AM1.5G Standard Spectrum Solar Simulator: SS-X

Introduction

Only accurate optical-electrical conversion efficiency testing can drive the positive development of the photovoltaic industry!

In 2020, the international standard IEC 60904-9:2020 " Photovoltaic devices – Part 9: Classification of solar simulator characteristics" released a major update that has implications for both users and manufacturers of solar simulators. The main purpose of this renew is to respond to the increase in demand for high quality solar simulators due to advances in new solar cell materials (perovskite photovoltaics and organic photovoltaics materials) and structures (PERC, HJT, TopCon, tandem).

The new version of the standard has three important key updates:

1. A+ class: IEC 60904-9:2020 introduces new class A+ in three indicators including spectral distribution match, irradiance non-uniformity in the test plane and temporal instability of irradiance.
2. 300 nm~1200 nm: IEC 60904-9:2020 extends spectral evaluation bands of 300nm~400nm and 1100nm~1200nm.
3. Two new metrics are introduced: Spectral Coverage (SPC) and Spectral Deviation

Class A+ (A Plus) in spectral distribution (300nm ~ 1200nm; distribution value of 0.875~1.125) is the largest difference in IEC 60904-9:2020 compared to the past decade. It reflects the technical improvement of today's solar simulators. The practical significance is to generate a more accurate spectrum, so that the error of the conversion efficiency testing result of the solar cell can be lower and more accurate.

Spectral Coverage (SPC), one of two new metrics introduced by IEC 60904-9:2020, measures the percent spectral coverage of a solar simulator's spectral output between 300nm and 1200nm. The SPC is specially designed for the emerging LED-type solar simulators. Generally, the SPC coverage of xenon lamp solar simulators can reach 100%.

Another newly introduced metric in IEC 60904-9:2020 is Spectral Deviation (SPD). SPD is the overall indicator to which the overall solar simulator spectrum is above or below the specified AM1.5G spectrum. The closer the SPD is to 0%, the closer it is to the AM1.5G spectrum. The lower SPD value represents the smaller deviation from AM1.5G standard spectrum, which means that the overall error for solar cell conversion efficiency testing results can also be lower.

In response to the latest spectral requirements of IEC 60904-9:2020, Enlitech has launched the SS-X series of AM1.5G Standard Spectrum Solar Simulator. The AM1.5G filter of SS-X Solar Simulators is made with advanced plasma deposition technology for high spectral accuracy and longer lifetime. The spectral rating from 300nm ~1200nm reaches the class A+ (0.875~1.125). The spectral deviation SPD of SS-X solar simulators even reaches 3.3%, which is compatible to the SPD value of the dual-lamp solar simulator. These two new metrics distinguish between "average A" solar simulators and "excellent A+" solar simulators. These two new metrics distinguish between "average A" solar simulators and "excellent A+" solar simulators.

It is also shown that the SS-X simulator provides a wider wavelength range from 300nm to 1200nm, lower errors and more accurate test results when used to test the IV conversion efficiency of novel solar cell materials and structures.

Solar Simulator

A+AA+ Steady-State
SS-X50
SS-X100R
SS-X200R

Light Source For I-V Characteristic Measurement & Solar Simulator For Power Of Solar Cells Measurement

SS-X is a new series of comprehensive A+ spectrum grade solar simulators developed in accordance with IEC 60904-9:2020 standard. Combined with advanced software, SS-X series can further analyze the physics behind the IV curves, such as performing Sun-Voc and Sun-Jsc simultaneously for analyzing ideality factor n automatically.

Features

- ◆ Spectral match against AM 1.5G, mismatch <12.5% , grade A+
- ◆ Non-uniformity <2% , grade A
- ◆ Temporal instability <1% , grade A+
- ◆ Max light intensity up to 1.5sun
- ◆ Adjustable light intensity from 0%-100%, with adjustment resolution of 1%
- ◆ Flexible integration ability

IVS-KA 6000 Software

- ◆ Ideal factor analysis
- ◆ Light intensity linearity measurement
- ◆ Sun-voc measurement
- ◆ Voc, Isc, FF, Imax, Vmax, Pmax, η, Rs, Rsh
- ◆ Reverse saturation current analysis
- ◆ Delay time IV measurement

