M8199A 128 GSa/s Arbitrary Waveform Generator

Version 1.3

Key Benefits

- Up to 16 synchronized channels at 128 GSa/s with nominal analog bandwidth exceeding 50 GHz
- Provides R&D engineers a high-performance signal source for arbitrary signals, enabling development of designs of higher-order QAM (e.g., 64QAM) at 128 GBaud and above
- First arbitrary waveform generator enabling ≥200 Gb/s per lane in IM/DD or ≥800 Gb/s per carrier in coherent optical communications
- Integrated, ready-to-use instrument, works with M8008A clock module
- Operates with well-known software, including MATLAB, Keysight IQtools, and SCPI programming interfaced based on M8070B

M8199A system: 8 channels, 128 GSa/s

KEYSIGHT

M8199A at a glance

Analog bandwidth exceeding 50 GHz

- Up to 1.4 Vpp differential output voltage at 128 GBaud
- Continuous sample rate range: 100 to 128 GSa/s
- 512 KSa of waveform memory per channel
- Synchronization of up to 16 channels across 4 modules
- Channel-to-channel skew adjustment with 25 fs resolution
- 6 bits ENOB, DC to 50 GHz, Fs 100 GSa/s
- Intrinsic jitter: < 75 fs
- Transition time (20/80) as low as 5 ps
- < 140 dBc wideband phase noise > 1 MHz
- Built-in frequency and phase response calibration for clean output signals

Coherent Optical Applications

800G and 1 Terabit applications demand a new class of generators that provide high speed, precision and flexibility at the same time. The M8199A is the ideal solution to test various optical systems from discrete components like optical power amplifiers to more complex dual polarization systems such as optical modulators or optical receivers. Even for tests of signal processor ASICs or algorithm, the M8199A is an excellent signal source to provide stressed signals to these devices.

With up to 4 channels per 2-slot AXIe module, each running at up to 128 GSa/s with analog bandwidth exceeding 60 GHz, the M8199A allows dual polarization testing in a small form factor and the generation of complex signals with any modulation scheme (QPSK, nQAM, etc.) up to 128 GBaud.

Compensation for distortions generated e.g. by cables and amplifiers can be compensated by embedding/de-embedding the S-parameters of the respective circuits or by performing an in-situ calibration using the Keysight Technologies vector signal analysis software.

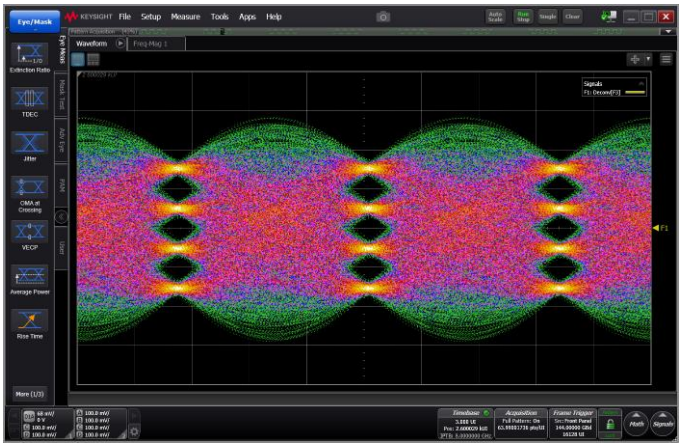

Figure 1. PAM-4, 144 GBaud (= 288 Gbps)

Multi-Level / Multi-Channel Digital Signals

With increasing data rates in servers and computers, the trace loss increases, which reduces the signal-to-noise ratio. Standard modulation formats, such as NRZ or PAM-4 may not be sufficient anymore. Here the M8199A is the right tool that provides the flexibility for advanced research on improved and more advanced modulation formats to boost transmission rates to the next level, for example, PAM-3, PAM-6, PAM-8 or proprietary modulation formats at data rates up to 128 GBaud.

