M8199A 128/256 GSa/s Arbitrary Waveform Generator

Version 1.2

Key Benefits of the New Arbitrary Waveform Generator

- 4 channels at 128 GSa/s or 2 channels 256 GSa/s with up to 70 GHz nominal analog bandwidth
- Provides research engineers a high-performance signal source for arbitrary signals, enabling development of designs up to 140 GBd.
- Keysight's M8199A 256 GSa/s AWG delivers twice the sampling rate of any AWG on the market today, coupled with at least 50 percent higher analog bandwidth. As a result, research engineers can quickly develop advanced components for terabit transmission systems
- Integrated, ready-to-use instrument
- Operates with well-known software, like MATLAB or Keysight IQTools and
- SCPI programming interface based on M8070B
- High flexibility with upgrade options from 2 channels at 128 GSa/s to 4 channels at 256 GSa/s

2 x 2 Channels, 256 GSa/s

2 x 4 Channels, 128 GSa/s

KEYSIGHT

M8199A at a glance

The Keysight M8199A arbitrary waveform generator (AWG) has the highest sample rate and the widest bandwidth in its class with up to four synchronized channels operating simultaneously in one module

- Up to 70 GHz analog bandwidth
- Built-in frequency and phase response calibration for clean output signals
- 6 bits ENOB, DC to 50 GHz, Fs 100 GSa/s
- Intrinsic jitter: < 75 fs
- Continuous sample rate range: 100 to 128 GSa/s resp. 200 to 256 GSa/s
- Up to 1.4 Vpp differential output voltage @128 GBd
- Transition time (20/80) as low as 5 ps
- Channel-to-channel skew adjustment with 25 fs resolution
- Synchronization of up to 16 channels across 4 modules
- < 140 dBc wideband phase noise > 1 MHz
- 512 KSa / 1 MSa of waveform memory per channel

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 65 GHz of analog bandwidth, 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 GBd.

Using option ILV boosts the sample rate from 128 GSa/s on 4 channels to 256 GSa/s on two channels.

An optionally available remote head increases the output amplitude so that it can directly drive a modulator amplifier.

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.

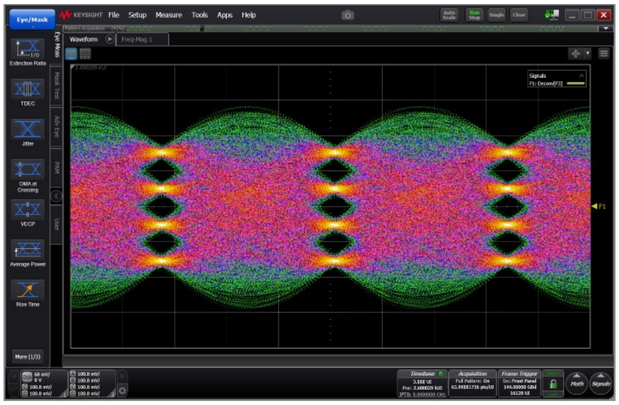

Figure 1. PAM-4, 144 GBd (= 288 Gbps)

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, high-speed research is already experimenting using PAM-3, PAM-6, PAM-8 or proprietary modulation formats at data rates up to 128 GBd. Interleaving can boost the sample rate to 256 GSa/s, enabling symbol rates beyond 128 GBd.

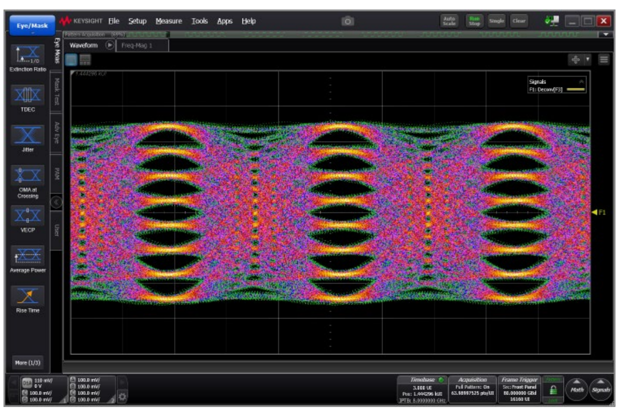

Figure 2. 80 GBd PAM8 (= 240 Gpbs)

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.

