Moku:Delta

Specifications



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Moku:Delta Hardware

Specifications

All specifications are typical, unless otherwise stated as measured.

Analog I/O

Analog inputs

Channels	8
Bandwidth (-3 dB)	2 GHz in 50 Ω input (measured)[1]; user configurable 6 GHz analog path 1 MHz into 1 M Ω input
Sampling rate	5 GSa/s with 8 channels simultaneously
Resolution	14 bits (high bandwidth) / 20 bits (low bandwidth)
Maximum voltage range	40 V_{pp} into 1 MΩ; 10 V_{pp} into 50 Ω
Absolute max input (damage)	5.5 V_{rms} into 50 Ω
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC
Input voltage ranges	40 V_{pp} with 32 dB input attenuation and 1 MΩ input impedance 10 V_{pp} with 20 dB input attenuation 1 V_{pp} with 0 dB input attenuation 100 mVpp with 20 dB input gain 2 V_{pp} with 20 dB input attenuation in 6 GHz input mode
AC coupling corner (-3 dB)	16 kHz into 50 Ω 1.6 Hz into 1 MΩ
Input referred noise	10 nV/√Hz @ 100 Hz < 10 nV/√Hz > 2 MHz < 6 nV/√Hz > 100 MHz
Input Noise Vrms	Measured with 100 mV input range, 50 Ω 9.1 µV (2 MHz bandwidth) 33 µV (20 MHz bandwidth) 74 µV (200 MHz bandwidth) 152 µV (1 GHz bandwidth) 248 µV (2 GHz bandwidth)
Effective number of bits (ENOB)	10.8 bits
Connector	SMA

[1] -3 dB from 100 MHz to 2 GHz

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Analog outputs

Channels	8	
Maximum output frequency	2 GHz	
Sampling rate	5 GSa/s per channel (10 GSa/s with interpolation)	
Resolution	14-bit	
Output amplitude 1 Vpp range	DC to 200 MHz	1 Vpp / 3.98 dBm
	200 MHz to 700 MHz	2 dBm
	700MHz to 1.2GHz	0 dBm
	1.2 GHz to 1.5 GHz	-2 dBm
	1.5 GHz to 2 GHz	-8 dBm
Output amplitude 10 Vpp range	DC to 100 MHz	10 Vpp / 24 dBm
Output impedance	50 Ω	
Output coupling	DC	
Connector	SMA	

Digital I/O

Digital input/outputs

Channels	2 banks of 16 digital I/O, each independently configurable as input or output
Signal levels	LVCMOS, 3.3 V, inputs 5 V tolerant (supplied accessory required)
Input impedance	22 kΩ
High level input V_{IH}	Min 2 V, typical 3.3 V, max 5.0 V
Low level input V_{IL}	Min 0 V, max 0.8 V
Output impedance	100 Ω
High level output V_{OH}	Min 2.4 V, typical 2.7 V at I_{OH} = 8 mA
Low level output V_{OL}	Min 0.28 V, typical 0.4 V at I_{OL} = 8 mA
Power supply pins	5 V up to 1 A; 3.3 V up to 1 A



Moku:Delta digital interface module

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Clock reference

Onboard clock

Stability	± 1 ppb

10 / 100 MHz reference input

Expected waveforms	Sine / square
Input frequency	10 MHz / 100 MHz (selectable) ± 20 kHz
Input range	300 mVpp to 2 Vpp
Input impedance	1 kΩ
Input coupling	AC coupled
Connector	BNC

10 / 100 MHz reference output

Waveform type	Square
Output frequency	10 MHz / 100 MHz switchable
Output level	0.7 V_{PP}
Output impedance	50 Ω
Output coupling	AC coupled
Connector	BNC

GPS/GNSS reference

1 PPS input amplitude	TBD
1 PPS output waveform	TBD
1 PPS output amplitude	TBD
Connector	3 x SMA (Antenna, 1 PPS input, 1 PPS output)

Storage

Internal SSD drive	1 TB

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General characteristics

General and environmental characteristics

Power consumption	TBD W typical
Power voltage range	Supplied external power adaptor 100 - 240 V~ ± 10%, 50/60 Hz The power supply shall be plugged into a socket outlet with reliable protective earthing contact.
Temperature	Operating: 5 to +40 °C Non-operating: -10 to +60 °C Do not obstruct the cooling fan outlets. 20 cm ventilation clearance is required.
Humidity	R.H. 5% to 80% noncondensing
Operating Altitude	Up to 10,000 feet (3000 m)
Other requirements	Intended for indoor use only
Pollution degree	2
Overvoltage category	OVC II

Electromagnetic compliance

IEC/EN 61326 -1 (Group 1, Class A, Immunity test requirement for basic electromagnetic environment)
CISPR 11

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

Safety compliance

In line with IEC 61010 -1, AS61010 -1, UL61010 -1, CAN/CSA-C22.2 No. 61010 -1

Physical characteristics

Dimensions	Width: 440 mm (17.32 in.) Depth: 371 mm (14.61 in.) Height: 87 mm (3.43 in.)
Weight	Moku:Delta 11.2 kg (24.69 lb) External power supply 1.2 kg (2.645 lb) Total package 15.6 kg (34.30 lb)

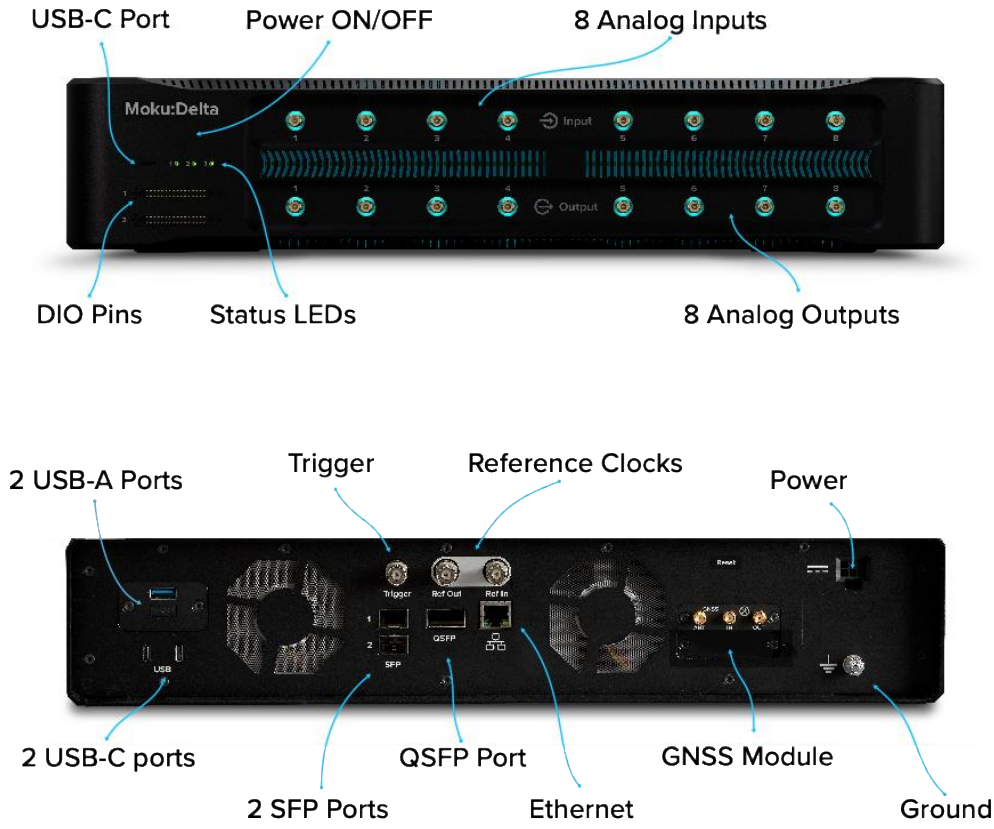
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General connectivity

Connectivity

Analog inputs	8 x SMA; tighten with 0.45 Nm torque wrench
Analog outputs	8 x SMA; tighten with 0.45 Nm torque wrench
Digital I/O	2 banks of 16 digital I/O pins, LVDS
Network	Ethernet (10/100/1000 Base-T) ** Optional, removeable Wi-Fi 802.11 b/g/n module
USB data port	Type-C (front) & Type-A (rear) // for connecting to the Moku:Delta
External trigger input	BNC, 1 MΩ DC coupled, fixed 1 V threshold
10 / 100 MHz clock reference input	BNC
10 / 100 MHz clock reference output	BNC
GNSS module	3 x SMA (1 PPS in, 1 PPS out, antenna); hand tighten only

** Use shielded ethernet cable



Moku Delta front and rear connectors

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Accessories
Rack mount brackets
Digital I/O adaptor (x2)
USB WiFi adapter
GPS patch antenna

Warnings and cautions

Item	Warning/caution
Front panel digital I/O module	Take care when fastening the DIO retaining screws. Ensure the DIO module is square to the Moku:Delta and the fastening screws are well located. Do not apply undue force to the screws to avoid cross threading
Front panel SMA connectors	The front panel SMA connectors are small and delicate. To avoid damage to the SMA connectors, do not connect rigid or protruding components (e.g. filters, attenuators). Only connect flexible SMA cables, tighten with SMA torque wrench to 0.45 Nm
Front panel SMA connectors	SMA connectors are precision components, and repeated plug/unplug cycles gradually wear the threads and center contacts, even with correct torque applied. We recommend adding adapters to act as sacrificial interfaces, protecting the connectors on Moku:Delta.
Front panel SMA connectors	We recommend keeping the SMA connectors clean and capped when not in use to prevent dust or debris from entering the connector.

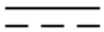
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Safety information

Safety

Manufacturer	Liquid Instruments Pty Ltd, 243 Northbourne Avenue, Suite 1, Level 1, Lyneham, ACT 2602, Australia
Cleaning	Clean loose dust on exterior with lint-free, dry cloth.
Impairment	If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.
Power cable	Do not use a mains power supply or cable, other than the one provided by the manufacturer. Please contact the manufacturer/representative office if a replacement mains power supply or cable is needed.
Lifting and carrying	The product is heavy. Use the product handles to move or carry the product. Do not lift by the accessories mounted on the product. Accessories are not designed to carry the weight of the product. To move the product safely, consider a 2 person lift and/or use of an equipment cart.

Symbols

	Caution: Consult accompanying documents
	Warning: Risk of electric shock
	Direct Current
	Functional earth
	Ethernet
	Do not torque
	Input
	Output

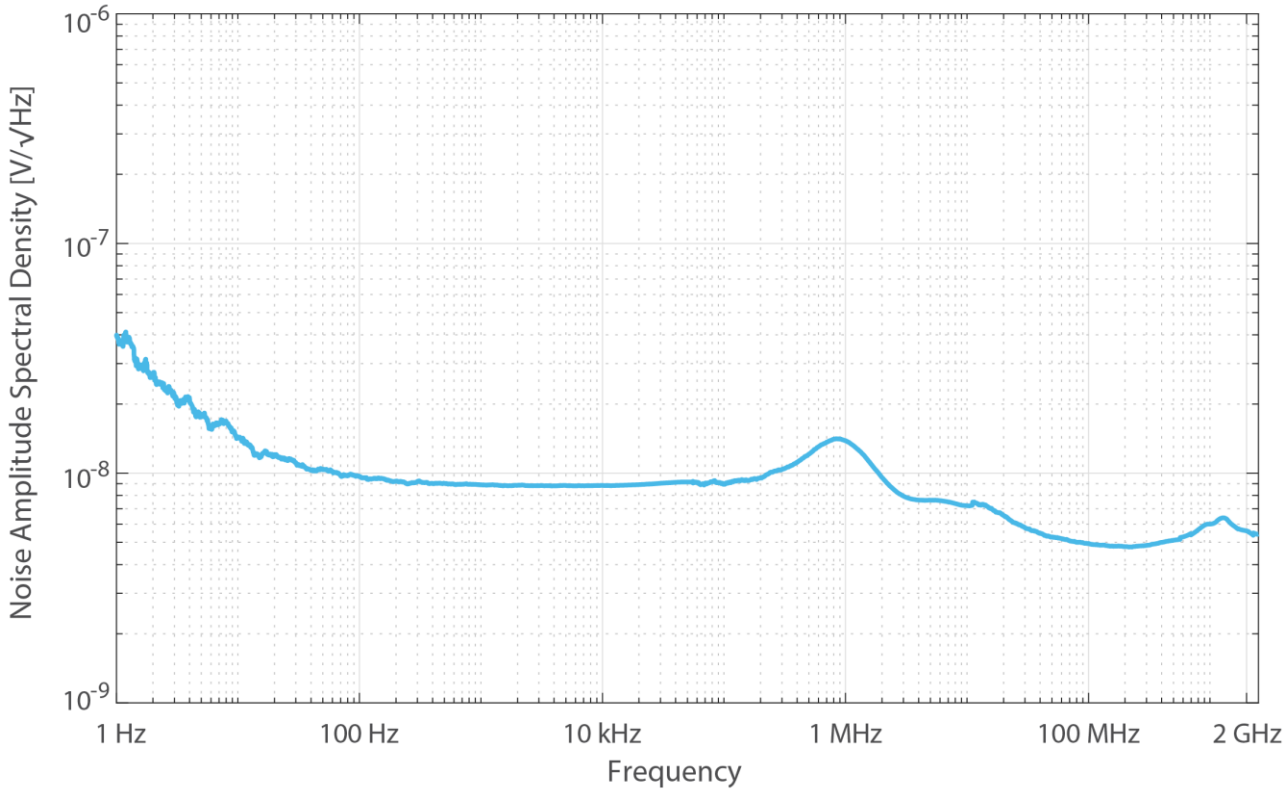
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Hardware measurements

ADC input noise

50 Ω // DC coupled // 0 dB attenuation

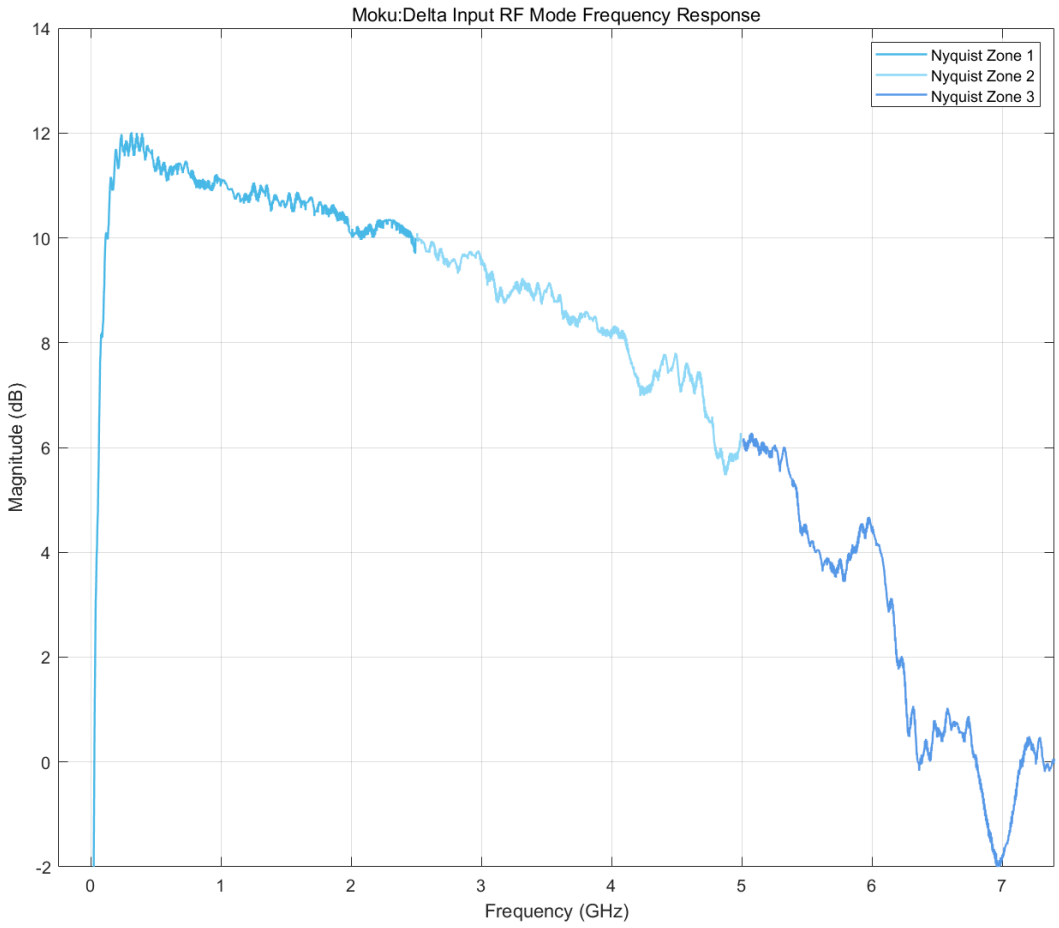
Acquisition mode: Precision



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6 GHz analog input path

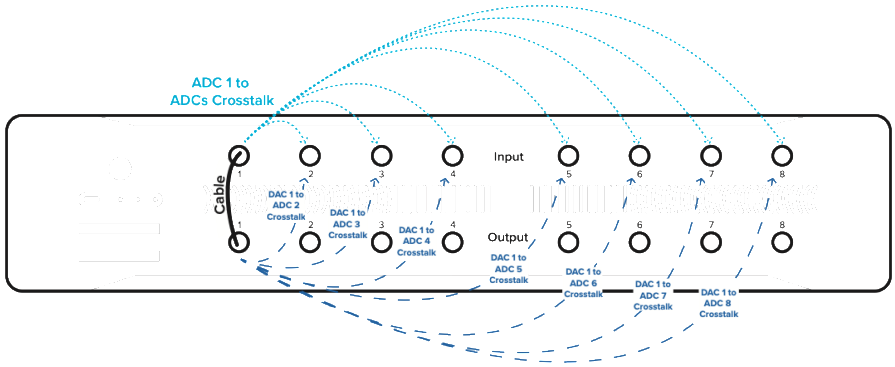
Moku:Delta allows the low-pass input filter to be disabled to permit observation of frequencies above the Nyquist frequency of 2.5 GHz.

