Moku:Lab

Specifications

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Hardware

Specifications

Analog I/O

Analog inputs

Channels	2
Bandwidth (-3 dB)	200 MHz into 50 Ω
Sampling rate	500 MSa/s per channel
Resolution	12-bit
Maximum voltage range	10 V_{pp} into 50 Ω with 20 dB attenuation
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC
AC coupling corner (-3 dB)	100 Hz into 50 Ω 30 Hz into 1 MΩ
SNR	60 dBFS (per sample)
Input referred noise	30 nV/√Hz above 100 kHz
Connector	BNC

Analog outputs

Channels	2
Bandwidth (-3 dB)	>300 MHz
Sampling rate	1 GSa/s per channel
Resolution	16-bit
Voltage range	2 V_{pp} into 50 Ω
Output impedance	50 Ω
Output coupling	DC
Connector	BNC

External trigger input

External trigger

Trigger waveform	TTL compatible
Trigger bandwidth	DC to 5 MHz
Trigger impedance	Hi-Z
Min trigger level	1.8 V
Max trigger level	5 V
Connector	BNC

Clock reference

On-board clock

Frequency	10 MHz
Stability	< 500 ppb

10 MHz reference input

Expected waveforms	Sine / square
Frequency	10 MHz ± 250 kHz
Input range	-10 dBm to +10 dBm
Connector	BNC

10 MHz reference output

Waveform type	Square
Output frequency	10 MHz
Output level	-3 dBm
Connector	BNC

General characteristics

General and environmental characteristics

Power consumption	20 W typical 30 W when charging USB
Power voltage range	100 to 240 V, 50/60 Hz
Temperature	Operating: 0 to +45 °C Non-operating: -10 to +60 °C

Electromagnetic compliance

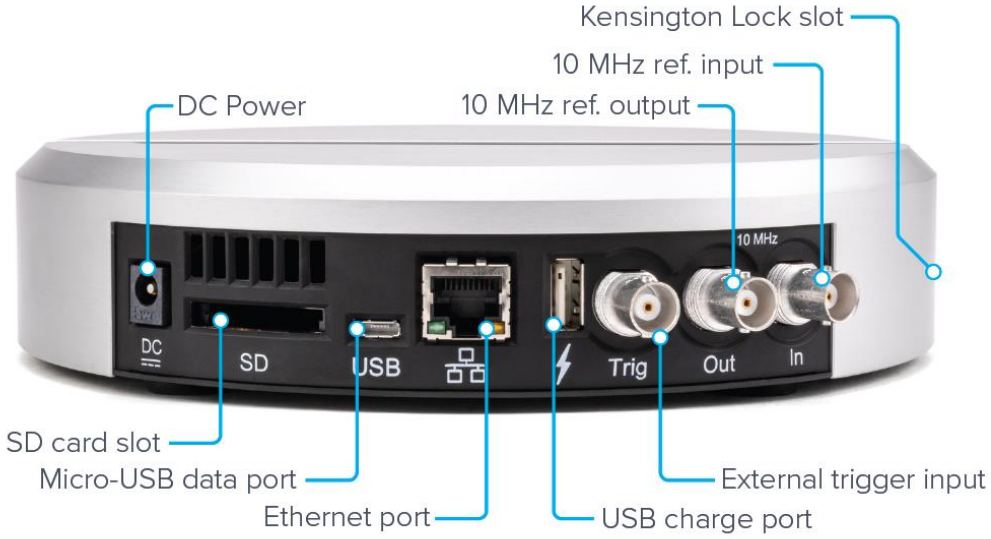
Physical characteristics

Dimensions	Diameter: 22 cm (8.66 in.) Height: 4.3 cm (1.70 in.)
Weight	1.69 kg (3.73 lbs)
Security	Kensington lock compatible

General connectivity

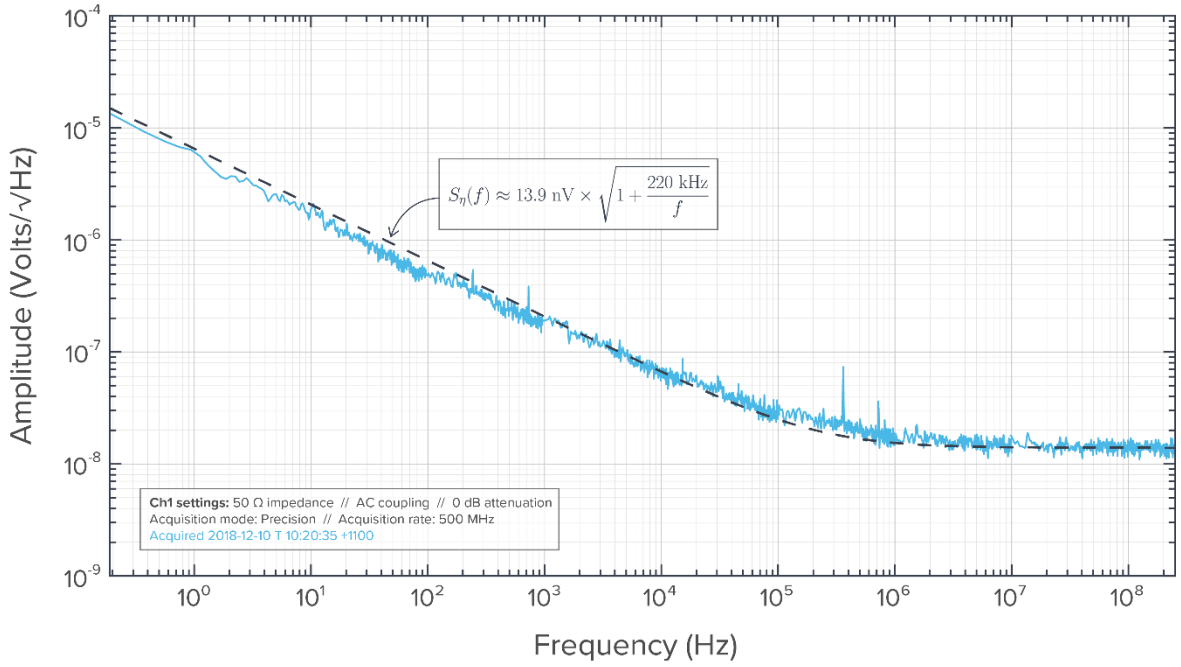
Connectivity

Analog inputs	2 x BNC
Analog outputs	2 x BNC
Network	Ethernet (10/100 Base-T) Wi-Fi 802.11 b/g/n
USB data port	Micro-USB // For connecting the iPad to the Moku:Lab via USB Requires an Apple USB connection kit and Micro-USB to USB cable
USB charge port	Type-A // For iPad charging only (no data connectivity) Maximum power draw 10 W
SD card	16 GB class 10 supplied
External trigger input	BNC
10 MHz clock reference input	BNC
10 MHz clock reference output	BNC
DC Power	12 V (power module supplied)

