M8199A 128/256 GSa/s Arbitrary Waveform Generator

Preliminary Datasheet Version 0.8 – September 2020

2 x 2 Channels, 256 GSa/s

2 x 4 Channels, 128 GSa/s

Key Benefits of the New Arbitrary Waveform Generator

- 2 channels at 256 GSa/s or 4 channels 128 GSa/s with 65 GHz nominal analog bandwidth, usable up to 80 GHz with roll-off calibration
- Provides research engineers a high-performance signal source for arbitrary signals, enabling development of designs up to 160 GBaud.
- 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 more 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

KEYSIGHT TECHNOLOGIES

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

- 65 GHz nominal analog bandwidth, 80 GHz useable signal bandwidth with roll-off calibration
- Built-in frequency and phase response calibration for clean output signals
- 6 bits ENOB, DC to 50 GHz, fs 100 GHz
- Intrinsic jitter: < 60 fs
- Continuous sample rate range: 100 to 128 GSa/s and 200 to 256 GSa/s
- 1.4 Vpp differential output voltage @128 Gbaud
- Transition time (20/80) as low as 3.5 ps
- Channel-to-channel skew adjustment with 15 fs resolution
- Synchronization of up to 16 channels across 4 modules
- < 150 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 GBaud.

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.

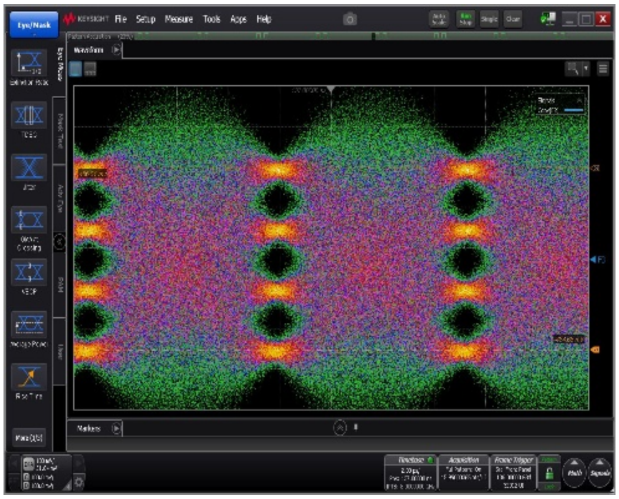


Figure 1. PAM-4, 136 GBaud (= 272 Gbps)

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 GBaud. Interleaving can boost the sample rate to 256 GSa/s, enabling symbol rates beyond 128 GBaud.

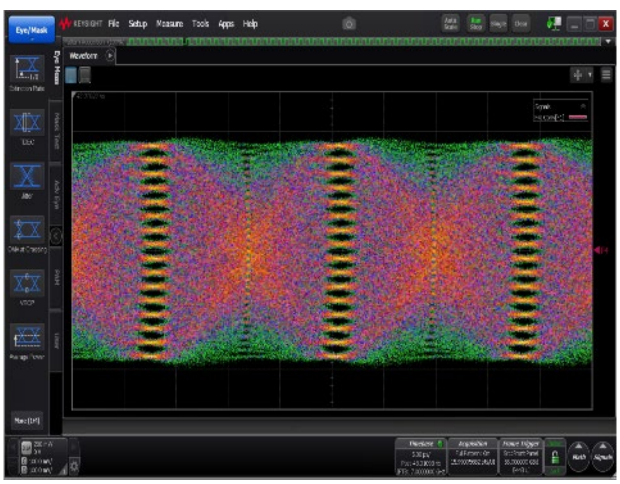


Figure 2. 56 GBaud PAM16 (= 224 Gpbs)

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.

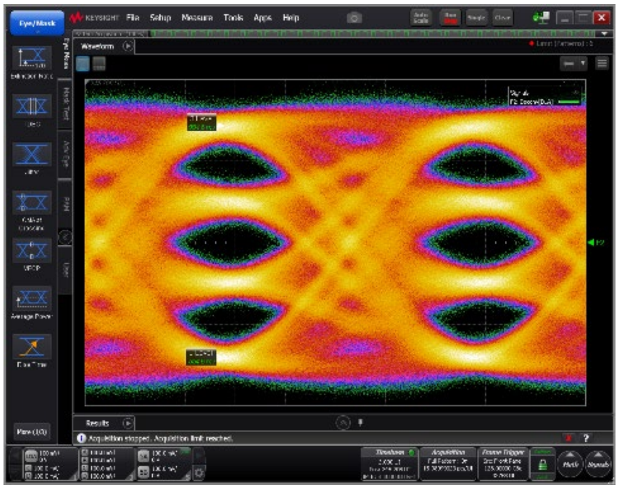


Figure 3. 128 GBaud PAM4 (= 256 Gpbs)

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.