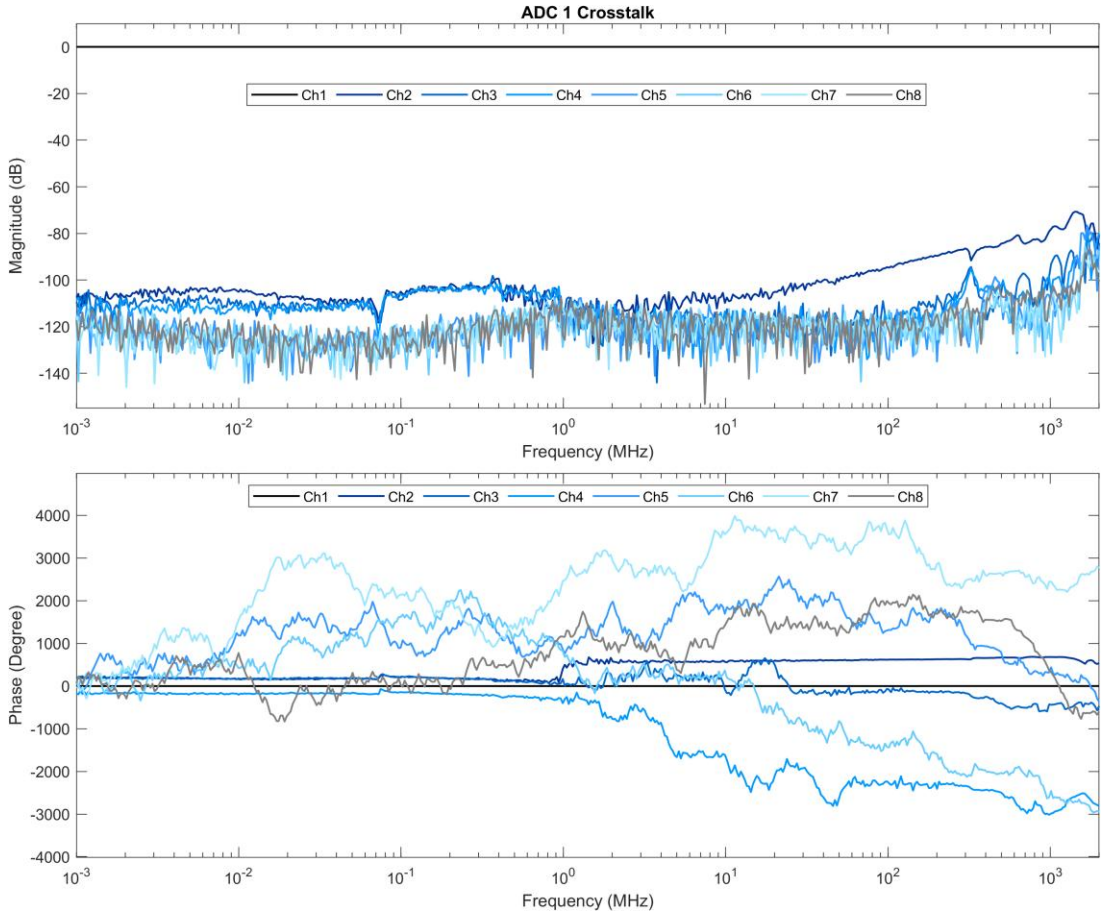


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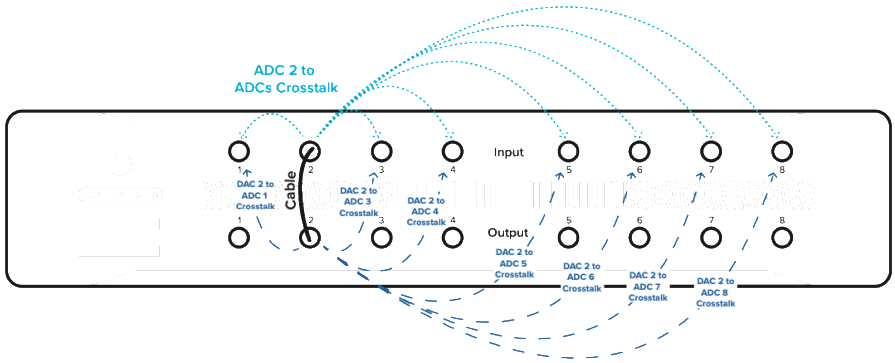
Compound crosstalk (ADC-ADC & DAC-ADC)

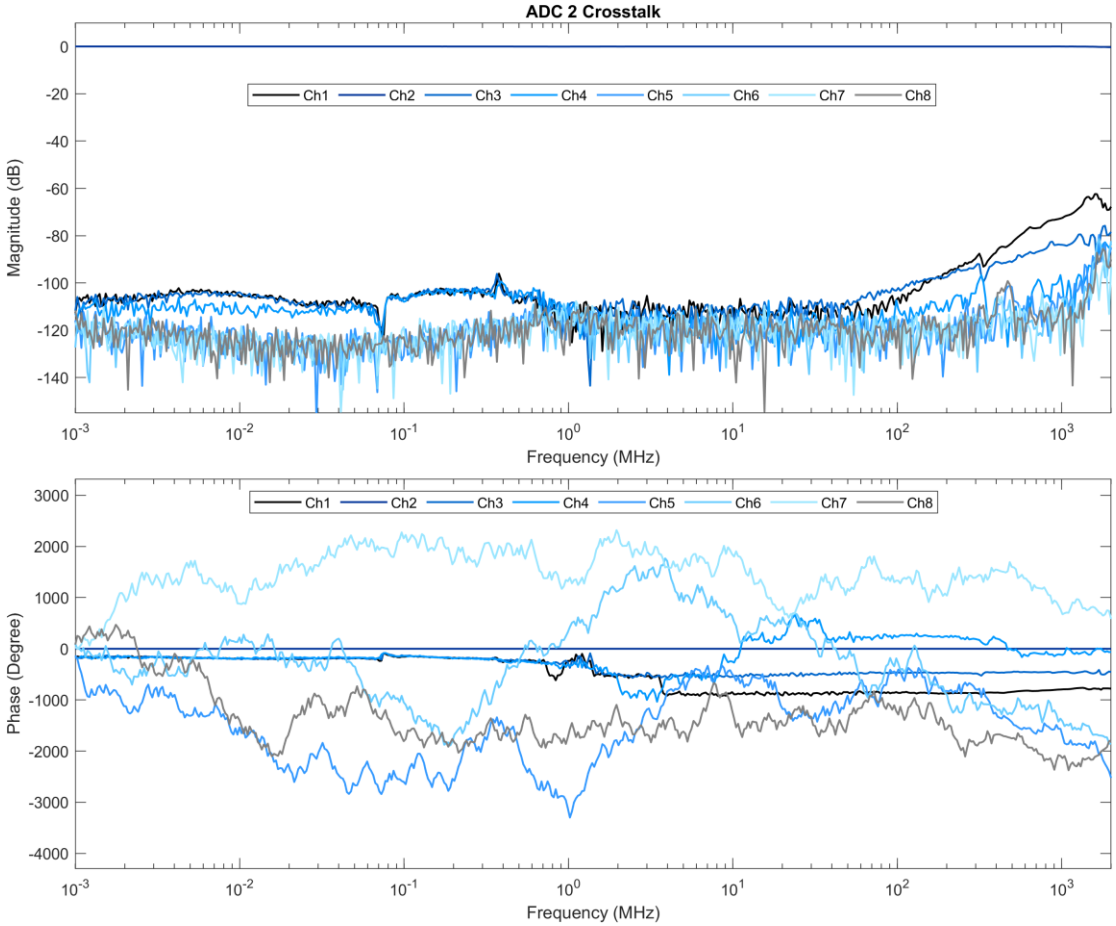
50 Ω // AC coupled // 0 dB attenuation



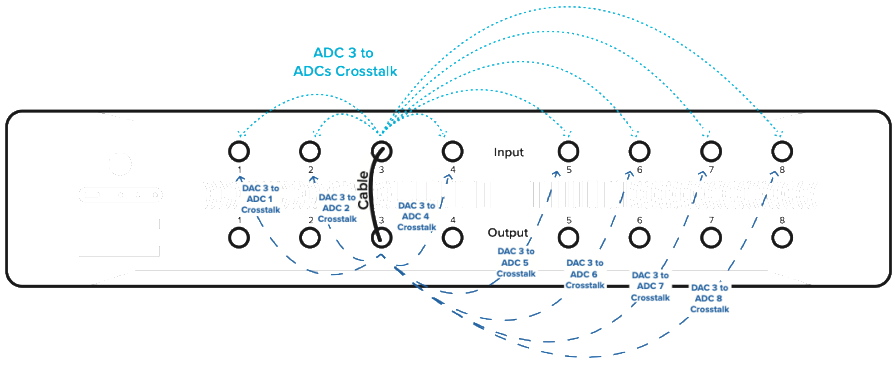


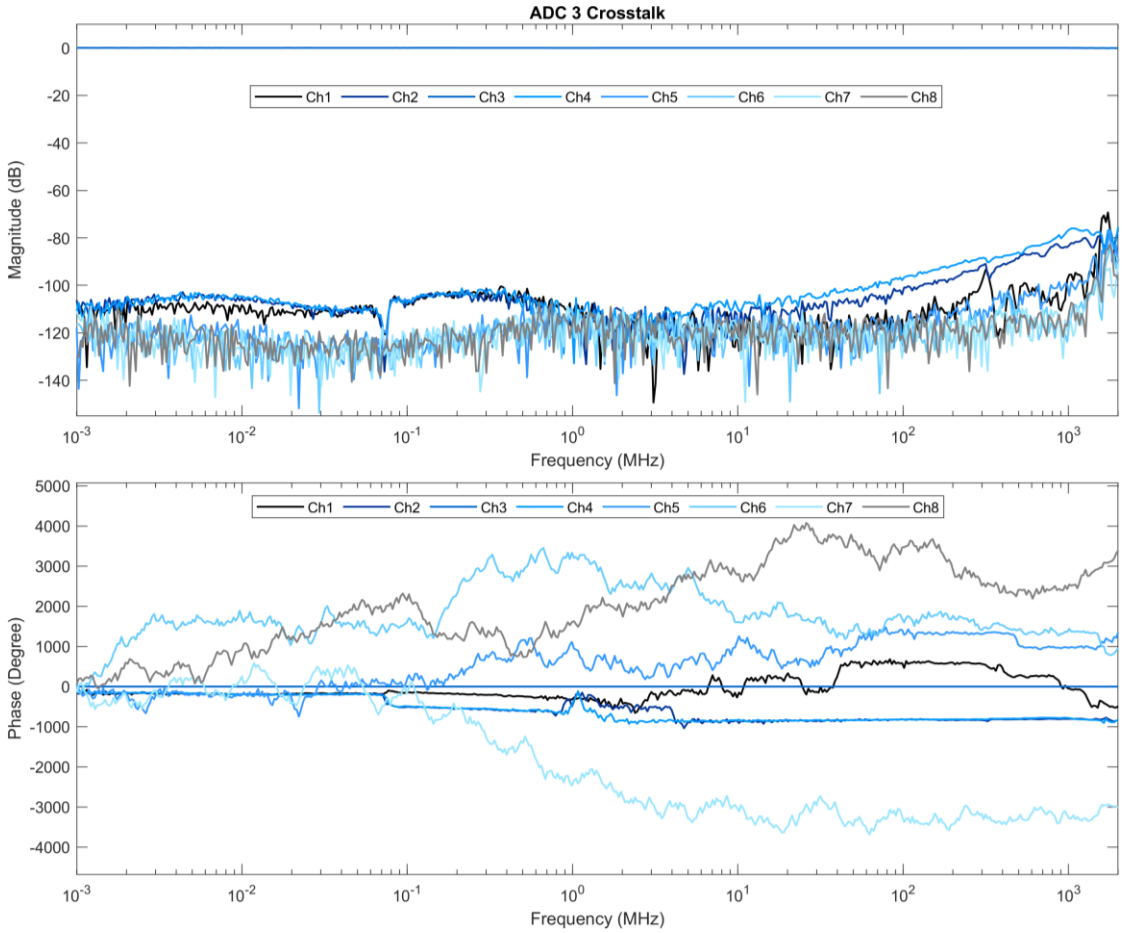
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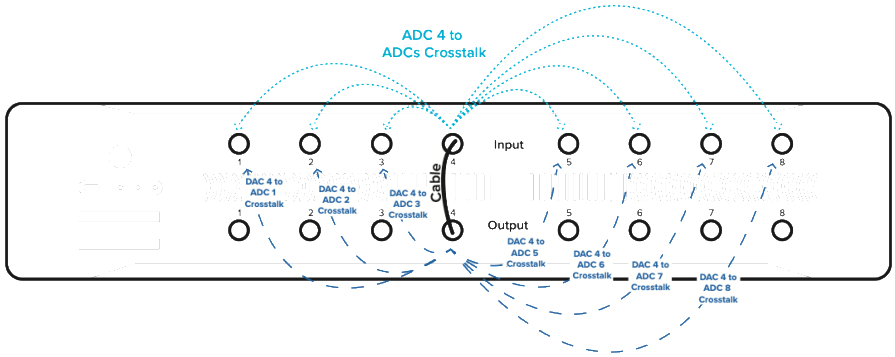


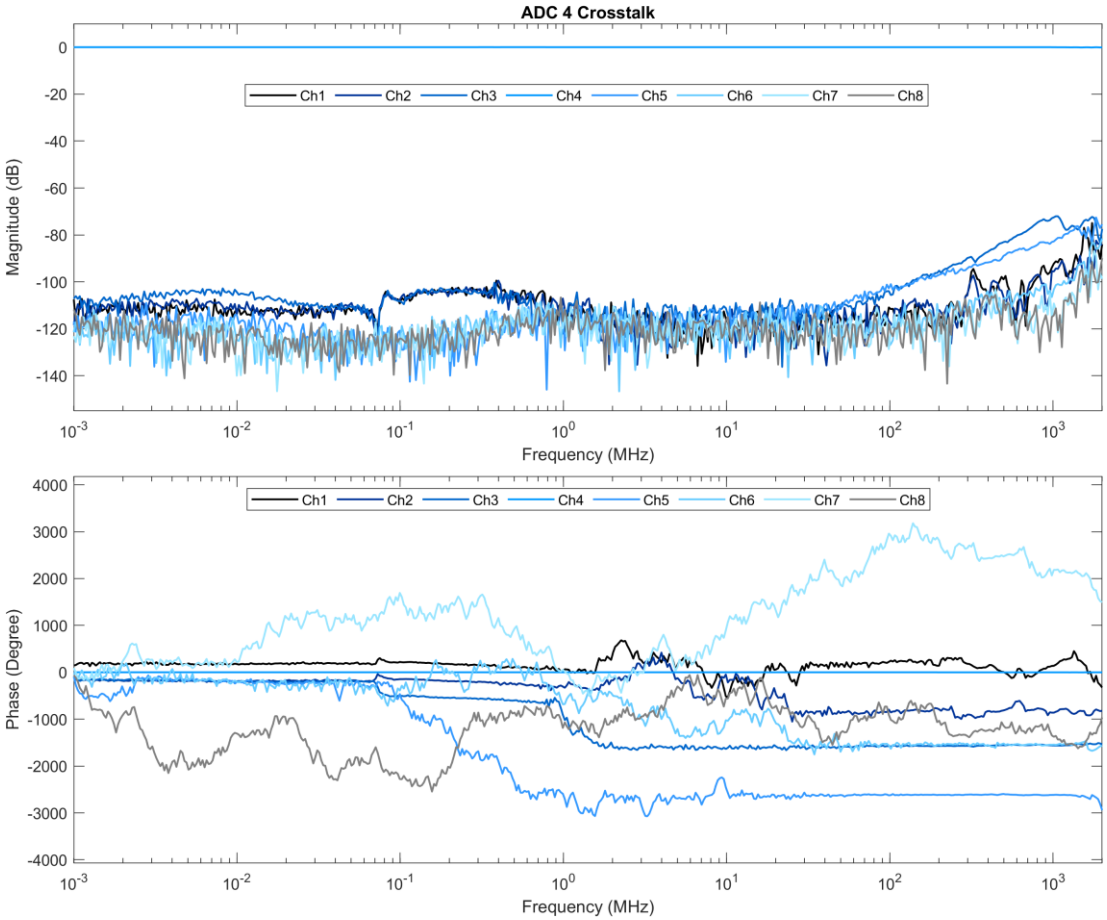
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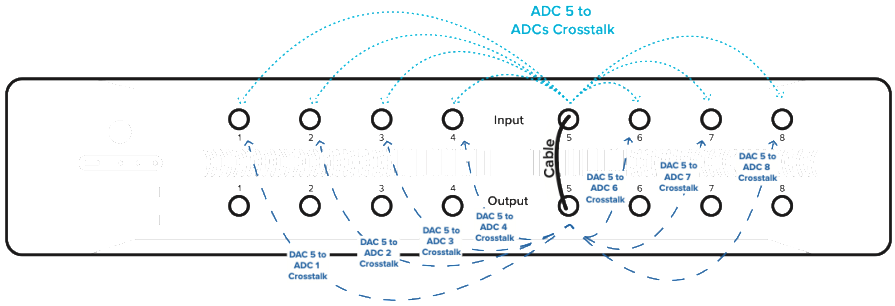


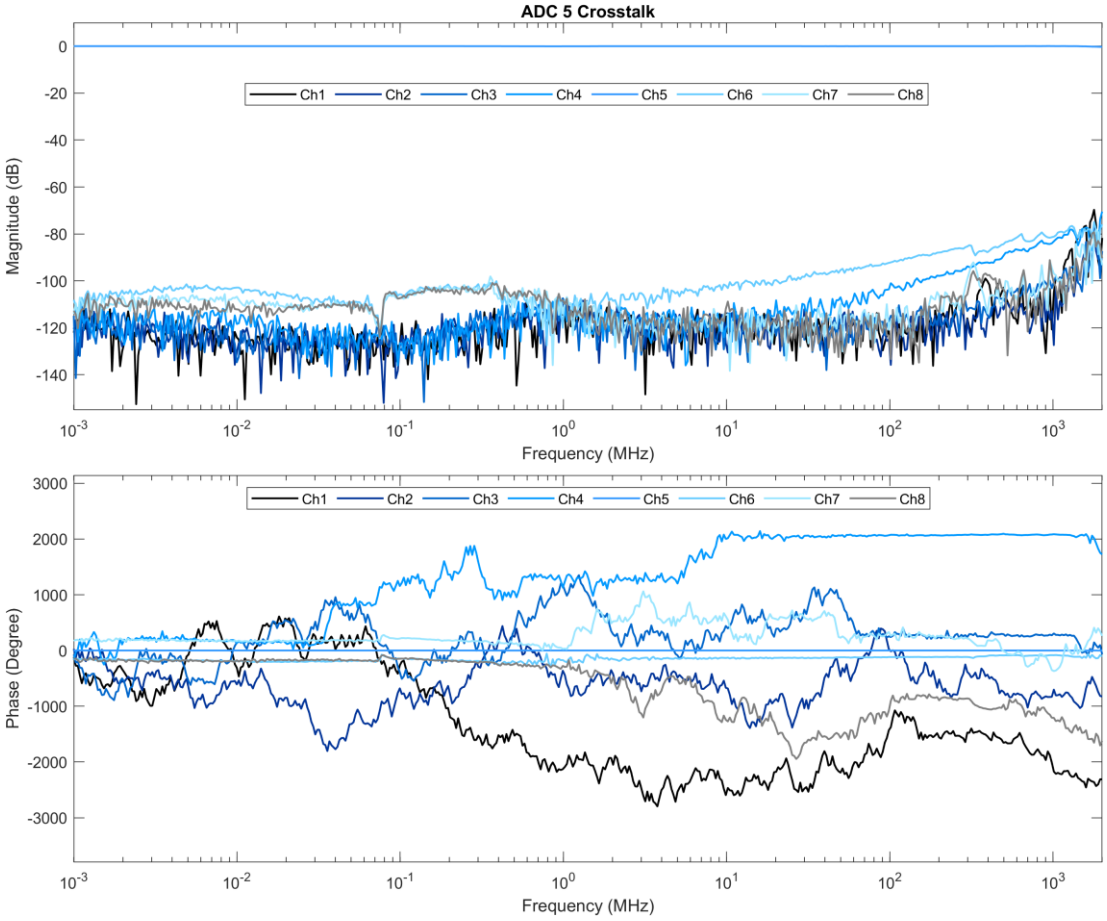
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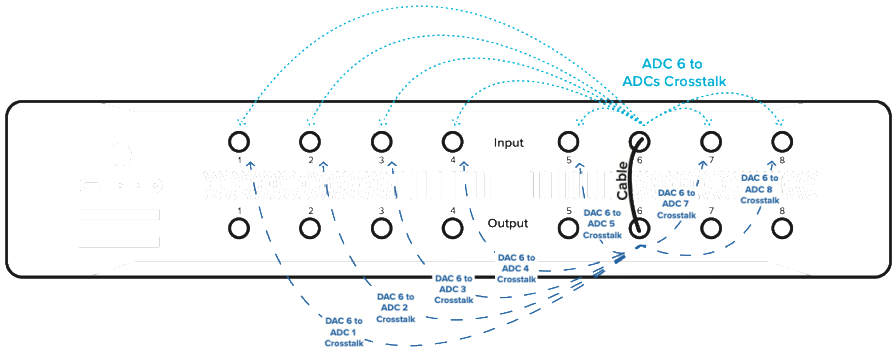