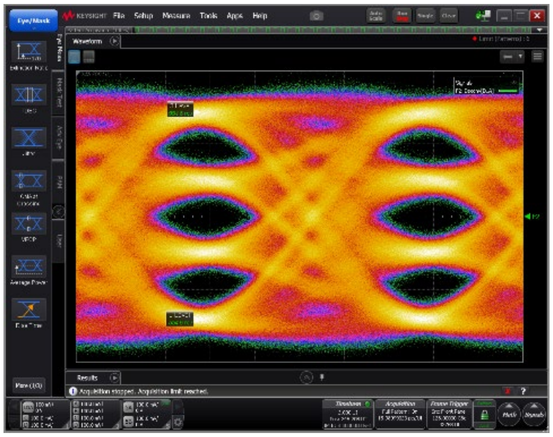

Figure 3. 128 GBd PAM4 (= 256 Gpbs)

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 or 256 GSa/s, 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.

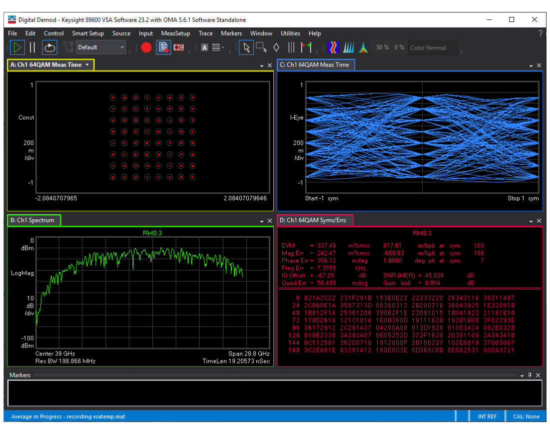

Figure 4. QAM-64, 16 GBd at 39 GHz carrier

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.

Interleaving Option and Remote Heads

The interleaving option (Opt. ILV) consists of a total of 4 power combiners that are connected to the outputs of the M8199A. For mechanical stability, the power combiners are mounted in a metal housing that is screwed onto the front panel of the M8199A making the setup mechanically stable and this avoids phase induced instabilities of the signal. The interleaving option is customer attachable and detachable and can also be ordered as an upgrade later.

Using the interleaving technique, the sample rate of the AWG can be doubled, at the expense of cutting the number of channels in half. I.e., a 4-channel M8199A can have two 256 GSa/s channels, while a

2-channel M8199A will have one 256 GSa/s channel with the ILV Option. The interleaving option supports always combining 4 channels at 128 GSa/s combined to two channels at 256 GSa/s, even if only a 2-channel version was ordered. This avoids any return to factory when upgrading from 2 channel 128 GSa/s to 4 channel 128 GSa/s.

The skew calibration between the channels is handled by the software. From a user's perspective, the interleaved instrument can be operated as if it would be a true 256 GSa/s AWG.

Due to the insertion loss of the power combiners, the signal amplitude at the output of the combiners might be not high enough for some applications. In order to compensate this loss, remote head amplifiers (M8158A) are offered optionally. In addition to boosting the signal amplitude back to higher levels, the remote head offer an excellent way to bring the signal close to the device-under-test.

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 or 8 sync'd channels at 256 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 free MATLAB based utility IQtools is included with the instrument software. IQtools provides a large number of waveform generation utilities 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. It can compensate skew between all channels. When using the ILV-option, IQtools additionally provides an automated skew calibration to optimize system performance.

Front Panel Connections

Front panel without interleaver

Front panel with interleaver attached

- **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
- **Remote Head 1/2** – power and control for remote heads for interleaved channels 1 and 2
- **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	
M8199A-ILV	Interleave option to combine 4 channels at 128 GSa/s to 2 channels at 256 GSa/s	In conjunction with M8199A-002, only one channel at 256 GSa/s will be available
M8158A	Optional Remote Head – 65 GHz amplifier Note: One M8158A needed per 256 GSa/s channel	The remote amplifier is only supported in conjunction with Option ILV
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
M8199AU-ILV	Upgrade Interleaving Option	Requires factory re-calibration of the M8199A module

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	Recommended as an anti-alias filter when operating the M8199A in non-interleaved mode with fractional oversampling. For interleaved operation, no filters are needed.	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 (without option ILV) 200 to 256 GSa/s (with option ILV)
DAC resolution	8 bits
Number of channels per M8199A module	2 or 4 channels (corresponds to options 002 and 004) (without option ILV) 1 or 2 channels (corresponds to options 002 and 004) (with option ILV)
Sample memory	512 kSa per channel in non-interleaved mode. 1024 kSa per channel in interleaved mode The waveforms in each channel can have different length
Waveform granularity	256 samples in non-interleaved mode. 512 samples in interleaved mode. The length of waveform segments must be a multiple of the granularity