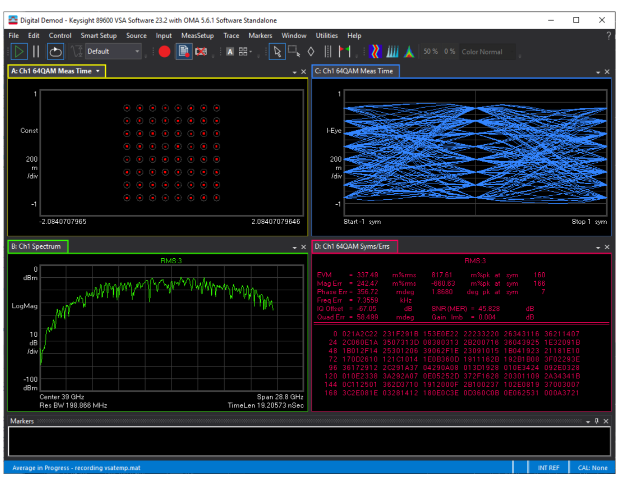


Figure 4. QAM-64, 16 GBaud at 39 GHz carrier

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.

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 +10 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.

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 not supported if an external signal generator is used for clock generation.

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.

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 M9502A 2-slot AXIe Chassis with USB Option	
M8100A-BU6	Pre-configured system consisting of one M9502A 2-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	Remote Head – 65 GHz amplifier Note: Two M8158A are required for two 256 GSa/s channels	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	

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-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 with fractional oversampling	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
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 (corresponds to options 002 and 004) 4 channels (without option ILV) 2 channels (with option ILV)
Sample memory	512 kSa per channel. The waveforms in each channel can have different length
Waveform granularity	256 samples. The length of waveform segments must be a multiple of the granularity

Output 1, 2, 3, 4

Output characteristics	
Output type	Single-ended or differential (terminate unused output with 50 Ohm in single ended mode)
Impedance	50 Ω (nom)
Amplitude range (valid at 100 MHz. At higher frequencies, please consider achievable amplitudes, shown below)	75 $mV_{pp,se}$ to 0.9 $V_{pp,se}$ into 50 Ω 150 $mV_{pp,diff}$ to 1.8 $V_{pp,diff}$ into 50 Ω
Amplitude resolution	390 μV_{se} (nom.)
Amplitude accuracy (measured peak-to-peak with 100 MHz sinewave)	±(tbd% + tbd mV) (into 50 Ω, spec.)
Voltage window	-tbd to +tbd V single-ended into 50 Ω
±Offset resolution	tbd µV (nom)
DC offset accuracy	± 20 mV (typ)
Differential offset	adjustable
Termination voltage window	tbd
Termination voltage resolution	tbd
Connector type	1.85 mm (female)

Timing characteristics	
Channel skew between any pair of outputs	0 ps ±tbd ps (typ) (also valid with ILV option) 0 ps ±tbd ps (typ) (after skew optimization)
Skew between normal and complement	0 ps ±tbd ps (nom) (without ILV option) 0 ps ±tbd ps (nom) (with ILV option) 0 ps ±tbd ps (nom) (with ILV option and remote head)
Random Jitter with M8008A with E8257D, Opt.567/UNY	 tbd 60 fsrms (typ)
Skew adjustment range	0 ps ± tbd ps (typ)
Skew adjustment resolution	30 fs

RF characteristics			
	Without Option ILV	With Option ILV	With Option ILV + Remote Head
Analog bandwidth (excl. sin(x)/x roll-off)			
3 dB	65 GHz (typ)	60 GHz	70 GHz
6 dB	tbd GHz (typ)	tbd GHz	tbd GHz
Rise/fall time (20/80)			
Uncorrected	4.5 ps (typ)	6 ps (typ)	9 ps (typ)
With freq./phase response corrections (DC…70 GHz) enabled	3.5 ps (typ)	4 ps (typ)	4.5 ps (typ)
Amplitude flatness (at output connector)	± tbd dB (typ), fout = DC...tbd GHz	± tbd dB (typ), fout = DC...tbd GHz	± tbd dB (typ), fout = DC...tbd GHz
Achievable amplitude with frequency/phase response corrections (DC…70 GHz) enabled			
96 GBaud	1.7 $V_{pp,diff}$ (typ)	0.69 $V_{pp,diff}$ (typ)	1.7 $V_{pp,diff}$ (typ)
112 GBaud	1.3 $V_{pp,diff}$ (typ)	0.63 $V_{pp,diff}$ (typ)	1.5 $V_{pp,diff}$ (typ)
128 GBaud	1.2 $V_{pp,diff}$ (typ)	0.53 $V_{pp,diff}$ (typ)	1.4 $V_{pp,diff}$ (typ)
136 GBaud	n.a.	0.47 $V_{pp,diff}$ (typ)	1.2 $V_{pp,diff}$ (typ)