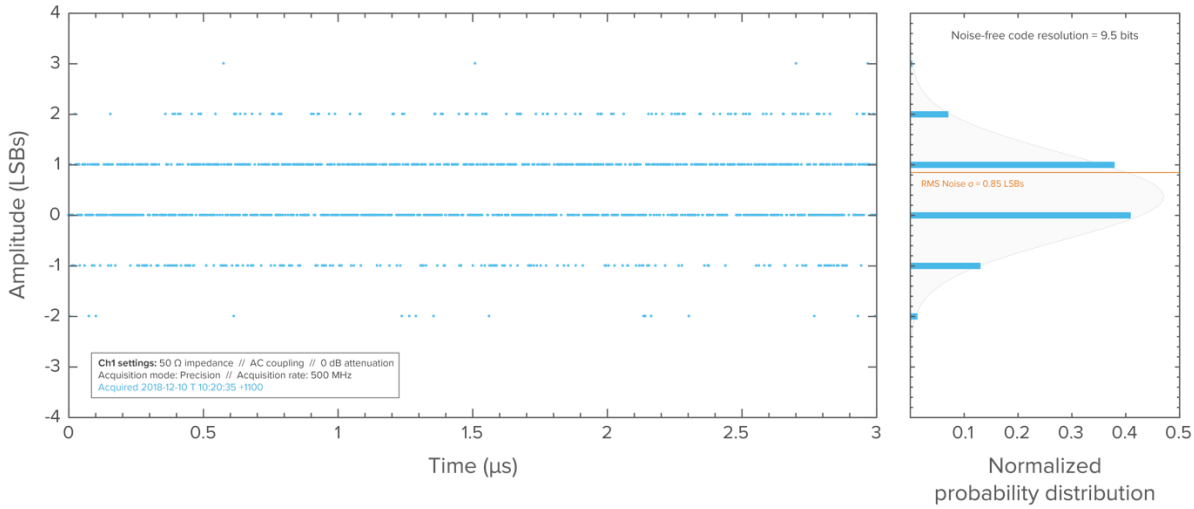


Hardware measurements

ADC input noise

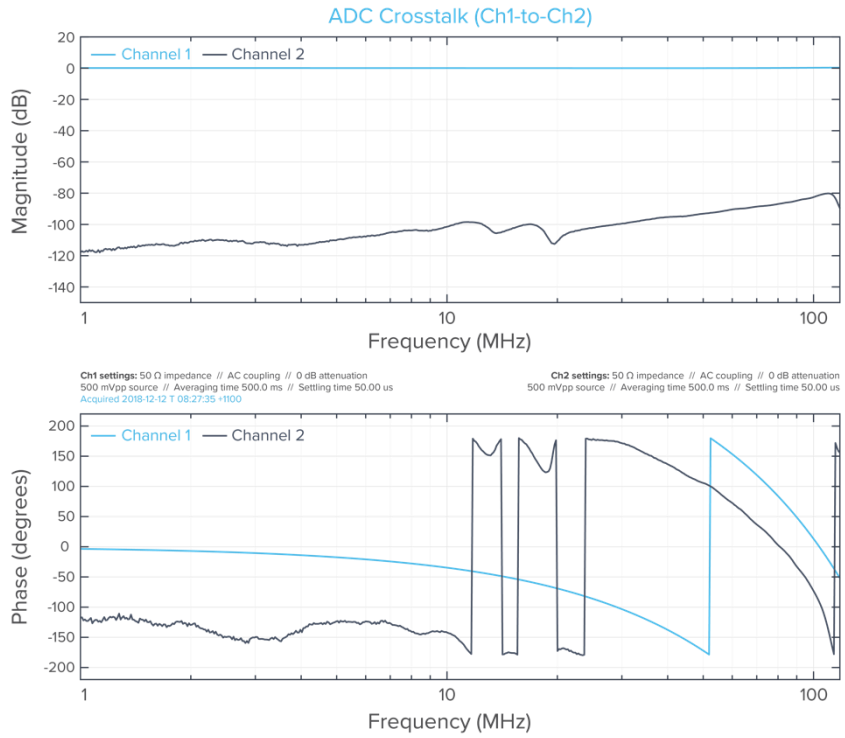


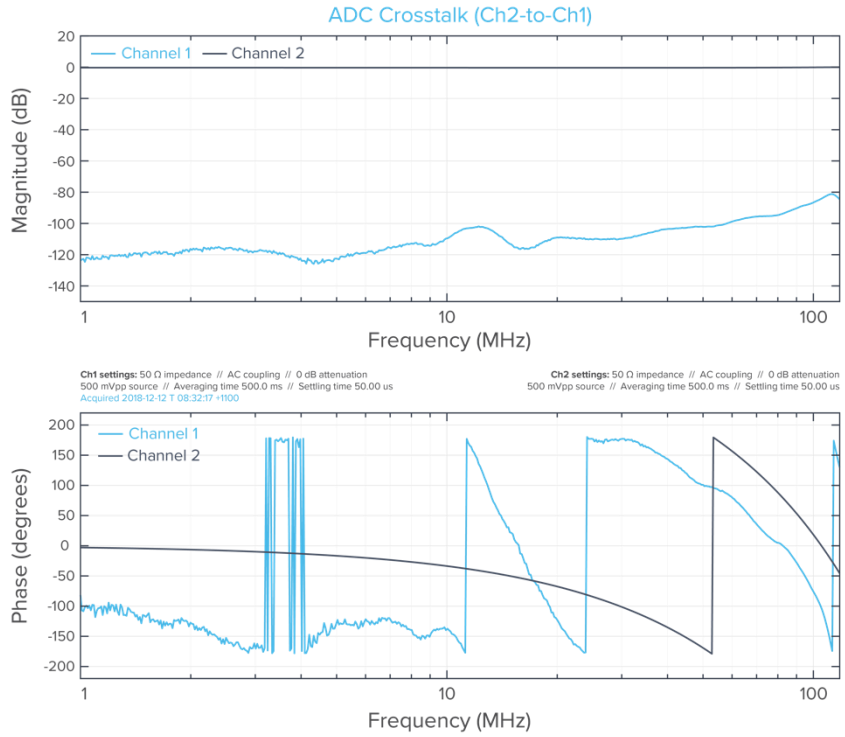
ADC Noise-Free Code Resolution



ADC crosstalk

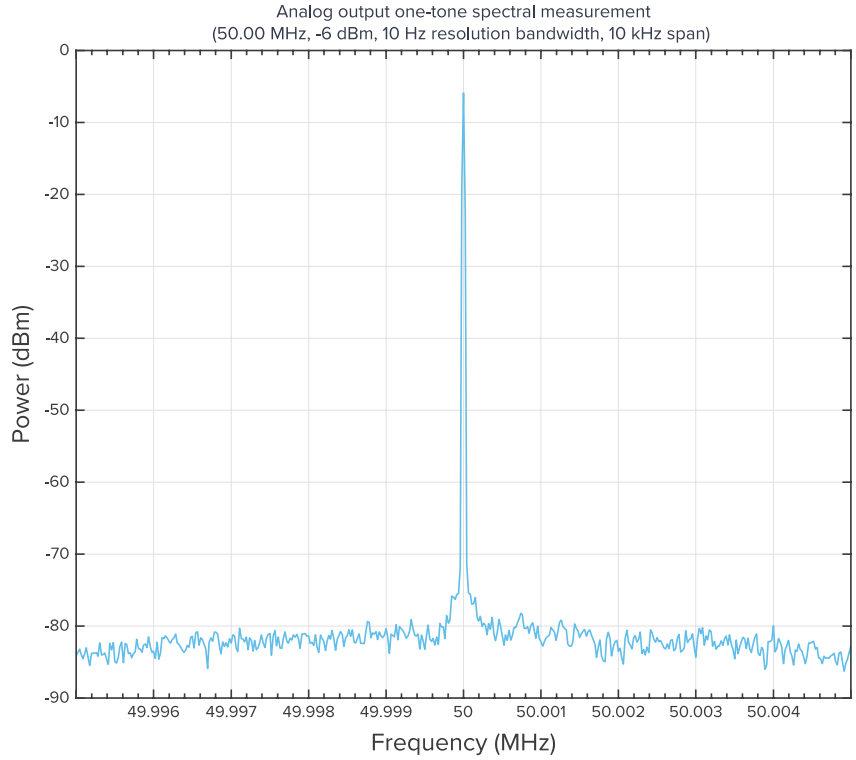
50 Ω // AC coupled // 0 dB attenuation



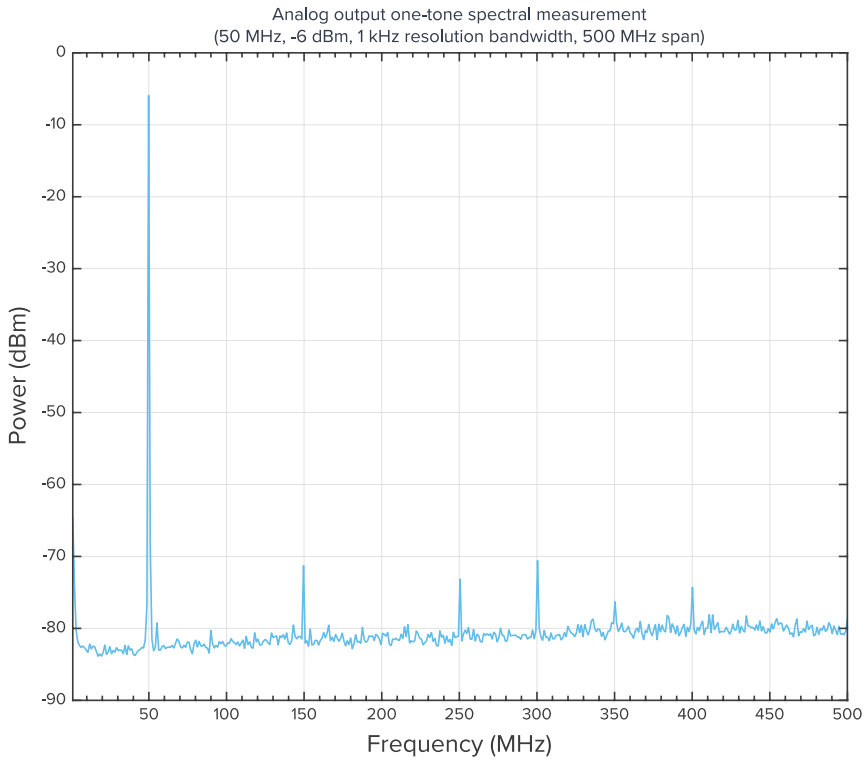


Analog output noise

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



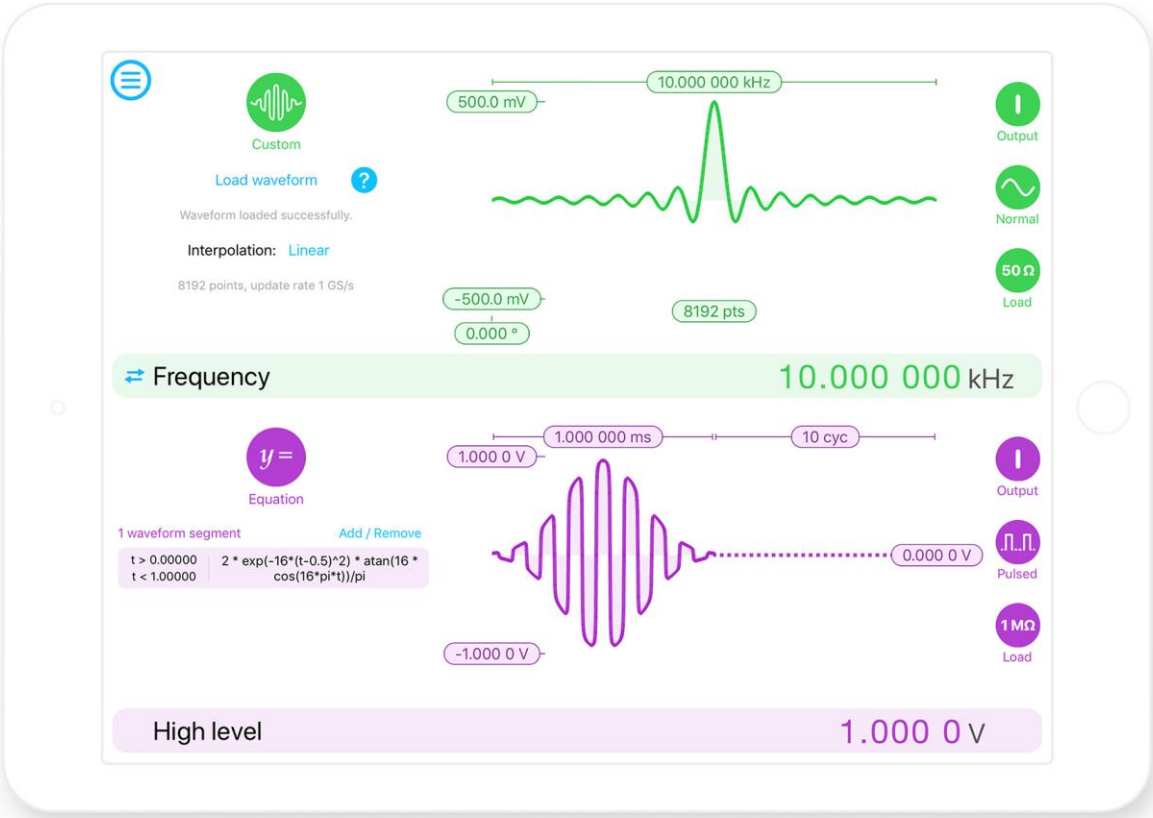
One-tone spectral measurement (50 MHz, -6 dBm, 1 kHz RBW, 500 MHz span)



Arbitrary Waveform Generator

Description

Moku:Lab's Arbitrary Waveform Generator can generate custom waveforms with up to 65,536 points at sample rates of up to 1 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 pulsed mode, waveforms can be output with more than 250,000 cycles of dead time between pulses, allowing you to excite your system with an arbitrary waveform at regular intervals over extended periods of time.