Specification

Parameters	SS-X50
Light Source	Ozone Free Xenon Lamp
Lamp Wattage	300W
Lamp Life	1000 hrs [1]
Mode of Operation	Continuous
Irradiance Area	50mm x 50mm
AM1.5G Spectral Match Range	300 – 1200nm (in accordance with IEC 60904-9:2020)
Spectral Mis-Match with AM1.5G	0.875 – 0.1.125 (< 12.5%); Class A+
Spatial Non-Uniformity	< 2% ; Class A
Temporal In-Stability	< 1% ; Class A+
Maximum Irradiance	> 1.4 Sun (Typ. 1.5 Sun (1500W/m^2)
Irradiance Control	Touch Screen and software controlled [2]
Irradiance Control Mechanism	Via motorized Iris aperture (in 1% step)
Irradiance Control Range	< 0.2 Sun to Max
Shutter Control Mechanism	Touch Screen and software controlled [2]
Working Distance	20 – 25mm
Light Orientation Direction	Vertically Downwards (can be oriented horizontally or vertically upwards)
Divergent Angle	≤ 2 degree
System Cooling	Fan Cooled (Forced Air cooling)
Display Parameters	a. Light Source Status b. Shutter Status c. Operational Lamp Hours d. Light Source Electrical Parameters e. Over temperature warning indicator f. Iris Opening level (in %) g. Irradiance Intensity h. Power On/Off Indicator
System Safety Protection/Interlocks	a. Over Voltage Protection [4] b. Over Current Protection [4] c. Over Temperature Protection [5] d. Door Interlocks
Interface	USB & RS232
Power Requirement	Single phase 220V AC±10%, 50Hz [6]

1. – Lamp life is defined as expected operational hours till lamp glows. The intensity will gradually decrease over its life.
2. – Software control available when IV software is procured.
3. - If Temperature controlled stage is procurred
4. – System includes surge protector to protect system from over voltage and over current. However customer is responsible to provide stable power to the system.
5. - Light Source shuts down if there is an abnormal increase in temperature.
6. - Stable power via UPS is recommended.

ENLITECH

Model Selection

| Parameters	SS-X50	SS-X100R	SS-X200R
Irradiance Area	50 x 50 mm^2	100 x 100 mm^2	200 x 200 mm^2
Xenon Lamp Wattage	300W	450W	450W
Spectral Mis-Match (AM1.5G)	< 12.5% Class A+	< 12.5% Class A+	< 12.5% Class A+
Non-Uniformity of Irradiance	< 2% Class A	< 2% Class A	< 2% Class A
Temporal Instability	< 1% Class A+	< 1% Class A+	< 1% Class A+
Divergent Angle	≤ 2 degree	≤ 3.5 degree	≤ 3.5 degree
Irradiance Mode	Horizontal / Vertical	Horizontal / Vertical	Horizontal / Vertical
Power Requirements	100 - 240VAC/10A 50-60Hz	100 - 240VAC/15A 50-60Hz	100 - 240VAC/20A 50-60Hz

Stages & Contact Probes:
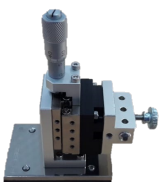

Si Sample Stage with vacuum Pump

XYZ-Manipulator

Temp. controlled Si Stage
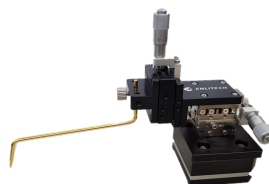
Sample Stage with IC Clips
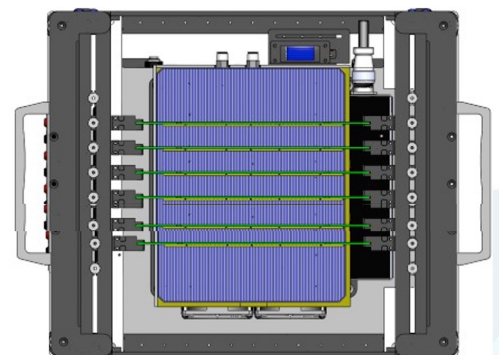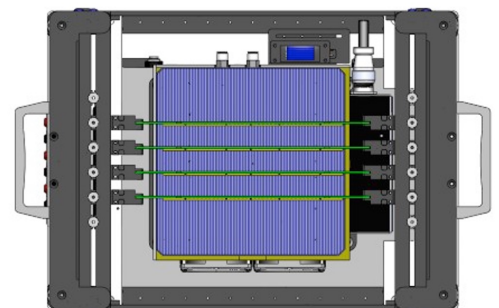
Sample Stage with Bus Bar (4BB & 6BB)

Z-Manipulator

ENLITECH

SRC-2020 Series Solar Reference Cell

SRC-2020 series solar reference cell is used for adjusting the intensity of solar simulator and measuring the characterization of I-V. Enlitech uses unique optical filter technology to substantially reduce the spectral mismatch. With the standard 20 mm x 20 mm Si solar cell and unique optical filters, it can be applicable to different type of solar cell measurement by choosing the proper model.