Spectral purity (w/o Option ILV), measured with 1 Vpp (diff) output amplitude		
ENOB, (measured according to IEEE 1658-2011)	f_s = 128 GHz	5.5 bits (typ), f_{out} = DC…35 GHz 5.0 bits (typ), f_{out} = 35 GHz… 64 GHz
	f_s = 100 GHz	6.0 bits (typ), f_{out} = DC…50 GHz
SNDR	f_s = 128 GHz	35 dB (typ), f_{out} = DC…35 GHz 30 dB (typ), f_{out} = 35 GHz… 64 GHz
	f_s = 100 GHz	38 dB (typ), f_{out} = DC…35 GHz 35 dB (typ), f_{out} = 35 GHz … 50 GHz
SNR (excluding harmonic distortions and SFDR spur)	f_s = 128 GHz	38 dB (typ), f_{out} = DC…35 GHz 30 dB (typ), f_{out} = 35 GHz…64 GHz
	f_s = 100 GHz	40 db (typ), f_{out} = DC…35 GHz 35 db (typ), f_{out} = 35…50 GHz
SFDR (excluding harmonic distortions)	f_s = 128 GHz	-42 dBc (typ), f_{out} = DC…35 GHz -38 dBc (typ), f_{out} = 30 GHz…50 GHz
	f_s = 100 GHz	-49 dBc (typ), f_{out} = DC…30 GHz -44 dBc (typ), f_{out} = 30 GHz…50 GHz
Total Harmonic Distortion (over the entire band)	f_s = 128 GHz	-35 dBc (typ)
	f_s = 100 GHz	-40 dBc (typ)
2nd harmonic (DC ... f_s/2)	Differential	-45 dBc (typ)
	Single-ended	-35 dBc (typ)
3rd harmonic (DC ... f_s/2)		-38 dBc (typ)
Spectral purity (with Option ILV), fs = 256 GS/s (after skew optimization)		
ENOB	w/o remote head with remote head	
SNDR	w/o remote head with remote head	
SNR (excluding harmonic distortions and SFDR spur)	w/o remote head with remote head	
SFDR (excluding harmonic distortions)	w/o remote head with remote head	
THD	w/o remote head with remote head	

CLK in

Input coupling	AC
Input impedance	50 Ohm
Input level	0 dBm ... +5 dBm
Frequency range	50 GHz … 64 GHz
Connector type	1.85 mm

Sync In, Sync Out A/B

The Sync In and Sync Out connectors are used for synchronization of multiple AWG modules.

Sync MRK Out A/B

tbd

Sample MRK out

tbd

Frequency Response

Frequency response of differential output is measured with a sample rate of 128 GSa/s, and 1 $V_{pp,diff}$ amplitude. Sin(x)/x roll-off has been corrected in the graph.