The flexibility of the waveform generation with highest speeds, combined with excellent intrinsic jitter performance makes the M8199A a truly unique and versatile instrument.

At data rates of multiple Gb/s, the effect of cables, board traces, and connectors etc. must be considered in order to generate the desired signal at the test point of the device under test. The M8199A incorporates digital correction techniques for frequency- and phase-response compensation of the AWG output and any external circuit to generate the desired signal at the device under test. Channels can be embedded/de-embedded if the S-parameters of the respective circuits are provided.

Wideband RF Signal Generation in Wireless and Aerospace/Defense Applications

Latest developments in radar and wireless technologies require signals with modulation bandwidths beyond 10 GHz, in some cases up to 30 GHz, with good signal quality. Generating those signals on an IF rather than I/Q is another important capability to support these applications.

With sample rates of 128, the M8199A has enough oversampling gain to generate extremely broad bandwidth, yet high fidelity RF signals. As an example, figure 4 shows a QAM-64 signal with 16 GHz of modulation bandwidth on a 39 GHz carrier signal generated directly by the M8199A.

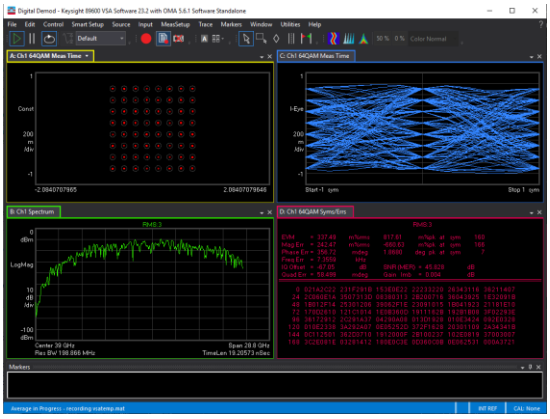

Figure 4. QAM-64, 16 GBaud at 39 GHz carrier

Physics, Chemistry and General-Purpose Electronics Research

The M8199A AWG allows users to generate any arbitrary waveform that can be mathematically described. E.g., a signal calculated in MATLAB can be downloaded directly into the M8199A.

This includes ultra-short, yet precise pulses down to 5 ps pulse width or extremely short, wideband RF pulses and chirps which are needed to investigate in chemical reactions, elementary particle excitation and quantum effects.

Clocking

The M8199A has a single sample clock input connector that drives all 4 channels. The sample clock signal can be provided from a companion clock module (M8008A). Any external signal generator that runs up to 64 GHz with +11 dBm output power and low phase noise can also be used to provide a clock to the M8199A AWG.

With the clock input directly fed into the Digital-to-Analog converter (DAC), all DAC clocks are fully synchronous, i.e. any jitter on the clock will be passed through to the AWG output 1:1.

With the M8008A as a clock source, channels will be automatically de-skewed. If an external clock generator is used, a semi-automated de-skew step is required after power up or change of sample rate.

Multi-Module Operation

The clock module M8008A can drive up to four M8199A AWG modules, hence up to 16 fully synchronized channels at 128 GSa/s. Note, that multi-module synchronization is limited to two modules if an external signal generator is used for clock generation. With the M8008A as a clock source, channels will be automatically de-skewed. If an external clock generator is used, a semi-automated de-skew step is required after power up or change of sample rate.

Software

The M8199A is controlled by the M8070B systems application software. In addition, the MATLAB based utility IQtools is included with the instrument software. IQtools provides a large number of waveform generation functionalities as well as an option to download user-defined waveforms. IQtools also supports “in-system calibration” to measure and compensate the frequency and phase response of the AWG and any external circuitry.