Features

- Select a pre-set waveform, load custom waveforms from a file, or describe your waveform mathematically using the in-built equation editor
- Configure pulsed arbitrary waveforms with up to 250,000 cycles of dead time between pulses
- Synchronize the phase of both output channels
- Generate arbitrary waveforms with up to 65,536 points

Specifications

Common

Overview

Channels	2
Bandwidth (-3 dB)	> 300 MHz into 50 Ω
Sampling rate	1 GSa/s per channel
Source impedance	50 Ω
Output load	50 Ω / 1 MΩ
Waveforms	Sine, Gaussian, Exponential Fall, Exponential Rise, Sinc, Equation, Custom (from file)

Amplitude

Output voltage range	± 1 V into 50 Ω ± 2 V into 1 MΩ
Resolution	100 µV

DC offset

Range (peak AC + DC)	± 1 V into 50 Ω ± 2 V into high-impedance
Resolution	100 µV

Phase offset

Range	0º to 360º
Resolution	0.001º

Waveform

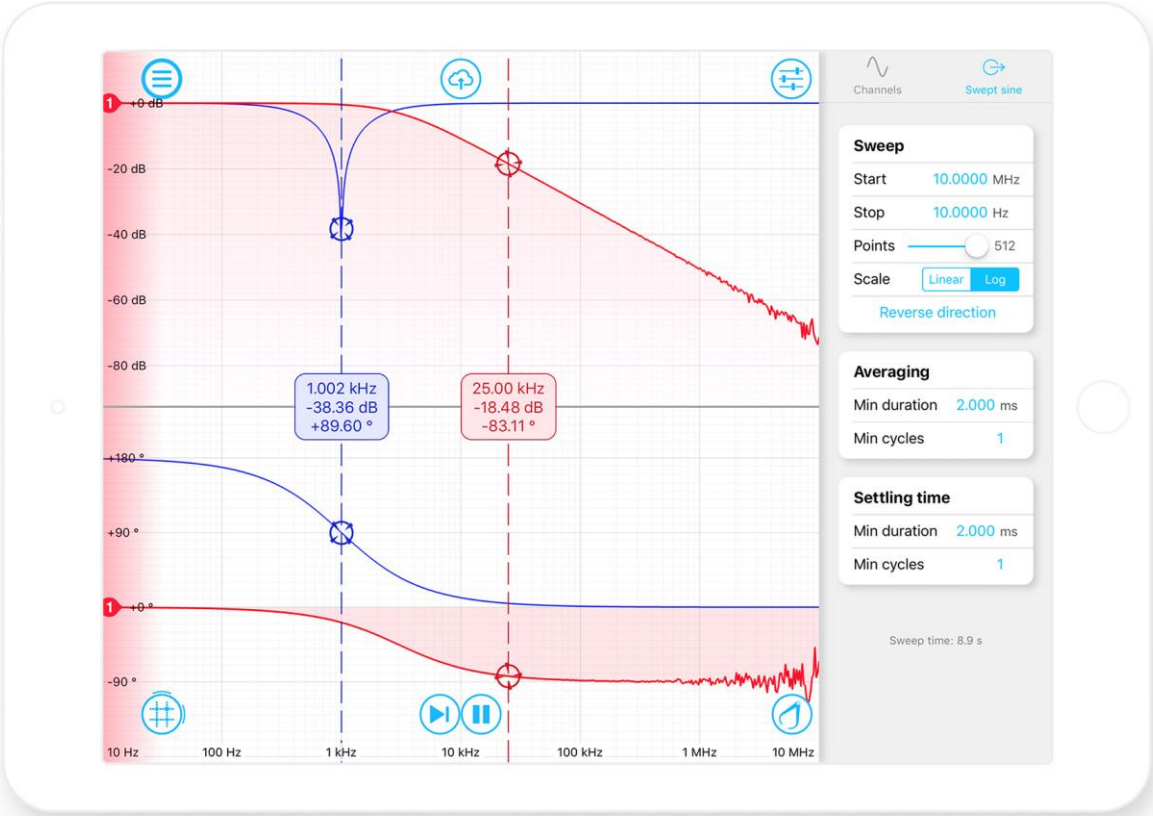
Custom

Maximum output rate	125 MSa/s	65536 points
	250 MSa/s	32768 points
	500 MSa/s	16384 points
	1 GSa/s	8192 points
Text file type	Comma- or newline-delimited text	
File import options	SD card, Clipboard, My Files	
Interpolation	None, Linear	
Minimum edge time	2 ns	
Overshoot	≤ 10% for edge times between 2 ns and 8 ns ≤ 2% for edge times greater than 8 ns	
Jitter (cycle-to-cycle)	< 1 ns	
Pulse width	2 ns to period	
Period range	1000 s to 10 ns	

Frequency Response Analyzer

Description

Moku:Lab's Frequency Response Analyzer enables you to measure the frequency response of a system in both magnitude and phase using a swept sine output from 10 mHz to 120 MHz. Select from between 32 and 512 points per sweep and configure settling and averaging time to balance total sweep duration and signal-to-noise ratio.



Features

- Measure the frequency response of a system from 10 mHz up to 120 MHz
- Select between Linear or logarithmic sweep scales
- Probe two systems simultaneously or one system at two points
- Add, subtract, multiply or divide response functions as they are acquired with a dedicated math channel
- Use cursors and markers to accurately measure features in both magnitude and phase
- Precisely adjust settling and averaging time to suit device under test
- Calibrate your measurement to compare systems or compensate for delays

Specifications

Source

Source

Waveform	Sine
Frequency range	10 mHz to 120 MHz
Frequency resolution	3.55 µHz
Sweep type	Linear / Logarithmic
Sweep points	32, 64, 128, 256, 512
Output amplitude range	±0.5 mV to ±1 V into 50 Ω
Output load	50 Ω / 1 MΩ
Source impedance	50 Ω

Input

Input characteristics

Input impedance	50 Ω / 1 MΩ	
Input coupling	AC / DC	
Input attenuation	0 dB / 20 dB	
Input voltage range	± 0.5 V into 50 Ω with 0 dB attenuation ± 5 V into 50 Ω with 20 dB attenuation	
Input noise	30 nV/√Hz above 100 kHz	
Flatness prior to calibration	10 mHz to 100 kHz	< 0.02 dB into 50 Ω < 0.05 dB into 1 MΩ
	100 kHz to 1 MHz	< 0.02 dB into 50 Ω < 0.03 dB into 1 MΩ
	1 MHz to 50 MHz	< 0.3 dB into 50 Ω < 0.7 dB into 1 MΩ
	1 MHz to 120 MHz	< 0.7 dB into 50 Ω < 2.2 dB into 1 MΩ
Crosstalk	< 80 dB at 50 Ω < 60 dB at 1 MΩ	

Measurement

Measurement characteristics

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
Noise-floor • 100 ms averaging time • 500 mV_{pp} amplitude • DC coupled input	10 mHz to 100 kHz	-100 dB into 0 dB attenuation -80 dB into 20 dB attenuation
	100 kHz to 1 MHz	-125 dB into 0 dB attenuation -105 dB into 20 dB attenuation
	1 MHz to 50 MHz	-130 dB into 0 dB attenuation -110 dB into 20 dB attenuation
	50 MHz to 120 MHz	-120 dB into 0 dB attenuation -100 dB into 20 dB attenuation
Calibration	Calibrates magnitude and phase using a reference sweep[1]	
Calibrated gain error	<0.05 dB	
Calibrated phase error	< 0.5°	

Saving Data

Saving data

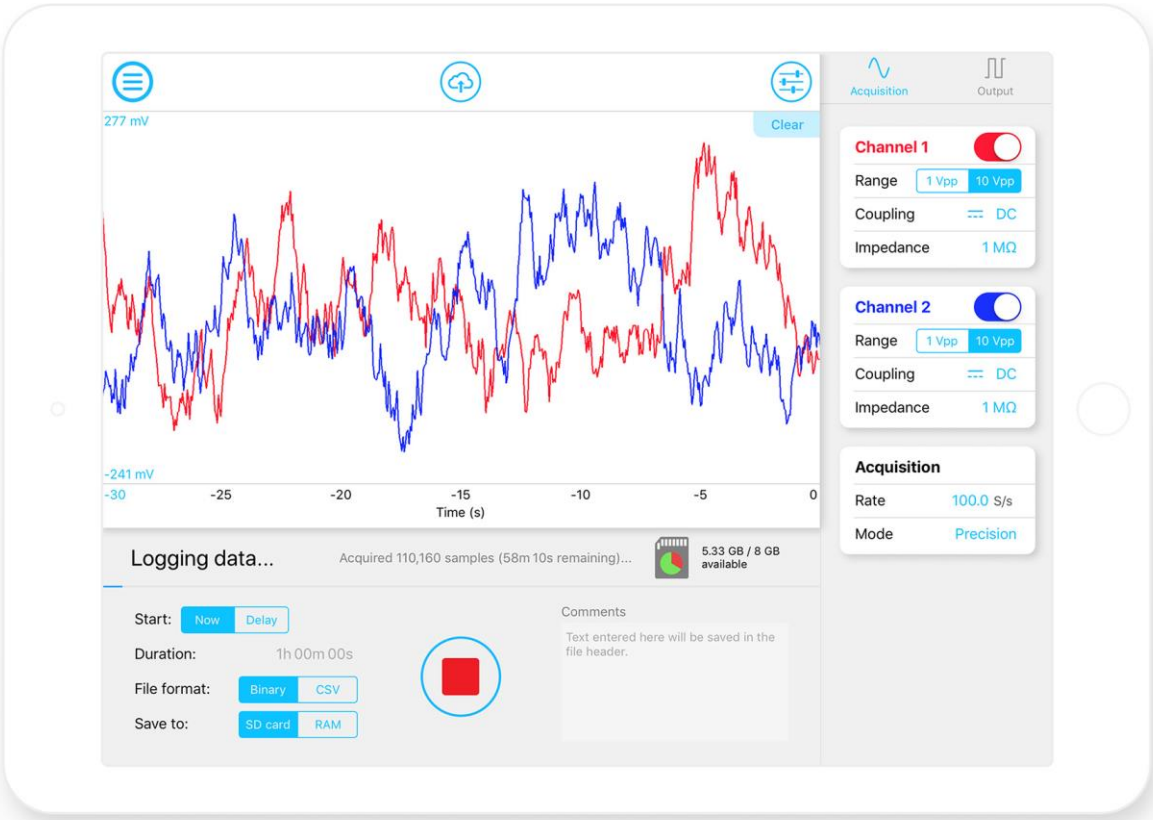
File formats	Plain text: records data using a standard *.csv format
	Binary: records data using MathWorks' *.mat format which can be opened using MATLAB
Export modes	SD Card, Dropbox, E-mail and iCloud, My Files (iOS 11)

[1] The calibration 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:Lab's analog frontend.