Specification

Dimensions	90 mm x 70 mm x 17mm
Solar Cell Material	c-Si
Solar Cell Size	20 mm x 20 mm
Window Material	Quartz, KG1, KG2, KG3, KG5
External Material	Anodized Aluminum
Temperature Sensor	Pt 100 RTD Sensor or Thermocouple K type (TC)
Interface	PV: LEMO connector RTD: LEMO connector
Electrical Contact	Electrical measurement wiring x1 (4W) Temperature measurement wiring x1 (4W)
Calibration Irradiance	1000 W/m^2 (1 sun)
Operating Current	< 200 mA
Operating Temperature	10℃~ 50℃
Calibration Report	Isc, Imax, Voc, Vmax, Pmax, FF, Area, Spectral Response (ISO/IEC 17025:2005)

Application

- Solar Simulator Calibration
- Solar Cell Calibration
- In accordance with WPVS
- In accordance with IEC 60904-2
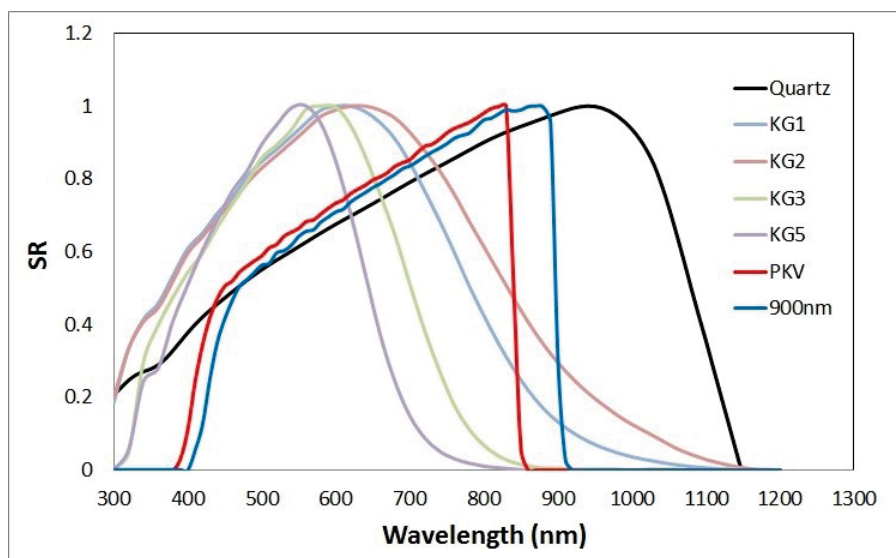- In accordance with ISO/IEC 17025:2005, traceability to SI unit

SRC-2020 Spectral Response

Spectral Mismatch Factor Calculation

Test sample / Reference cell	Spectral Mismatch Factor MMF				
	Mono-Si	DSSC	OPV	LBG-OPV	PVK
Mono-Si	1.000000	1.115042	1.118173	1.074864	1.078538
KG5	0.895156	0.998136	1.000939	0.962171	0.965460
KG3	0.910652	1.015415	1.018266	0.978827	0.982173
Enli-PVK	0.930576	1.037632	1.040545	1.000243	1.003662

Recommended Model for your device

Your Device	Cell and Window Materials	Recommended Model
Mono-crystalline Silicon (c-Si) Multi-crystalline Si (mc-Si) Cadmium Indium Gallium di-Selenide (CIGS)	Si with Quartz	SRC-2020-QZ-RTD
Amorphous Si (a-Si) Dye sensitized cells (DSSC) Organic Photovoltaics (OPV)	Si with KG5	SRC-2020-KG5-RTD
Amorphous Si (a-Si) Microcrystalline (u-Si)	Si with KG2 and RG610	SRC-2020-KG2-RTD and SRC-2020-RG610-RTD

If the user requires thermocouple K type, then please change from -RTD to -TC. Ex: SRC-2020-KG2-TC