Front Panel Connections

Front panel

- **Data Out, Data Out** – differential AWG output channels
- **Sync In** – connected to Sync Out of the M8008A clock module
- **Sync Out A/B** – reserved for future use
- **Sample Marker Out, Sample Marker Out** – differential sample marker output
- **Sync Marker Out A/B** – two single ended sync marker outputs
- **Clk In** – Sample clock input, connected to Clock Out of M8008A clock module
- **LB In, LB Out** – reserved for future use

Configuration

Product numbers	Description	Comments
M8100A	AWG System – use this product number for configuring a larger AWG system, that consists of multiple AWG modules, a clock module and an AXIe chassis	
M8100A-BU5	Pre-configured system consisting of one M9505A 5-slot AXIe Chassis with USB Option	
M8100A-BU6	Pre-configured system consisting of one M9505A 5-slot AXIe Chassis with USB Option and one M9537A AXIe Embedded PC Controller	
M8199A-002	Arbitrary waveform generator, 2 channels, 128 GSa/s, 2-slot AXIe module	Must choose either 2- or 4-channel model, number of channels is software upgradable
M8199A-004	Arbitrary waveform generator, 4 channels, 128 GSa/s, 2-slot AXIe module	
M8008A-064	Clock Generator 32 - 64 GHz, 1-slot AXIe module	M8008A clock generator module or external synthesizer required to operate M8199A

Upgrade options

Product numbers	Description	Comments
M8199AU-004	Upgrade from 2-channels to 4-channels	Software license only

Accessories

Product numbers	Description	Comments
M8199A-801	RF cable matched pair, 150 mm, 1.85 mm, male/male	Recommended for connecting AWG outputs to device under test
M8199A-802	50 Ohm termination, 2.4 mm	2 / 4 terminations included
M8199A-810	Replacement Channel Clock Cable	All necessary clock cables are included with the M8199A module. These accessories are just replacements
M8199A-811	Replacement M-Clock Cable	
M8199A-812	Multi-Coax Local Bus cable	Only required for multi-chassis setups
M8199A-820	55 GHz an anti-alias filter	One filter per single-ended channel required. Two filters per differential channel.
M8158A-801	Remote head cable, matched pair, 150 mm, 1.85 mm connectors, male/male	One cable pair per remote head is recommended
M8008A-801	Clock module extension cable	Required only with more than one clock module
M8008A-802	50 Ohm termination, 2.4 mm	3 terminations are already included
N6171A-M02	MATLAB license (standard)	Required to run/view/edit source code version of IQtools
N6171A-M03	MATLAB license (extended)	

In order to be operational, an AXI chassis plus either an embedded controller or external PC or laptop are required in addition to one or more M8199A modules: (See http://www.keysight.com/find/AXIe for more details)

Product numbers	Description
M9505A-U20	5-slot AXIe chassis with USB Option
M9537A	AXIe embedded controller
8121-1243	Cable assembly USB Type A-MINI B
M9048A	PCIe® desktop card adapter Gen 2 x8
Y1202A	PCIe cable for M9048A desktop adapter

Specifications

General characteristics

Sample rate	100 to 128 GSa/s
DAC resolution	8 bits
Number of channels per M8199A module	2 or 4 channels (corresponds to options 002 and 004)
Sample memory	512 kSa per channel The waveforms in each channel can have different length
Waveform granularity	128 samples The length of waveform segments must be a multiple of the granularity

Output 1, 2, 3, 4

Mode	**Modul Output 1, 2, 3, 4**
Output type	Single-ended or differential (terminate unused output with 50 Ohm in single ended mode)
Impedance	50 Ω (nom)
Amplitude range (valid at 400 MHz. At higher frequencies, please consider achievable amplitudes, shown below)	100 $mV_{pp,se}$ to 0.83 $V_{pp,se}$ into 50 Ω 200 $mV_{pp,diff}$ to 1.66 $V_{pp,diff}$ into 50 Ω
Amplitude resolution	1 mV_{se} (nom.)
Amplitude accuracy (measured peak-to-peak with 400 MHz square wave)	±(10 mV +7.5%) (typ)
Voltage window	–1 to +3.0 V depends on external termination voltage [1]
DC offset accuracy	±(10 mV +2%) (typ)
Common Mode Voltage Accuracy[2]	±(25 mV +12.5%)
Termination voltage (VTerm) window	–1 to +3.0 V
Connector type	1.85 mm (female)

