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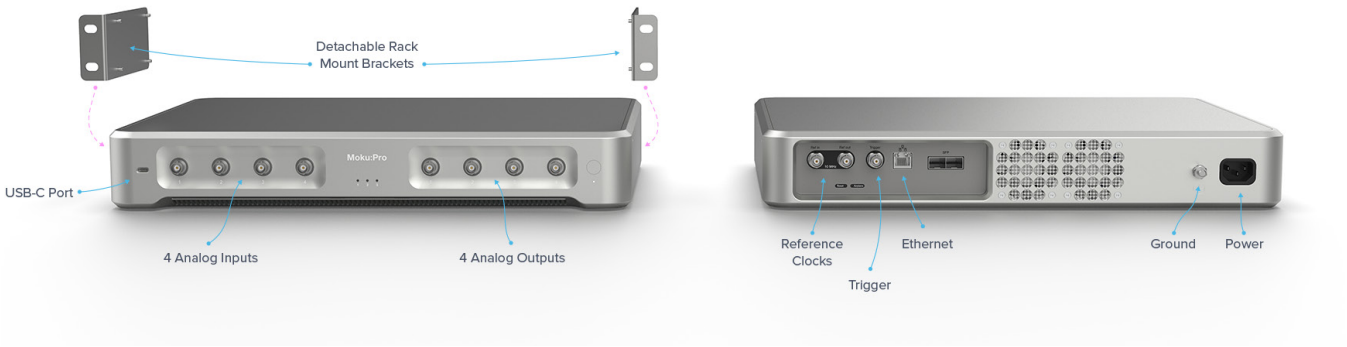
Moku:Pro

The Ultimate Test and Measurement Solution

LIQUID INSTRUMENTS

Moku:Pro combines high performance hardware with the versatility of software-defined instrumentation to deliver the ultimate test and measurement solution. A high-performance Xilinx Ultrascale+ FPGA is coupled with a high-bandwidth analog front-end and robust networking and storage. Moku:Pro's suite of software-defined instruments support high speed data acquisition, processing and visualization, waveform generation, and real-time control applications. An innovative hybrid front-end design performs frequency-dependent signal blending from multiple ADCs, delivering exceptional noise performance from acoustic to radio frequencies.



Analog Inputs	Input Bandwidth	Analog Outputs	Output Bandwidth	Deep Memory & Storage
4 channel, up to 5 GSa/s	**Up to 600 MHz**	**4 channel, 1.25 GSa/s**	**Up to 500 MHz**	**120 GB SSD**

9 Powerful Instruments

- Arbitrary Waveform Generator
- Data Logger
- Frequency Response Analyzer
- Lock-in Amplifier
- Oscilloscope
- Phasemeter
- PID Controller
- Spectrum Analyzer
- Waveform Generator

Hardware Highlights

- Exceptional low-frequency noise performance: 500 µVpp RMS noise at full input bandwidth
- 0.3 ppm stability onboard clock
- < 650 ns input to output latency

Specifications

Four Analog Inputs

- 10-bit and 18-bit ADCs with frequency-dependent blending
- 5 GSa/s sampling rate with 1 channel, 1.25 GSa/s with 4 channels
- Input noise: 30 nV/√Hz above 100 Hz
- User selectable 300/600 MHz analog bandwidth
- AC or DC coupling, 50 Ω or 1 MΩ input impedance
- 400 mVpp, 4 Vpp, or 40 Vpp input range

Four Analog Outputs

- 16 bit, 1.25 GSa/s DACs
- ± 1 V up to 500 MHz, ± 5 V up to 100 MHz

Additional I/O

- Dedicated trigger input
- 10 MHz reference input and output
- Onboard Wi-Fi, Ethernet, and USB-C
- 120 GB high-speed SSD

Programming Environment

- API support for Python and MATLAB
- Class-leading, multi-touch user interface

Applications

- High speed data logging
- Automated test sequence
- System prototyping and simulation
- Closed loop control design
- Optical metrology and spectroscopy
- Control hub for optical, imaging, and other custom-made systems
- Quantum computing

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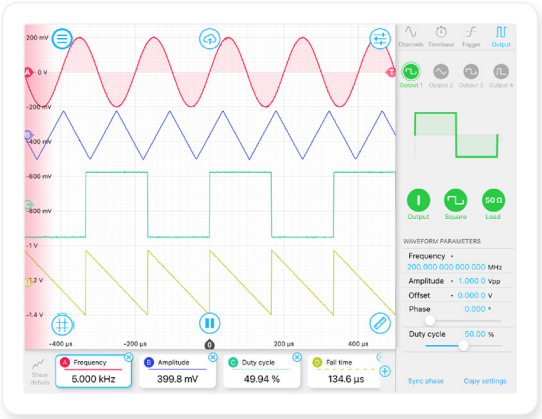
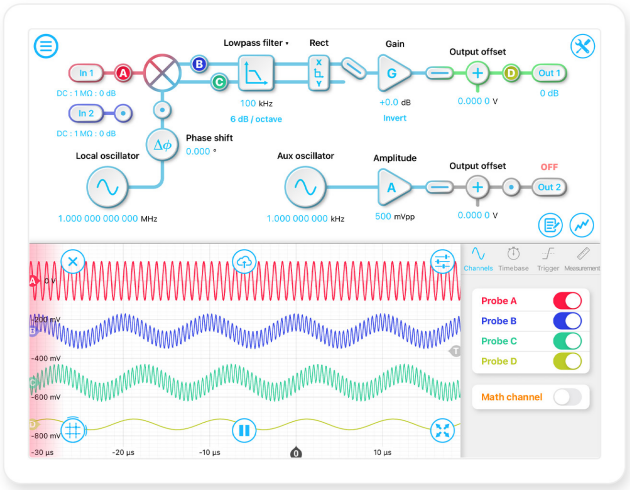
High-speed Data Acquisition