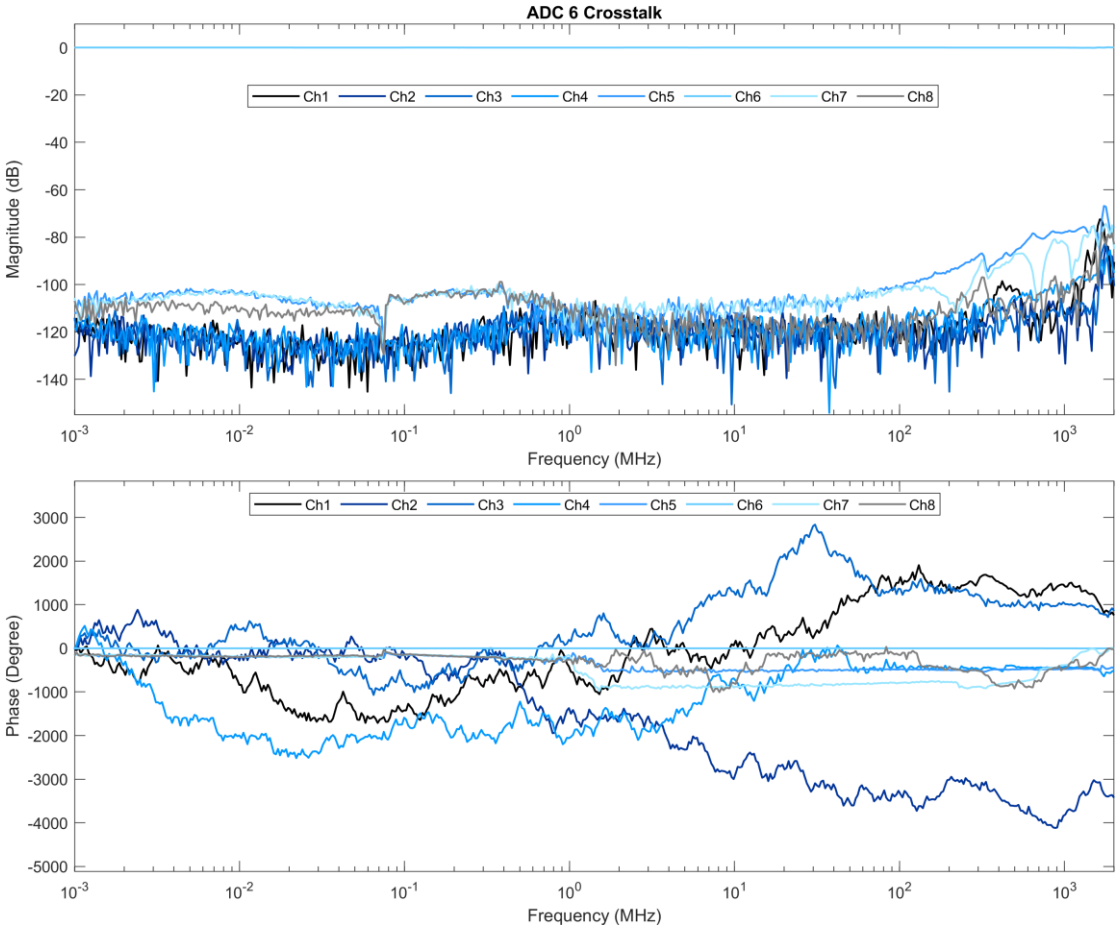
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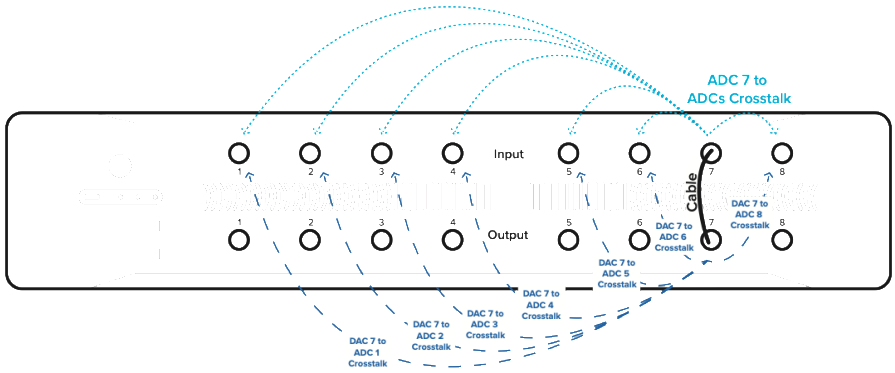


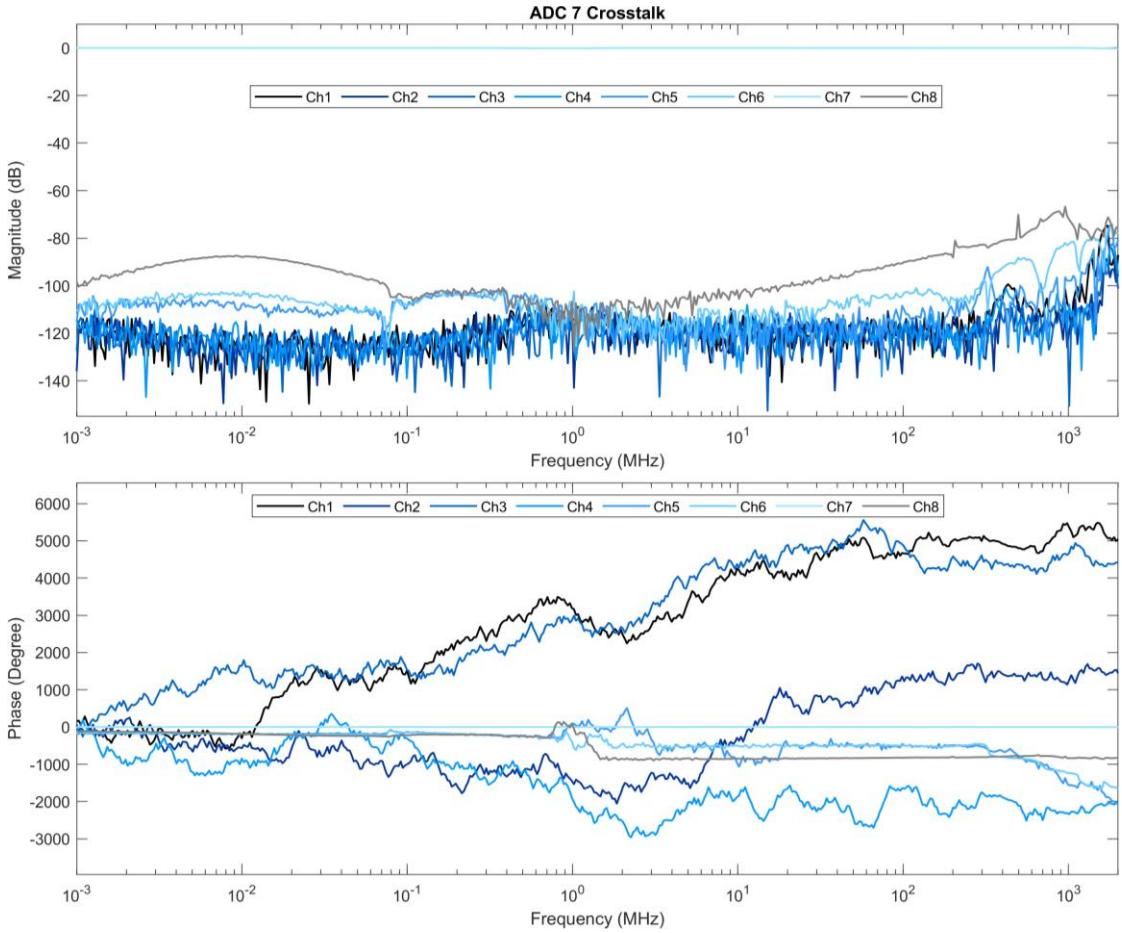
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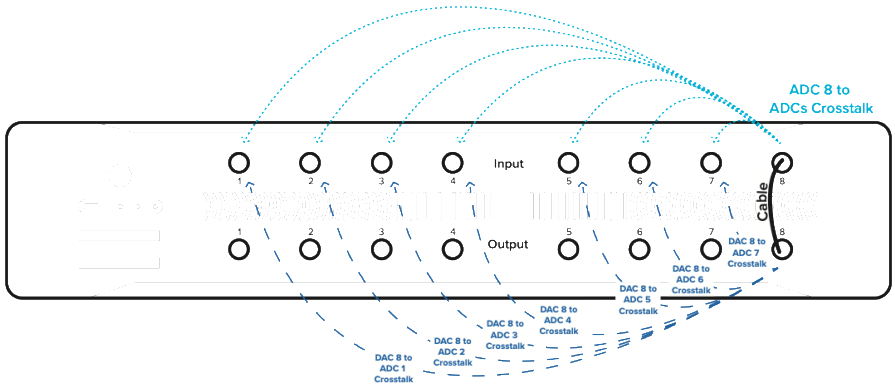


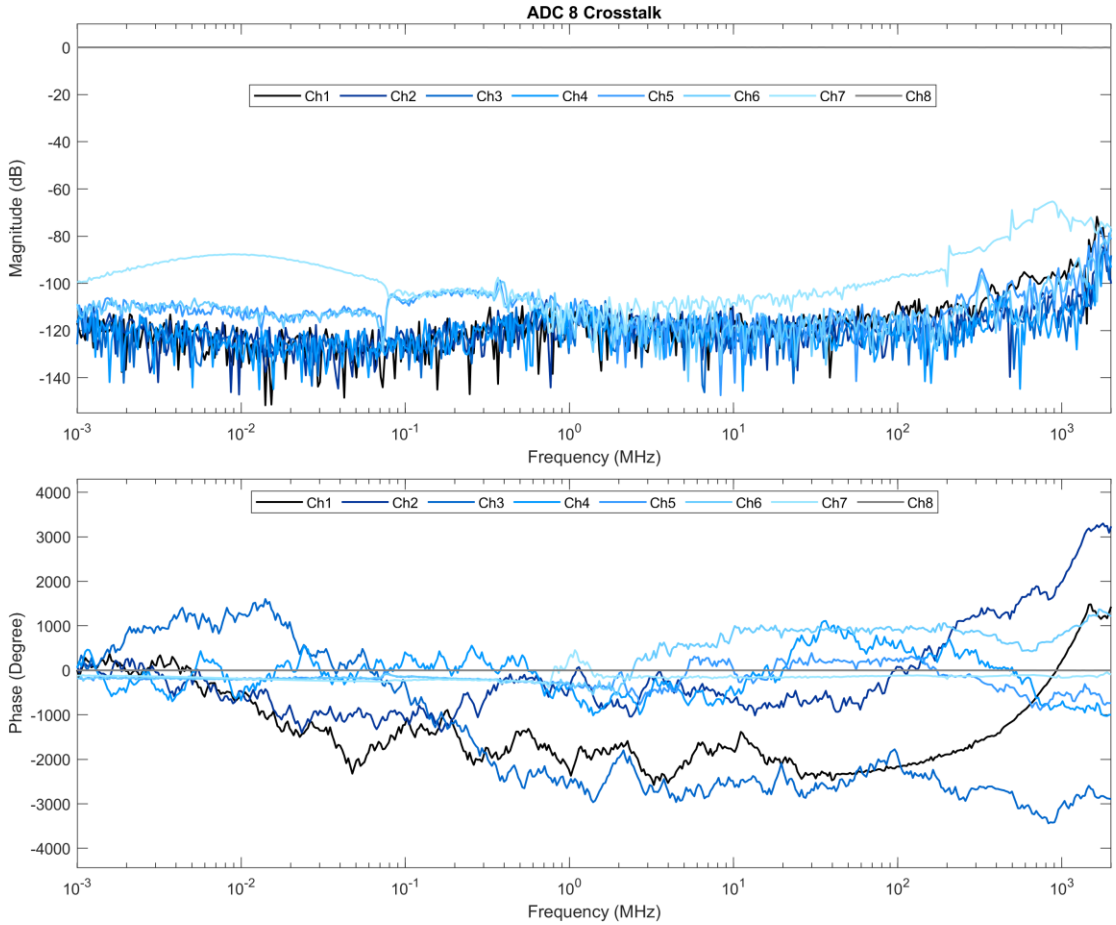
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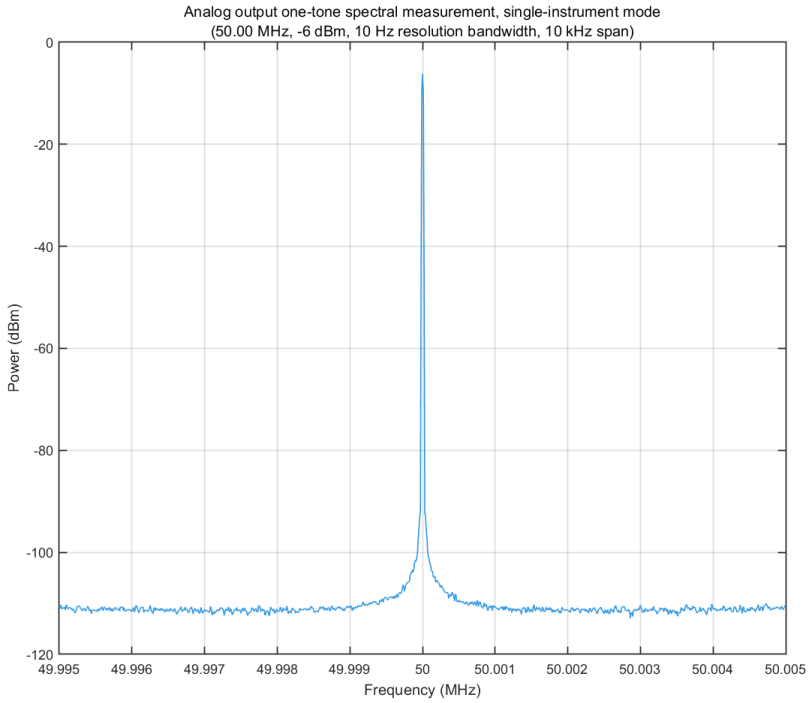




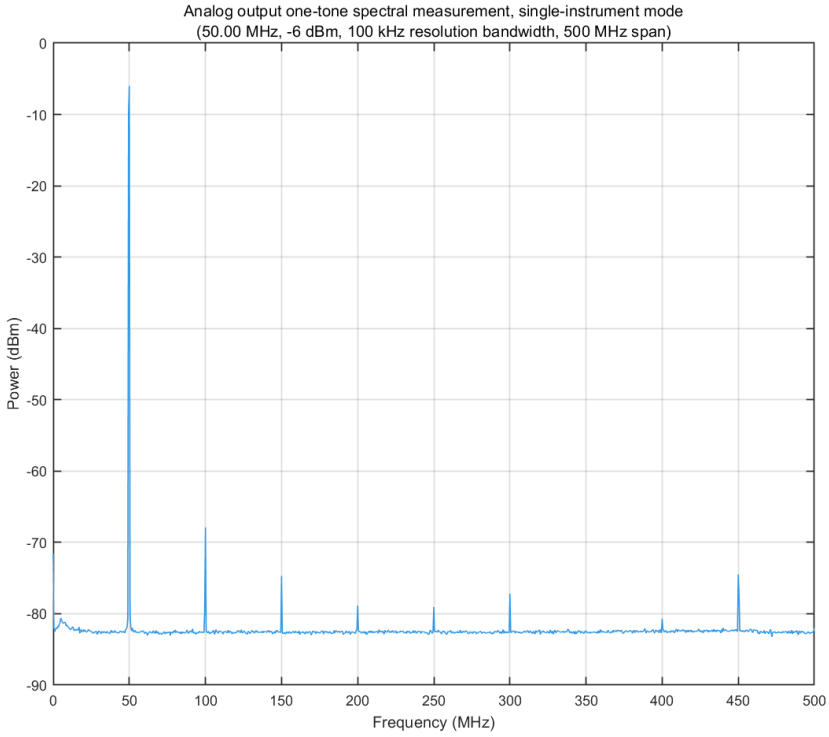
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Analog output noise

One-tone spectral measurement 50 MHz, -6 dBm (10 Hz RBW, 10 kHz span)

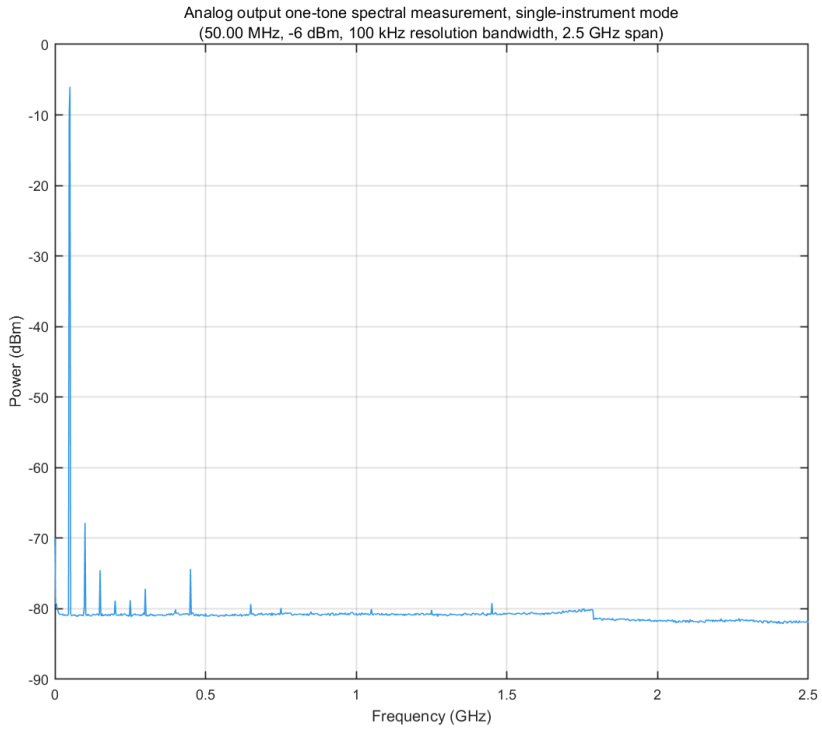


One-tone spectral measurement 50 MHz, -6 dBm (100 kHz RBW, 500 MHz span)



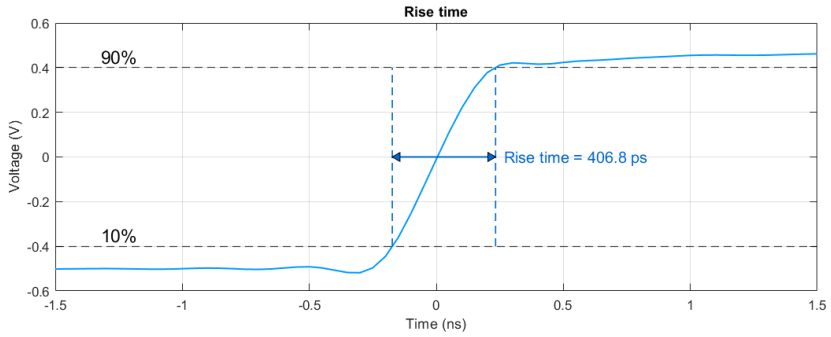
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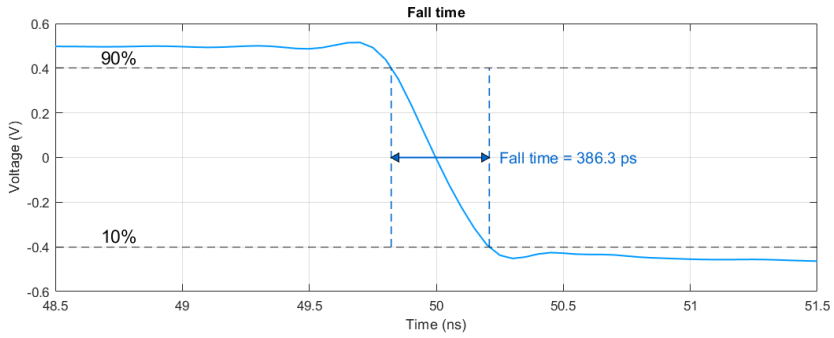
One-tone spectral measurement 50 MHz, -6 dBm (100 kHz RBW, 2.5 GHz span)



Analog output step response

Rise time (10 % to 90 %) and fall time (90 % to 10 %) of 1 Vpp output step, 10,000 averages.