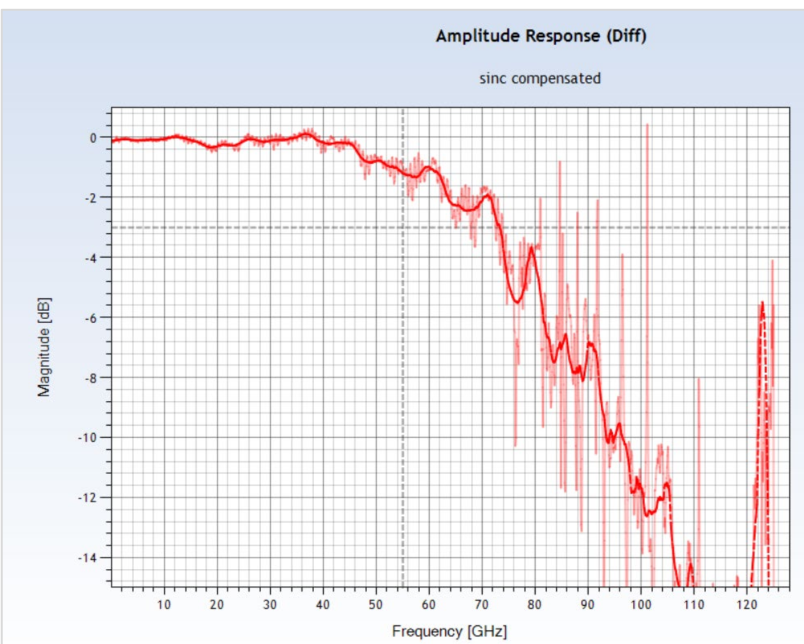
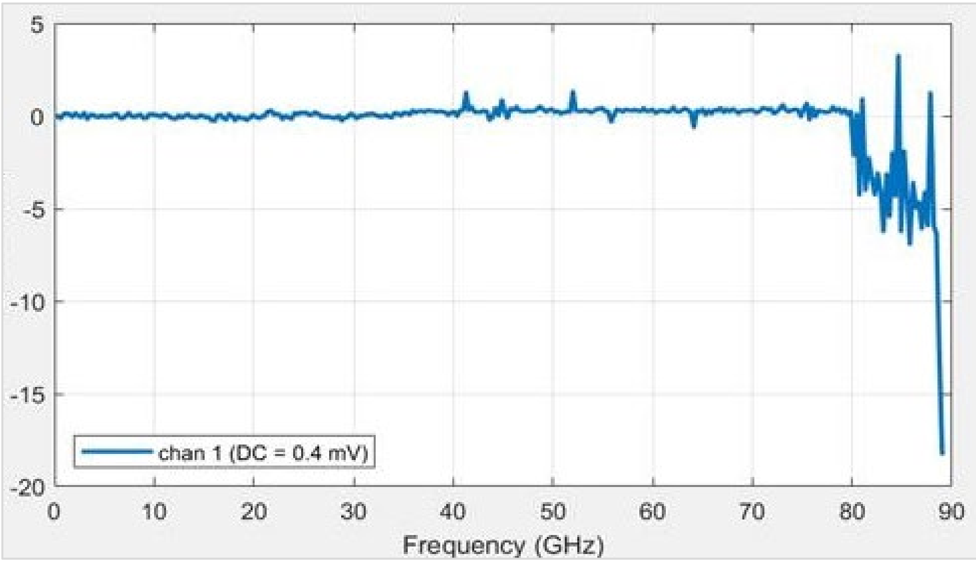


Figure 5. Multitone frequency response, measured at 128 GS/s (sin(x)/x roll-off compensated, light red graph is measured, dark red is a curve fit)

The following graph shows the frequency response after applying digital frequency-response correction up to 80 GHz.