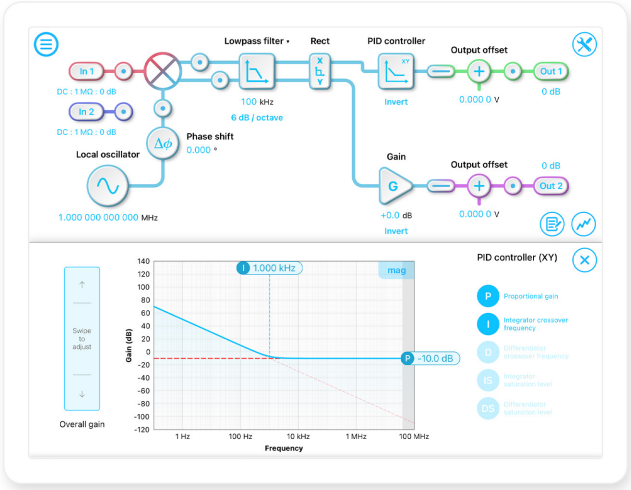
Moku:Pro is designed with high-speed data acquisition in mind. The Data Logger is capable of continuously writing data from the four analog inputs to the 120 GB high-speed SSD, up to 1 MSa/s per channel. Shorter snapshots can be taken at up to 5 GSa/s with the Oscilloscope. Aside from the direct analog inputs, users can access Oscilloscope and data logger capabilities within instruments such as the PID Controller and Lock-in Amplifier through built-in probe points.



600 MHz Lock-in Amplifier

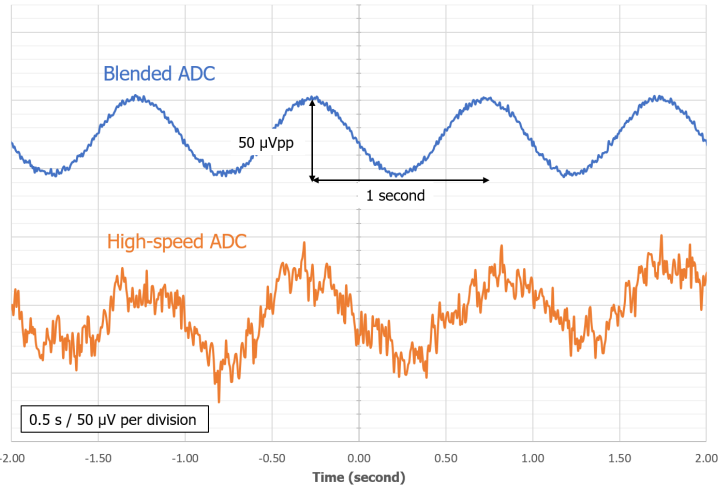
Moku:Pro's digital Lock-in Amplifier supports dual-phase demodulation (XY/Rθ) from DC to 600 MHz, with more than 120 dB of dynamic reserve. Local oscillators can be generated by its onboard waveform generator or an external device. The blended ADC technology provides a low noise floor across the entire 600 MHz input bandwidth. The built-in probe points allow you to monitor and log the signal at various stages of signal processing. A PID controller can be used for closed-loop control and phase-locked loop applications.





Blended ADC

Moku:Pro is equipped with a 10 MSa/s, 18-bit ADC and a high-speed, 5 GSa/s 10-bit ADC. With the powerful FPGA, the system combines the information from the ADCs, providing class-leading input noise performance over the entire 600 MHz bandwidth. Our innovative blending algorithm ensures that the signal-to-noise ratio is optimized across all Fourier frequencies without impacting latency, or signal bandwidth.



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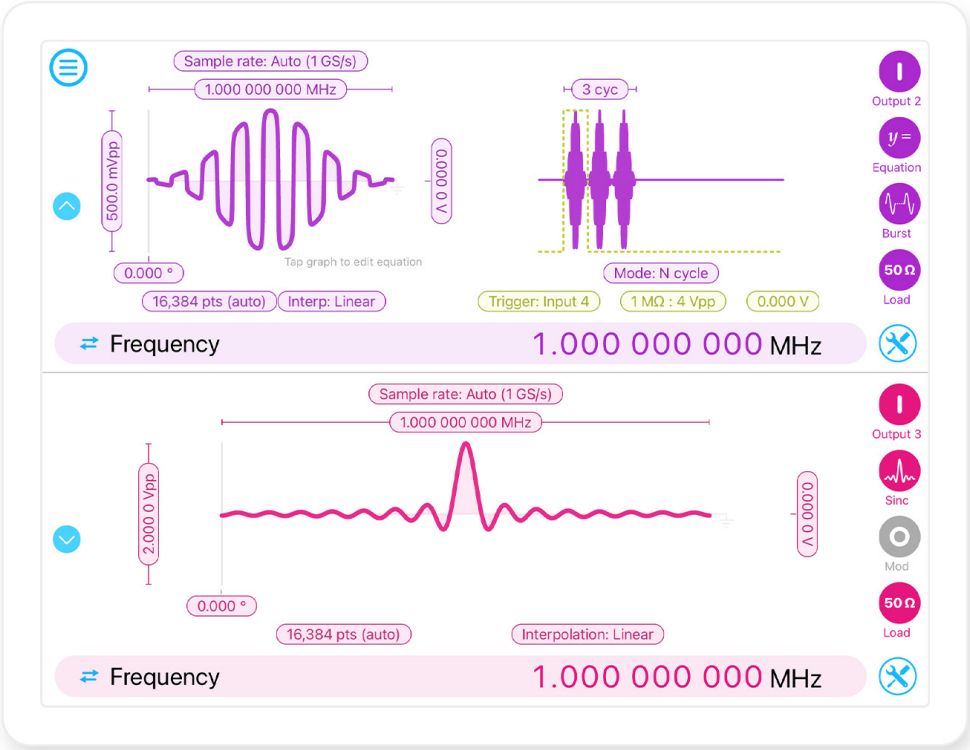
Moku:Pro Instrument Datasheet

4 Channel 500MHz Arbitrary Waveform Generator

Moku:Pro's 4 channel Arbitrary Waveform Generator can generate 4 custom waveforms with up to 65,536 points and sample rates ranging from 250 MSa/s 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 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 250,000 cycles of dead time between pulses.