Output 1, 2, 3, 4

Output characteristics

Mode	Modul Output 1, 2, 3, 4	ILV Output 1, 2	Remote Head Output 1, 2
Output type	Single-ended or differential (terminate unused output with 50 Ohm in single ended mode)	Single-ended or differential (terminate unused output with 50 Ohm in single ended mode)	Single-ended or differential (terminate unused output with 50 Ohm in single ended mode)
Impedance	50 Ω (nom)	50 Ω (nom)	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	100 $mV_{pp,se}$ to 0.625 $V_{pp,se}$ into 50 Ω 200 $mV_{pp,diff}$ to 1.25 $V_{pp,diff}$ into 50 Ω	100 $mV_{pp,se}$ to 1 $V_{pp,se}$ into 50 Ω 200 $mV_{pp,diff}$ to 2 $V_{pp,diff}$ into 50 Ω
Amplitude resolution	1 mV_{se} (nom.)	1 mV_{se} (nom.)	1 mV_{se} (nom.)
Amplitude accuracy (measured peak-to-peak with 400 MHz square wave)	±(10 mV +7.5%) (typ)	±(10 mV +7.5%) (typ)	±(10 mV +7.5%) (typ)
Voltage window	–1 to +3.0 V depends on external termination voltage [1]	-0.5 to +2.5 V depends on external termination voltage [2]	-1 to +3 V depends on external termination voltage [3]
DC offset accuracy	±(10 mV +2%) (typ)	±(10 mV +2%) (typ)	±(10 mV +2%) (typ)
Common Mode Voltage Accuracy[4]	±(25 mV +12.5%)	n/a	±(25 mV +12.5%)
Termination voltage (VTerm) window	–1 to +3.0 V	-0.5 to +2.5 V	–1 to +3.0 V
Connector type	1.85 mm (female)	1.85 mm (female)	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
2. High level voltage range = 2/3* Vterm - 0.4 V < HIL < Vterm + 1.5 V
   Low level voltage range = 2/3 * Vterm – 0.5 V < LOL < Vterm + 1.4 V
3. 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
4. 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

	Without Option ILV	With Option ILV	With Option ILV + Remote Head
Analog bandwidth (excl. 128 GSa/s sin(x)/x roll-off, measured with differential signal at the AWG resp. remote head connector, smoothed graph)			
3 dB	65 GHz (typ)	60 GHz (typ)	70 GHz (typ) [1]
6 dB	>70 GHz (meas)	>70 GHz (meas)	>70 GHz (meas)
Rise/fall time (20/80)	5 ps (typ) [2]	5.5 ps (meas) [3]	4.5 ps (meas) [3,1]
Achievable amplitude with digital corrections enabled. Measured with a PAM4 signal			
100 GBd	1.6 Vpp,diff (meas) [4]	0.7 Vpp,diff (meas)	1.2 Vpp,diff (meas)
112 GBd	1.5 Vpp,diff (meas) [4]	0.6 Vpp,diff (meas)	1.2 Vpp,diff (meas)
128 GBd	1.4 Vpp,diff (meas) [4]	0.6 Vpp,diff (meas)	1.0 Vpp,diff (meas)
136 GBd	n/a	0.5 Vpp,diff (meas)	0.9 Vpp,diff (meas)

1. User-defined peaking adjustment may be necessary to achieve the specified bandwidth
2. No frequency/phase response correction applied
3. Frequency/phase response correction (DC to 70 GHz) applied. Amplitude will be reduced.
4. Measured at 1 sample/symbol

Spectral purity (w/o Option ILV), 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