B2900B/B2900BL Series
Precision Source/Measure Unit

KEYSIGHT

Comparison table by model

Model number	B2901BL	B2910BL	B2901B/B2902B	B2911B/B2912B
Number of channels	1	1	1 or 2	1 or 2
Output range				
Max. voltage	21 V	210 V	210 V	210 V
Max. current (DC)	1.5 A	1.5 A	3.03 A	3.03 A
Max. current (Pulse)	No	No	10.5 A	10.5 A
Source resolution				
Digit	5.5 digit	5.5 digit	5.5 digit	6.5 digit
Min. voltage	1 µV	1 µV	1 µV	100 nV
Min. current	10 pA	100 fA	1 pA	10 fA
Lowest current range	1 µA	10 nA	100 nA	10 nA
Measurement resolution				
Digit	6.5 digit	6.5 digit	6.5 digit	6.5 digit
Min. voltage	100 nV	100 nV	100 nV	100 nV
Min. current	1 pA	10 fA	100 fA	10 fA
Min. trigger interval	200 µs	50 µs	20 µs	10 µs
Max. trigger count	10,000	100,000	Infinite	Infinite
Max. data buffer size	10,000	100,000	100,000	100,000
Limit test	No	Yes	Yes	Yes
Fast transient mode	No	No	Yes	Yes
Easy file access	No	No	Yes	Yes
View mode				
Single view	Yes	Yes	Yes	Yes
Dual view	No	No	Yes (B2902B)	Yes (B2912B)
Graph view	Yes	Yes	Yes	Yes
Roll view	No	No	No	Yes

Specifications

Specification conditions

Temperature	23 °C ±5 °C
Humidity	30% to 80% RH
After 60 minutes warm-up	Ambient temperature change less than ±3 °C after self-calibration execution
Calibration period	1 year
Measurement speed	1 PLC (power line cycle)

Maximum voltage and current

	Max voltage	Max current
DC or pulsed [1]	210 V	0.105 A
	21 V	1.515 A [2]
	6 V	3.03 A [2]
Pulsed only [1]	200 V	1.515 A
	6 V	10.5 A

DC or pulsed[1]

Pulsed only[1]
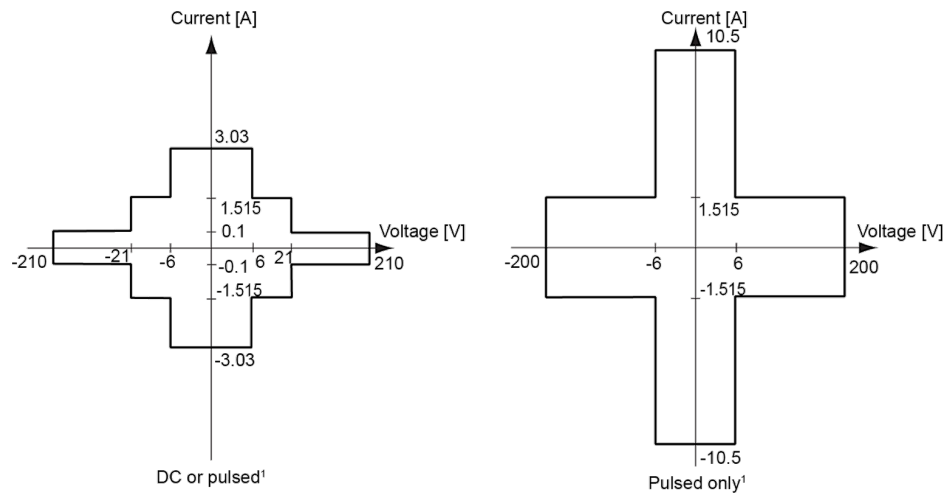
Maximum current limitation

Ch 1 voltage	Ch 2 voltage	Max total current limitation of Ch 1 and Ch 2
± (0 V < V ≤ 6 V)	± (0 V < V ≤ 6 V)	Ch 1 current + Ch 2 current ≤ 4 A
± (0 V < V ≤ 6 V)	± (6 V < V ≤ 21 V)	Ch 1 current + Ch 2 current x 1.6 ≤ 4 A
± (6 V < V ≤ 21 V)	± (0 V < V ≤ 6 V)	Ch 1 current + Ch 2 current x 0.625 ≤ 2.5 A
± (6 V < V ≤ 21 V)	± (6 V < V ≤ 21 V)	Ch 1 current + Ch 2 current ≤ 2.5 A

1. See "Maximum pulse width and duty cycle" in Pulse Source Supplemental Characteristics for applicable maximum voltage and current. Pulse mode is not available for B2901BL/B2910BL SMUs.
2. Max current limitation: For 21 V/1.515 A and 6 V/3.03 A ranges, total max current is limited by the table below for using 2 channels. Max current is not limited for using 1 channel only.