Maximum Sample Rate	Output Bandwidth	DAC Resolution	Independent Triggering	Supported Waveforms
1 GSa/s	**Up to 500 MHz**	**16-bits**	**Burst/Pulsed**	**5 predefined, segmented equations (up to 32) or custom**

Features

- Four independent AWG channels with up to 500 MHz bandwidth
- Choose between preset waveforms, load points from a file, or input an equation directly
- Phase synchronization output between the four channels
- Configure pulsed output with up to 250,000 cycles of dead time between pulses

Specifications

- Supported waveforms: Sine, Gaussian, Exponential fall, Exponential rise, Sinc, equation editor, and custom (from file)
- Output bandwidth:
  - Up to 500 MHz @ 2 Vpp
  - Up to 100 MHz @ 10 Vpp
- DC offset: ± 5 V with 100 µV resolution
- Phase offset: 0° to 360° with 0.001° resolution
- Maximum output rate:
  - 250 MSa/s with 65,536 points
  - 500 MSa/s with 32,768 points
  - 1 GSa/s with 16,384 points

Applications

- Random pattern scanning
- System response simulation
- Additive manufacturing
- Quantum optics
- Quantum computing

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Moku:Pro Instrument Datasheet

4-Channel Ultra-Low-Noise Data Logger

Moku:Pro's Data Logger enables you to log data to its 120 GB internal solid-state drive with sampling rates of up to 1 MSa/s. Four inputs are equipped with dual 10-bit and 18-bit ADCs. With blended ADC technology, input noise is down to 30 nV/√Hz at 100 Hz, providing ultra-low noise data logging from acoustic to RF frequencies. Moku:Pro is also equipped with a 10 MHz clock synchronization I/O, and four 500 MHz outputs, allowing flexible integration with other electronics.

Number of Inputs	Acquisition Rate	Input Range	Input Coupling	Input Impedance	Waveform Generator
4	1 MSa/s to SSD	Up to 40 Vpp	AC or DC	50 Ω / 1 MΩ	Integrated

Features

- Log voltage data on four independent channels to its 120 GB SSD.
- Built-in four-channel 500 MHz waveform generator.
- 10 MHz clock synchronization ports.
- Easily export data to computer, Dropbox, and other cloud-based services.
- Schedule your log to start with a delay of up to 10 days

Specifications

- Input ranges: 0.4 Vpp, 4 Vpp or 40 Vpp
- Input Impedance: 50 Ω/1 MΩ
- Input coupling: AC/DC
- Maximum sampling rate:
  1 MSa/s with 4 channels enabled to SSD
- Minimum sampling rate: 10 Sa/s
- Acquisition mode:
  Normal: direct downsampling
  Precision mode: improves resolution by averaging

Applications

- Temperature monitoring
- Vibration analysis
- Environment monitoring
- Sensor logging

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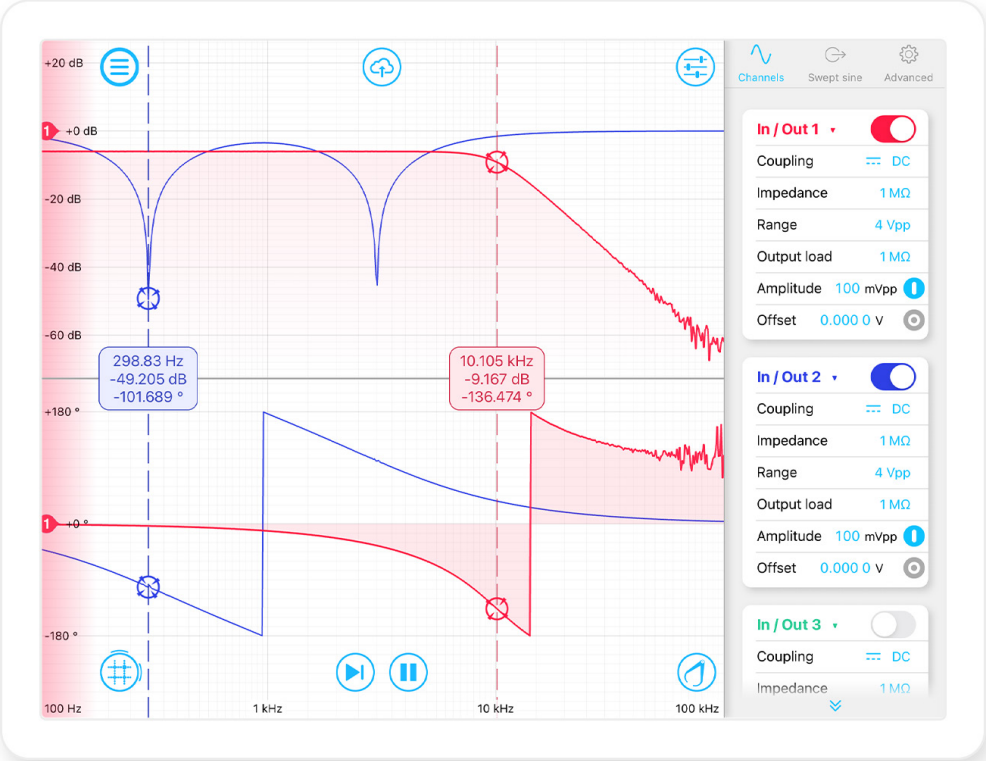
Moku:Pro Instrument Datasheet

Ultra Low-noise Frequency Response Analyzer

Moku:Pro'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 250 MHz. It has a noise floor of -135 dBm across the entire frequency range. Moku:Pro is equipped with four inputs and outputs ports, enabling differential or ratiometric measurements. Select from between 32 and 512 points per sweep and configure settling and averaging times to balance total sweep duration and signal-to-noise ratio.



