach within 0.1% of final value after source level command is processed on a fixed range[22]	
	Voltage source range	**Settling time with C_{LOAD} = 4.7 µF**
	1 V	75 µs
	10 V	170 µs
	20 V	200 µs
	40 V	180 µs
Mode change delay	Current ranges of 100 µA and above: ▪ 11 ms delay for both in and out of high-capacitance mode Current ranges below 100 µA: ▪ 250 ms delay into high-capacitance mode ▪ 11 ms delay out of high-capacitance mode	
Measure input impedance	> 10 GΩ in parallel with 25 nF	
Voltage source range change overshoot	< 400 mV + 0.1% of larger range ▪ Overshoot into a 100 kΩ load, 20 MHz bandwidth	

[18] Includes measurement of SENSE HI to HI and SENSE LO to LO contact resistances.
[19] High-capacitance mode specifications are for dc measurements only and use locked ranges. Autorange is disabled.
[20] 100 nA range is not available in high-capacitance mode.
[21] Add an additional 2 nA to the source current accuracy and measure current accuracy offset for the 1 µA range.
[22] With measure and compliance set to the maximum current for the specified voltage range.

MEASUREMENT SPEED CHARACTERISTICS[23, 24]

MAXIMUM SWEEP OPERATION RATES (OPERATIONS PER SECOND) FOR 60 HZ (50 HZ):

A/D converter speed	Trigger origin	Measure to memory using user scripts	Measure to GPIB using user scripts	Source measure to memory using user scripts	Source measure to GPIB using user scripts	Source measure to memory using sweep API	Source measure to GPIB using sweep API
0.001 NPLC	Internal	20000 (20000)	9800 (9800)	7000 (7000)	6200 (6200)	12000 (12000)	5900 (5900)
0.001 NPLC	Digital I/O	8100 (8100)	7100 (7100)	5500 (5500)	5100 (5100)	11200 (11200)	5700 (5700)
0.01 NPLC	Internal	4900 (4000)	3900 (3400)	3400 (3000)	3200 (2900)	4200 (3700)	4000 (3500)
0.01 NPLC	Digital I/O	3500 (3100)	3400 (3000)	3000 (2700)	2900 (2600)	4150 (3650)	3800 (3400)
0.1 NPLC	Internal	580 (480)	560 (470)	550 (465)	550 (460)	560 (470)	545 (460)
0.1 NPLC	Digital I/O	550 (460)	550 (460)	540 (450)	540 (450)	560 (470)	545 (460)
1.0 NPLC	Internal	59 (49)	59 (49)	59 (49)	59 (49)	59 (49)	59 (49)
1.0 NPLC	Digital I/O	58 (48)	58 (49)	59 (49)	59 (49)	59 (49)	59 (49)
High-speed ADC	Internal	38500 (38500)	18000 (18000)	10000 (10000)	9500 (9500)	14300 (14300)	6300 (6300)
High-speed ADC	Digital I/O	12500 (12500)	11500 (11500)	7500 (7500)	7000 (7000)	13200 (13200)	6000 (6000)

High-speed ADC burst measurement rates:[25]

Burst length (readings)	Readings per second	Bursts per second
100	1,000,000	400
500	1,000,000	80
1000	1,000,000	40
2500	1,000,000	16
5000	1,000,000	8

[23] Tests performed with a 2651A on channel A using the following equipment: Computer hardware (Intel® Pentium® 4 2.4 GHz, 2 GB RAM, National Instruments™ PCI-GPIB); driver (NI-488.2 Version 2.2 PCI-GPIB); software (Microsoft® Windows® XP, Microsoft® Visual Studio® 2010, NI-VISA™ version 4.1).

[24] Exclude current measurement ranges less than 1 mA.

[25] `smua.measure.adc` must be enabled and the `smua.measure.count` set to the burst length.