1. High level voltage range = 2/3* Vterm - 0.9 V < HIL < Vterm + 2 V
   Low level voltage range = 2/3 * Vterm - 1 V < LOL < Vterm + 1.9 V

   Low level voltage range = 2/3 * Vterm - 1 V < LOL < Vterm + 1.9 V
2. Common Mode Voltage = 0.5 * (measured offset at Norm. + measured offset at Comp.), measured with DCA N1046A and 10 dB attenuator, constant DAC value 0, termination voltage: 0 V, amplitude: 0.5 Vpp,se

Timing characteristics

Skew between any pair of channels within the same M8199A module	0 ps +/- 1 ps (typ.) [1]
Skew between any pair of outputs across different M8199A modules	Can be adjusted to 0 ps using in-system calibration. After change of sample rate a +/- 1 clock cycle deviation can occur.
Random Jitter with M8008A or E8257D, Opt. UNY	75 fs_{rms} (typ) [2]
Skew adjustment range	± 1 ns
Skew adjustment resolution	25 fs

1. Measured single ended at front panel
2. Calculated from SNR at fout = 39.34 GHz, fsa = 128 GSa/s

RF characteristics

Analog bandwidth (including sin(x)/x roll-off, measured single-ended output, smoothed graph)	
3 dB	50 GHz (typ)
6 dB	55 GHz (meas)
Rise/fall time (20/80)	5 ps (typ) [1]
Achievable amplitude with digital corrections enabled. Measured with a PAM4 signal	
100 GBaud	1.6 Vpp,diff (meas) [2]
112 GBaud	1.5 Vpp,diff (meas) [2]
128 GBaud	1.4 Vpp,diff (meas) [2]

1. No frequency/phase response correction applied
2. Measured at 1 sample/symbol

Spectral purity, measured with 1 Vpp (diff) output amplitude

ENOB, (measured according to IEEE 1658-2011)	f_{sa} = 128 GHz	5.5 bits (typ), f_{out} = DC…35 GHz 5.0 bits (typ), f_{out} = 35 GHz… 64 GHz
	f_{sa} = 100 GHz	5.7 bits (typ), f_{out} = DC…50 GHz
SINAD	f_{sa} = 128 GHz	35 dB (typ), f_{out} = DC…35 GHz 30 dB (typ), f_{out} = 35 GHz… 64 GHz
	f_{sa} = 100 GHz	35 dB (typ), f_{out} = DC…35 GHz 32 dB (typ), f_{out} = 35 GHz … 50 GHz
SNR (excluding harmonic distortions and SFDR spur)	f_{sa} = 128 GHz	37 dB (typ), f_{out} = DC…35 GHz 29dB (typ), f_{out} = 35 GHz…64 GHz
	f_{sa} = 100 GHz	37 dB (typ), f_{out} = DC…35 GHz 33 dB (typ), f_{out} = 35…50 GHz
SFDR (excluding harmonic distortions)	f_{sa} = 128 GHz	-48 dBc (typ), f_{out} = DC…20 GHz -33 dBc (typ), f_{out} = 20 GHz…64 GHz
	f_{sa} = 100 GHz	-45 dBc (typ), f_{out} = DC…15 GHz -39 dBc (typ), f_{out} = 15 GHz…30 GHz -35 dBc (typ), f_{out} = 30 GHz…50 GHz
Total Harmonic Distortion (over the entire band)	f_{sa} = 128 GHz	-37 dBc (typ)
	f_{sa} = 100 GHz	-38 dBc (typ)
2nd harmonic (DC ... f_{sa}/2)	Differential	-42 dBc (typ)
	Single-ended	-32 dBc (typ)
3rd harmonic (DC ... f_{sa}/2)	f_{sa} = 128 GHz	-35 dBc (typ)
	f_{sa} = 100 GHz	-38 dBc (typ)

CLK in

Input coupling	AC
Input impedance	50 Ohm
Input level	+4 dBm ... +8 dBm
Frequency range	50 GHz ... 64 GHz
Connector type	1.85 mm

Sync In, Sync Out A/B

Sync In must be connect to Sync Out of the M8008A clock module.