Frequency Range	Input Impedance	Averaging time	Sweep	Output Voltage Range	Harmonics Detection
Up to 250 MHz	**50 Ω or 1 MΩ**	**1 µs to 10 s**	**Linear/Logarithmic**	**Up to 10 Vpp**	**Up to 15th**

Features

- Linear or logarithmic swept sine output
- Math channel to add, subtract, multiply or divide response functions as they are acquired
- Measure key metrics with cursors and markers
- Configurable measurement averaging and settling times
- Easily save data and upload to the cloud or Dropbox in common formats
- Probe 4 systems simultaneously, or one system at multiple points
- Demodulate up to 15th harmonic

Specifications

- Frequency range: 10 mHz to 250 MHz
- Averaging time: 1 µs to 10 s
- Settling time: 1 µs to 10 s
- Sweep points: 32, 64, 128, 256, 512
- Source impedance: 50 Ω
- Output Voltage Range: 2 Vpp
  10 Vpp (< 100 MHz)
- Input Impedance: 50 Ω or 1 MΩ
- Input range: 400 mVpp, 4 Vpp, or 40 Vpp
- Noise-floor: 10 mHz to 100 kHz: -100 dB
  100 kHz to 1 MHz: -125 dB
  1 MHz to 50 MHz: -130 dB
  50 MHz to 240 MHz: -120 dB

Applications

- Impedance measurement
- Capacitance/inductance measurement
- Stability analysis
- Power supply analysis
- EMI filter characterization

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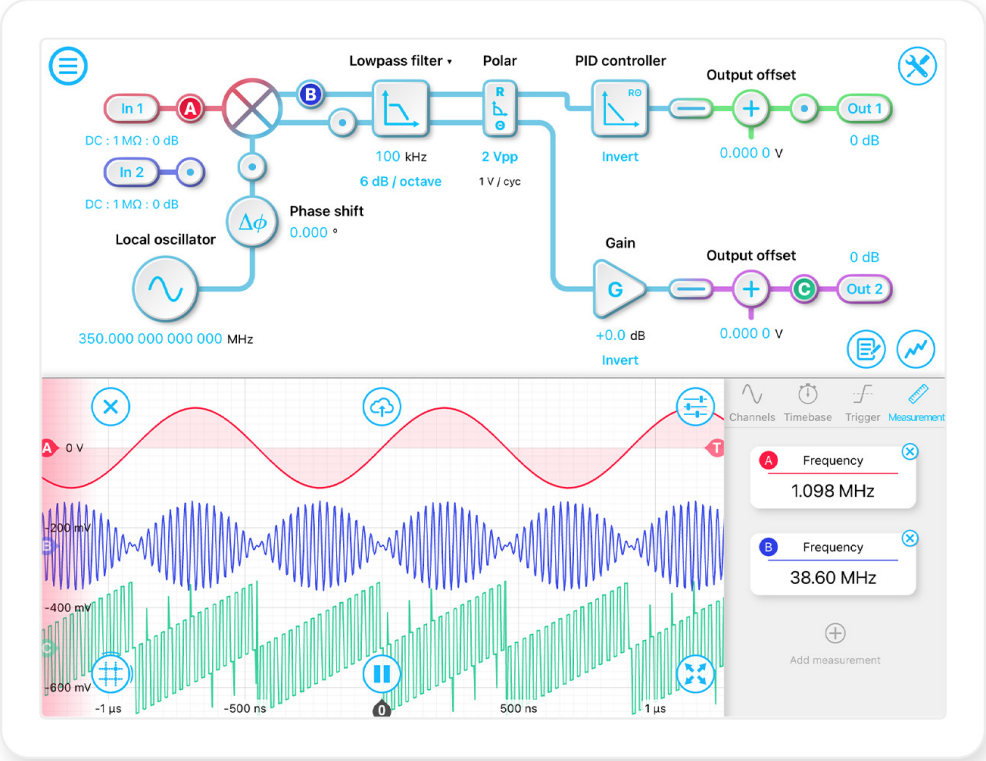
Moku:Pro Instrument Datasheet

600 MHz Lock-in Amplifier

Moku:Pro's digital Lock-in Amplifier supports dual-phase demodulation (XY/Rθ) from 1 mHz to 600 MHz with more than 120 dB dynamic reserve. A PID controller can be placed after the demodulation stage for phase-locked loop applications. It also features an integrated 4-channel oscilloscope and data logger, enabling you to observe signals at up to 1.25 GSa/s and log data at up to 1 MSa/s.



Demod. Frequency	Dynamic Reserve	Time Constant	Filter Slopes	Input Noise	Built-in Feature
1 mHz to 600 MHz	> 120 dB	From 12.8 ns	6, 12, 18, 24 dB/Oct	30 nV/√Hz @ 100Hz	PID Controller

Features

- Measure signals obscured by noise with more than 120 dB dynamic reserve
- Block diagram view of the digital signal processing chain
- Built-in probe points for signal monitoring and data logging
- Internal or external demodulation modes including a PLL (phase-locked loop)
- Toggle between rectangular (X/Y mode) or polar coordinates (R/Theta mode)
- Built-in PID Controller