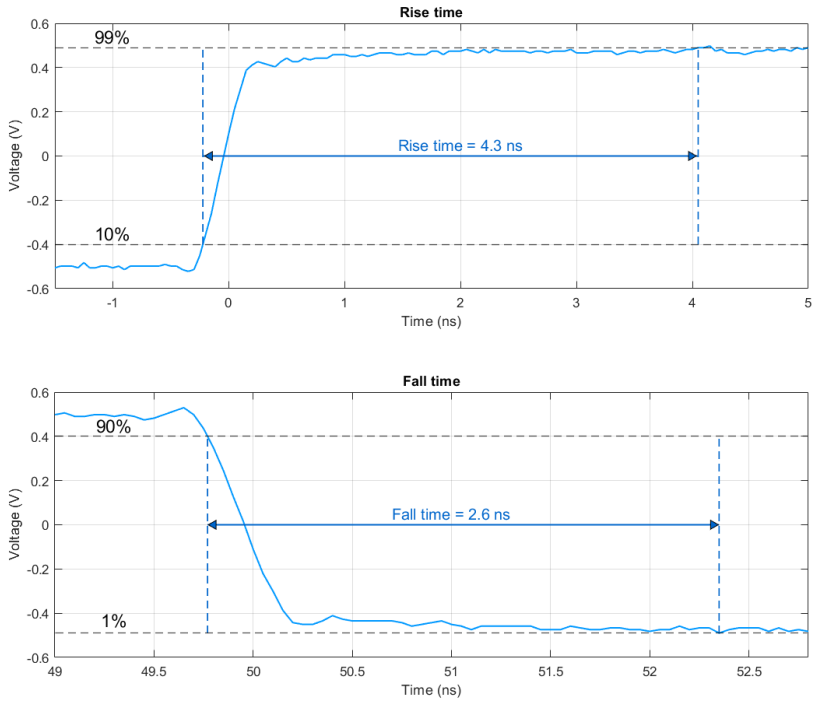




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Analog output settling time

Settling time, 1 Vpp step, to within 1 % of final level



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Moku:Delta Arbitrary Waveform Generator

Description

Moku:Delta Arbitrary Waveform Generator can generate eight custom waveforms with up to 65,536 points each and sample rates ranging from 312.5 MSa/s to 5 GSa/s. Waveforms can be loaded from a file or input as a piece-wise mathematical function with up to 32 segments, enabling you to generate truly arbitrary waveforms. In burst mode, waveform generation can be triggered from input channels with start or N-cycle modes. In pulsed mode, waveforms can be output with more than 262,144 cycles of dead time between pulses.



Features

- Eight independent AWG channels with up to 2 GHz bandwidth
- Choose between preset waveforms, load points from a file, or input an equation directly
- Phase synchronization output between the eight channels
- Configure pulsed output with up to 262,144 cycles of dead time between pulses

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Specifications

Common

Overview

Channels	8
Sampling rate	312.5 MSa/s, 625 MSa/s, 1.25 GSa/s, 2.5 GSa/s, 5 GSa/s
Source impedance	50 Ω
Output load	50 Ω / 1 MΩ
Waveforms	Sine, Gaussian, Exponential Fall, Exponential Rise, Sinc, Equation, Cardiac, Custom (from file)

Amplitude

Output voltage range	1 Vpp at 5 GSa/s, 2.5 GSa/s, 1.25 GSa/s and 625 MSa/s 10 Vpp at 312.5 MSa/s; <= 100 MHz
Resolution	100 µV

DC offset

Range (peak AC + DC)	± 5 V into 50 Ω ± 10 V into high impedance
Resolution	100 µV

Phase offset

Range	0° to 360°
Resolution	0.000 001°

Waveform

Custom

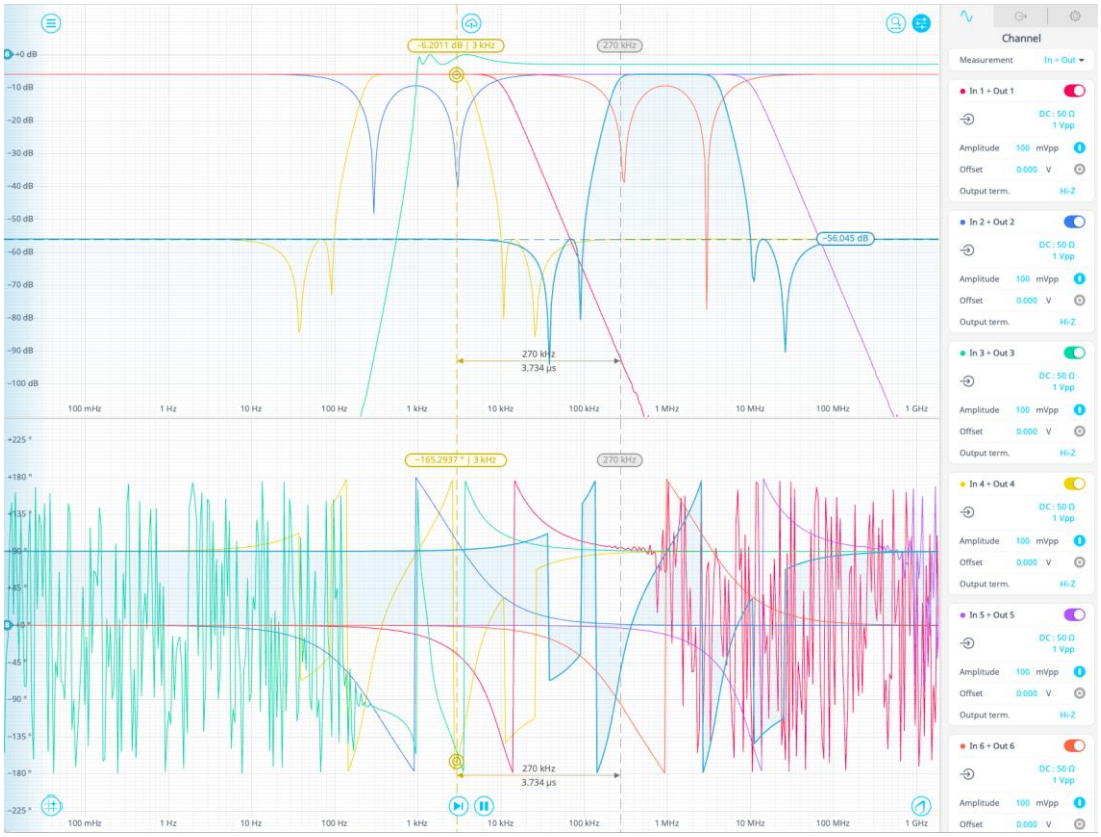
Maximum output rate	312.5 MSa/s	65,536 points
	625 MSa/s	32,768 points
	1.25 GSa/s	16,384 points
	2.5 GSa/s	8,192 points
	5 GSa/s	4,096 points
Text file type	Comma- or newline-delimited text	
File import options	Clipboard, My Files, Desktop file	
Interpolation	None, Linear	
Minimum edge time	TBD	
Overshoot	TBD	
Period range	1 ns to 1 ks	

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Moku:Delta Frequency Response Analyzer

Description

Moku:Delta Frequency Response Analyzer enables you to measure the frequency response of a system in both magnitude and phase using a swept sine output ranging from 10 mHz to 2 GHz with a noise floor as low as -135 dBm. Moku:Delta is equipped with eight inputs and eight outputs, enabling differential or ratio metric measurements. Select up to 8192 points per sweep and configure settling and averaging times to balance total sweep duration and signal-to-noise ratio.



Features

- Linear or logarithmic swept sine output
- Math channel to add, subtract, multiply, or divide response functions as they are acquired, or calculate arbitrary complex-valued equations
- Saturation detection and dynamic output amplitude control optimizes response detail
- Demodulate inputs up to the 15th harmonic

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Specifications

Source

Source

Waveform	Sine
Frequency range	10 mHz to 2 GHz
Sweep type	Linear / Logarithmic
Sweep points	32, 64, 128, 256, 512, 1024, 2048, 4096, 8192
Output amplitude range	±0.5 mV to ±5 V into 50 Ω up to 100 MHz +/-0.5mV to +/- 500 mV into 50 Ω from >100 MHz to 2 GHz
Source impedance	50 Ω

Input

Input characteristics

Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC
Input attenuation	0 dB / 20 dB / 40 dB
Input voltage range	100 mV_{PP} into 50 Ω with 0 dB attenuation 1 V_{PP} into 50 Ω with 20 dB attenuation 10 V_{PP} into 50 Ω with 40 dB attenuation 40 Vpp into 1 M Ω
Input noise	10 nV/√Hz @ 100 Hz
Crosstalk	TBD
Noise floor	< 100 kHz: < -100 dBm 100 kHz – 500 MHz: < -120 dBm

Measurement

Measurement characteristics

Measurement mode	In/Out (dB), In/In1 (dB) or In (dBm, dBVpp, dBVrms)	
Settling time	Min.	Greater of 1 µs or 1 cycle
	Max.	10.0 seconds
Averaging time	Min.	Greater of 1 µs or 1 cycle
	Max.	10.0 seconds
Normalization	Normalizes magnitude and phase using a reference sweep[2]	
Delay compensation	Automatic or manual; removes phase shifts causes by a constant time delay	
Absolute gain error	<0.05 dB	

[2] The normalization feature can be used to isolate the magnitude and phase response of the system under test by compensating for deviations in magnitude and phase caused by delays (e.g., caused by cables) and the frequency response of the Moku:Delta's analog front end. As an alternative the In/In1 mode may also be used, removing the need to take a normalization sweep.

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Measurement characteristics	
Absolute phase error	< 0.5°

Saving data

Saving data	
File formats	Plain text: records data using a standard *.csv format
	MATLAB: records data using MathWorks' *.MAT format which can be opened using MATLAB
Export modes	Dropbox, E-mail, My Files (iOS), Desktop, and iCloud

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Moku:Delta Data Logger

Description

Moku:Delta Data Logger stores measurements directly to its 1 TB internal solid-state drive at sampling rates of up to 10 MSa/s. The instrument can log up to eight inputs simultaneously at a maximum rate of 1.25 MSa/s. The eight inputs are equipped with dual 14-bit and 20-bit ADCs. This blended architecture reduces input noise to 10 nV √Hz at 100 Hz, providing ultralow noise data logging from acoustic to RF frequencies. The Data Logger can also make use of the 10/100 MHz reference clock or on-board GNSS adapter for precise timestamping of input data.



Features

- Log voltage data on eight independent channels to its 1 TB SSD
- Built-in eight-channel 2 GHz waveform generator
- 10 / 100 MHz clock synchronization ports
- GPS time stamped data logs
- Easily export data to computer, Dropbox, and other cloud-based services
- Schedule your log to start with a delay of up to 10 days, or configure a trigger event to start

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Specifications

Input

Voltage

Input voltage range	100 mV_{PP} into 50 Ω with 20 gain 1 V_{PP} into 50 Ω with 0 dB attenuation 10 V_{PP} into 50 Ω with 20 dB attenuation 40 V_{PP} into 1 MΩ with 32 dB attention
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC

Logging

Acquisition

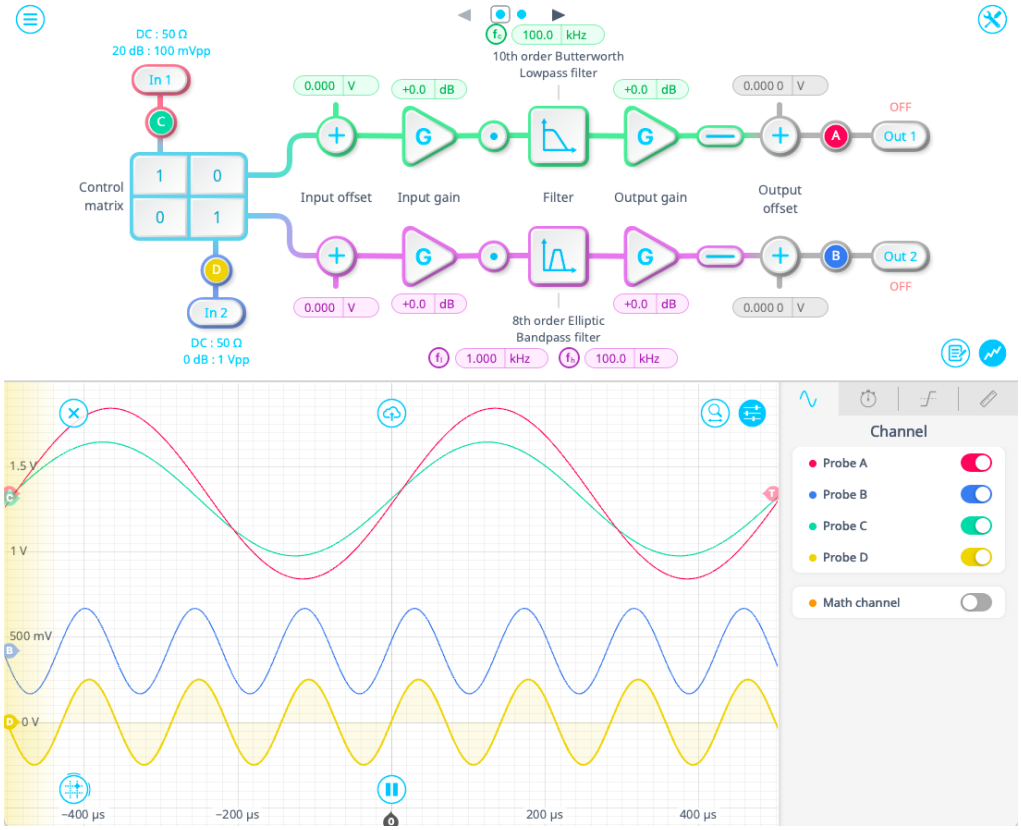
File formats	Binary: Records data using a proprietary LI format for high-speed data logging. Data saved using the LI format may be converted to other formats when downloading from Moku. iPad can convert to .CSV, MATLAB or NumPy. Desktop can convert to .CSV, MATLAB, NumPy or HDF5.
Export modes	Dropbox, E-mail, My Files (iOS 11), Desktop, and iCloud
Maximum sampling rate	10 MSa/s for 1 channel 5 MSa/s for 2 channels 2.5 MSa/s for 4 channels 1.25 MSa/s for 8 channels
Delayed log start time	Up to 240 hours
Log duration	1 second to 10000 hours

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Moku:Delta Digital Filter Box

Description

With Moku:Delta Digital Filter Box, you can interactively design and generate different types of infinite impulse response (IIR) filters with output sampling rates of 305.18 kHz, 4.8828 MHz, or 39.063 MHz. Select between lowpass, highpass, bandpass, and bandstop filter shapes with eight fully configurable types including Butterworth, Chebyshev, and Elliptic.