Sync Out A/B are reserved for future use.

Sync Marker Out A/B

Output type	Single ended
Coupling	DC
Impedance	50 Ohm (nom)
Amplitude	0.1 V … 2 V (nom) into 50 Ohm
Voltage window	-0.5 V … 1.75 V (nom) into 50 Ohm
Rise/fall time (20/80)	125 ps (typ) measured at 0.5 V
Connector type	3.5 mm, female

Sample Marker Out

Output type	Single ended[1] or differential
Coupling	DC
Impedance	50 Ohm (nom)
Amplitude	0.1 $V_{pp,se}$ … 1 $V_{pp,se}$ (nom) into 50 Ohm
Voltage window	-1.0 V … 3.7 V (nom) into 50 Ohm
Rise/fall time (20/80)	25 ps (typ)
Connector type	3.5 mm, female

1. Unused outputs must be terminated with 50 Ohm to GND. In case the termination voltage is not GND, the unused output must be either terminated AC coupled or terminated to $V_{Term.}$

Frequency Response

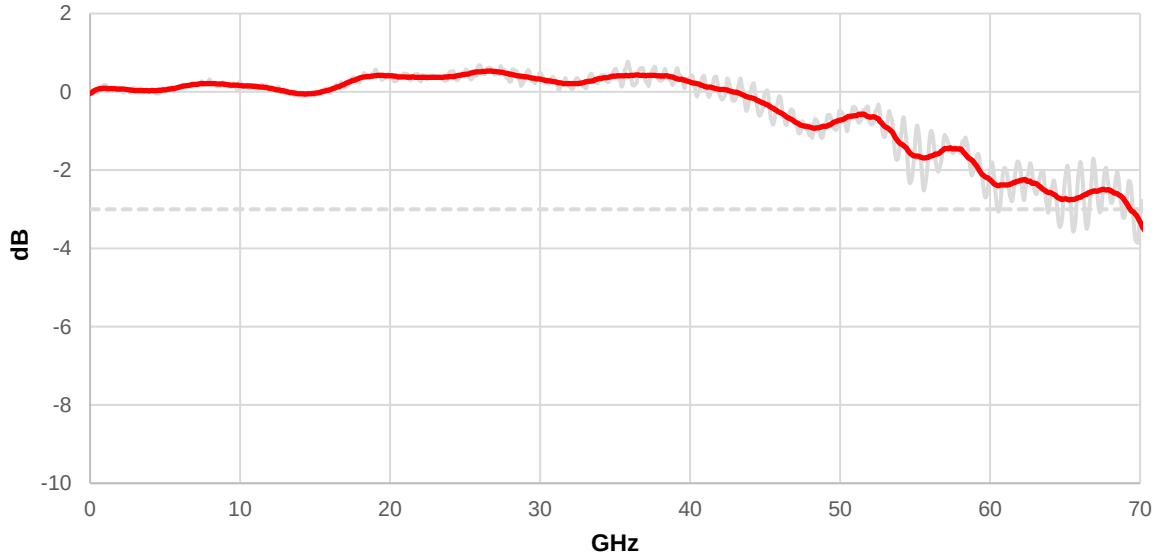

Figure 5. Frequency response at front panel output, measured at sample rate of 128 GSa/s, and 1 Vpp,diff amplitude. Sin(x)/x roll-off mathematically compensated. Red: Savitzky–Golay filters polynomial fit, window size: 5%, grey: measured data.