Data Logger

Description

Moku:Lab's Data Logger enables you to log data directly to an SD card for long-term measurements at rates of up to 100 kSa/s, where the duration is limited only by the capacity of the SD card. Data can also be acquired at up to 1 MSa/s by saving directly to Moku:Lab's internal memory. Data saved to Moku:Lab's internal memory can be uploaded to the cloud for analysis once the measurement is complete.



Features

- Record two channels of data at up to 100 kSa/s to SD card and 1 MSa/s to internal storage
- Effortlessly upload recorded data to the cloud for analysis

Specifications

Input

Voltage

Input voltage range	± 0.5 V into 50 Ω with 0 dB attenuation ± 5 V into 50 Ω with 20 dB attenuation
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC

Logging

Acquisition

File formats	Plain text: records data using a standard *.csv format
	Binary: records data using a proprietary *.li format for high-speed data logging. **Note:** data saved using the *.li format must be converted to plain text using the LI file converter available here: https://github.com/liquidinstruments/lireader
Export modes	SD Card, Dropbox, E-mail and iCloud, My Files (iOS 11)
Maximum sampling rate	1 MSa/s into RAM (format: *.li binary) 100 kSa/s into SD card (format: *.li binary) 20 kSa/s into RAM / SD card (format: *.csv) **Note:** data saved to the Moku:Lab's on-board RAM will be lost when the device is rebooted.
Delayed log start time	Up to 240 hours
Log duration	1 second up to 240 hours

Digital Filter Box

Description

With Moku:Lab's Digital Filter Box, you can interactively design and generate different types of infinite impulse response filters with output sampling rates of 122 kHz and 15.625 MHz. Select between lowpass, highpass, bandpass and bandstop filter shapes with up to seven fully configurable types including Butterworth, Chebyshev and Elliptical.

Features

- Design IIR filters using an interactive Bode plot
- Observe signals at different stages in the digital signal processing chain using probe points
- View the frequency response of your filter in both magnitude and phase
- Filter up to two channels of data simultaneously with the ability to blend input signals using a control matrix
- Implement custom filters by uploading your own coefficients

Specifications

Inputs

Input characteristics

Channels	2
Input control matrix coefficients	-20 to +20
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC
Input attenuation	0 dB / 20 dB
Input voltage range	± 0.5 V into 50 Ω with 0 dB attenuation

Filter characteristics

Pre-filter

Input offset range	± 500 mV
Input offset resolution	100 µV
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 µV
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	122 kHz, 15.625 MHz
Filter types	Butterworth, Chebyshev I, Chebyshev II, Elliptic, Bessel, Gaussian, Legendre
Passband ripple	0.1 dB to 10 dB
Stopband attenuation	10 dB to 100 dB
Zoom view	Allows the user to zoom in on the filter's frequency response

Low-pass filter

Filter order	2, 4, 6, 8
Low-pass corner frequency	1.221 Hz to 48.83 kHz at 122 kHz sampling rate 156.3 Hz to 6.250 MHz at 15.625 MHz sampling rate

High-pass filter

Filter order	2, 4, 6, 8
High-pass corner frequency	1.221 Hz to 48.83 kHz at 122 kHz sampling rate 156.3 Hz to 6.250 MHz at 15.625 MHz sampling rate

Band-pass / band-stop filter

Filter order	2, 4
Low corner frequency	1.221 Hz to 48.83 kHz at 122 kHz sampling rate 156.3 Hz to 6.250 MHz at 15.625 MHz sampling rate
High corner frequency	2.002 Hz to 48.83 kHz at 122 kHz sampling rate 256.3 Hz to 6.250 MHz at 15.625 MHz sampling rate
Minimum bandwidth	770 mHz at 122 kHz sampling rate 100 Hz at 15.625 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-round 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.
Elliptical	Elliptical (Cauer) filters have ripple in both passband and stopband, but also have the sharpest possible transition. Elliptical filters are useful in applications requiring extremely aggressive stopband attenuation.
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, and 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.

FIR Filter Builder

Description

With Moku:Lab's FIR Filter Builder, you can design and implement lowpass, highpass, bandpass, and bandstop finite impulse response (FIR) filters with up to 14,819 coefficients at a sampling rate of 244.1 kHz. Moku:Lab's iPad interface allows you to fine tune your filter's response in the frequency and time domains to suit your specific application. Select between four frequency response shapes, five common impulse responses, and up to eight window functions.

Features

- Design filters in the time domain or in the frequency domain using common impulse responses and window functions
- Upload your own filter coefficients, or define your own custom impulse response mathematically using an equation editor
- View your filter's transfer function, impulse and step response, or group and phase delay
- Save measurement data to SD card or the cloud at the touch of a button

Specifications

Inputs

Input characteristics

Channels	2
Input control matrix coefficients	-20 to +20
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC
Input attenuation	0 dB / 20 dB
Input voltage range	± 0.5 V into 50 Ω with 0 dB attenuation ± 5 V into 50 Ω with 20 dB attenuation

Filter characteristics

Pre-filter

Input offset range	± 1 V
Input offset resolution	100 µV
Input gain range	-40 dB to +40 dB
Input gain resolution	0.1 dB

Post-filter

Output offset range	± 2 V
Output offset resolution	100 µV
Output gain range	-40 dB to +40 dB
Output gain resolution	0.1 dB

General filter characteristics

Sampling rates	122.1 kHz, 244.1 kHz, 488.3 kHz, 976.6 kHz, 1.953 MHz, 3.906 MHz, 7.813 MHz, 15.63 MHz
Number of coefficients	2 to 232 @ 15.63 MHz
	2 to 464 @ 7.813 MHz
	2 to 928 @ 3.906 MHz
	2 to 1856 @ 1.953 MHz
	2 to 3712 @ 976.6 kHz
	2 to 7424 @ 488.3 kHz
	2 to 14819 @ 244.1 kHz and 122.1 kHz
Design domains	Time (impulse response) Frequency (frequency response)

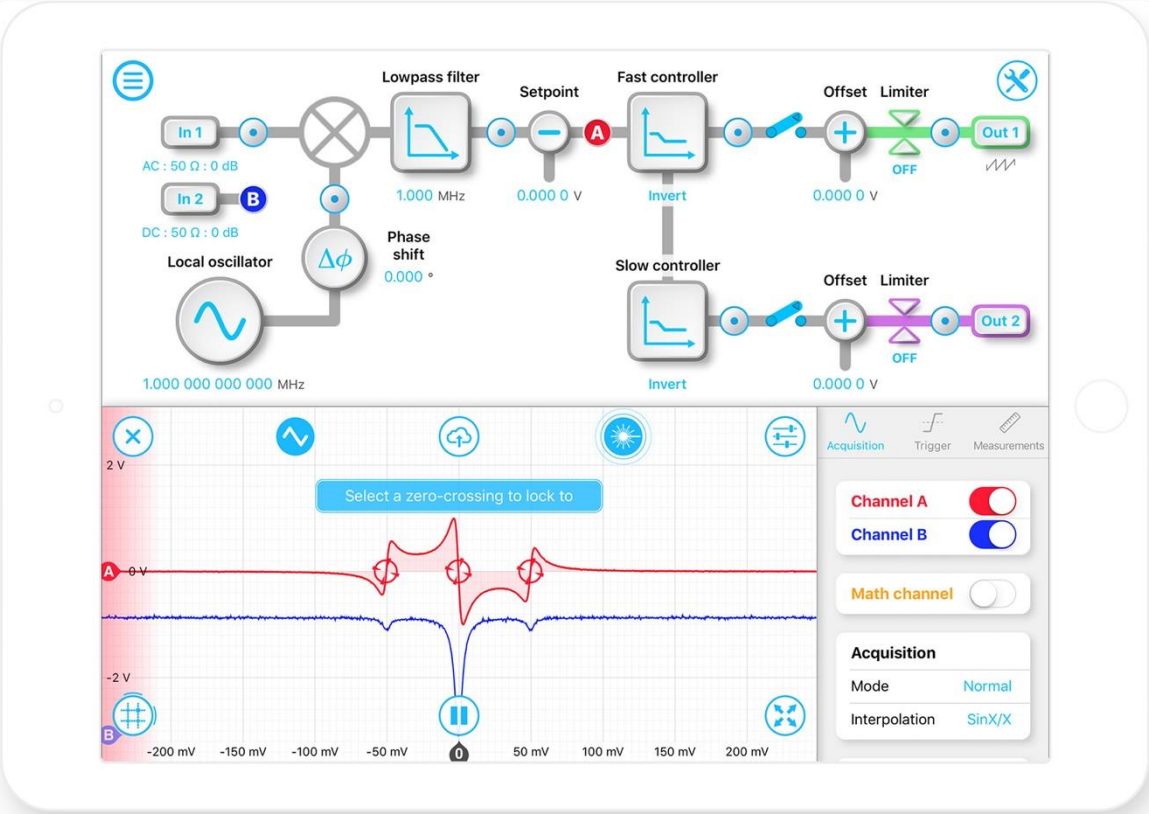
Filter design / configuration

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, Hanning, Hamming, Blackman, Nuttall, Tukey, Kaiser
Minimum filter cut-off frequency	Sampling rate / 10,000 • e.g., f_{min} = 12.21 Hz @ 122.1 kHz
Maximum filter cut-off frequency	Sampling rate / 2 (approximately) • e.g., f_{max} = 59.81 kHz @ 122.1 kHz

Laser Lock Box

Description

Moku:Lab's Laser Lock Box enables you to stabilize a laser's frequency to a reference cavity or atomic transition using high-performance modulation locking techniques. The Laser Lock Box includes a 'Tap-to-Lock' feature, enabling you to quickly lock to any zero-crossing on the demodulated error signal.