Features

- Design IIR filters using an interactive Bode plot
- Observe and log signals at different stages in the digital signal processing chain using probe points[3]
- View the frequency response of your filter in both magnitude and phase
- Filter up to four channels of data simultaneously; ability to linearly combine input signals
- Implement custom filters by uploading your own coefficients

[3] See Moku:Delta Data Logger or Moku:Delta Oscilloscope for specifications on integrated instruments

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Specifications

Inputs

Input characteristics

Channels	4
Input control matrix coefficients	-20 to +20
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC
Input gain	20 dB / 0 dB / -20 dB / -32 dB
Input voltage range	100 mV_{pp} into 50 Ω with 20 dB gain 1 V_{pp} into 50 Ω with 0 dB attenuation 10 Vpp into 50 Ω with 20 dB attenuation 40 V_{pp} into 1 MΩ with 32 dB attenuation

Filter characteristics

Pre-filter

Input offset range	± 500 mV
Input offset resolution	1 mV
Input gain range	-40 dB to +40 dB
Input gain resolution	0.1 dB

Post-filter

Output offset range	± 500 mV
Output offset resolution	100 uV
Output gain range	-40 dB to +40 dB
Output gain resolution	0.1 dB

General filter characteristics

Filter shapes	Lowpass, Highpass, Bandpass, Bandstop, Custom
Sampling rates	305.18 kHz, 4.8828 MHz, 39.063 MHz
Filter types	Butterworth, Chebyshev I, Chebyshev II, Elliptic, Cascaded, Bessel, Gaussian, Legendre
Passband ripple	0.1 dB to 10 dB (Chebyshev I and Elliptic)
Stopband attenuation	10 dB to 100 dB (Chebyshev II and Elliptic)
Zoom view	Allows you to zoom in on the filter's frequency response (iPad only)

Lowpass filter

Filter order	2, 4, 6, 8, 10, 12, 14, 16

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Lowpass filter

Lowpass corner frequency	58.63 mHz to 137.3 kHz at 305.18kHz sampling rate 7.505 Hz to 17.58 MHz at 39.063 MHz sampling rate

Highpass filter

Filter order	2, 4, 6, 8, 10, 12, 14, 16
High-pass corner frequency	723.7 mHz to 137.3 kHz at 305.18 kHz sampling rate 92.63 Hz to 17.58 MHz at 39.063 MHz sampling rate

Bandpass / bandstop filter

Filter order	2, 4, 6, 8
Low-corner frequency	3.052 Hz to 137.3 kHz at 305.18 kHz sampling rate 390.6 Hz to 17.58 MHz at 39.063 MHz sampling rate
High-corner frequency	3.443 Hz to 137.3 kHz at 305.18 kHz sampling rate 440.6 Hz to 17.58 MHz at 39.063 MHz sampling rate
Minimum bandwidth	390 mHz at 305.18 kHz sampling rate 50 Hz at 39.063 MHz sampling rate

Selecting the right IIR filter

Filter type

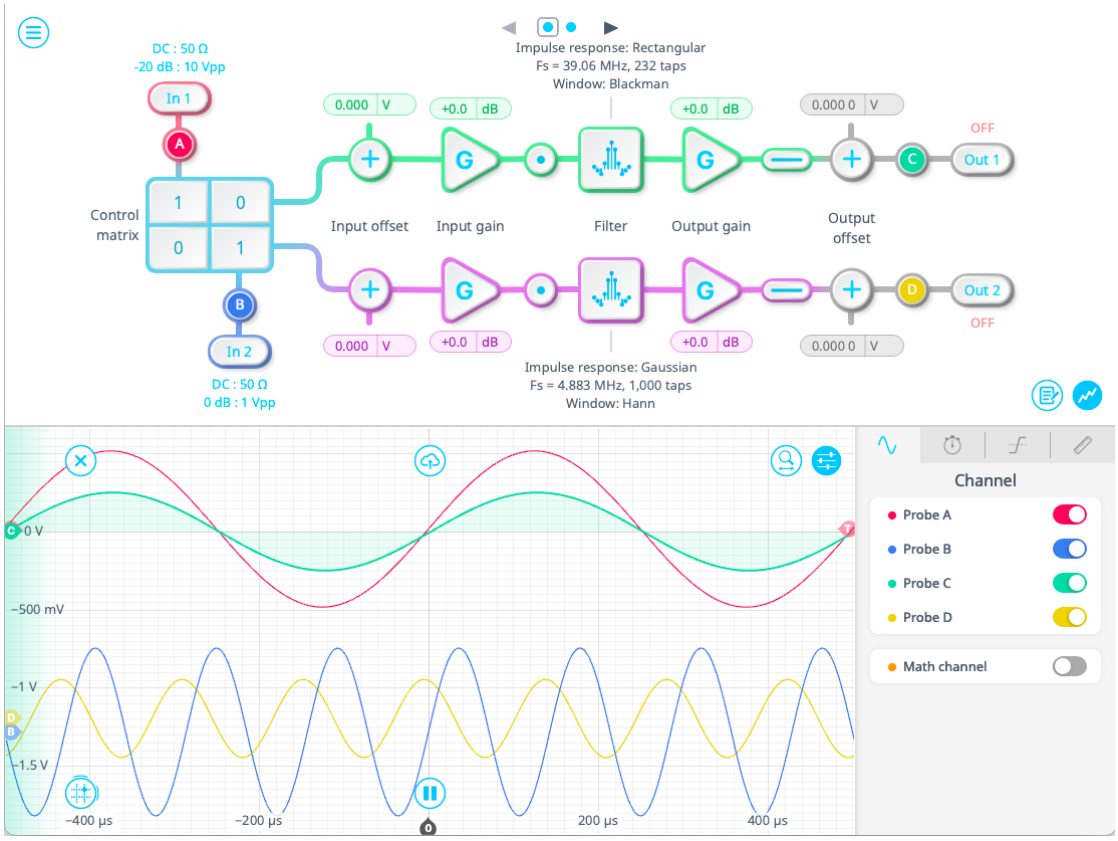
Butterworth	Butterworth filters have a maximally flat passband and a monotonic frequency response, making them a good all-around filter type suitable for most applications.
Chebyshev I	Chebyshev I filters have ripple in the passband but a sharper transition than Butterworth filters, making them useful for applications requiring aggressive stopband attenuation but can tolerate passband ripple between 0.1 dB and 10 dB.
Chebyshev II	Chebyshev II filters have ripple in the stopband but a sharper transition than Butterworth filters, making them useful in applications requiring flat passbands and aggressive stopband attenuation.
Elliptic	Elliptic (Cauer) filters have ripple in both the passband and stopband, but also have the sharpest possible transition. Elliptic filters are useful in applications requiring extremely aggressive stopband attenuation.
Cascaded	Cascaded first-order filters have zero overshoot in the time domain.
Bessel	Bessel filters have maximally flat group and phase delay in the passband, thus preserving the wave shape of passband signals.
Gaussian	Gaussian filters have the minimum possible group delay, a step response with no overshoot, and minimum rise and fall time.
Legendre	Legendre (Optimum L) filters have the sharpest possible transition while maintaining a monotonic frequency response.

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Moku:Delta FIR Filter Builder

Description

With the Moku:Delta FIR Filter Builder, you can design and implement lowpass, highpass, bandpass, and bandstop finite impulse response (FIR) filters with up to 14,819 coefficients and sample rate up to 39.06 MHz. Select between four frequency response shapes, four common impulse responses, and seven window functions. You can also define the impulse response by an equation or setting custom coefficients.



Features

- Design filters in the time or frequency domain using common impulse responses and window functions
- Upload your own filter coefficients, or define a custom impulse response in the equation editor
- View your filter's complex transfer function, impulse and step response, or group and phase delay
- Filter up to four channels of data simultaneously with the ability to linearly combine input signals
- Observe and log signals at different stages in the digital signal processing chain using probes[4]

[4] See Moku:Delta Data Logger or Moku:Delta Oscilloscope for specifications on integrated instruments

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Specifications

Inputs

Input characteristics

Channels	4
Input control matrix coefficients	-20 to +20
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC
Input gain	20 dB / 0 dB / -20 dB / -32 dB
Input voltage range	100 mV_{pp} into 50 Ω with 20 dB gain 1 V_{pp} into 50 Ω with 0 dB attenuation 10 Vpp into 50 Ω with 20 dB attenuation 40 V_{pp} into 1 MΩ with 32 dB attenuation

Filter characteristics

Pre-filter

Input offset range	± 500 mV
Input offset resolution	1 mV
Input gain range	-40 dB to +40 dB
Input gain resolution	0.1 dB

Post-filter

Output offset range	± 500 mV
Output offset resolution	100 uV
Output gain range	-40 dB to +40 dB
Output gain resolution	0.1 dB

General filter characteristics

Sampling rates	305.18 kHz, 610.4 kHz, 1.221 MHz, 2.441 MHz, 4.883 MHz, 9.766 MHz, 19.53 MHz, 39.06 MHz
Number of coefficients	2 to 14819 @ 305.18 kHz 2 to 14819 @ 610.4 kHz 2 to 7424 @ 1.221 MHz 2 to 3712 @ 2.441 MHz 2 to 1856 @ 4.883 MHz 2 to 928 @ 9.766 MHz 2 to 464 @ 19.53 MHz 2 to 232 @ 39.06 MHz
Design domains	Time (impulse) Frequency (frequency))

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General filter characteristics

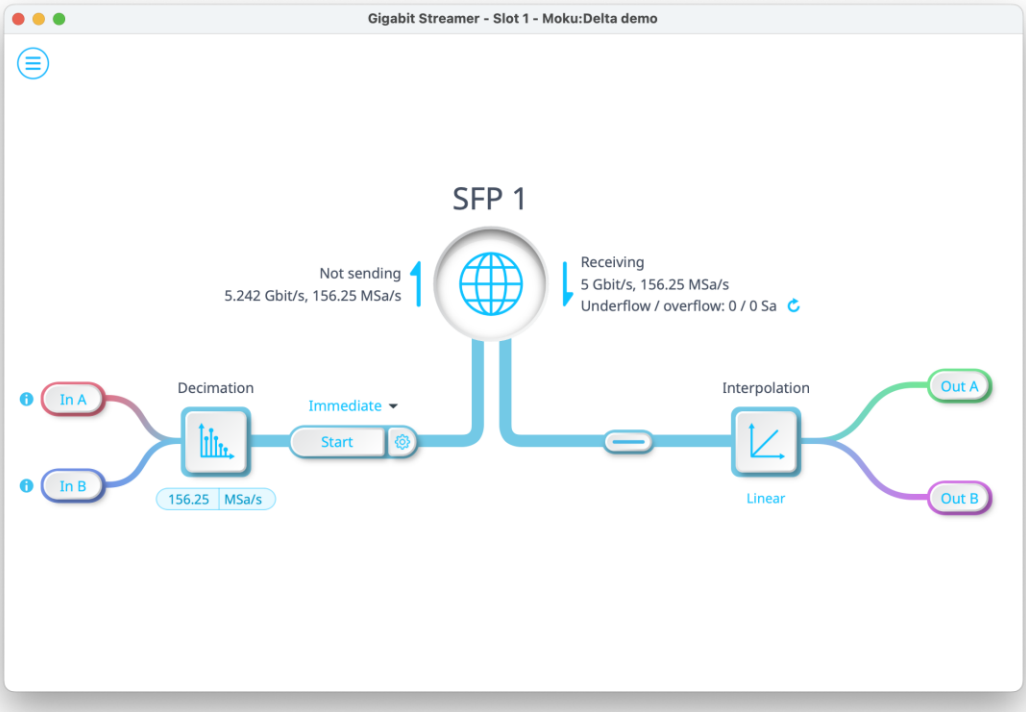
Display options	Magnitude / Phase Impulse / Step Response Group / Phase Delay
Frequency response	Lowpass, highpass, bandpass, bandstop
Impulse response	Rectangular, Sinc, Triangular, Gaussian, Equation, Custom
Window	None, Bartlett, Hann, Hamming, Blackman, Nuttall, Tukey, Kaiser
Minimum filter cut-off frequency	Sampling rate / 10,000 e.g. 30.52 Hz at sample rate of 305.2 kHz
Maximum filter cut-off frequency	Sampling rate / 2 (approximately) e.g. 149.5 kHz at sampling rate of 305.2 kHz

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Moku:Delta Gigabit Streamer

Description

With Moku Gigabit Streamer provides a fast, flexible way to transfer high-rate sample data between a Moku device and external systems. It supports dual-channel streaming at up to a 5 Gbit/s line rate, large MTU sizes, and deterministic UDP transport for reliable, low-latency performance. With both transmit and receive modes, it enables real-time capture, waveform playback, sensor signal emulation, and hardware-in-the-loop applications.



Features

- Stream high speed data to (transmit) and from (receive) external systems
- Stream from or to a Moku instrument in Multi-Instrument Mode
- Stream from Moku analog inputs (ADCs) or stream to Moku analog outputs (DACs)
- Trigger mode with automatic re-arm for segmented captures

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Specifications

Inputs – receiver

Input characteristics

Channels	2
Bandwidth	2 GHz
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC
Input gain	20 dB / 0 dB / -20 dB / -32 dB
Input voltage range	100 mV_{pp} into 50 Ω with 20 dB gain 1 V_{pp} into 50 Ω with 0 dB attenuation 10 Vpp into 50 Ω with 20 dB attenuation 40 V_{pp} into 1 MΩ with 32 dB attenuation
Input sample rate / decimation	Configurable 5 kSa/s to 156.25 MSa/s (2 ch) / 312.5 MSa/s (1 ch)
Sample size	16 bit or 32 bit
Start mode	Manual, time delayed, triggered, gated with automatic re-arm

Outputs – transmitter

Output characteristics

Channels	2
Digital output gain	-20 dB to +20 dB
Output interpolation	None, Linear
Output sample rate	Auto detect
Output analog gain	0 dB or +20 dB
Output sample rate	Up to 156.25 MSa/s per channel

Interface, Data format

SFP interface

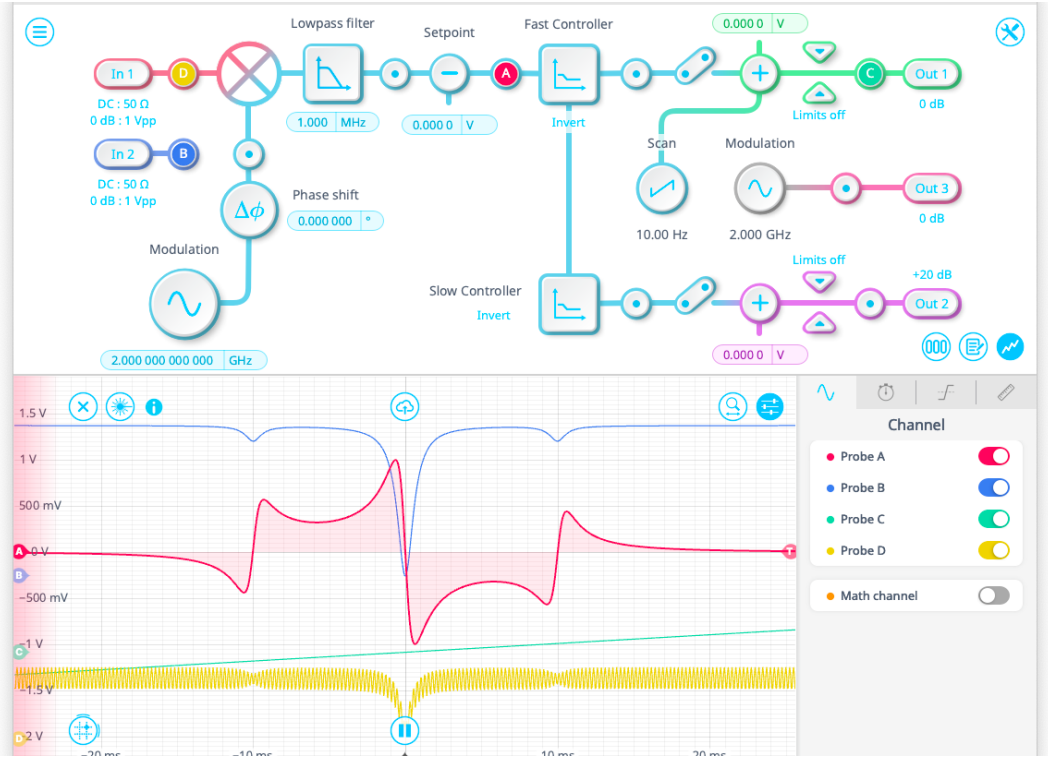
Media	10G SFP+ and 25G SFP28 DAC copper cables
Packets	DIFI-aligned VITA 49.2 packet structure
MTU	Up to 9,000 bytes
Transport	UDP over IPv4

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Moku:Delta Laser Lock Box

Description

Moku:Delta Laser Lock Box enables you to lock a laser's frequency to a reference cavity or atomic transition using high-performance modulation locking techniques. The Laser Lock Box includes a "Lock Assist" feature, enabling you to quickly lock to any zero-crossing on the demodulated error signal. With Multi-Instrument Mode, you can deploy up to eight laser lock modules simultaneously on a single Moku:Delta. Each module shares the same clock base from the internal or an external source. This is an ideal solution for multi-laser stabilization systems.



Features

- Generate modulation signals at up to 2 GHz
- Demodulate signals with an internal local oscillator, or external local oscillator at the fundamental or up to the 250th harmonic
- Scan resonances with sawtooth or triangle waveforms at up to 10 MHz
- Observe and log signals at different stages in the digital signal processing chain using probe points
- Quickly lock to any zero-crossing in the error signal using the "Lock Assist" feature
- Filter demodulated signals with up to fourth order infinite impulse response filters
- Individually configure high- and low-bandwidth PID controllers for fast and slow feedback

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Specifications

Signal input

Signal input	
Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
Frequency range	DC to 2 GHz
Input gain[5]	-32 dB / -20 dB / 0 dB / +20 dB / +24 dB / +48 dB
Gain accuracy	± 1%
Input range	40 V_{pp} with -32 dB input gain 10 V_{pp} with -20 dB input gain 1 V_{pp} with 0 dB input gain 100 mVpp with 20 dB input gain 25 mV_{pp} with +24 dB input gain[4] 1.6 mV with +48 dB input gain[4]
Input noise	< 10 nV/√Hz above 2 MHz at 100 mV_{pp} input range

Internal demodulation local oscillator

Internal reference waveform	
Waveform	Sine
Frequency range	1 mHz to 2 GHz
Frequency resolution	1 µHz
Phase offset range	0 to 360°
Phase offset resolution	0.000 001°
Output impedance	50 Ω
Can be phase-locked to external 10 or 100 MHz timebase?	Yes

Demodulation reference

Demodulation reference input	
Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
Frequency range	DC to 2 GHz
Input gain	-32 dB / -20 dB / 0 dB / 20 dB

[5] +24 dB and +48 dB input gains are applied digitally and can be used to maximize the Laser Lock Box's dynamic range for weak input signals

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Demodulation modes

Demodulation modes	Internal reference oscillator, external direct, external with phase-locked loop External with phase-locked loop : multiply to 250th harmonic of input or divide down to 1/8th of fundamental

Phase-locked loop

PLL frequency range	10 Hz to 2 GHz
PLL tracking bandwidth	1Hz, 10Hz, 100Hz, 1kHz, 10kHz, 100kHz, 1MHz
Phase offset range	0 to 360°
Phase offset resolution	0.000 001°
Orthogonality	90° ± 0.000,002°
PLL multiplier	1/8th to 250x of the fundamental

Lowpass filter

Lowpass filter

Filter architecture	Infinite Impulse Response (IIR)
Filter shape	Lowpass, Bandstop, or Custom
Sampling rate	78.125 MHz
Filter types	Butterworth, Chebyshev I, Chebyshev II, Elliptic, Cascaded, Bessel, Gaussian, Legendre
Filter order	2, 4
Min. corner frequency	2.601 kHz
Max. corner frequency	35.16 MHz
Passband ripple[6]	0.1 dB to 10 dB
Stopband attenuation[7]	10 dB to 100 dB

Auxiliary oscillator

Auxiliary oscillator waveform

Waveform	Sine
Frequency range	1 mHz to 2 GHz
Frequency resolution	1 µHz
Amplitude range (AC)	1 mV_{pp} to 1 V_{pp} into 50 Ω at up to 2 GHz 10 mV to 10 Vpp into 50 Ω at up to 100 MHz with +20 dB ouput gain
Amplitude resolution	1 mV
Output limit (AC + DC)	± 1 V with 0 dB ± 10 V with 20 dB
Amplitude accuracy	1%

[6] Applies to Chebyshev I and Elliptical filter types.
[7] Applies to Chebyshev II and Elliptical filter types.