Specifications

- Demodulate with frequencies ranging from 1 mHz to 600 MHz with µHz resolution
- Phase shift precision of 0.001°
- 50 Ω / 1 MΩ input impedance
- Adjustable time constant from 12.8 ns to 0.215 s
- 6, 12, 18, or 24 dB/octave filter roll-off
- Output gain range: -80 to +160 dB
- LO output up to 500 MHz with variable amplitude
- Ultra-fast data acquisition: snapshot mode up to 1.25 GSa/s, continuous mode up to 1 MSa/s

Applications

- Pump probe / ultrafast spectroscopy
- Laser scanning microscopy
- Magnetic sensing (magneto-optical Kerr effect)
- Laser frequency stabilization

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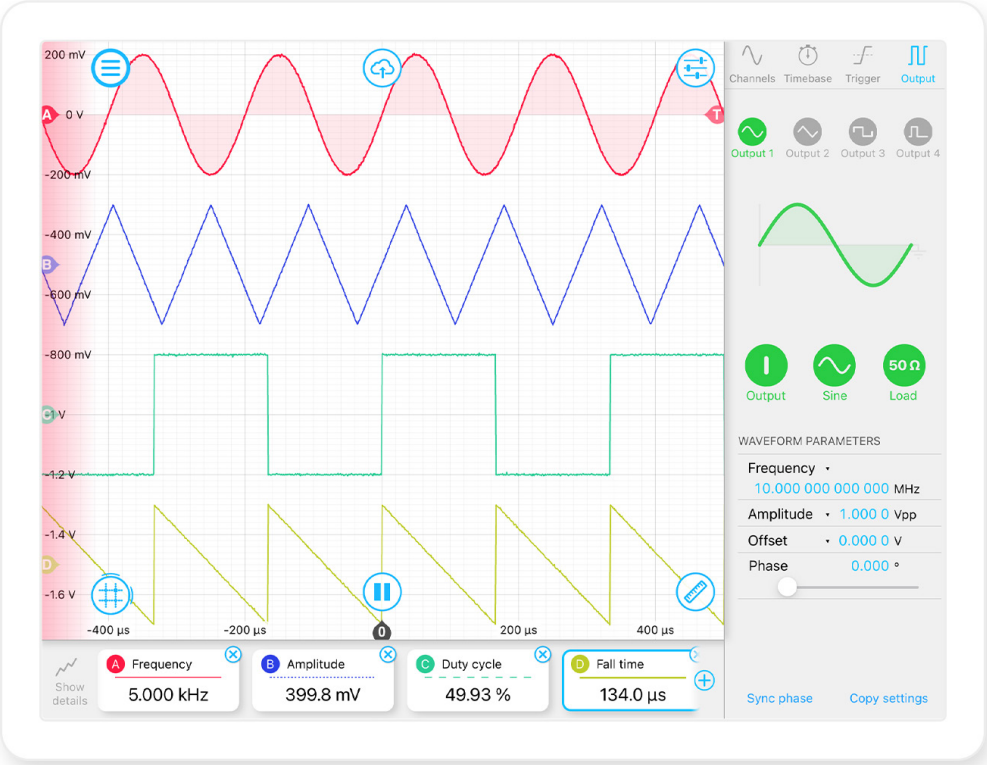
Moku:Pro Instrument Datasheet

600 MHz Oscilloscope

Moku:Pro's Oscilloscope features four highspeed, ultra-low noise input channels with 600 MHz analog bandwidth. An innovative blended ADC technology combines the information from 10 bit and 18 bit ADCs to cover a broad spectrum, providing class-leading input noise performance at 30nV/√Hz @ 100Hz with large dynamic range. The built-in four-channel waveform generators are capable of producing waveforms with a bandwidth of up to 500 MHz.



Sampling Rate	Bandwidth	ADC Resolution	Input Impedance	Input Noise	Waveform Generator
Up to 5 GSa/s	**600 MHz**	**10 / 18 bits**	**50 Ω/ 1 MΩ**	**30 nV/√Hz @ 100Hz**	**4 Channels up to 500 MHz**

Features

- Four analog inputs with 600 MHz bandwidth
- Exceptional low-frequency noise performance: 30 nV/√Hz @ 100 Hz
- Dual-ADC design with blended ADC technology
- Ultra stable 0.3 ppm onboard oscillator with 10 MHz synchronization in and out
- Integrated high-speed waveform generator channels with analog bandwidths up to 500 MHz

Specifications

- Input range: 400 mVpp, 4 Vpp, or 40 Vpp
- Input noise: 30 nV/√Hz @ 100 Hz
- Sampling rate: 5 GSa/s on 1 channel
  1.25 GSa/s on 4 channels
- Input bandwidth: 300/600 MHz switchable
- Input coupling: AC or DC
- Input Impedance: 50 Ω or 1 MΩ
- Output bandwidth: 500 MHz (2 Vpp)
  100 MHz (10 Vpp)
- Output waveforms: sine, square, ramp, pulse, DC
- Math channel: Add, subtract, multiply, divide, XY mode, integrate, differentiate, FFT, min hold, max hold, and equation editor

Applications

- Signal monitoring and analysis
- Circuit design and characterization
- Jitter/clock analysis
- Photo detector alignment
- Automated system test
- System test and debug