Features

- Generate modulation signals at up to 200 MHz
- Demodulate signals with internal or external local oscillators
- Scan resonances with sawtooth or triangle waveforms at up to 1 MHz
- Observe signals at different locations in the signal processing chain using an integrated oscilloscope
- Quickly lock to any zero-crossing in the error signal using the 'Tap-to-Lock' 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

Specifications

Signal input

Signal input

Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
AC coupling corner (-3 dB)	100 Hz into 50 Ω 30 Hz into 1 MΩ
Frequency range	DC to 200 MHz
Input gain[2]	-20 dB / 0 dB / +24 dB / +48 dB
Gain accuracy	± 1%
Input range	10 V_{pp} with -20 dB input gain 1 V_{pp} with 0 dB input gain 60 mV_{pp} with +24 dB input gain 3 mV_{pp} with + 48 dB input gain
Input noise	< 10 nV/√Hz above 1 MHz at 1 V_{pp} input range

Internal demodulation local oscillator

Internal reference waveform

Waveform	Sine
Frequency range	1 mHz to 200 MHz
Frequency resolution	3.55 µHz
Phase offset range	0 to 360°
Phase offset resolution	0.001°
Output impedance	50 Ω
Can be phase-locked to external 10 MHz timebase?	Yes

External demodulation reference

Demodulation reference input

Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
Frequency range	DC to 200 MHz
Input gain	-20 dB / 0 dB
External reference modes	Direct, phase-locked

Phase-locked loop

PLL frequency range	2 MHz to 200 MHz

[2] +24 dB and +48 dB input gains are applied digitally and can be used to maximise the Laser Lock Box's dynamic range for weak input signals

Phase-locked loop

PLL tracking bandwidth	10 kHz
Phase offset range	0 to 360º
Phase offset resolution	0.001º
Orthogonality	90º ± 0.000,002º

Low-pass filter

Low-pass filter

Filter architecture	Infinite Impulse Response (IIR)
Filter shape	Low-pass filter
Sampling rate	31.25 MHz
Filter types	Butterworth, Chebyshev I, Chebyshev II, Elliptic, Bessel, Gaussian, Legendre
Filter order	2, 4
Min. corner frequency	1.040 kHz
Max. corner frequency	14.06 MHz
Passband ripple[3]	0.1 dB to 10 dB
Stopband attenuation[4]	10 dB to 100 dB

Auxiliary oscillator

Auxiliary oscillator waveform

Waveform	Sine
Frequency range	DC to 200 MHz
Frequency resolution	3.55 µHz
Amplitude range (AC)	1 mV_{pp} to 1 V_{pp} into 50 Ω
Amplitude resolution	1 mV
Offset range (DC)	± 1 V
Output limit (AC + DC)	± 1 V into 50 Ω
Amplitude accuracy	1%
Output distortion	< -70 dBc for frequencies lower than 10 kHz < -60 dBc for frequencies greater than 10 kHz
Output impedance	50 Ω
Can be phase-locked to demodulation local oscillator?	Yes

[3] Applies to Chebyshev I and Elliptical filter types.
[4] Applies to Chebyshev II and Elliptical filter types.

Scan waveform

Scanning waveform

Waveform	Sawtooth, Triangle
Frequency range	DC to 1 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)	± 1 V
Output limit (AC + DC)	± 1 V into 50 Ω
Amplitude accuracy	1%
Output impedance	50 Ω

PID Controllers

Set point

Set point range	-1 V to +1 V
Set point resolution	100 µV

Fast controller

Sampling rate	31.25 MHz
Proportional gain	± 60 dB
Integrator crossover frequency	1.25 Hz to 125 kHz
Int. saturation crossover frequency	1.25 Hz to 125 kHz
Integrator gain range	Proportional gain to +60 dB
Differentiator crossover frequency	12.5 Hz to 1.25 MHz
Diff. saturation crossover frequency	12.5 Hz to 1.25 MHz
Differentiator gain range	Proportional gain to +60 dB

Slow controller

Sampling rate	488.28 kHz
Proportional gain	± 60 dB
Integrator crossover frequency	19.53 mHz to 1.953 kHz
Int. saturation crossover frequency	19.53 mHz to 1.953 kHz
Integrator gain range	Proportional gain to +60 dB
Differentiator crossover frequency	195.3 mHz to 19.53 kHz
Diff. saturation crossover frequency	195.3 mHz to 19.53 kHz
Differentiator gain range	Proportional gain to +60 dB

Saving data

Integrated oscilloscope

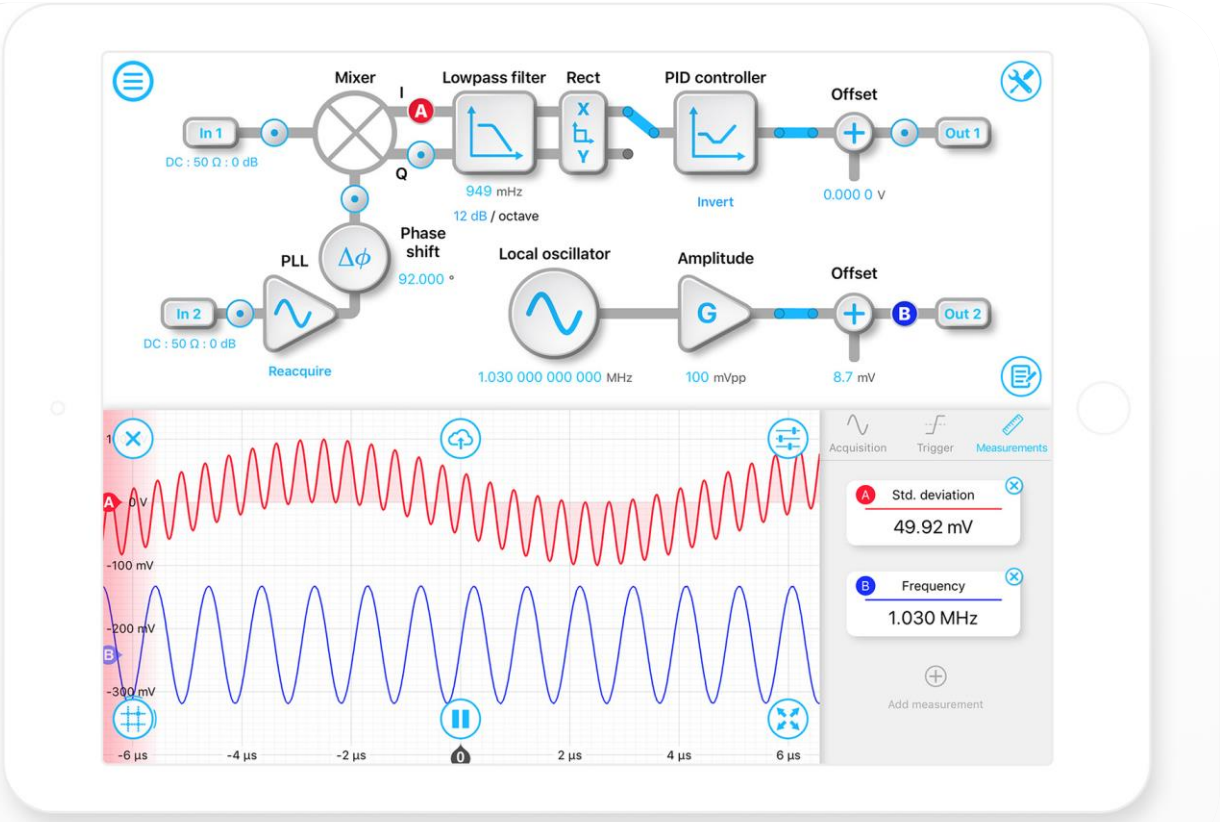
Acquisition mode	Normal, Precision[5]
Maximum sampling rate	500 MSa/s
Memory depth	16,384 Samples per channel 32.7 µs at 2 ns/div
Averaging (linear)	Off, 2 to 100 waveforms
Persistence	Off, 100 ms to 10 s, infinite
Interpolation	Linear, SinX/X, Gaussian

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

Lock-In Amplifier

Description

Moku:Lab's digital Lock-In Amplifier supports dual-phase demodulation (XY/RΘ) from 1 mHz to 200 MHz with up to 120 dB of dynamic reserve. It also features an integrated 2-channel oscilloscope and data logger, enabling you to observe signals at up to 500 MSa/s and log data at up to 1 MSa/s.