Spectral Purity

Spectral noise and distortions are measured with a single tone and 1 Vpp,diff amplitude. A 10 dB attenuator is connected between AWG and sampling oscilloscope (N1046A). The frequency response of the oscilloscope has been de-embedded in FlexDCA.

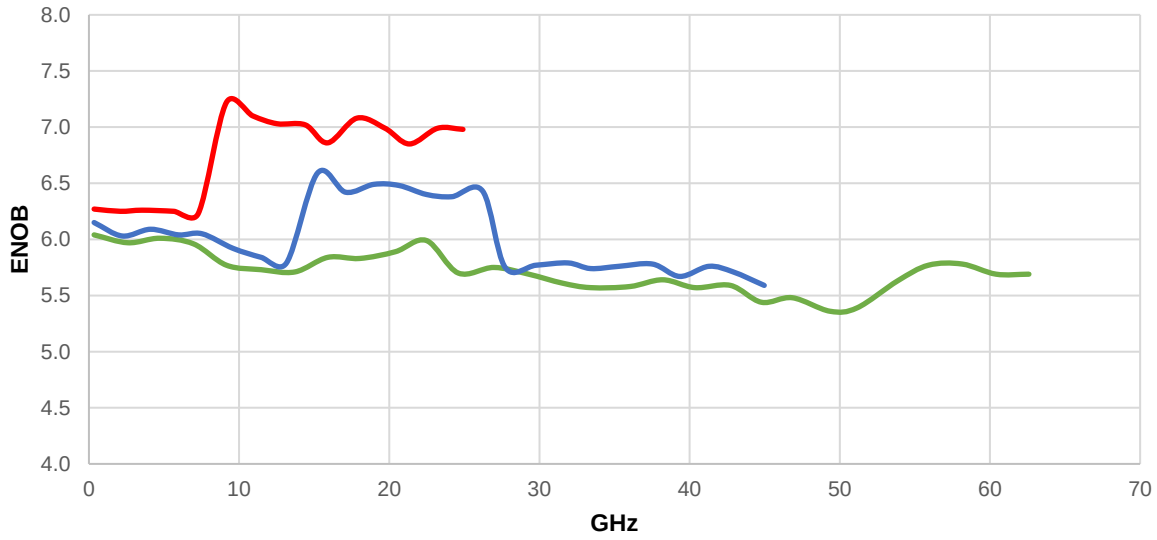

Figure 7. ENOB at front panel output, according to IEEE 1658-2011, fsa = 128 GSa/s
Measured bandwidth: Red: 25 GHz, blue: 45 GHz, green 63 GHz

General

Parameter	M8199A
Power consumption	190 W (nom)
Operating temperature	0 °C to 40 °C
Operating humidity	15% to 95% relative humidity at 40°C, non-condensing
Operating altitude	Up to 2000 m
Storage temperature	-40 °C to +70 °C
Storage humidity	24% to 90% relative humidity at 65°C, non-condensing
Stored states	User configurations and factory default
Interface to controlling PC	PCIe (see AXIe chassis specification) or USB
Form factor	2-slot
AXIe Dimensions (W x H x D)	351 mm x 60 mm x 309 mm
Weight	5.95 kg
Safety designed to	IEC 61010-1, UL 61010, CSA 22.2 61010.1 tested
EMC tested to	IEC 61326-1
Warm-up time	30 min
Calibration interval	2 years recommended
Cooling requirements	Slot air flow direction is from right to left. When operating the system choose a location that provides at least 80 mm of clearance at rear, and at least 50 mm of clearance at each side

Definitions

Specification (spec.)

The warranted performance of a calibrated instrument that has been stored for a minimum of 2 hours within the operating temperature range of 0 °C to 40 °C and a 15-minute warm up period. Within

+/- 10 °C after auto calibration. All specifications include measurement uncertainty and were created in compliance with ISO-17025 methods. Data published in this document are specifications (spec) only where specifically indicated.