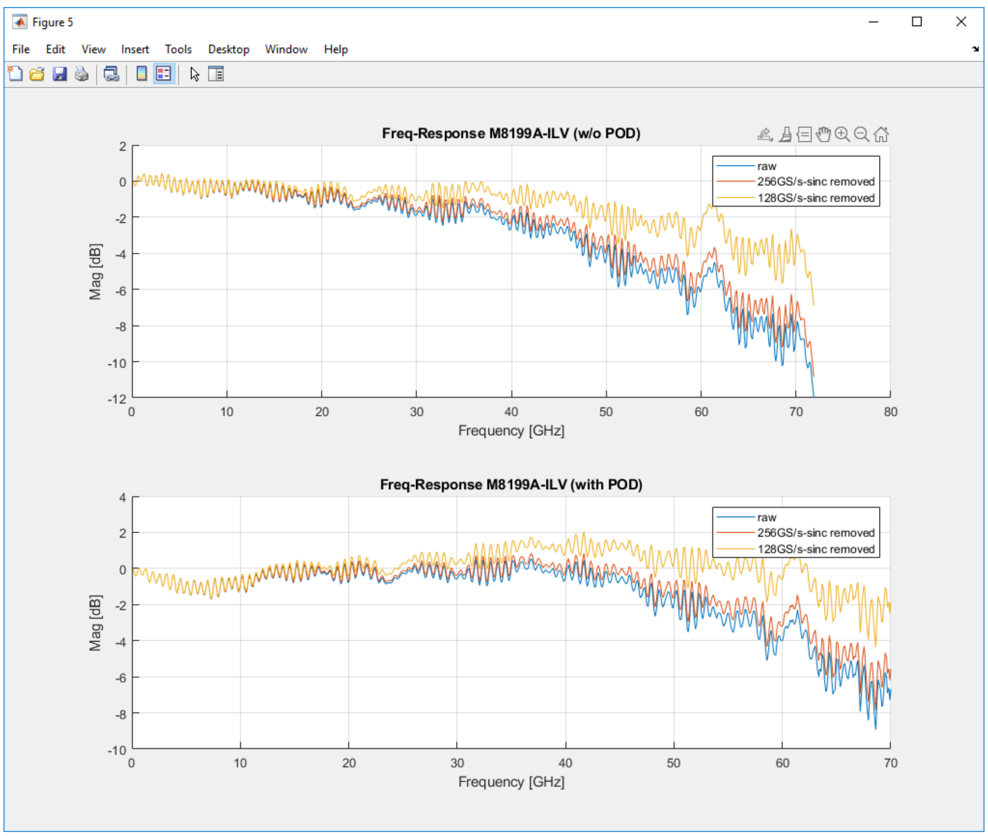


Figure 6. Frequency response M8199A with Option ILV (top), and options ILV+ remote-remote head (bottom)

Spectral Purity

Spectral noise and distortions are measured with a single tone and 1 $V_{pp,diff}$ amplitude. A 6 dB attenuator is connected between AWG and sampling oscilloscope. The frequency response of the oscilloscope has been de-embedded in FlexDCA.