Features

- Measure XY or RΘ simultaneously relative to an internal or external reference
- Observe signals at different stages in the signal processing chain using probe points
- Demodulate signals at frequencies up to 200 MHz
- Reveal signals obscured by noise with more than 120 dB dynamic reserve
- Log data from any probe point at up to 1 MSa/s

Specifications

Signal channel

Signal input

Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
AC coupling corner (-3 dB)	100 Hz into 50 Ω 30 Hz into 1 MΩ
Frequency range	DC to 200 MHz
Input attenuation	0 dB / 20 dB
Input range	10 V_{pp} with 20 dB input attenuation 1 V_{pp} with 0 dB input attenuation
Input noise	< 200 nV/√Hz above 1 kHz at 1 V_{pp} input range < 30 nV/√Hz above 100 kHz at 1 V_{pp} input range < 10 nV/√Hz above 1 MHz at 1 V_{pp} input range

External reference

Reference input

Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
Frequency range	DC to 200 MHz
Input attenuation	0 dB / 20 dB
External reference modes	Direct, phase-locked
Direct demodulation	X = Rcosθ
Harmonic distortion	< -60 dBc

Phase-locked loop

PLL frequency range	10 kHz to 200 MHz
PLL tracking bandwidth	10 kHz, 2.5 kHz, 600 Hz, 150 Hz, 40 Hz, 10 Hz
Phase range	0 to 360º
Phase resolution	0.001º
Demodulation	XY / Rθ
Orthogonality	90º ± 0.000,002º

Internal reference

Internal reference waveforms

Waveform	Sine
Frequency range	1 mHz to 200 MHz
Frequency resolution	3.55 µHz
Phase range	0 to 360º
Phase resolution	0.001º

Internal reference waveforms

Demodulation	XY / RΘ
Harmonic demodulation	2F, 3F, ..., nF up to 200 MHz
Orthogonality	90º ± 0.000,002º
Output distortion	< -70 dBc for frequencies lower than 10 kHz < -60 dBc for frequencies greater than 10 kHz

Internal reference auxiliary output

Amplitude range	1 mV_{pp} to 1 V_{pp} into 50 Ω
Amplitude resolution	1 mV
Offset range	± 1 V
Output limit (AC + DC)	± 1 V
Amplitude accuracy	1%
Output impedance	50 Ω
Can be phase-locked to external 10 MHz timebase?	Yes

Demodulator

Demodulator characteristics

Sources	Internal reference oscillator, external direct, external with phase-locked loop
Types	Internal: XY / RΘ External direct: X = RcosΘ External with PLL: XY / RΘ
Filter mode	Low-pass filter
Filter cut-off frequency (-3dB)	300 mHz to 4.97 MHz
Filter time-constant	32 nanoseconds to 0.537 seconds
Filter slope	6, 12, 18, 24 dB per octave
Phase shift precision	0.001º
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
Channel 2 output	Y/Θ, auxiliary oscillator, or local oscillator
Output gain mode	Direct, PID[6]

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

Output characteristics

Gain range (direct)	-80 dB to 160 dB
Phase scale (RΘ mode)	1 V/cycle
Output voltage offset	± 1 V into 50 Ω
Output voltage range (AC + DC)	± 1 V into 50 Ω
Output impedance	50 Ω
D/A conversion	16-bits, 1 GSa/s, 300 MHz analog bandwidth

PID controller

Controller frequency range	100 mHz to 10 MHz
Proportional gain	± 120 dB (XY mode), ± 60 dB (RΘ mode)
Integrator crossover frequency	1 Hz to 100 kHz
Int. saturation crossover frequency	1 Hz to 100 kHz
Integrator gain range	Proportional gain to +120 dB (XY mode), +60 dB (RΘ mode)
Differentiator crossover frequency	10 Hz to 1 MHz
Diff. saturation crossover frequency	10 Hz to 1 MHz
Differentiator gain range	Proportional gain to +120 dB (XY mode), +60 dB (RΘ mode)

Saving data

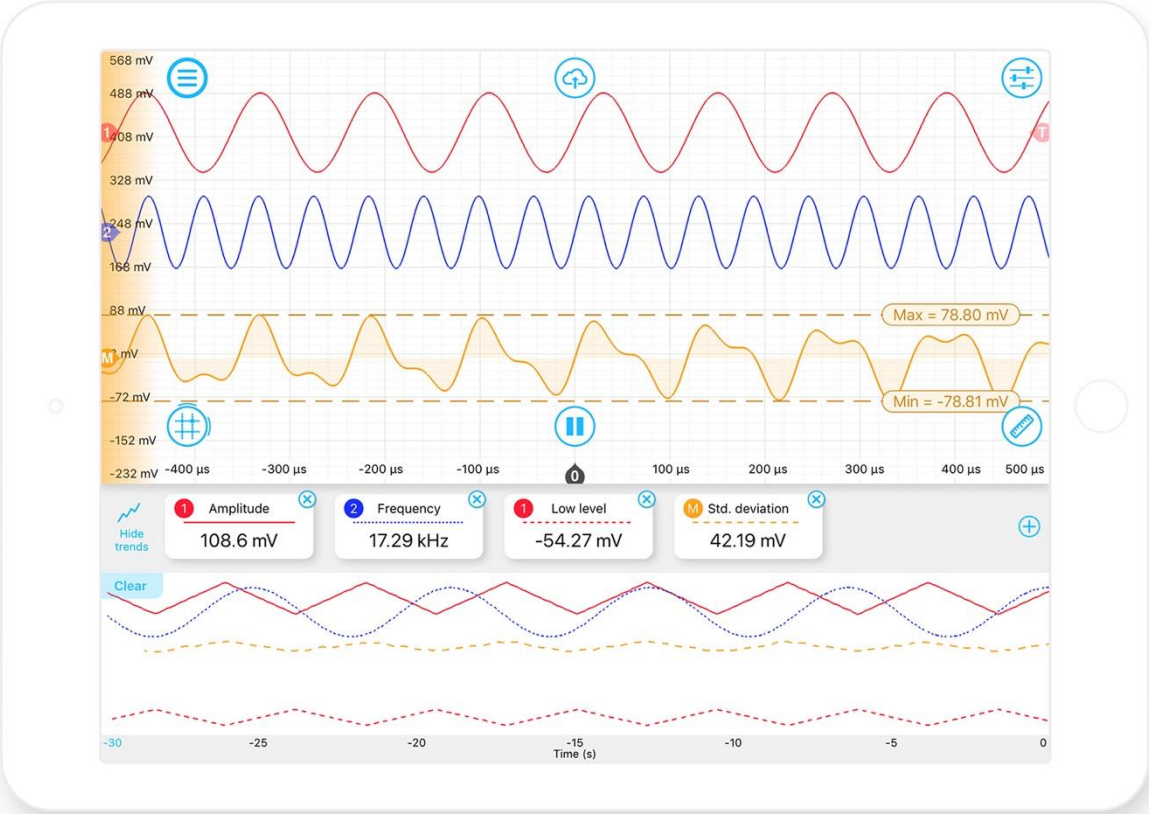
Saving data

File formats	Plain text: records data using a standard CSV format
	Binary: records data using a proprietary LI format.
	Note: data saved using the LI format must be converted to plain text using the LI file converter available here: https://www.liquidinstruments.com/utilities
Maximum sampling rate	1 MSa/s into RAM (format: *.li binary) (single channel) 500 kSa/s into RAM (format: *.li binary) (two channels) 100 kSa/s into SD card (format: *.li binary) 20 kSa/s into RAM / SD card (format: *.csv) **Note:** data saved to the Moku:Lab's on-board RAM will be lost when the device is rebooted.
Export modes	SD Card, Dropbox, E-mail and iCloud, My Files (iOS 11 or later)
Delayed log start time	Up to 240 hours
Log duration	1 second up to 240 hours

Oscilloscope

Description

Moku:Lab's Oscilloscope features two 500 MS/s analog input channels with 200 MHz analog bandwidth, 10 Vpp input voltage range, and user-configurable AC / DC coupling and 50 Ω / 1 MΩ impedance. The Oscilloscope also features two integrated waveform generators capable of producing sine waves at up to 250 MHz and square, sawtooth and triangle waves at up to 100 MHz, enabling it to stimulate a system and measure it's response simultaneously.



Features

- Analyse two voltage channels with a vertical range of ±5 Volts, 200 MHz analog bandwidth, and maximum sampling rate of 500 MSa/s
- Measure data in precision mode to increase measurement resolution by rejecting noise
- Synthesize sine, square, ramp, pulse, and DC waveforms
- Analyse signals in XY mode
- Quickly measure waveform characteristics, trends and statistics

Specifications

Vertical characteristics

Voltage

Channels	2
Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
Input bandwidth (-3 dB)	> 200 MHz into 50 Ω
Input voltage range	± 5 V
Input voltage noise	< 200 nV/√Hz above 1 kHz at 1 V_{pp} input range < 30 nV/√Hz above 100 kHz at 1 V_{pp} input range < 10 nV/√Hz above 1 MHz at 1 V_{pp} input range
Vertical resolution[7]	12 bits at 500 MSa/s (ADC resolution) 13 bits at 125 MSa/s 22 bits at 1 kSa/s
Channel-to-channel isolation	> 40 dB

Horizontal characteristics

Time

Time mode	Normal, Roll	
Horizontal range	1 ns/div to 10 s/div	
Delay range	Pre-trigger:	16 kSamples Greater of 32.768 µs or screen width
	Post-trigger:	2^{30} samples 2.147 s to 1 Ms

Acquisition

Acquisition mode	Normal, Precision[8]
Maximum sampling rate	500 MSa/s
Memory depth	16,384 Samples per channel 32.7 µs at 2 ns/div
Averaging (linear)	Off, 2 to 100 waveforms
Persistence	Off, 100 ms to 10 s, infinite
Interpolation	Linear, SinX/X, Gaussian

[7] Higher effective number of bits (ENOB) above the physical ADC specification is only available in precision mode.