Maximum single measurement rates (operations per second) for 60 Hz (50 Hz):

A/D converter speed	Trigger origin	Measure to GPIB	Source measure to GPIB	Source measure pass/fail to GPIB
0.001 NPLC	Internal	1900 (1800)	1400 (1400)	1400 (1400)
0.01 NPLC	Internal	1450 (1400)	1200 (1100)	1100 (1100)
0.1 NPLC	Internal	450 (390)	425 (370)	425 (375)
1.0 NPLC	Internal	58 (48)	57 (48)	57 (48)

Maximum measurement range change rate	> 4000 per second for > 10 µA
Maximum source range change rate	10 ms for ranges > 100 µA and < 5 A 30 ms for ranges ≥ 5 A
Command processing time	Maximum time required for the output to begin to change following the receipt of the `smua.source.levelv` or `smua.source.leveli` command; < 1 ms

TRIGGERING AND SYNCHRONIZATION CHARACTERISTICS

Triggering

Trigger in to trigger out	0.5 µs
Trigger in to source change[26]	10 µs
Trigger timer accuracy	± 2 µs
Source change[26] after LXI trigger	280 µs

Synchronization

Single-node synchronized source change[26]	< 0.5 µs
Multi-node synchronized source change[26]	< 0.5 µs

[26] Fixed source range with no polarity change.

SUPPLEMENTAL INFORMATION

Front-panel interface	Two-line vacuum fluorescent display (VFD) with keypad and navigation wheel
Display	▪ Show error messages and user-defined messages ▪ Display source and limit settings ▪ Show current and voltage measurements ▪ View measurements stored in dedicated reading buffers
Keypad operations	▪ Change host interface settings ▪ Save and restore instrument setups ▪ Load and run factory and user-defined test scripts that prompt for input and send results to the display ▪ Store measurements into dedicated reading buffers
Programming	Embedded Test Script Processor (TSP™) accessible from any host interface; responds to high-speed test scripts comprised of remote commands and statements (for example, branching, looping, and math); able to execute test scripts stored in memory without host intervention
Minimum user memory available	16 MB (approximately 250,000 lines of TSP code)
Reading buffers	Nonvolatile memory uses dedicated storage areas reserved for measurement data. Reading buffers are arrays of measurement elements; each element can hold the following items: ▪ Measurement ▪ Source setting (at the time the measurement was made) ▪ Measurement status ▪ Range information ▪ Timestamp Two reading buffers are reserved for each 2651A channel; reading buffers can be filled using the front-panel STORE key and retrieved using the RECALL key or host interface
Buffer size, with timestamp and source setting	> 60,000 samples
Buffer size, without timestamp and source setting	> 140,000 samples