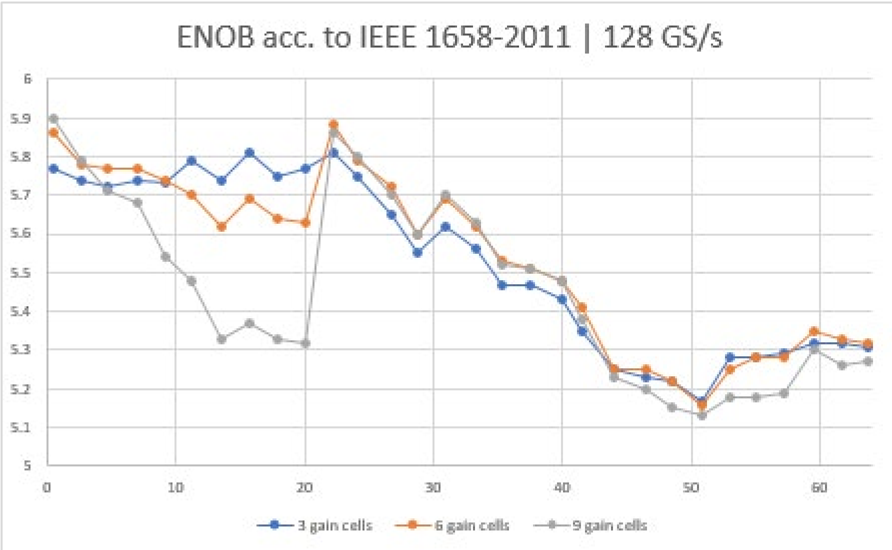


Figure 8. ENOB according to IEEE 1658-2011, fs = 128 GS/s

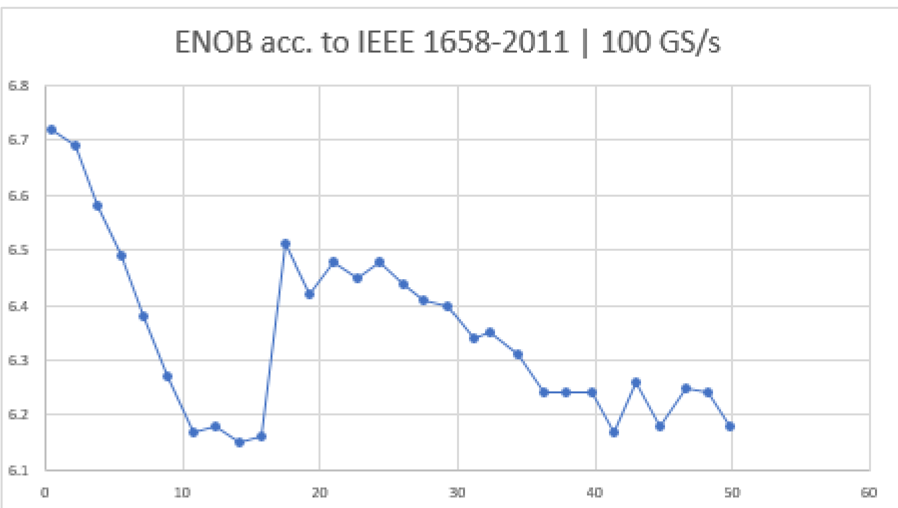


Figure 7. ENOB according to IEEE 1658-2011, fs = 100 GS/s

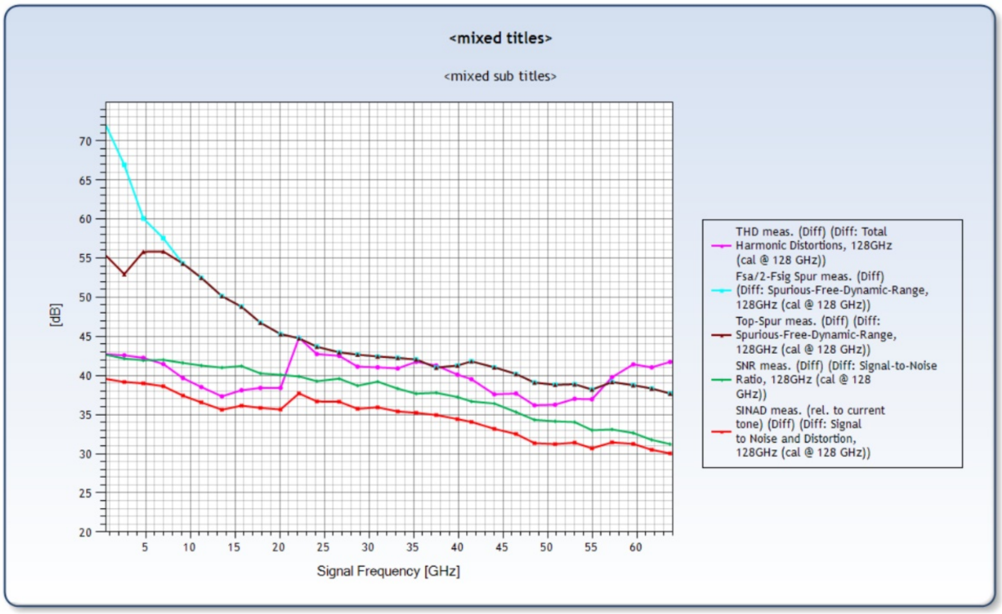


Figure 10. SNDR (red), SNR (green), THD (pink), SFDR (brown), f_{sig}-f_s/2 spur (blue) for f_s = 128 GS/s

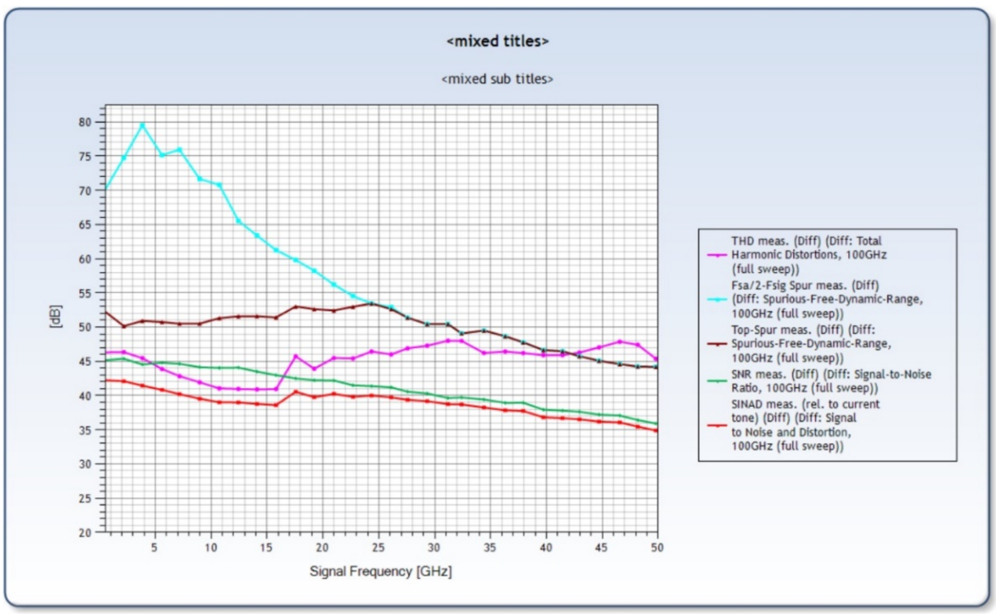


Figure 9. SNDR (red), SNR (green), THD (pink), SFDR (brown), f_{sig}-f_s/2 spur (blue) for f_s = 100

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 timebase error, and calibration source uncertainty.