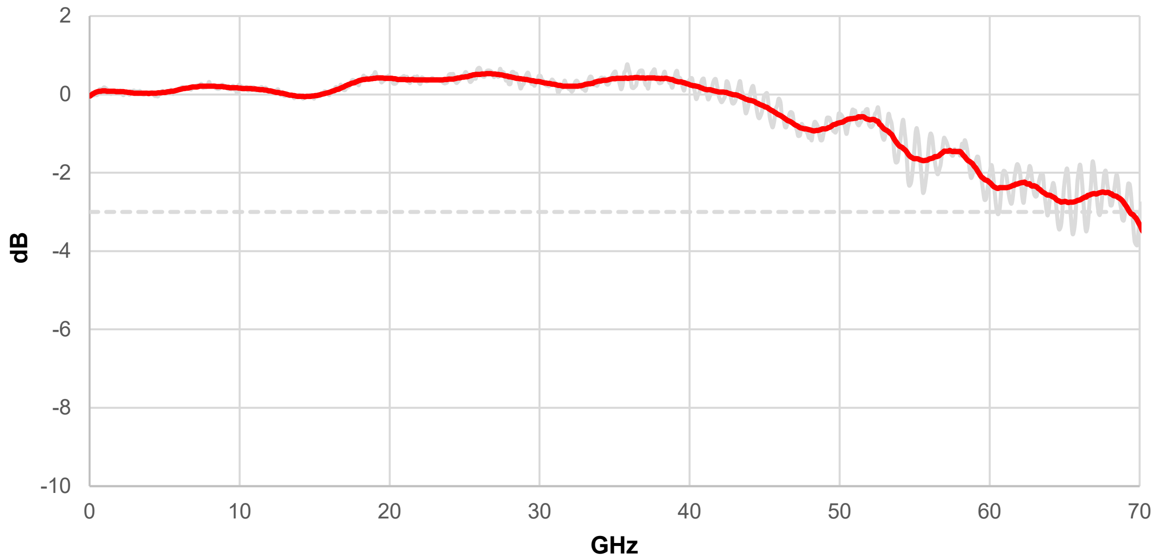

Figure 5. Frequency response at front panel output, measured at sample rate of 128 GSa/s, and 1 Vpp,diff amplitude. Sin(x)/x roll-off mathematically compensated. Red: Savitzky–Golay filters polynomial fit, window size: 5%, grey: measured data.

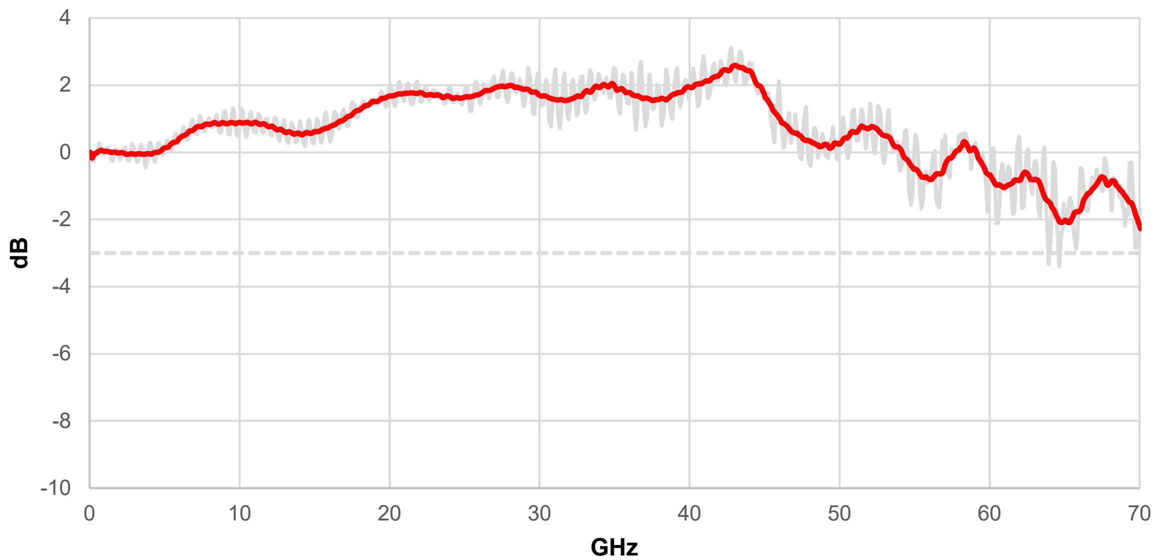

Figure 6. Frequency response at remote head output, measured at sample rate of 256 GSa/s, and 1 $V_{pp,diff}$ amplitude. 128 GSa/s sin(x)/x roll-off mathematically compensated. Red: Red: Savitzky–Golay filters polynomial fit, window size: 5%, grey: measured data.

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.