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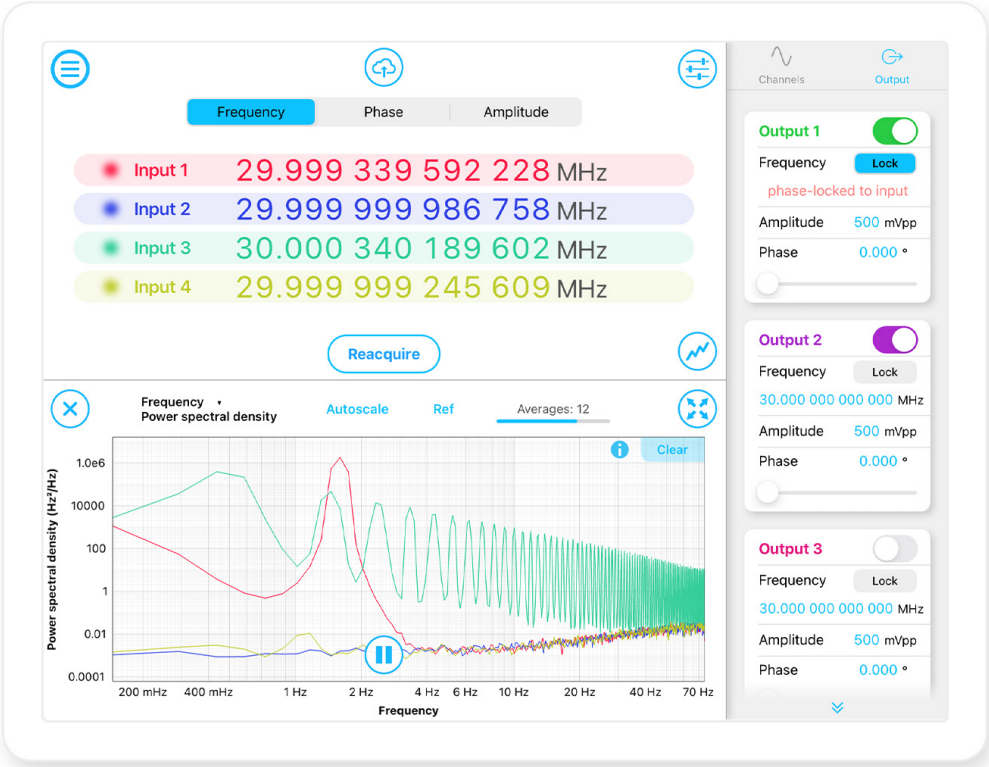
Moku:Pro Instrument Datasheet

400 MHz Phasemeter

Moku:Pro's Phasemeter measures phase (relative to a reference clock) of up to four input signals with better than 6 µradian precision from 1 kHz up to 400 MHz. Based on a digitally implemented phase-locked loop architecture, Moku:Pro's Phasemeter provides exceptional dynamic range, zero dead-time, and measurement precision that exceeds the performance of conventional lock-in amplifiers and frequency counters.



Frequency Range	Tracking Bandwidth	Phase precision	Frequency precision	Data capturing rates	Built-in Analysis
1 kHz to 400 MHz	Up to 10 kHz	6 µrad/√Hz	10 µHz/√Hz	30 Hz, 120 Hz, 477 Hz	Allan Deviation

Features

- Four independent phasemeter channels with output options that track and record the phase, frequency, and amplitude of two independent signals
- Phase-locked output option enables you to generate sine waves that are phase-locked to the inputs
- Real-time spectral analysis to display and save Power Spectral Densities, Allan Deviation, and more
- Phase-locked loop tracking bandwidths from 10 Hz up to 10 kHz

Specifications

- Input frequency range: 1 kHz - 600 MHz
- Input voltage range: 400 mVpp, 4 Vpp, or 40 Vpp
- Frequency set-point precision: 1.4 µHz
- Tracking bandwidth: 10 Hz, 40, Hz, 150 Hz, 600 Hz, 2.5 kHz, 10 kHz
- Data acquisition rates: 30 Hz, 120 Hz, 477 Hz
- Phase precision: down to 6 µrad/√Hz
- Frequency precision: down to 10 µHz/√Hz
- Sine wave generators: Four-channel 500 MHz (manual or input-locked)

Applications

- Oscillator analysis
- Optical/ultrasound ranging
- Gravitational wave detection
- Interferometry
- Phase-locked loop

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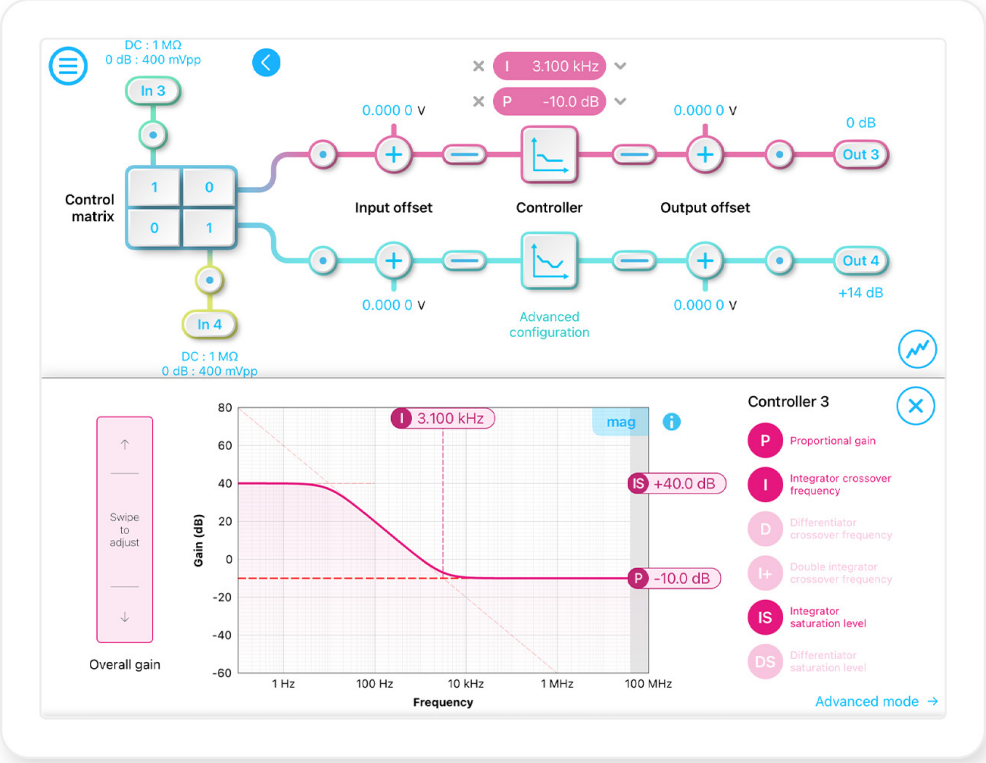
Moku:Pro Instrument Datasheet

Multiple-Input Multiple-Output PID Controller

Moku:Pro's PID Controller features four fully configurable PID controllers with sub-microsecond latency. 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.