Voltage source specifications

Range	Programming resolution				Accuracy (% reading + offset)	Noise (peak to peak) 0.1 Hz to 10 Hz [1]	Max voltage (over range)
	B2901BL	B2910BL	B2901B/ B2902B	B2911B/ B2912B			
±200 mV	1 µV	1 µV	1 µV	100 nV	± (0.015 % + 225 µV)	≤ 10 µV	±210 mV
±2 V	10 µV	10 µV	10 µV	1 µV	± (0.02 % + 350 µV)	≤ 20 µV	±2.1 V
±20 V	100 µV	100 µV	100 µV	10 µV	± (0.015 % + 5 mV)	≤ 200 µV	±21 V
±200 V [2]	—	1 mV	1 mV	100 µV	± (0.015 % + 50 mV)	≤ 2 mV	±210 V

Current source specifications

Range	Programming resolution				Accuracy (% reading + offset)	Noise (peak to peak) 0.1 Hz to 10 Hz [1]	Max voltage (over range)
	B2901BL	B2910BL	B2901B/ B2902B	B2911B/ B2912B			
±10 nA [3]	—	100 fA	—	10 fA	± (0.10 % + 50 pA)	≤ 1 pA	±10.5 nA
±100 nA [4]	—	1 pA	1 pA	100 fA	± (0.06 % + 100 pA)	≤ 2 pA	±105 nA
±1 µA	10 pA	10 pA	10 pA	1 pA	± (0.025 % + 500 pA)	≤ 25 pA	±1.05 µA
±10 µA	100 pA	100 pA	100 pA	10 pA	± (0.025 % + 1.5 nA)	≤ 60 pA	±10.5 µA
±100 µA	1 nA	1 nA	1 nA	100 pA	± (0.02 % + 25 nA)	≤ 2 nA	±105 µA
±1 mA	10 nA	10 nA	10 nA	1 nA	± (0.02 % + 200 nA)	≤ 6 nA	±1.05 mA
±10 mA	100 nA	100 nA	100 nA	10 nA	± (0.02 % + 2.5 µA)	≤ 200 nA	±10.5 mA
±100 mA	1 µA	1 µA	1 µA	100 nA	± (0.02 % + 20 µA)	≤ 600 nA	±105 mA
±1 A	10 µA	10 µA	10 µA	1 µA	± (0.03 % + 1.5 mA)	≤ 70 µA	±1.05 A
±1.5 A	10 µA	10 µA	10 µA	1 µA	± (0.05 % + 3.5 mA)	≤ 100 µA	±1.515 A
±3 A [5]	—	—	100 µA	10 µA	± (0.4 % + 7 mA)	≤ 120 µA	±3.03 A
±10 A [4], [5][6]	—	—	100 µA	10 µA	± (0.4 % + 25 mA) [7]	—	±10.5 A

1. Supplemental characteristics.
2. 200 V range is not available for B2901BL.
3. 10 nA range is not available for B2901BL/B2901B/B2902B.
4. 100 nA range is not available for B2901BL.
5. 3A, 10 A ranges are not available for B2901BL/B2910BL.
6. 10 A range is available only for pulse mode, not available for DC mode.
7. Measurement speed: 0.01 PLC.