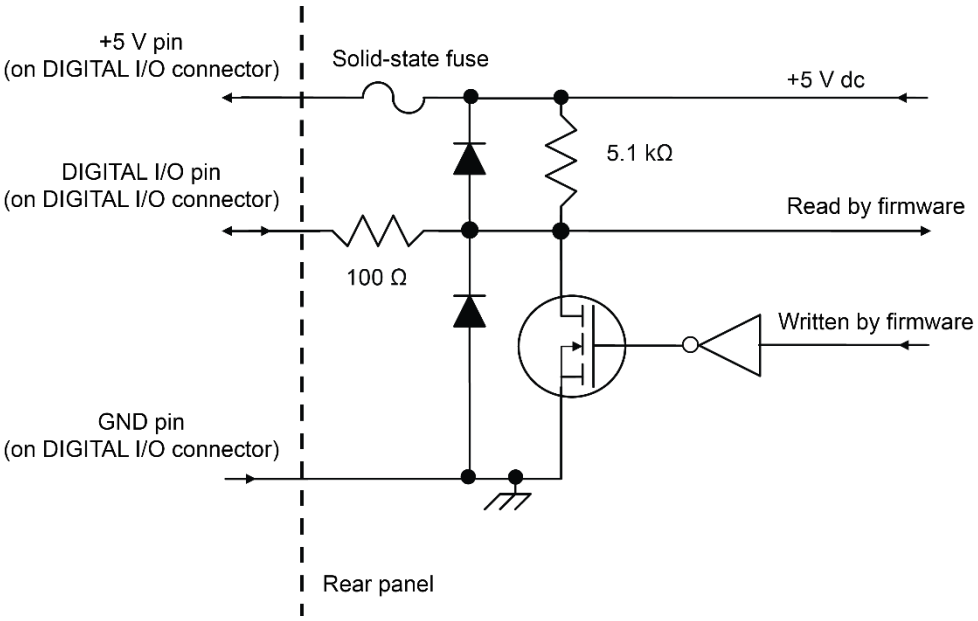
TIMING

Timer	Free-running 47-bit counter with 1 MHz clock input; reset each time instrument power is turned on; if the instrument is not turned off, the timer is reset to zero (0) every four years
Timestamp	TIMER value is automatically saved when each measurement is triggered
Resolution	1 µs
Timestamp accuracy	± 100 ppm

GENERAL SPECIFICATIONS

IEEE-488	IEEE Std 488.1 compliant. Supports IEEE Std 488.2 common commands and status model topology
RS-232	▪ Baud rates from 300 bps to 115200 bps ▪ Programmable number of data bits, parity type, and flow control (RTS/CTS hardware or none) ▪ When not programmed as the active host interface, the 2651A can use the RS-232 interface to control other instrumentation
Ethernet	RJ-45 connector, LXI Class C, 10/100BT, Auto MDIX
LXI compliance	LXI version 1.4 Core 2011
Expansion interface	▪ The TSP-Link™ expansion interface allows TSP-enabled instruments to trigger and communicate with each other ▪ Cable type: Category 5e or higher LAN crossover cable ▪ Three meter (9.84 ft) maximum between each TSP-enabled instrument ▪ A maximum of 32 TSP-Link nodes can be interconnected ▪ Each source-measure instrument uses one TSP-Link node
USB File System	USB 2.0 Host: Mass storage class device
Power supply	100 V ac to 240 V ac, 50 Hz to 60 Hz (autosensing), 550 VA maximum
Cooling	Forced air; side and top intake and rear exhaust
Warranty	1 year
EMC	Conforms to European Union EMC Directive
Safety	UL listed to UL61010-1:2004 Conforms to European Union Low Voltage Directive
Environment	For indoor use only **Altitude:** Maximum 2000 m (6562 ft) above sea level **Operating:** 0 °C to 50 °C, 70% relative humidity up to 35 °C. Derate 3% relative humidity/°C, 35 °C to 50 °C Storage: −25 °C to 65 °C
Dimensions	Rack mount: 89 mm high × 435 mm wide × 549 mm deep (3.5 in. × 17.1 in. × 21.6 in.) Bench configuration (with handle and feet): 104 mm high × 483 mm wide × 620 mm deep (4.1 in. × 19 in. × 24.4 in.)
Weight	10.2 kg (22.5 lb)

Digital I/O interface



Connector: 25-pin female D

Input/output pins: 14 open drain I/O bits

Absolute maximum input voltage: 5.25 V

Absolute minimum input voltage: –0.25 V

Maximum logic low input voltage: 0.7 V, +850 µA maximum

Minimum logic high input voltage: 2.1 V, +570 µA

Maximum source current (flowing out of digital I/O bit): +960 µA

Maximum sink current at maximum logic low voltage (0.7): –5.0 mA

Absolute maximum sink current (flowing into digital I/O pin): –11 mA

5 V power supply pin: Limited to 250 mA, solid-state fuse protected

Output enable pin: Active high input pulled down internally to ground with a 10 kΩ resistor; when the output enable input function has been activated, the 2651A channel will not turn on unless the output enable pin is driven to > 2.1 V
(nominal current = 2.1 V/10 kΩ = 210 µA)