Versatile input	Proportional Gain	DAC resolution	Input-output latency	Gain configuration	Advanced mode
4 inputs with MIMO	**- 60 dB to 60 dB**	**16-bits**	**<1 µs**	**Real-time**	**Multi-section builder**

Features

- 4 input channels, 4 output channels, and 4 independent PID controllers with control matrix for MIMO
- Design your control system's frequency response using the interactive Bode plot in realtime
- 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
- Intergrated probe points for signal monitoring

Specifications

- Control matrix linear gain: ± 0.1 to ± 20
- Input offset range: ± 1 V
- Output offset range: ± 5 V
- Offset precision: 100 µV
- Gain profiles: Proportional (P), integral (I), differential (D), double-integral (I+), integral saturation (IS), differential saturation (DS)
- Proportional gain: -60 dB to 60 dB
- Integrator crossover frequency: 3.125 Hz to 312.5 kHz
- Differentiator crossover frequency: 31.25 Hz to 31.25 MHz

Applications

- Feedback and control systems design
- Laser frequency stabilization
- Temperature regulation
- Scan heads/sample stage positioning
- Pressure, force, flow rate, and other controls

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Moku:Pro Instrument Datasheet

4 Channel Spectrum Analyzer

Moku:Pro's Spectrum Analyzer allows you to observe input signals in the frequency domain between DC and 400 MHz with an ultra-low noise floor. View four channels simultaneously with a resolution bandwidth as low as 2.2 Hz and a minimum span of 100 Hz. The Spectrum Analyzer also features four 500 MHz sinewave generators.

Frequency Range	Frequency Span	Minimum RBW	Input Noise	Signal Generator	Output Frequency
DC to 400 MHz	100 Hz to 400 MHz	2.2 Hz	30 nV√Hz @ 100Hz	4 channels	Up to 500 MHz

Features

- Display and record power spectra or power spectral densities in the frequency domain from DC to 400 MHz
- Generate four sine waves up to 500 MHz using Moku:Pro's built-in analog outputs
- Quickly measure key metrics by dragging measurement cursors onto features of interest using the multi-touch interface
- Live measurement functions: peak level, peak frequency, noise level, peak SNR, and occupied bandwidth

Specifications

- Frequency range: DC to 400 MHz
- Frequency span: 100 Hz to 400 MHz
- Resolution bandwidth (RBW): span dependent, minimum RBW is 2.2 Hz
- Number of input channels: 4
- Input range: 400 mVpp, 4 Vpp, or 40 Vpp
- Input impedance: 50 Ω / 1 MΩ
- Number of output channels: 4
- Output range: up to 500 MHz (2 Vpp)
  up to 100 MHz (10 Vpp)
- Video filter bandwidth: 2.3 Hz to 4.6 MHz

Applications

- Frequency domain analysis
- System response characterization
- Noise measurement
- RF system design
- Spurious signal identification

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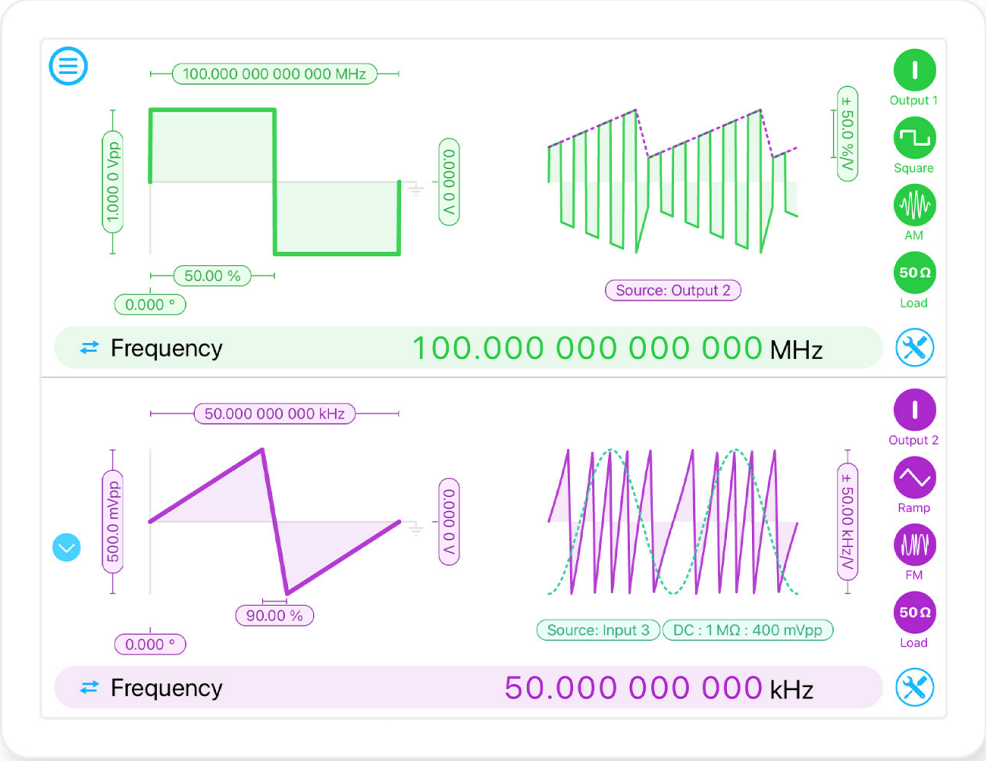
Moku:Pro Instrument Datasheet

4-Channel 500 MHz Waveform Generator

Moku:Pro's Waveform Generator enables you to generate four independent waveforms with a maximum bandwidth of 500 MHz. Select between sine, square, ramp, pulsed, or DC waveform shapes. High bandwidth modulation of phase, frequency, or amplitude, or generate triggered bursts or sweeps from an internal or external source.