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Auxiliary oscillator waveform

Output impedance	50 Ω
Can be phase-locked to demodulation local oscillator?	Yes

Scan waveform

Scanning waveform

Waveform	Positive ramp, Negative ramp, Triangle
Frequency range	1 mHz to 10 MHz
Frequency resolution	1 µHz
Amplitude range (AC)	1 mV_{pp} to 1 V_{pp} into 50 Ω
Amplitude resolution	1 mV
Offset range (DC)	± 500 mV
Output limit (AC + DC)	± 500 mV into 50 Ω
Amplitude accuracy	1%
Output impedance	50 Ω

PID Controllers

Set point

Set point range	-500 mV to + 500 mV
Set point resolution	100 µV

Fast controller

Sampling rate	78 MHz
Proportional gain	± 60 dB
Integrator crossover frequency	3.125 Hz to 312.5 kHz. (single integrator) 3.125 Hz to single integrator crossover frequency (double integrator)
Int. saturation crossover frequency	3.125 Hz to integrator crossover frequency
Integrator gain range	Proportional gain to +80 dB
Differentiator crossover frequency	31.25 Hz to 3.125 MHz
Diff. saturation crossover frequency	Differentiator crossover frequency to 3.125 MHz
Differentiator gain range	Proportional gain to +80 dB

Slow controller

Sampling rate	1.22 MHz
Proportional gain	± 60 dB
Integrator crossover frequency	48.83 mHz to 4.883 kHz
Int. saturation crossover frequency	48.83 mHz to integrator crossover frequency

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Slow controller

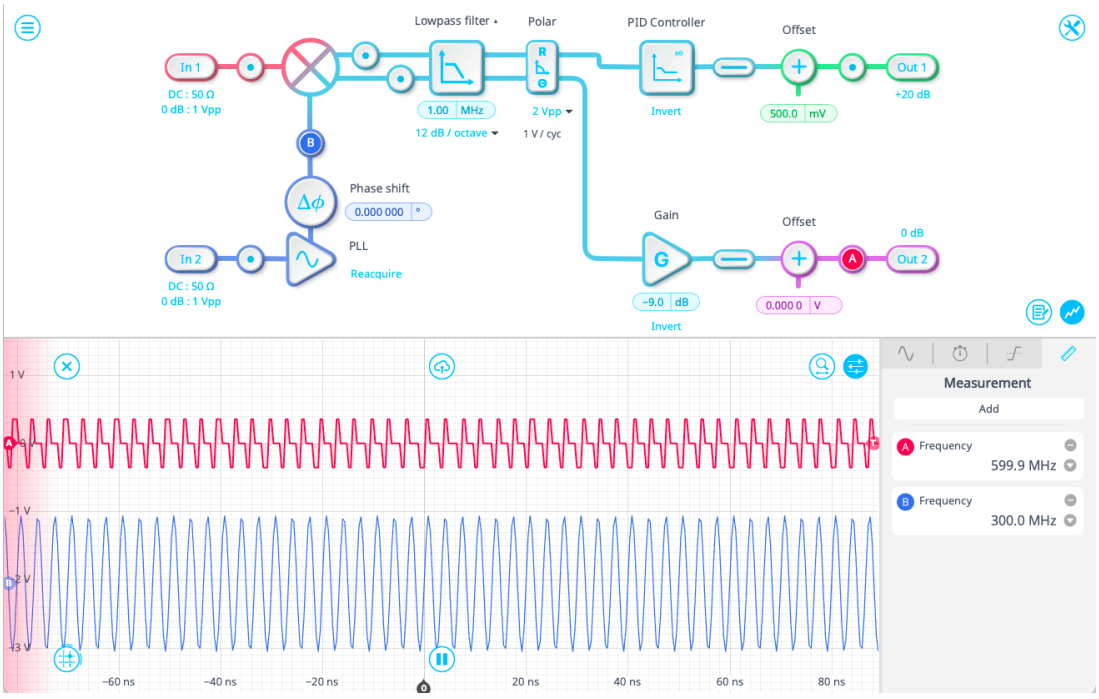
Integrator gain range	Proportional gain to +80 dB
Differentiator crossover frequency	488.3 mHz to 48.83 kHz
Diff. saturation crossover frequency	Differentiator crossover frequency to 48.83 kHz
Differentiator gain range	Proportional gain to +80 dB

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Moku:Delta Lock-In Amplifier

Description

Moku:Delta Lock-in Amplifier supports dual-phase demodulation (XY/Rθ) from 1 mHz to 2 GHz, with either an internal oscillator or up to the 250th harmonic of an externally applied reference, with more than 120 dB dynamic reserve. A PID controller can be placed after the demodulation stage for a phase-locked loop or other applications requiring active feedback. An integrated two-channel Oscilloscope and Data Logger lets you observe signals at up to 5 GSa/s and log data at up to 10 MSa/s.



Features

- Measure signals obscured by noise with more than 120 dB dynamic reserve
- Block diagram view of the digital signal processing chain
- Observe and log signals at different stages in the digital signal processing chain using probe points[8]
- Demodulate signals with an internal local oscillator, or external local oscillator at the fundamental or up to 250th harmonic
- Toggle between rectangular (X/Y mode) or polar coordinates (R/θ mode)

[8] See Moku:Delta Data Logger or Moku:Delta Oscilloscope for specifications on integrated instruments

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Specifications

Signal channel

Signal input

Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
AC coupling corner (-3 dB)	16 kHz into 50 Ω 1.6 Hz into 1 MΩ
Frequency range	DC to 2 GHz; user selectable 6 GHz analog path
Input attenuation	-20 dB / 0 dB / 20 dB / 32 dB
Input range	40 V_{pp} with -32 dB input gain and 1 MΩ input impedance 10 V_{pp} with -20 dB input gain 1 V_{pp} with 0 dB input gain 100 mVpp with 20 dB input gain
Input noise	10 nV/√Hz at 100 Hz with 100 mV_{pp} input range < 9 nV/√Hz at 10 kHz with 100 mV_{pp} input range < 10 nV/√Hz above 2 MHz with 100 mV_{pp} input range

External reference

Direct reference input

Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
Frequency range	DC to 2 GHz
Input gain	-32 dB / -20 dB / 0 dB / 20 dB
External reference modes	Direct, phase-locked
Direct demodulation	X = Rcosθ

Phase-locked loop

PLL frequency range	10 Hz to 2 GHz
PLL tracking bandwidth	1 MHz, 100 kHz, 10 kHz, 1 kHz, 100 Hz, 10 Hz, 1 Hz
Phase range	0 to 360°
Phase resolution	0.000 001°
Demodulation	XY / Rθ
PLL multiplier	$1/8^{th}$ to 250x of the fundamental

Internal reference

Internal reference waveforms

Waveform	Sine
Frequency range	1 mHz to 2 GHz
Frequency resolution	1 µHz

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Internal reference waveforms

Phase range	0 to 360°
Phase resolution	0.000 001°
Demodulation	XY / RΘ

Internal reference auxiliary output

Amplitude range	1 mV_{pp} to 10 V_{pp} at <= 100 MHz into 50 Ω 1 mV_{pp} to 1 V_{pp} at > 100 MHz into 50 Ω
Amplitude resolution	1 mV
Frequency range	1 mHz to 2 GHz
Offset range	± 500 mV
Output limit (AC + DC)	± 500 mV with 0 dB ± 5 V with 20 dB
Amplitude accuracy	1%
Output impedance	50 Ω
Can be phase-locked to external 10 or 100 MHz time base?	Yes

Demodulator & filter

Demodulator characteristics

Sources	Internal reference oscillator, external direct, external with phase-locked loop External with phase-locked loop : multiply to 250th harmonic or divide down to 1/8th of fundamental
Types	Internal: XY / RΘ External direct: X = RcosΘ External with PLL: XY / RΘ

Filter characteristics

Filter mode	Lowpass filter
Filter cutoff frequency (-3dB)	700 mHz to 12.4 MHz
Filter time constant	12.8 ns to 0.215 s
Filter slope	6, 12, 18, 24 dB per octave
Phase shift precision	0.000 001°
Dynamic reserve	> 120 dB

Signal output

Output characteristics

Modes	XY (Cartesian mode); RΘ (polar mode); Auxiliary Oscillator
Number of output channels	2
Channel 1 output	X/R

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Output characteristics

Channel 2 output	Y/θ, auxiliary oscillator, or local oscillator
Output gain mode	Direct, PID[9]
Gain range (direct)	-80 dB to +160 dB
Phase scale (R/θ mode)	1 V/cycle
Amplitude scale (R/θ mode)	2 V_{pp}, 7.5 mV_{pp}, 25 uV_{pp}
Output voltage offset	± 500 mV into 50 Ω
Output voltage range (AC + DC)	± 5 V into 50 Ω with +20 dB gain
Output impedance	50 Ω
D/A conversion	14-bits, 5 GSa/s, 2 GHz analog bandwidth

PID controller

Controller frequency range	DC to 40 MHz
Proportional gain	± 120 dB (XY mode), ± 60 dB (Rθ mode)
Integrator crossover frequency	3.125 Hz to 312.5 kHz
Int. saturation crossover frequency	3.125 Hz to integrator crossover frequency
Integrator gain range	Proportional gain to +120 dB (XY mode), +80 dB (Rθ mode)
Differentiator crossover frequency	31.25 Hz to 3.125 MHz
Diff. saturation crossover frequency	Differentiator crossover frequency to 3.125 MHz
Differentiator gain range	Proportional gain to +120 dB (XY mode), +80 dB (Rθ mode)

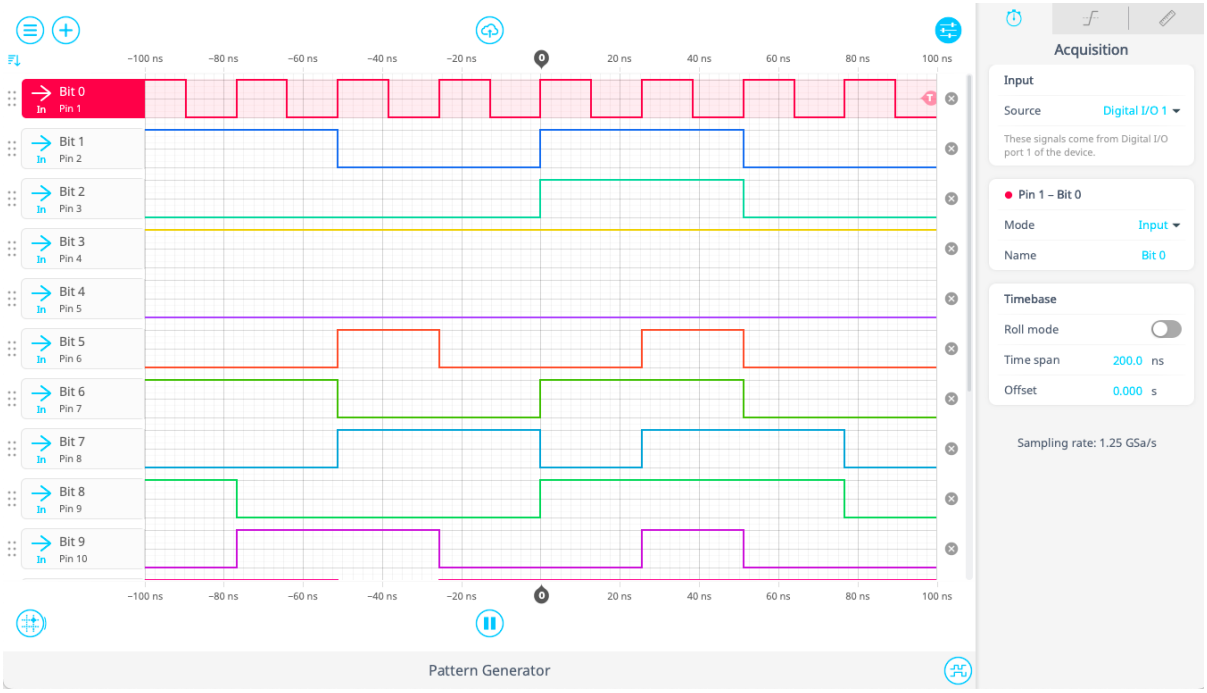
[9] Only one output may have a PID controller enabled at a time

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Moku:Delta Logic Analyzer

Description

Moku:Delta Logic Analyzer is equipped with one digital input and two digital outputs with sampling rates up to 312.5 MSa/s. It supports 262k × 16 input memory depth and up to 32,764 x 16 output memory depth. The Logic Analyzer can decode a number of standard industry protocols, as well as generate arbitrary 16-bit binary patterns. Data, screenshots, and instrument settings can be captured and downloaded to a computer.



Features

- 16-bit single channel digital input with a sampling rate up to 312.5 MSa/s
- Two outputs that include selectable clock, pulse, and random patterns, or upload a custom file
- Ultra deep 262k × 16 points input memory depth, 32,764 × 16 points output memory depth
- Decode up to two protocols at a time, including UART, SPI, I²C, I²S, Parallel, CAN and USB
- Powerful, intuitive graphical user interface with Python, and MATLAB API support

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Specifications

Digital I/O

Interface

Number of I/O	16 bits individually configurable as Input or Output
I/O sources	Digital I/O 1, Digital I/O 2

Horizontal characteristics

Acquisition

Sampling rate	1.25 GSa/s
Memory depth	262k points per channel
Maximum clock signal frequency	312.5 MHz

Generation

Sampling rate	312.5 MSa/s
Memory depth	32,764 points per channel
Maximum clock signal frequency	156.25 MHz
Clock divider	1 to 1,000,000

Trigger

Trigger

Trigger modes	Auto:	Triggers automatically after timeout (1 second if previously triggered, 0.05 seconds otherwise)
	Normal:	Triggers only on trigger event
	Single:	Triggers once on a trigger event. Press the ‘play’ button to re-trigger
Trigger sources	An input bit	
Nth event	Trigger on the 1st to 65,535th event	
Holdoff	up to 10 seconds	
Trigger types	Basic: Rising or falling edge; Advanced: logical AND or OR of bit logic or edges	

Measurements

Measurements

Time measurements	Frequency, phase, period, duty cycle, positive pulse width, negative pulse width
Math	AND, OR, XOR, NAND, NOR, XNOR

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Protocol decoder

UART

Data width	5 bits to 9 bits
Stop width	1 bit to 2 bits
Parity	None, Even, Odd
Baud rate	1 to 2,000,000
Bit order	LSB first, MSB first
Max standard baud rate	2,000,000

SPI

CLK	Serial Clock bit
CS	Chip Select bit
DATA	Serial Data bit
Data width	5 bits to 9 bits
Bit order	LSB first, MSB first
Clock polarity	Idle low, Idle high
Clock phase	Sample on leading, Sample on trailing
Max decoder frequency	30 MHz

I²C

Address size	7 bits
SCL[10]	Serial clock bit
SDA	Serial data bit
Max decoder frequency	>1 MHz

I²S

SCK	Serial clock bit
WS	Word select bit
SD	Serial data bit
Bit order	LSB first, MSB first
Offset	Number of clock cycle to wait after WS transition before data transmission starts
Data Width	2 bits to 32 bits
Max decoder frequency	40 MHz

[10] Some protocols like I²C and I²S require the user to select a bit for their input data to the protocol decoder. Ensure the bits labelled on the interface match the bits you set for your input data.

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Parallel

Data width	1-12 bits
CLK	Configurable CLK bit, sampling on rising, falling or both edges

CAN

Rx	Configurable Rx bit
Baud rate	1 – 1,000,000
Data	MSB or LSB first

USB

D+/D-	Configurable data bits
Speed mode	Low Speed, Full Speed, or Custom

Saving data

Exporting data

File formats	Binary: records data using a proprietary LI format for high-speed data logging. Can be converted to .csv, .txt, .mat, .npy, and HDF5.
Export modes	Dropbox, email, iCloud, and My Files (iOS)

Export types

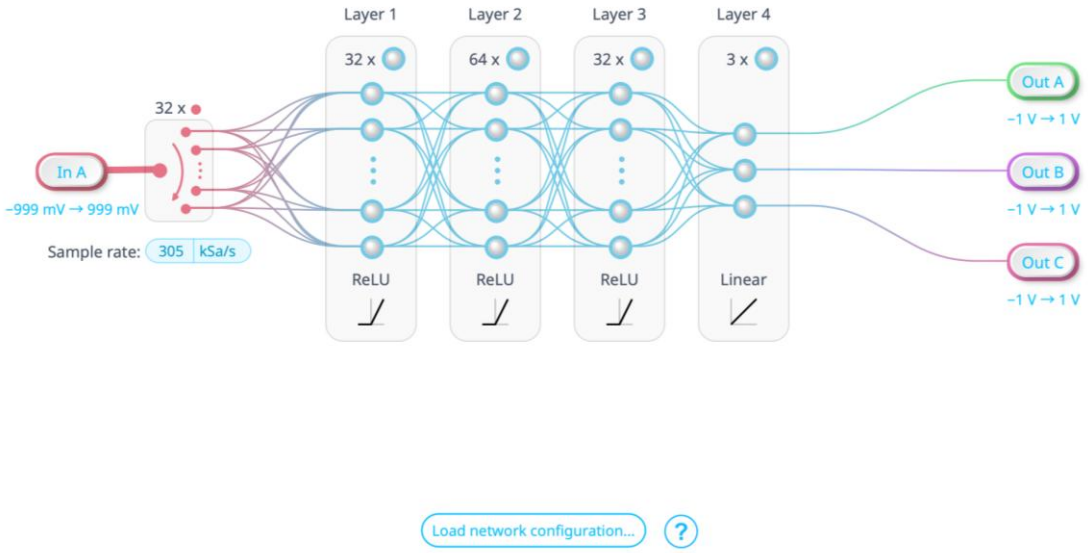
Traces	Save 1024 points of data from each visible input bit in the current time span
Protocol data	Save protocol decoder states and data as comma-separated values
Screenshot	Save the app window as a PNG or JPG
Settings	Save the current instruments settings to a text file
Measurements	Save all active measurements as comma-separated values
High-res data	Save up to 262k points per active bit

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Moku:Delta Neural Network

Description

Moku:Pro Neural Network[11] enables fast, agile implementation and evaluation of user-defined neural networks utilizing Multi-Instrument Mode. Design and train your network configuration offline in a Python supported environment, then upload it to the Moku app for real-time Neural Network operation.



Features

- Training: Collect training data on any Moku; or simulate a desired complex process offline
- Choose from 5 activations functions
- Upload weights, biases, and activation functions in a single file
- Input and output serial or parallel signals
- Data log Neural Network outputs with the Moku Data Logger, Oscilloscope, or other Moku instruments

[11] Moku Neural Network is only available in Multi-Instrument Mode.