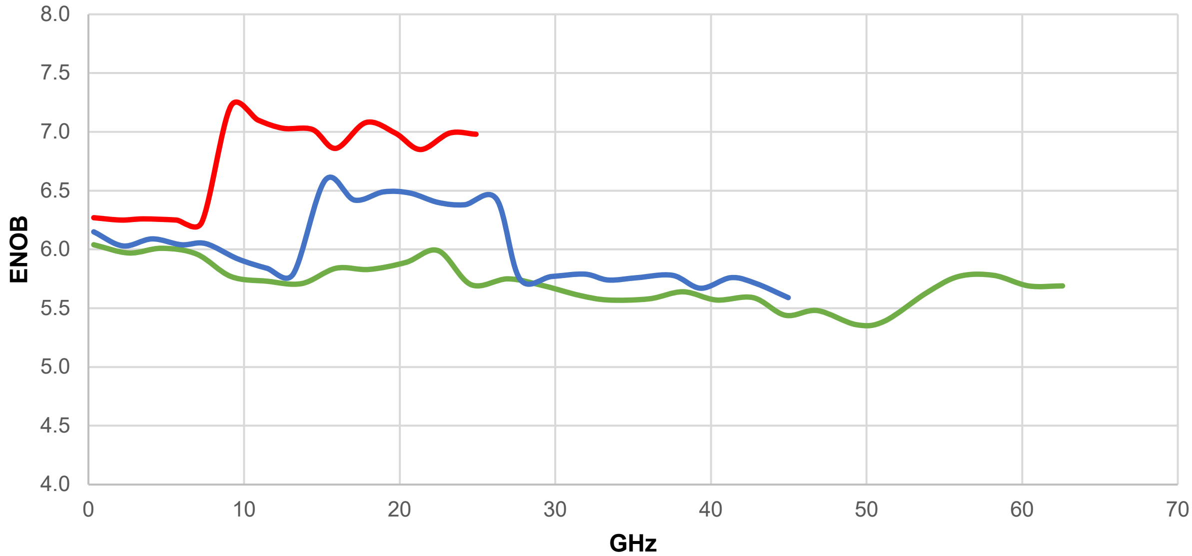

Figure 7. ENOB at front panel output, according to IEEE 1658-2011, fsa = 128 GSa/s
Measured bandwidth: Red: 25 GHz, blue: 45 GHz, green 63 GHz

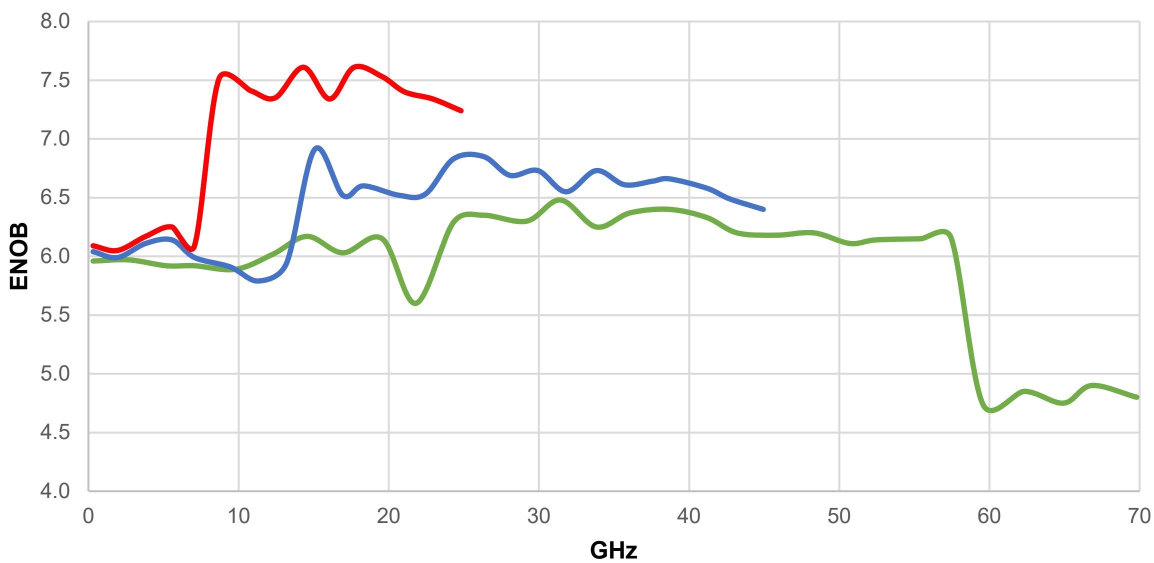

Figure 8. ENOB at remote head output, according to IEEE 1658-2011, fsa = 100 GSa/s
Measured bandwidth: Red: 25 GHz, blue: 45 GHz, green 70 GHz

General

Parameter	M8199A
Power consumption	220 W (nom) incl 2x M8158A 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 (351 mm x 60 mm x 450 mm incl ILV)
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

Physical Dimensions for M8158A Remote Heads

Parameter	
Physical dimensions (W x H x D)	150 mm x 90 mm x 44 mm (remote head without cables)
Length of cable connection between M8199A and M8158A	60 cm
Weight net	1.0 kg
Weight shipping	Shipment of one remote head: 3.7 kg Shipment of two remote heads: 4.7 kg

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.

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