KEYSIGHT

Source supplemental characteristics

Temperature coefficient (0 to 18 °C and 28 to 50 °C)		± (0.1 x accuracy)/°C
Max output power and source/sink limits	B2901BL	31.8 W
		±6 V @ ±1.515 A, ±21 V @ ±1.515 A, four quadrant source or sink operation
	B2910BL	31.8 W
		±6 V @ ±1.515 A, 21 V @ ±1.515 A, ±210 V @ ±105 mA, four quadrant source or sink operation
	Other models	31.8 W
		±6 V @ ±3.03 A, ±21 V @ ±1.515 A, ±210 V @ ±105 mA, four quadrant source or sink operation
Current limit/compliance		Accuracy is same as current source. Minimum value is 1 % of range, or 1 nA in 10 nA range.
Voltage limit/compliance		Accuracy is same as voltage source. Minimum value is 1 % of range, or 20 mV in 200 mV range
Over range		101 % of source range for 1.5 A and 3 A ranges. 105 % of source range other than 1.5 A and 3 A ranges. No over range for 200 V range with current exceeding 105 mA pulse only condition.
Over temperature protection		Output turns off then resets at over temperature sensed internally
Voltage Output Settling time		Time required to reach within 0.1 % of final value at open load condition. Step is 10 % to 90 % range
	200 mV, 2 V ranges	< 50 µs
	20 V range	< 110 µs
	200 V range	< 700 µs
Slew rate		≤ 0.36 V/µs, 20 V and 10 mA ranges, 10 MΩ load resistance
Current output settling time		Time required to reach within 0.1 % (0.3 % for 3 A range) of final value at short condition. Step is 10 % to 90 % range
	10 nA, 100 nA ranges	< 10 ms
	1 µA range	< 500 µs
	10 µA, 100 µA ranges	< 250 µs
	1 mA to 3 A ranges	< 80 µs
Noise 10 Hz to 20 MHz (V source)		3 mVrms, 20 V range
V source overshoot		< ± (0.1 % + 10 mV). Step is 10 % to 90 % range, resistive load
I source overshoot		< ±0.1 % (< ±0.3 % for 3 A range). Step is 10 % to 90 % range, resistive load
Voltage source range change overshoot		≤ 250 mV. 100 kΩ load, 20 MHz bandwidth
Current source range change overshoot		≤ 250 mV/R load, 20 MHz bandwidth

Pulse source supplemental characteristics

Minimum programmable pulse width	50 µs
Pulse width programming resolution	1 µs
Pulse width definition	The time from 10 % leading to 90 % trailing edge as follows
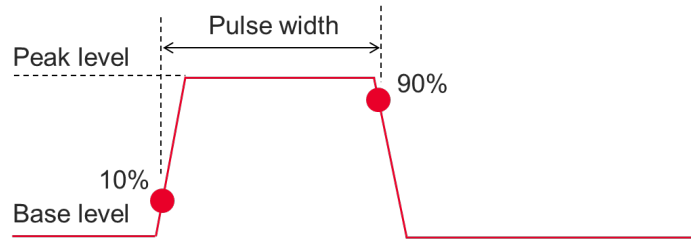
	Pulsed					DC	
	Max voltage	Max peak current	Max base current	Pulse width	Max duty cycle	Max voltage	Max current
DC or pulsed	210 V	0.105 A	0.105 A	50 µs to 99999.9 s	99.9999 %	210 V	0.105 A
	21 V	1.515 A [1]	1.515 A [1]	50 µs to 99999.9 s	99.9999 %	21 V	1.515 A [1]
	6 V	3.03A [1]	3.03 A [1]	50 µs to 99999.9 s	99.9999 %	6 V	3.03 A [1]
Pulsed only	200 V	1.515 A	50 mA	50 µs to 2.5 ms	2.5 %		
	180 V	1.05 A	50 mA	50 µs to 10 ms	2.5 %		
	6 V	5.25 A	0.1 A	50 µs to 3 ms	3.0 %		
	6 V	10.5 A	0.5 A	50 µs to 1 ms	2.5 %		

Minimum pulse width at the given voltage, current and settling conditions

Source value	Limit value	Load	Source settling (% of range)	Min pulse width
200 V	1.5 A	200 Ω	0.1%	1 ms
6 V	10.5 A	0.6 Ω	0.1%	0.2 ms
1.5 A	200 V	65 Ω	0.1%	2.5 ms
10.5 A	6 V	0.5 Ω	0.1%	0.2 ms
10.5 A [2]	6 V [2]	0.1 Ω [2]	0.1% [2]	0.1 ms [2]

1. Max current limitation: For 21 V/1.515 A and 6 V/3.03 A ranges, total max current is limited by the table in page 13 for using 2 channels. Max current is not limited for using 1 channel only.
2. Transient speed mode is set to FAST.