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

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	Input 1, Input 2, Output 1, Output 2, External	
Nth event	Trigger on the 1st to 65,535th event	
Holdoff	1 nanosecond to 10 seconds	
Trigger types	Edge: Rising edge, falling edge, both edges Pulse: Positive / negative polarity • 10.0 seconds > pulse width > 816.0 nanoseconds	

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 5.00 V	

Measurements

Measurements

Time measurements	Frequency, 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
Math	Add, subtract, multiply, divide, XY mode, integrate, differentiate, FFT, min hold, max hold, arbitrary equation mode (using equation editor)
Visualisations	Histogram, time trend

Cursors

Maximum voltage cursors	5 per channel
Maximum time cursors	5 per channel
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

Integrated waveform synthesizer

Synthesizer

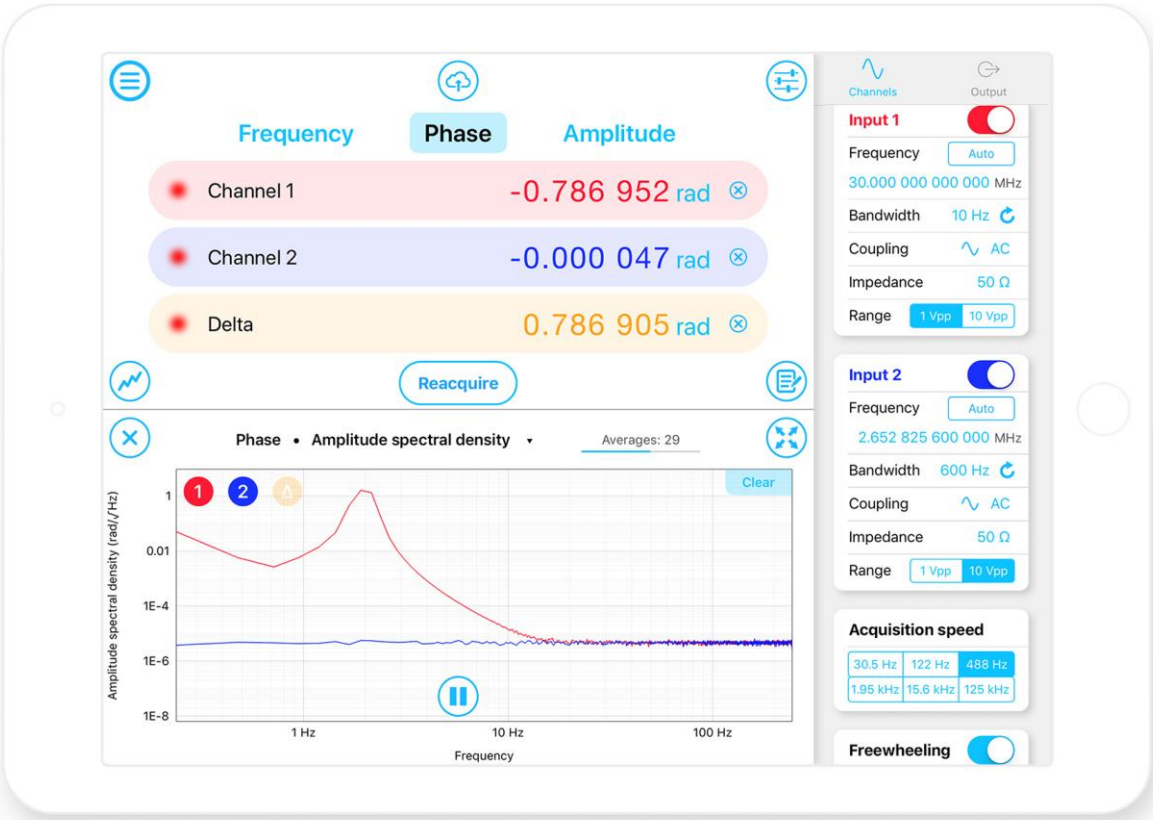
Channels	2
Output impedance	50 Ω
Waveforms[9]	Sine, Square, Ramp, Pulse, DC
Output frequency range	1 mHz to 250 MHz
Output voltage range	± 1 V into 50 Ω

[9] Modulation not available for waveforms synthesized using the oscilloscope instrument.

Phasemeter

Description

Moku:Lab's Phasemeter measures phase of up to two input signals with better than 6 µradian precision from 1 kHz up to 200 MHz. Based on a digitally implemented phase-locked loop architecture, Moku:Lab's phasemeter provides exceptional dynamic range, zero dead-time and measurement precision that exceeds the performance of conventional lock-in amplifiers and frequency counters.



Features

- Measure phase over a range of more than 65 million cycles with better than 1 µcycle precision
- Simultaneously measure the phase, frequency and amplitude of an incoming signal
- Acquire data at up to 125 kSa/s
- Observe measurement data in the frequency domain using the Phasemeter's integrated spectral analysis toolkit

Specifications

Inputs

Input characteristics

Input frequency range	1 kHz to 200 MHz
Input voltage range	± 0.5 V into 50 Ω
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC

Measurement

Measurement characteristics

Frequency set-point precision	3.55 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	10 Hz / 40 Hz / 150 Hz / 600 Hz / 2.5 kHz / 10 kHz (user selectable)	
Frequency precision	***Input Frequency***	***Precision (f = Fourier frequency)***
	< 10 MHz	*f* x 10 µHz/√Hz from 1 mHz to 1 kHz
	< 100 MHz	*f* x 20 µHz/√Hz from 1 mHz to 1 kHz
	> 100 MHz	20 µHz/√Hz below 1 Hz *f* x 20 µHz/√Hz from 1 Hz to 1 kHz
Phase precision[10]	< 10 MHz	100 nCycles/√Hz above 1 Hz
	< 100 MHz	2 µCycles/√Hz above 1 Hz
	> 100 MHz	20 µCycles/√Hz above 1 Hz

Data visualisation

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

[10] Frequency and phase measurement precision is limited by sampling jitter at low Fourier frequencies.

Saving Data

Saving data

Logging rates	30 Sa/s, 120 Sa/s, 490 Sa/s, 1.95 kSa/s, 15.6 kSa/s, 125 kSa/s
File formats	Plain text: records data using a standard CSV format
	Binary: records data using a proprietary LI format for high-speed data logging.
	Note: data saved using the LI format must be converted to plain text using the LI file converter available here: https://github.com/liquidinstruments/lireader
Export modes	SD Card, Dropbox, E-mail and iCloud, My Files (iOS 11)
Delayed log start time	Up to 240 hours
Log duration	1 second up to 240 hours

Synthesizer

Synthesizer[11]

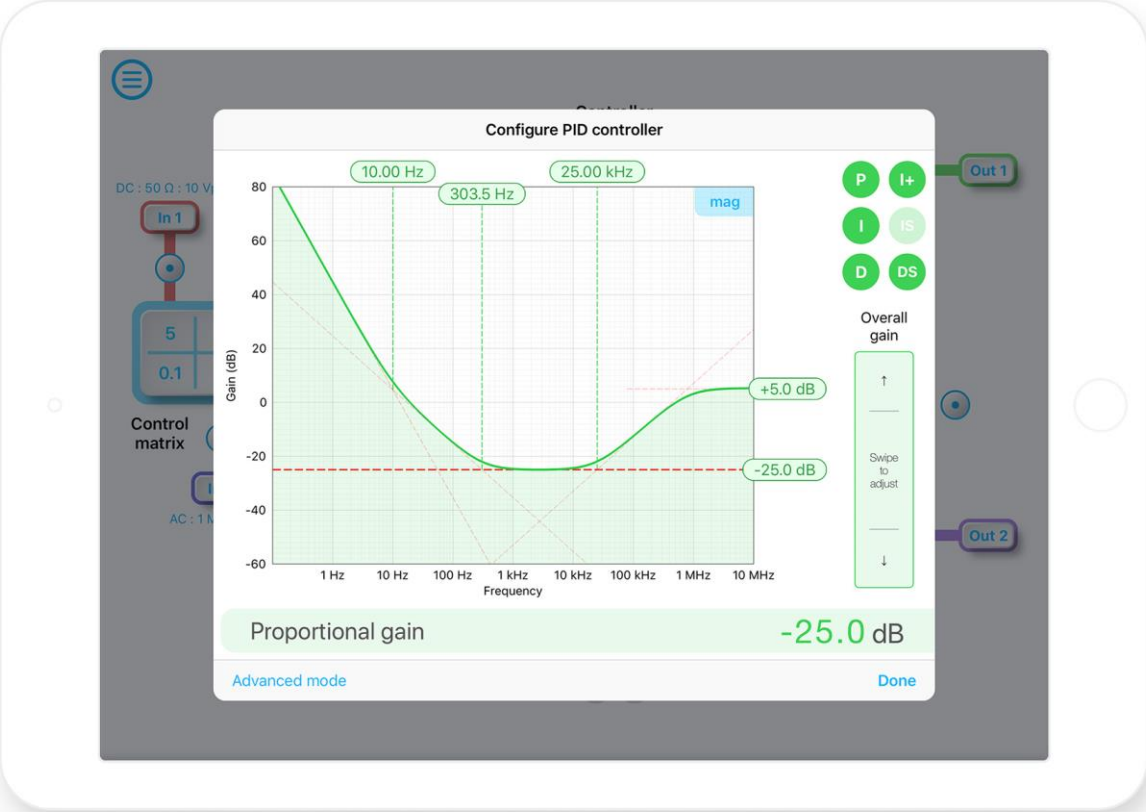
Channels	2
Output impedance	50 Ω
Waveform shape	Sine
Output modes	Manual, phase-locked to input signal
Sampling rate	1 GSa/s per channel
Voltage range	± 1 V into 50 Ω

[11] Where not stated, the phasemeter's synthesizer specifications match those of the Moku:WaveformGenerator instrument.

PID Controller

Description

Moku:Lab's PID Controller features two fully configurable PID controllers with an output sample rate of 10 MSa/s. This enables them to be used in applications requiring both low and high feedback bandwidths such as temperature and laser frequency 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

- Rapidly configure the PID controller's frequency response using an interactive Bode plot
- Observe signals at different stages in the signal processing chain using probe points
- Control up to two channels of data simultaneously with the ability to blend input signals using a control matrix
- Configure controller parameters in basic or advanced editing modes
- Implement lead-lag compensators using saturated integral and differential controllers

Specifications

Inputs

Input characteristics

Channels	2
Input control matrix coefficients (linear gain)	-20 to +20
Input impedance	50 Ω / 1 MΩ
Input coupling	AC / DC
Input attenuation	0 dB / 20 dB
Input voltage range	± 0.5 V into 50 Ω with 0 dB attenuation

Controller

General characteristics

Gain profiles	Proportional (P), integral (I), differential (D), double-integral (I+), integral saturation (IS), differential saturation (DS)
Maximum bandwidth	100 kHz with a phase delay of 30°
Input / output offset range	± 1 V
Offset precision	100 µV

Gain characteristics

Gain profiles	Proportional (P), integral (I), differential (D), double-integral (I+), integral saturation (IS), differential saturation (DS)
Controller frequency range	100 mHz to 10 MHz
Input / output offset range	± 1 V
Offset precision	100 µV
Proportional gain	± 60 dB
Integrator crossover frequency	1.00 Hz to 100 kHz
Double integrator crossover frequency	1.00 Hz to integrator crossover frequency
Integral saturation level	Between proportional gain and +60 dB The integrator saturation crossover frequency cannot be lower than 10 Hz
Differentiator crossover frequency	10.0 Hz to 1.00 MHz
Differentiator saturation level	Between proportional gain and +60 dB The differentiator saturation crossover frequency cannot be higher than 1 MHz

Spectrum Analyzer

Description

Moku:Lab's Spectrum Analyzer allows you to observe input signals in the frequency domain between DC and 250 MHz. View two channels of data simultaneously with a resolution bandwidth as low as 1 Hz over a minimum span of 100 Hz. The Spectrum Analyzer also features two integrated waveform generators capable of producing sine waves at up to 250 MHz.