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Specifications

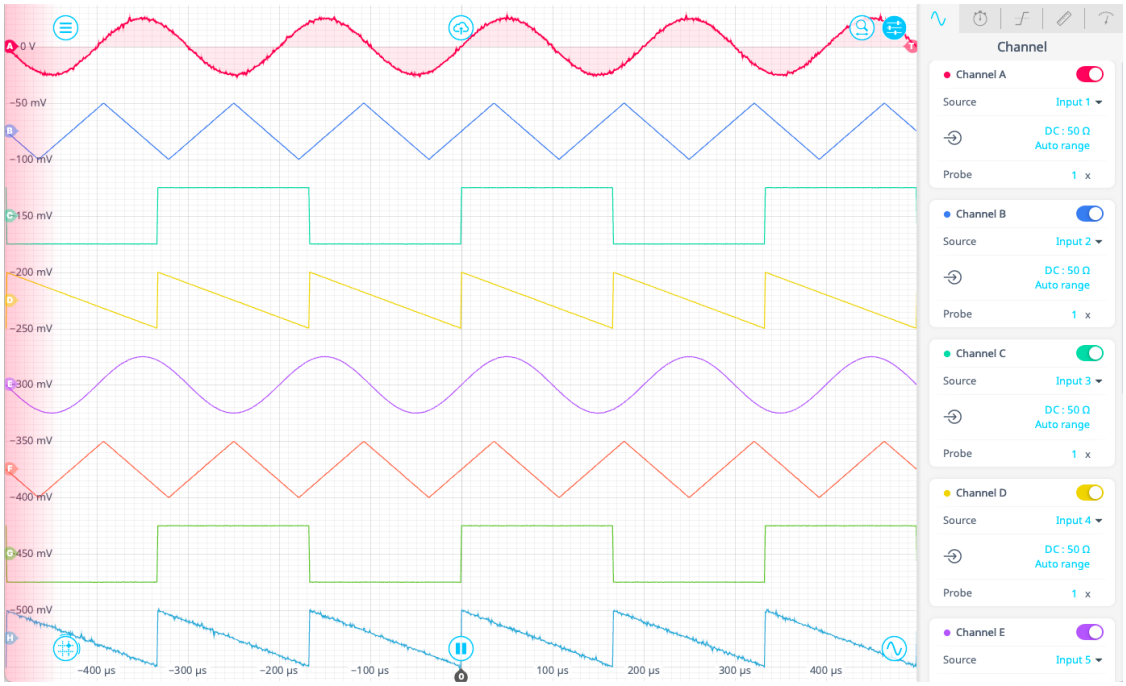
Input channels (parallel)	Up to 2
Input channels (serial)	1 to 100
Output channels (parallel)	Up to 4
Output channels (serial)	1 to 100
Layers	Up to 4
Neurons per layer	Up to 100
Sample rate	1 Sa/s to 305 kSa/s
Activation functions	ReLU, Softsign, Tanh, Sigmoid, Linear
Precision	18-bit fixed point

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Moku:Delta Oscilloscope

Description

Moku:Delta Oscilloscope features eight high-speed, ultra-low noise input channels with 2 GHz analog bandwidth. An innovative blended ADC technology combines the information from 14-bit and 20-bit ADCs to cover a broad spectrum, providing class-leading input noise performance of 10nV/ √ Hz at 100Hz and a large dynamic range. The embedded four-channel waveform generator can produce waveforms up to 2 GHz.



Features

- Eight analog inputs at 5 GSa/s with 2 GHz bandwidth
- Exceptional low-frequency noise performance: 10 nV/ √ Hz at 100 Hz
- Eight input channels with dual ADC design with blending ADC technology
- Ultra-stable ± 1 ppb onboard oscillator with 10 or 100 MHz input and output synchronization
- Four integrated high-speed waveform generator channels, analog bandwidths up to 2 GHz
- Deep memory captures > 134 million samples on 1 channel @ 5 GSa/s

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Specifications

Vertical characteristics

Voltage

Channels	8
Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
Input bandwidth (-3 dB)	2 GHz; user selectable 6 GHz analog path
Input voltage range	40 V_{pp} with 32 dB input attenuation and 1 MΩ input impedance 10 V_{pp} with 20 dB input attenuation 1 V_{pp} with 0 dB input attenuation 100 mVpp with 20 dB input gain
Input voltage noise	10 nV/√Hz at 100 Hz with 100 mV_{pp} input range < 9 nV/√Hz at 10 kHz with 100 mV_{pp} input range < 10 nV/√Hz above 2 MHz with 100 mV_{pp} input range
Channel-to-channel isolation	TBD

Horizontal characteristics

Time

Time mode	Normal, Roll
Horizontal span	1 ns to 100 s

Acquisition

Acquisition mode	Normal, Precision[12], Peak Detect, Deep memory (> 134 million points)
Maximum sampling rate	5 GSa/s
ENOB	10.8
Averaging (linear)	Off, 2 to 100 waveforms
Persistence (iPadOS only)	Off, 100 ms to 10 s, infinite
Interpolation	Linear, SinX/X, Gaussian

[12] Precision mode samples the waveform at the full rate and applies a finite impulse response (FIR) lowpass filter to attenuate noise above the usable bandwidth of the measurement sampling rate and prevent aliasing.

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Trigger

Trigger

Trigger modes	Auto:	Triggers automatically after timeout (1 second if previously triggered, 0.05 seconds otherwise)
	Normal:	Triggers only on trigger event
	Single:	Triggers once on a trigger event. Press the play button to retrigger
Trigger sources	Input 1-8, Output 1-4, External	
Nth event	Trigger on the 1st to 65,535th event	
Holdoff	1 ns to 10 seconds	
Trigger types	Edge: Rising edge, falling edge, both edges Runt: Positive / negative polarity, high and low levels Pulse: Positive / negative polarity • Pulse width 3.2 ns – 10 s	

Trigger sensitivity

Sensitivity modes	Auto:	Automatically configures trigger sensitivity based on horizontal and vertical scales Select *Noise Reject* or high-frequency *HF Reject* options
	Manual:	Manually configure trigger sensitivity
Manual modes	Relative, Absolute	
Hysteresis	Relative: 0.01 div to 5.00 div Absolute: 100 µV to 1.00 V	

Measurements

Measurements

Time measurements	Frequency, phase, period, duty cycle, positive pulse width, negative pulse width, rise time, fall time, rise rate, fall rate
Amplitude measurements	Peak-to-peak, amplitude, maximum, minimum, mean, cycle mean, RMS, cycle RMS, standard deviation, high-level, low-level, overshoot, undershoot, fringe visibility
Math	Add, subtract, multiply, divide, XY mode, integrate, differentiate, FFT, min hold, max hold, arbitrary equation mode (using equation editor)
Visualizations (iPadOS only)	Histogram, time trend

Cursors

Voltage cursor options	Manual, track mean, track maximum, track minimum, maximum hold, minimum hold
User defined reference	A single cursor can be set as a reference for differential measurements using all other active cursors

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Integrated waveform generator

Synthesizer

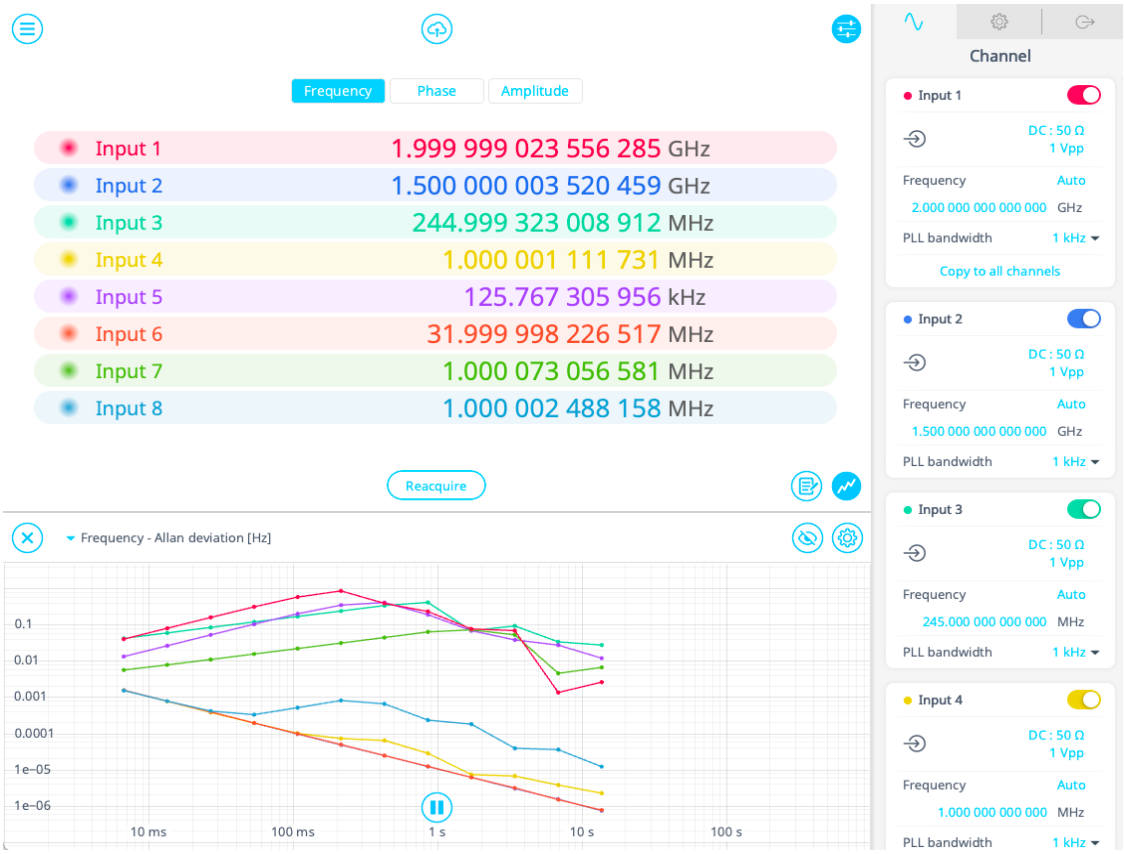
Channels	4
Output impedance	50 Ω
Waveforms	Sine, DC
Output frequency range	1 mHz to 2 GHz
Output voltage range	> 100 MHz: 10 V_{pp} into 50 Ω 1 mHz to 100 MHz: 1 V_{pp} into 50 Ω

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Moku:Delta Phasemeter

Description

Moku:Delta Phasemeter measures the phase of up to eight input signals, relative to a clock reference, with 1 nrad precision over a frequency range of 1 kHz to 2 GHz. Based on a digitally implemented phase-locked loop architecture, Moku:Delta's Phasemeter provides exceptional dynamic range, zero deadtime, and measurement precision that exceeds the performance of conventional lock-in amplifiers and frequency counters.



Features

- Eight independent phasemeter channels with output options that track and record the phase, frequency, and amplitude of each input
- Phase-locked output option enables you to generate sine waves that are phase locked to the inputs, with frequency division to 1/8th or multiplication to 250x
- Calculate Allan deviation, spectral density, and other functions using the Phasemeter's integrated spectral analysis toolkit
- Phase-locked loop tracking bandwidths from 1 Hz up to 1 MHz
- Convert measured phase, frequency offset or amplitude directly to an analog output

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Specifications

Inputs

Input characteristics

Input frequency range	1 kHz to 2 GHz
Input voltage range	40 V_{pp} with 32 dB input attenuation and 1 MΩ input impedance 10 V_{pp} with 20 dB input attenuation 1 V_{pp} with 0 dB input attenuation 100 mVpp with 20 dB input gain
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC

Measurement

Measurement characteristics

Phase error	0.1 µradian/√Hz @ 10 Hz	
Phase precision	1 nradian	
Frequency precision	1 µHz	
Modes of operation	Auto-acquire	Automatically determines input frequency for signals above 1 MHz
	Manual	Initializes the phasemeter to a specific frequency
Tracking bandwidth	1 Hz / 10 Hz / 100 Hz/ 1 kHz / 10 kHz / 100 kHz / 1 MHz (user selectable)	
Advanced option	Phase wrapping, single input, auto-reset, invert, and user-configurable mV/cycle output scaling	

Data visualization

Visualizations	Timeseries, Power Spectral Density, Amplitude Spectral Density, Coherence, Rayleigh Spectrum, Allan Deviation

Outputs

Phase, frequency offset or amplitude output

Channels	8
Modes of operation	Sine wave (option to phase-lock to the input signal) Output measured signal phase, frequency offset, or amplitude with user-defined scaling and configurable DC offset
Output range	1 Vpp (> 100 MHz) or 10 Vpp (<= 100 MHz)

Saving Data

Saving data

Acquisition rates	37 Sa/s, 150 Sa/s, 596 Sa/s, 2.4 kSa/s, 19.1 kSa/s, 152 kSa/s

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Saving data

File format	Binary: Records data using a proprietary LI format for high-speed data logging. Data saved using the LI format may be converted to other formats when downloading from Moku. iPad can convert to .CSV, MATLAB or NumPy. Desktop can convert to .CSV, MATLAB, NumPy or HDF5.
Export modes	Dropbox, E-mail, My Files (iOS 11), Desktop, and iCloud
Delayed log start time	Up to 240 hours
Log duration	1 second to 10,000 hours

Synthesizer

Synthesizer[13]

Channels	8
Output impedance	50 Ω
Waveform shape	Sine
Output modes	Manual, phase-locked to input signal, with scaling to 250x harmonic or division to 1/8th
Sampling rate	5 GSa/s per channel
Voltage range	± 5 V <= 100 MHz, ± 500 mV > 100 MHz (into 50 Ω)

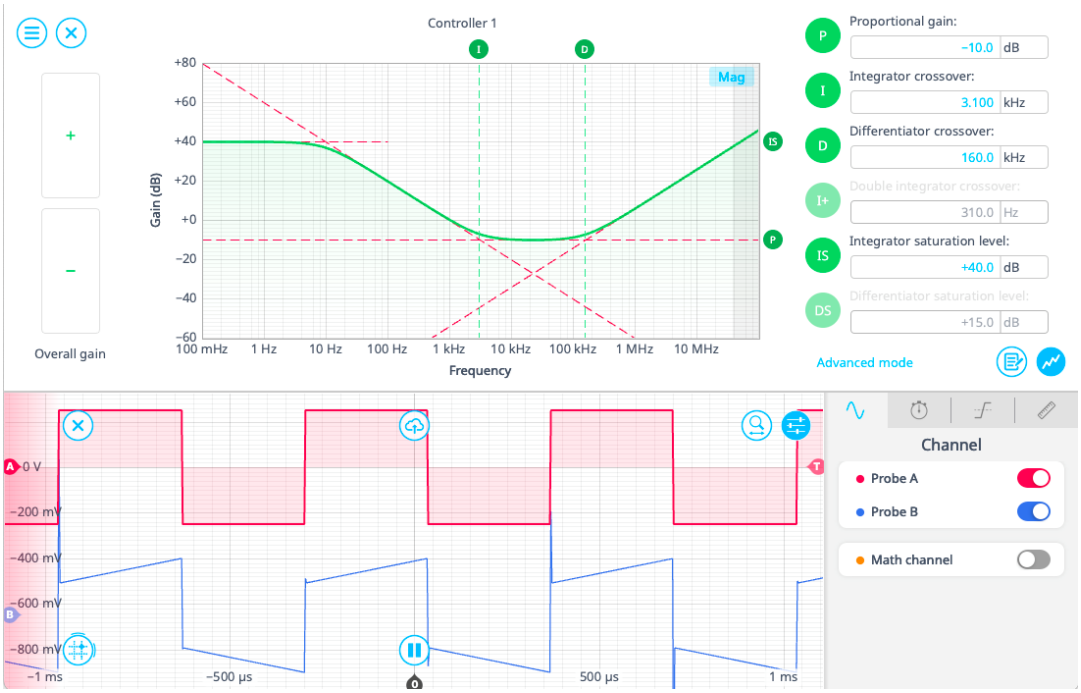
[13] Where not stated, the Phasemeter's synthesizer specifications match those of the Moku:Delta Waveform Generator instrument.

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Moku:Delta PID Controller

Description

Moku:Delta PID Controller features four fully configurable PID controllers with an open loop bandwidth of 35.38 MHz. This enables them to be used in applications requiring both low and high feedback bandwidths such as laser temperature and current stabilization. The PID Controller can also be used as a lead-lag compensator by saturating the integral and differential controllers with independent gain settings.



Features

- Four input channels, four output channels, and four independent PID Controllers with control matrix for MIMO
- Design the control system's frequency response using the interactive Bode plot in real time
- Block diagram view of the digital signal processing with built-in probe points in signal processing chain
- Advanced multi-section PID builder with single or double integrators and differentiators with low- and high-frequency gain saturation
- Integrated probe points for signal monitoring and data logging
- Observe and log signals at different stages in the digital signal processing chain using probe points

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Specifications

Inputs

Input characteristics

Channels	4
Input control matrix coefficients (linear gain)	-20 to +20
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC
Input attenuation	32 dB / 20 dB / 0 dB / -20 dB
Input voltage range	40 V_{pp} with 32 dB input attenuation and 1 MΩ input impedance 10 V_{pp} with 20 dB input attenuation 1 V_{pp} with 0 dB input attenuation 100 mVpp with 20 dB input gain

Controller

General characteristics

Gain profiles	Proportional (P), integral (I), differential (D), double-integral (I+), integral saturation (IS), differential saturation (DS)
Controller frequency range	DC to 40 MHz
Maximum bandwidth	400 kHz with a phase margin of 30°
Input / output offset range	± 500 mV
Output limit (AC + DC)	± 500 mV into 50 Ω
Offset precision	100 µV
Proportional gain	± 60 dB
Integrator crossover frequency	3.125 Hz to 312.5 kHz
Double integrator crossover frequency	3.125 Hz to integrator crossover frequency
Integral saturation level	Between proportional gain and +60 dB The integrator saturation crossover frequency cannot be lower than 3.125 Hz
Differentiator crossover frequency	31.25 Hz to 3.125 MHz
Differentiator saturation level	Between proportional gain and +60 dB The differentiator saturation crossover frequency cannot be higher than 3.125 MHz

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Moku:Delta Spectrum Analyzer

Description

Moku:Delta Spectrum Analyzer allows you to observe input signals in the frequency domain between DC and 2 GHz with an ultralow noise floor. View eight channels simultaneously with a resolution bandwidth as low as 618.5 mHz and a minimum span of 100 Hz. The Spectrum Analyzer also features four 2 GHz sinewave generators.



Features

- Display and record power spectra or power spectral densities in the from DC to 2 GHz
- User selectable 6 GHz analog input path allows observation of Nyquist zones
- Generate four sine waves up to 2 GHz using Moku:Delta's built-in analog outputs
- Quickly measure important metrics by dragging measurement cursors onto features of interest
- Live measurement functions: peak level, peak frequency, noise level, peak SNR, and occupied bandwidth

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Specifications

Frequency

Frequency

Range	DC to 2 GHz, user selectable 6 GHz analog input path
Span	100 Hz to 2 GHz
Axis scale	Linear or Log

Resolution bandwidth (RBW)

Modes	Auto	Automatically sets the RBW based on the current span and window function
	Manual	Allows the user to manually set the RBW within the limits tolerated by the span and window function
	Min	Sets the RBW at the minimum possible value for the current span and window function The minimum RBW is 618.5 mHz
Windows	Rectangular, Bartlett, Hamming, Hann, Blackman-Harris. Flat top, Nuttall, Gaussian, Kaiser	

Amplitude

Voltage

Channels	8
Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
Input attenuation	32 dB / 20 dB / 0 dB / -20 dB
Input bandwidth (-3 dB)	2 GHz
Input voltage range	40 V_{pp} with 32 dB input attenuation and 1 MΩ input impedance 10 V_{pp} with 20 dB input attenuation 1 V_{pp} with 0 dB input attenuation 100 mVpp with 20 dB input gain

Display

Scales	Vpp, Vrms, dBm, dBV
Display modes	Power, Power Spectral Density (PSD)
Video filter bandwidth (VBW)	580 mHz to 24 MHz depending on span
Averages	1 to 100
Frame rates	Auto, 10/s to 10s
Persistence (iPadOS only)	Off, 100 ms to 10 s, infinite

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Synthesizer

Synthesizer

Channels	4
Output impedance	50 Ω
Waveforms	Sine
Output frequency range	1 mHz to 2 GHz
Output voltage range	> 100 MHz: 1 V_{pp} into 50 Ω 1 mHz to 100 MHz: 10 V_{pp} into 50 Ω

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Moku:Delta Time & Frequency Analyzer

Description

Moku:Delta Time & Frequency Analyzer measures time intervals between user-configurable start and stop events with sub-ns precision. Select between continuous, windowed, or gated acquisition mode, compute histograms of interval duration losslessly and in real-time, or log high-resolution event timestamps to on-board storage. Output the measured interval count or current interval to analog output channels for active feedback control.