KEYSIGHT

Voltage measurement specifications

Range	Measurement resolution				Accuracy (% reading + offset)
	B2901BL	B2910BL	B2901B/B2902B	B2911B/B2912B	
±200 mV	100 nV	100 nV	100 nV	100 nV	± (0.015 % + 225 µV)
±2 V	1 µV	1 µV	1 µV	1 µV	± (0.02 % + 350 µV)
±20 V	10 µV	10 µV	10 µV	10 µV	± (0.015 % + 5 mV)
±200 V [1]	—	100 µV	100 µV	100 µV	± (0.015 % + 50 mV)

Current measurement specifications

Range	Measurement resolution				Accuracy (% reading + offset)
	B2901BL	B2910BL	B2901B/B2902B	B2911B/B2912B	
±10 nA [2]	—	10 fA	—	10 fA	± (0.10 % + 50 pA)
±100 nA [3]	—	100 fA	100 fA	100 fA	± (0.06 % + 100 pA)
±1 µA	1 pA	1 pA	1 pA	1 pA	± (0.025 % + 500 pA)
±10 µA	10 pA	10 pA	10 pA	10 pA	± (0.025 % + 1.5 nA)
±100 µA	100 pA	100 pA	100 pA	100 pA	± (0.02 % + 25 nA)
±1 mA	1 nA	1 nA	1 nA	1 nA	± (0.02 % + 200 nA)
±10 mA	10 nA	10 nA	10 nA	10 nA	± (0.02 % + 2.5 µA)
±100 mA	100 nA	100 nA	100 nA	100 nA	± (0.02 % + 20 µA)
±1 A	1 µA	1 µA	1 µA	1 µA	± (0.03 % + 1.5 mA)
±1.5 A	1 µA	1 µA	1 µA	1 µA	± (0.05 % + 3.5 mA)
±3 A [4]	—	—	10 µA	10 µA	± (0.4 % + 7 mA)
±10 A [3, 5]	—	—	10 µA	10 µA	± (0.4 % + 25 mA) [6]

Measurement supplemental characteristics

Temperature coefficient (0 to 18 °C and 28 to 50 °C)	± (0.1 x accuracy)/°C
Over range	102 % of measurement range for 1.5 A and 3 A ranges
	106 % of measurement range other than 1.5 A and 3 A ranges
Voltage measurement range change overshoot	< 250 mV. 100 kΩ load, 20 MHz bandwidth
Current measurement range change overshoot	< 250 mV/R load, 20 MHz bandwidth
Derating accuracy for measurement speed less than 1 PLC	Add % of range using the following table for measurement with PLC < 1

1. 200 V range is not available for B2901BL.
2. 10 nA range is not available for B2901BL/B2901B/B2902B.
3. 100 nA range is not available for B2901BL.
4. 3 A, 10 A ranges are not available for B2091BL/B2910BL.
5. 10 A range is available only for pulse mode, not available for DC mode.
6. Measurement speed: 0.01 PLC.

Derating accuracy with PLC setting < 1 PLC

	Voltage range			Current range		
	0.2 V	2 V to 200 V	10 nA	100 nA	1 µA to 100 mA	1 A to 3 A
0.1 PLC	0.01%	0.01%	0.1%	0.01%	0.01%	0.01%
0.01 PLC	0.05%	0.02%	1%	0.1%	0.05%	0.02%
0.001 PLC	0.5%	0.2%	5%	1%	0.5%	0.2%

Timer and triggering specification

Timer	Time stamp	TIMER value automatically saved when each measurement is triggered
	Trigger timing resolution	1 µs to 100 ms
	Accuracy	±50 ppm
	Arm/trigger delay	0 µs to 100,000 s
	Arm/trigger interval	B2901BL: 200 µs to 100,000 s
		B2910BL: 50 µs to 100,000 s
		B2901B/B2902B: 20 µs to 100,000 s
		B2911B/B2912B: 10 µs to 100,000 s
	Arm/trigger event	B2901BL: 1 to 10,000
		Other models: 1 to 100,000
Triggering [1]	Digital I/O Trigger IN to Trigger OUT	≤ 5 µs
	Digital I/O Trigger IN to source change	≤ 5 µs
	LXI Trigger IN to source change	Minimum 100 µs, Typical 200 µs, Maximum unknown
	LXI Trigger IN to measurement	Minimum 100 µs, Typical 200 µs, Maximum unknown
	Internal event to external LXI trigger output	Minimum 100 µs, Typical 200 µs, Maximum unknown
	LXI event send/receive latency	Unknown
	Minimum trigger interval	10 µs

---

1. Supplemental characteristics.

KEYSIGHT