Features

- DC to 250 MHz frequency range
- 1 kHz to 250 MHz frequency span
- Quickly measure important metrics by dragging measurement cursors onto features of interest using the iPad's multi-touch interface
- View spectral data in units of Volts or dBm as either power or power spectral density

Specifications

Frequency

Frequency

Range	DC to 250 MHz
Span	1 kHz to 250 MHz

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 1 Hz
Windows	None (uniform), Hanning, Flat Top, Blackman-Harris	

Amplitude

Voltage

Channels	2
Input coupling	AC / DC
Input impedance	50 Ω / 1 MΩ
Input attenuation	0 dB / 20 dB
Input bandwidth (-3 dB)	> 200 MHz into 50 Ω > 180 MHz into 1 MΩ
Input voltage range	± 0.5 V into 50 Ω with 0 dB attenuation
	± 5 V into 50 Ω with 20 dB attenuation
Input voltage sensitivity	-130 dBm with 0 dB attenuation at minimum RBW

Display

Scales	Volts, dBm
Display modes	Power, Power Spectral Density (PSD)
Video bandwidth (VBW)	10 Hz to 2.4 MHz depending on span
Averages	1 to 100
Persistence	100 ms to 10 s, infinite, off

Synthesizer

Synthesizer

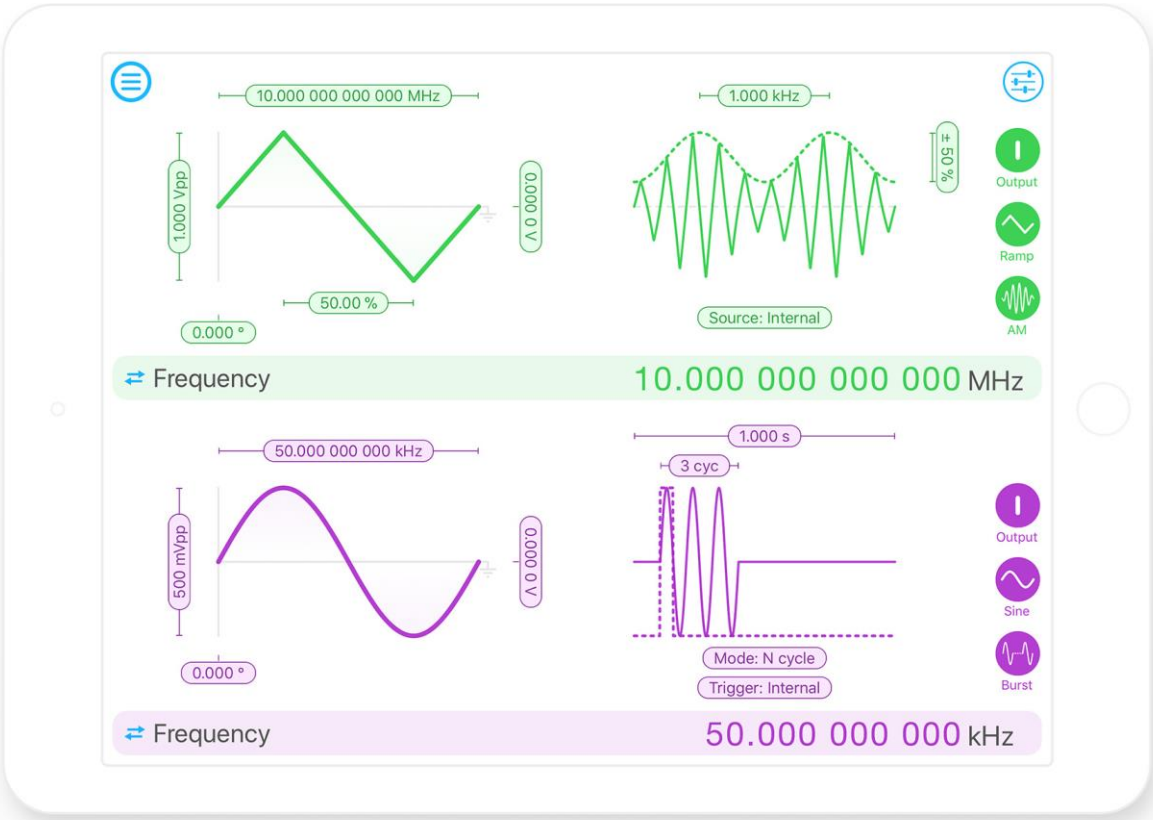
Synthesizer	
Channels	2
Output impedance	50 Ω
Waveforms[12]	Sine
Output frequency range	1 mHz to 250 MHz
Sweep mode	Sweeps the output frequency across the current span with a fixed sweep period of 5 seconds
Output voltage range	± 1 V into 50 Ω

[12] Modulation not available for waveforms synthesized using the oscilloscope instrument.

Waveform Generator

Description

Moku:Lab's Waveform Generator enables users to generate two independent waveforms with a sampling rate of 1 GSa/s, a maximum frequency of 250 MHz and a output voltage range of ± 1 V into 50 Ω. Select between sine, square, ramp, pulsed or DC waveform shapes. Modulate the phase, frequency or amplitude, or generate triggered bursts or sweeps from an internal or external source.



Features

- Generate sine waves from 1 mHz to 250 MHz
- Generate square and ramp waves from 1 mHz up to 100 MHz
- Generate pulsed waveforms with a minimum pulse width of 10 ns at up to 100 MHz
- Modulate waveforms in amplitude, frequency and phase at up to 62.5 MHz using both internal and external sources

Specifications

Common characteristics

Overview

Channels	2
Bandwidth (-3 dB)	300 MHz into 50 Ω
Sampling rate	1 GSa/s per channel
Output impedance	50 Ω
Waveforms	Sine, Square, Ramp, Pulse, DC

Amplitude

Range	1 mV_{pp} to 2 V_{pp} into 50 Ω
Offset error	< 500 µV into 50 Ω
Resolution	100 µV
Channel isolation	> 40 dB from DC to 200 MHz
Units	V_{pp}, dBm

DC offset

Range (peak AC + DC)	± 1 V into 50 Ω
Resolution	100 µV

Phase offset

Range	0º to 360º
Resolution	0.001º

Waveform characteristics

Sine

Frequency range	1 mHz to 250 MHz	
Amplitude flatness (into 50 Ω)	< 100 kHz	< 0.03 dB
	100 kHz to 10 MHz	< 0.08 dB
	10 MHz to 250 MHz	< 0.12 dB
Total harmonic distortion	< 0.5% (1.5 MHz, 5 harmonics)	
SFDR	> 50 dBc for frequencies less than 20 MHz	

Square

Frequency range	1 mHz to 100 MHz	
Edge time[13]	< 2.3 ns into 50 Ω < 2.6 ns into 1 MΩ	At frequencies < 75 MHz
	< 3.6 ns into 50 Ω < 2.8 ns into 1 MΩ	At frequencies < 100 MHz
Overshoot	< 2% for rise times greater than 8 ns < 15% for rise times between 2 ns and 8 ns	
Jitter (cycle-to-cycle)	< 1 ns	

Ramp

Frequency range	1 mHz to 100 MHz	
Symmetry[14]	20% to 80% at 100 MHz 4% to 96% at 20 MHz 0% to 100% at 5 MHz	
Linearity	Below 1 MHz	> 99%
	Between 1 MHz and 50 MHz	> 98%
	Above 50 MHz	> 95%

Pulse

Frequency range	1 mHz to 100 MHz
Period range	1000 s to 10 ns
Pulse width	2 ns to period
Edge time	2 ns to half the pulse width
Edge time resolution	1 ns
Overshoot	< 2% for rise times greater than 8 ns < 15% for rise times between 2 ns and 8 ns
Jitter	Same as square wave

Modulation

Amplitude

Carrier waveforms	Sine, Square, Ramp, Pulse
Source	Internal, External
Internal modulation	Sine
Frequency	1 mHz to 62.5 MHz
Depth	0% to 100%

[13] Measured for a 2 V_{pp} square wave at 10 MHz using a 4 GSa/s MSO7104B Mixed Signal Oscilloscope.
[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%.

Frequency

Carrier waveforms	Sine, Square, Pulse
Source	Internal, External
Internal modulation	Sine
Frequency	DC to 62.5 MHz
Deviation (carrier + deviation)	DC to 250 MHz

Phase

Carrier waveforms	Sine, Square, Pulse
Source	Internal, External
Internal modulation	Sine
Frequency	DC to 62.5 MHz
Phase shift	0.0º to 360.0º

External

Carrier waveforms	Sine, Square, Ramp, Pulse
Source	Ch1: Input 1, Output 2 Ch2: Input 2, Output 1
Voltage range	± 1 V into 50 Ω
Frequency	DC to 62.5 MHz
Variable deviation	AM: %/V FM: Hz/V PM: º/V

Burst

Modes of Operation	Start, N-Cycle, Gated
N-Cycle range	1 to 1,000,000
Trigger Sources	Ch1: Input 1, Output 2, External Ch2: Input 2, Output 1, External
Nominal Trigger Level	Input Channel: 1.8 V Output Channel: 0.5 V External: 1.2 V

Sweep

Sweep Frequency Start/End	Sine: 1 mHz to 250 MHz Square, Ramp, Pulse: 1 mHz to 100 MHz
Sweep Time	1 ms to 1 ks
Trigger Sources	Ch1: Input 1, Output 2, External Ch2: Input 2, Output 1, External
Nominal Trigger Level	Input Channel: 1.8 V Output Channel: 0.5 V External: 1.2 V

This information is subject to change without notice.