Features

- Jitter of < 5.0 ps for high timing resolution analysis
- Up to eight independent event detectors with configurable thresholds on rising edge, falling edge, or both
- Track up to eight different intervals independently
- Lossless, real-time histograms with a minimum bin width of 0.2 ps
- Output interval count or current interval as analog voltage with adjustable scaling factor
- High resolution raw event timestamp logging to on-board storage for post processing
- Real time calculation of second-order correlation ($g^{(2)}$) function

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Specifications

Events

Input characteristics

No. of independent analyzers	8
Source	Input 1 - 8, Ext. trig.
Input Coupling	AC / DC
Input Impedance	50 Ω / 1 MΩ
Input voltage range	100 mVpp, 1 Vpp, 10 Vpp (50 Ω), 40 Vpp (1 M Ω)
Frequency range	DC to 2 GHz
Max interval rate	312.5 MHz
Threshold	+/-50 mV, +/-500 mV, or +/-5 V (50 Ω). or +/- 10 V (1 M Ω)
Edge	Rising, Falling, Both
Jitter	< 5.0 ps
Optimum edge time	TBD

*Edge times faster than the optimum edge time can lead to a large bias in the measurement. We recommend adding an analog filter with a TBD MHz bandwidth on the input.

Interval Histogram or $g^{(2)}$ correlation

Bins	Up to 1024
Min bin width	0.2 ps

Acquisition

Acquisition mode	Windowed, Gated, Continuous
Window length	1 ms to 10 s
Gate source	Input 1 - 8, Ext. trig.
Gate threshold	-5 V to 5 V (50 Ω); -20 V to 20 V (1 MΩ)
Interpolation	None, Linear

Intervals

Intervals

No. of independent analyzers	8
Start	Events A, B, C, D, E, F, G, H
Stop	Events A, B, C, D, E, F, G, H

Real-time statistics

Current, Mean, Minimum, Maximum, Count, Standard deviation

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Signal output

Output characteristics

Number of output channels	8
Modes	Interval, Count
Zero point	0 s to 1 ks
Scaling (Interval)	1 mV/s to 100 MV/s
Scaling (Count)	10 nV/cnt to 1 V/cnt
Range	1 Vpp, 10 Vpp

Data logger

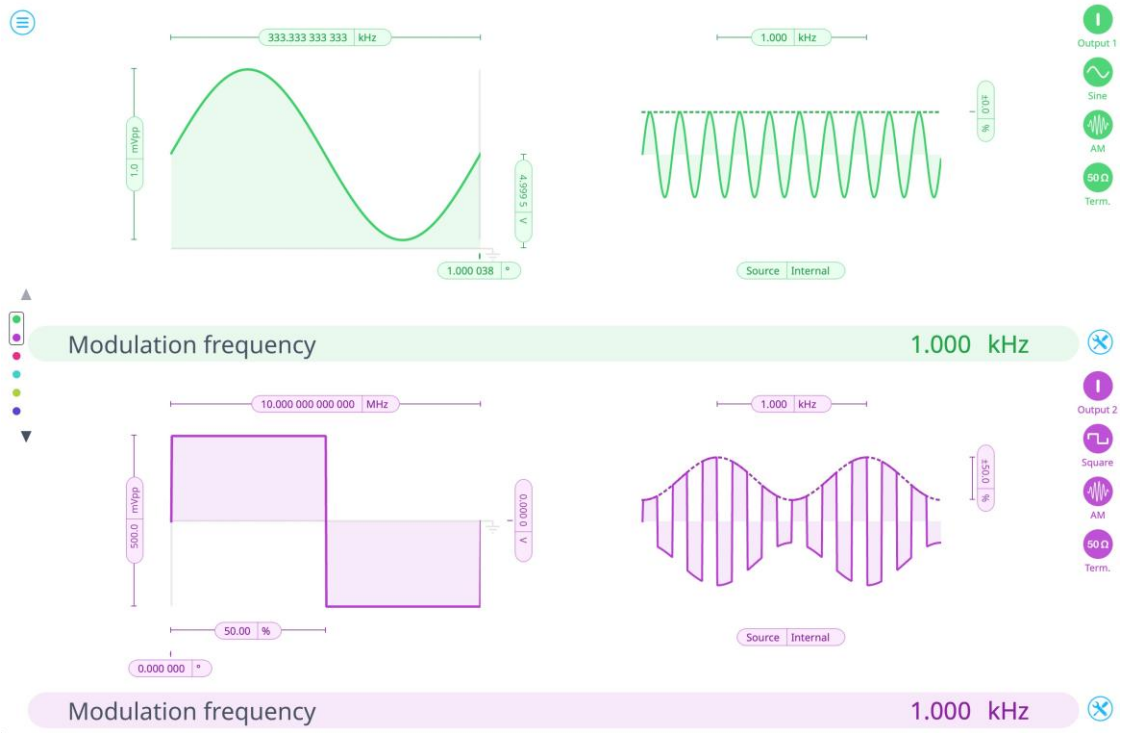
Rate	Up to 312.5 Mevnt/sec burst Up to 10 Mevnt/sec continuous
Available memory	1 TB
Start Mode	Immediate, Delayed
Duration	1 ms to 10,000 hours

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Moku:Delta Waveform Generator

Description

Moku:Delta Waveform Generator enables you to generate eight independent waveforms with a maximum frequency of 2 GHz. Select between sine, square, ramp, pulsed, noise or DC waveform shapes. Add high-bandwidth modulation of phase, frequency, amplitude, or pulse width, or generate triggered bursts or sweeps manually, or from an internal or external source.



Features

- Generate eight independent phase coherent waveforms from DC to 2 GHz.
- Five built-in waveforms: sine, square, ramp, pulse, noise, and DC.
- Broadband FM, AM, PM, and PWM modulation from internal waveform, cross-channel, or external input sources.
- Versatile trigger options: from manual, external input, dedicated TTL trigger port, or another channel.
- 10 & 100 MHz reference input and output for precise phase synchronization.

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Common characteristics

Overview

Channels	8
Bandwidth (maximum output frequency)	2 GHz (1 V_{pp} into 50 Ω), 100 MHz (10 V_{pp} into 50 Ω)
Sampling rate	5 GSa/s per channel, interpolated to 10 GSa/s
Output impedance	50 Ω
Total harmonic distortion	-60 dBc at 100 kHz
Waveforms	Sine, Square, Ramp, Pulse, Noise, DC

Amplitude

Range	1 mV_{pp} to 1 V_{pp} into 50 Ω (> 100 MHz) 1 mV_{pp} to 10 V_{pp} into 50 Ω (<= 100 MHz)
Offset error	< 500 µV into 50 Ω
Resolution	100 µV
Units	V_{pp}, dBm

DC offset

Range (peak AC + DC)	± 5 V into 50 Ω
Resolution	100 µV

Phase offset

Range	0° to 360°
Resolution	0.000 001°

Waveform characteristics

Sine

Frequency range	1 mHz to 2 GHz

Square

Frequency range	1 mHz to 300 MHz

Ramp

Frequency range	1 mHz to 300 MHz
Symmetry[14]	5% to 95% at 100 MHz 1% to 99% at 20 MHz 0.05% to 99.95% at 1 MHz

[14] Symmetry is limited by the minimum rise time of 2 ns and number of harmonics required to maintain a linearity of more than 99%.

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Pulse

Frequency range	1 mHz to 300 MHz
Period range	1 ks to 3 ns
Pulse width	500 ps to (period – edge time)
Edge time	500 ps to pulse width
Edge time resolution	100 ps

Noise

Amplitude	Up to 10 Vpp, minimum 1 mV
Resolution	100 µV
DC offset	Up to 4.9995 V

Modulation

Amplitude

Carrier waveforms	Sine, Square, Ramp, Pulse, Noise
Source	Ch1: Input 1, Input 2, Input 3, Input 4, Output 2, Output 3, Output 4, Internal Ch2: Input 1, Input 2, Input 3, Input 4, Output 1, Output 3, Output 4, Internal Ch3: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 4, Internal Ch4: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 3, Internal Ch5: Input 5, Input 6, Input 7, Input 8, Output 6, Output 7, Output 8, Internal Ch6: Input 5, Input 6, Input 7, Input 8, Output 5, Output 7, Output 8, Internal Ch7: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 8, Internal Ch8: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 7, Internal
Internal modulation	Sine
Frequency	1 mHz to 156 MHz
Depth	0% to 100%

Frequency

Carrier waveforms	Sine, Square, Ramp, Pulse

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Frequency

Source	Ch1: Input 1, Input 2, Input 3, Input 4, Output 2, Output 3, Output 4, Internal Ch2: Input 1, Input 2, Input 3, Input 4, Output 1, Output 3, Output 4, Internal Ch3: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 4, Internal Ch4: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 3, Internal Ch5: Input 5, Input 6, Input 7, Input 8, Output 6, Output 7, Output 8, Internal Ch6: Input 5, Input 6, Input 7, Input 8, Output 5, Output 7, Output 8, Internal Ch7: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 8, Internal Ch8: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 7, Internal
Internal modulation	Sine
Frequency	1 mHz to 156 MHz
Deviation (carrier + deviation)	1 mHz to 2 GHz

Phase

Carrier waveforms	Sine, Square, Ramp, Pulse
Source	Ch1: Input 1, Input 2, Input 3, Input 4, Output 2, Output 3, Output 4, Internal Ch2: Input 1, Input 2, Input 3, Input 4, Output 1, Output 3, Output 4, Internal Ch3: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 4, Internal Ch4: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 3, Internal Ch5: Input 5, Input 6, Input 7, Input 8, Output 6, Output 7, Output 8, Internal Ch6: Input 5, Input 6, Input 7, Input 8, Output 5, Output 7, Output 8, Internal Ch7: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 8, Internal Ch8: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 7, Internal
Internal modulation	Sine
Frequency	DC to 156 MHz
Phase shift	0.0° to 360.0°

Burst

Modes of Operation	Start, N-Cycle, Gated
N-Cycle range	1 to 1,000,000

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Burst

Trigger Sources	Ch1: Input 1, Input 2, Input 3, Input 4, Output 2, Output 3, Output 4, Internal, Manual Ch2: Input 1, Input 2, Input 3, Input 4, Output 1, Output 3, Output 4, Internal, Manual Ch3: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 4, Internal, Manual Ch4: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 3, Internal, Manual Ch5: Input 5, Input 6, Input 7, Input 8, Output 6, Output 7, Output 8, Internal Ch6: Input 5, Input 6, Input 7, Input 8, Output 5, Output 7, Output 8, Internal Ch7: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 8, Internal Ch8: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 7, Internal

Sweep

Sweep Frequency Start/End	Sine: 1 mHz to 2 GHz Square, Ramp, Pulse: 1 mHz to 300 MHz
Sweep Time	1 ms to 1 ks
Trigger Sources	Ch1: Input 1, Input 2, Input 3, Input 4, Output 2, Output 3, Output 4, Internal, Manual Ch2: Input 1, Input 2, Input 3, Input 4, Output 1, Output 3, Output 4, Internal, Manual Ch3: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 4, Internal, Manual Ch4: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 3, Internal, Manual Ch5: Input 5, Input 6, Input 7, Input 8, Output 6, Output 7, Output 8, Internal Ch6: Input 5, Input 6, Input 7, Input 8, Output 5, Output 7, Output 8, Internal Ch7: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 8, Internal Ch8: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 7, Internal
Nominal Trigger Level	Input Channel: configurable Output Channel: configurable External trigger: 1 V threshold

Pulse Width Modulation

Pulse Width Deviation	Programmable pulse width deviation with warnings if pulse width <0 or exceeds pulse period

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Pulse Width Modulation

PWM sources	Ch1: Input 1, Input 2, Input 3, Input 4, Output 2, Output 3, Output 4, Internal Ch2: Input 1, Input 2, Input 3, Input 4, Output 1, Output 3, Output 4, Internal Ch3: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 4, Internal Ch4: Input 1, Input 2, Input 3, Input 4, Output 1, Output 2, Output 3, Internal Ch5: Input 5, Input 6, Input 7, Input 8, Output 6, Output 7, Output 8, Internal Ch6: Input 5, Input 6, Input 7, Input 8, Output 5, Output 7, Output 8, Internal Ch7: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 8, Internal Ch8: Input 5, Input 6, Input 7, Input 8, Output 5, Output 6, Output 7, Internal

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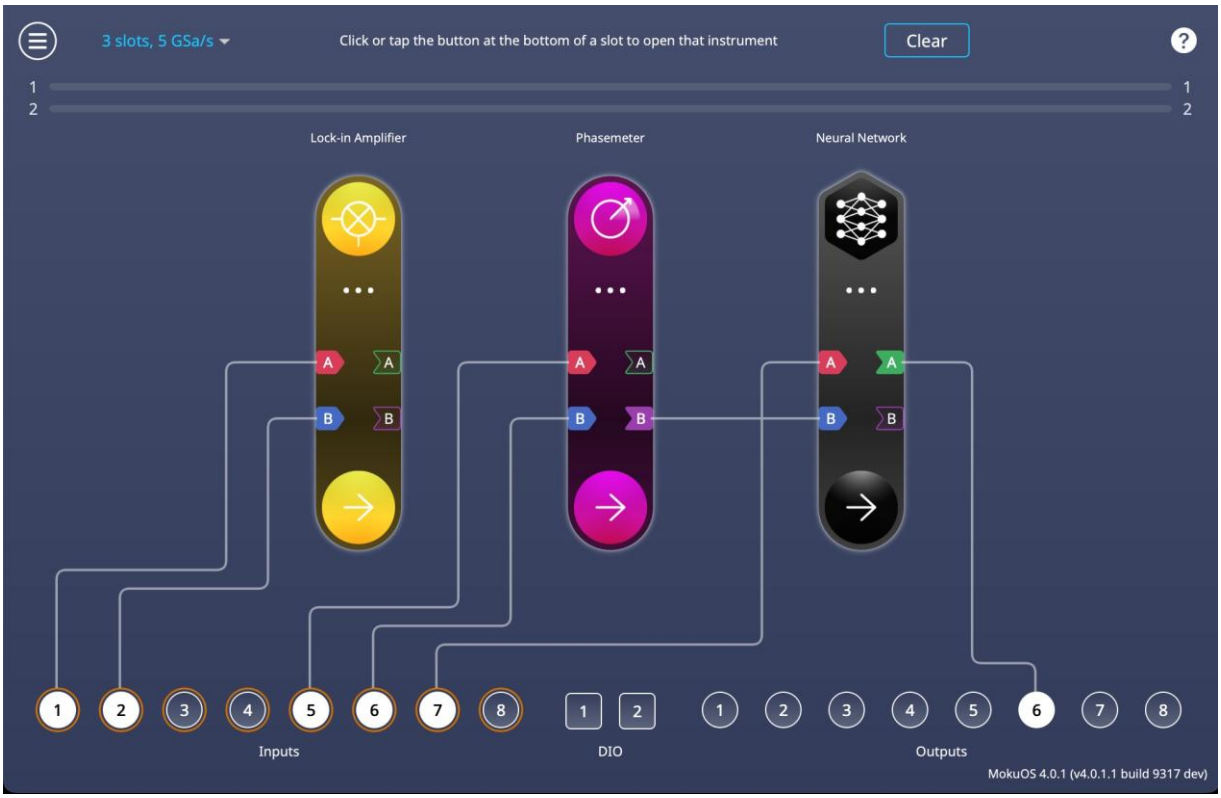
Moku:Delta Multi-Instrument Mode

Description

Moku:Delta Multi-Instrument Mode enables you to deploy either three, five, or eight instruments and operate them simultaneously. These instruments can exchange high-speed, low latency signals between themselves in the digital domain at 80 Gb/s. Source signals from the real world via the blended ADCs and drive signals to the real world via the high-speed digital-to-analog converters. Connect instrument slots to build customized signal processing chains or drop a custom configuration in one or more slots with Moku Custom Instrument.



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Features

- Configure three, five, or eight independent instruments, operating simultaneously
- Each of the instrument slots has up to four inputs and up to four outputs
- Flexible multiplexing allows all eight slots to access all eight ADC inputs, all eight DAC outputs and either of the 16 digital I/O ports
- High-speed, 80 Gb/s inter-instrument communication with drag and drop setup
- Use up to four internal bus channels to route signals between instruments
- Configurable input and output ranges, slot synchronization

Common characteristics

Overview

Instruments	Up to 8, each with up to 4 inputs and up to 4 outputs
Internal digital buses	2 for 3 slots, 3 for 5 slots, and 4 for 8 slots
Inputs / outputs	8 analog inputs, 8 analog outputs, 2 ports of 16 digital I/Os
Input ranges	100 mVpp, 1 Vpp, 10 Vpp (50 Ω). : 40 Vpp (1 M Ω)
Input bandwidth	2 GHz, user selectable 6 GHz analog path
Input sampling rate	3 slots : 5 GSa/s per channel 5 slots : 1.25 GSa/s per channel 8 slots : 625 MSa/s per channel
Input impedance	50 Ω / 1 M Ω
Output ranges	1 V_{pp}, 10 V_{pp} into 50 Ω
Output bandwidth	2 GHz at 1 V_{pp}, <= 100 MHz at 10 V_{pp}

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Overview

Output sampling rate	3 slots : 5 GSa/s per channel 5 slots : 1.25 GSa/s per channel 8 slots : 625 MSa/s per channel
Output impedance	50 Ω

Instrument slot

Inter-slot communication	Up to 4 input channels, up to 4 output channels, each with 16 bit resolution at 5 GSa/s (3 slot), 1.25 GSa/s (5 slot), or 625 MSa/s (8 slot)
Available instruments	Arbitrary Waveform Generator Data Logger Digital Filter Box FIR Filter Builder Frequency Response Analyzer Gigabit Streamer Gigabit Streamer+ Laser Lock Box Lock-in Amplifier Logic Analyzer Neural Network Oscilloscope Phasemeter PID Controller Spectrum Analyzer Time & Frequency Analyzer Waveform Generator Custom Instrument Custom Instrument+

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