Typical (typ.)

The characteristic performance, which 80% or more of manufactured instruments will meet. This data is not warranted, does not include measurement uncertainty, and is valid only at room temperature (approximately 23 °C).

Nominal (nom.)

The mean or average characteristic performance, or the value of an attribute that is determined by design such as a connector type, physical dimension, or operating speed. This data is not warranted and is measured at room temperature (approximately 23 °C).

Measured (meas.)

An attribute measured during development for purposes of communicating the expected performance. This data is not warranted and is measured at room temperature (approximately 23 °C).

Accuracy

Represents the traceable accuracy of a specified parameter. Includes measurement error and time base error, and calibration source uncertainty.

Confidently Covered by Keysight Services

Prevent delays caused by technical questions and reduce system downtime due to instrument maintenance and repairs with Keysight Services. Keysight Services are here to support your test needs with expert technical support, instrument repair and calibration, software support, training, alternative acquisition program options, and more.

A KeysightCare agreement provides dedicated, proactive support through a single point of contact for instruments, software, and solutions. KeysightCare covers an extensive group of instruments, application software, and solutions and ensures optimal uptime, faster response, faster access to experts, and faster resolution.

Keysight Services

Offering	Benefits
KeysightCare 	KeysightCare provides elevated support for Keysight instruments and software, with access to technical support experts who respond within a specified time and ensure committed repair and calibration turnaround times (TAT). KeysightCare offers multiple service agreement tiers, including KeysightCare Assured, Enhanced, and Application Software Support. See the KeysightCare data sheet for details.
KeysightCare Assured	KeysightCare Assured goes beyond basic warranty with repair services that include committed TAT and unlimited access to technical experts.
KeysightCare Enhanced	KeysightCare Enhanced includes all the benefits of KeysightCare Assured plus Keysight's accurate and reliable Calibration Services, accelerated, and committed TAT, and technical response.
Keysight Support Portal & Knowledge Center	All KeysightCare tiers include access to the Keysight Support Portal where you can manage support and service resources related to your assets such as service requests, and status, or browse the Knowledge Center.
Education Services	Build confidence and gain new skills to make accurate measurements, with flexible Education Services developed by Keysight experts. Including Start-up Assistance.
Alternative acquisition options	
KeysightAccess	Reduce budget challenges with a leased-based subscription service, that offers low monthly payments, enabling you to get the instruments, software, and technical support you want for your test needs.

Recommended services

Maximize your test system up-time by securing technical support, repair, and calibration services with committed response and turnaround times. 1-year KeysightCare Assured is included in every new instrument purchase. Obtain multi-year KeysightCare upfront to eliminate the need for lengthy and tedious paperwork and yearly requests for maintenance budget. Plus, you benefit from secured service for 2, 3, or 5 years.

Service	Function
KeysightCare Enhanced*	**Includes tech support, warranty and calibration**
R-55B-001-1	KeysightCare Enhanced – Upgrade 1 year
R-55B-001-2	KeysightCare Enhanced – Extend to 2 years
R-55B-001-3	KeysightCare Enhanced – Extend to 3 years (Recommended)
R-55B-001-5	KeysightCare Enhanced – Extend to 5 years (Recommended)
KeysightCare Assured*	**Includes tech support and warranty**
R-55A-001-2	KeysightCare Assured – Extend to 2 years
R-55A-001-3	KeysightCare Assured – Extend to 3 years
R-55A-001-5	KeysightCare Assured – Extend to 5 years
Start-Up Assistance	
PS-S40-01	Included – instrument fundamentals and operations starter
PS-S40-04	Recommended – instrument fundamentals and operations starter
PS-S40-02	Optional, technology & measurement science standard learning

* Available in select countries. For details, please view the datasheet. R-55B-001-2/3/5 must be ordered with R-55B-001-1.

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