Frequency Range	Output Voltage Range	Modulation	Other Modes	Timebase Accuracy
1 mHz to 500 MHz	**Up to 10 Vpp (50 Ω)**	**FM, AM, PM**	**Burst, Sweep**	**< 500 ppb**

Features

- Generate 4 independent phase coherent waveforms from DC to 500 MHz
- 5 built-in waveforms: sine, square, ramp, pulse, and DC
- Broadband FM, AM, and PM modulation with internal waveform (cross-channel modulation) or external input
- Versatile trigger options: from input, dedicated TTL trigger port, or another channel
- 10 MHz reference input and output

Specifications

- Output bandwidth:
  - 500 MHz (2 Vpp)
  - 100 MHz (10 Vpp)
- Frequency range (2 Vpp):
  - Sine: 1 mHz to 500 MHz
  - Square: 1 mHz to 200 MHz
  - Ramp: 1 mHz to 200 MHz
  - Pulse 1 mHz to 200 MHz
- Pulse width: 4 ns to period
- Modulation bandwidth: > 125 MHz
- Timebase accuracy: < 500 ppb
- Burst mode: start, N-cycle, gated
- Sweep time: 1 ms to 1 ks

Applications

- Signal simulation
- Laser scanning microscopy
- Circuit design and characterization
- System synchronization
- Clock source
- DAC/Op-amp characterization

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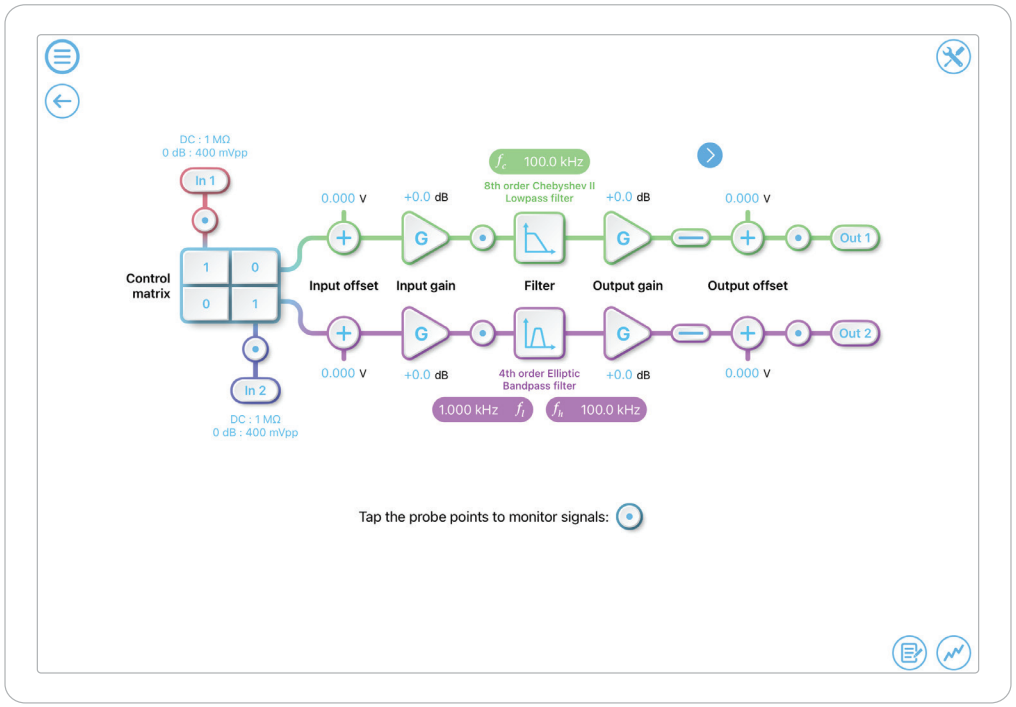
Moku:Pro Instrument Datasheet

Digital Filter Box

With Moku:Pro's Digital Filter Box, you can interactively design and generate different types of infinite impulse response filters with sampling rates of 305.18 kHz or 39.063 MHz. Select between lowpass, highpass, bandpass, and bandstop filter shapes with up to eight fully configurable types including Butterworth, Chebyshev, and Elliptic. This instrument can be deployed independently or used as filter components in the multi-instrument mode.



Sampling Rate	Filter Order	Input Range	Output Voltage Range	Filter Shapes
305.18 kHz or 39.063 MHz	2, 4, 6, 8	up to 40 Vpp	10 Vpp into 50 Ω	Lowpass, Highpass, Bandpass, Bandstop, Custom

Features

- Visualize your signal and configuration in real-time: design your filter's frequency response using the interactive Bode plot
- Block diagram view of the digital signal processing with built-in probe points for signal monitoring
- Versatile input and output options: 4 input channels, 4 output channels with optional blending for input signal mixing
- Supports custom filter designs
- Built-in Oscilloscope and Data Logger

Specifications

- Filter shapes: lowpass, highpass, bandpass, bandstop
- Filter types: Butterworth, Chebyshev I, Chebyshev II, Elliptic, Cascaded, Bessel, Gaussian, and Legendre
- Corner frequencies: 58.63 mHz - 17.58 MHz
- Input-output latency: sub-microsecond
- Passband ripple: configurable 0.1 – 10 dB
- Stopband attenuation: configurable 10 – 100 dB
- Independently adjustable input and output offsets and gains

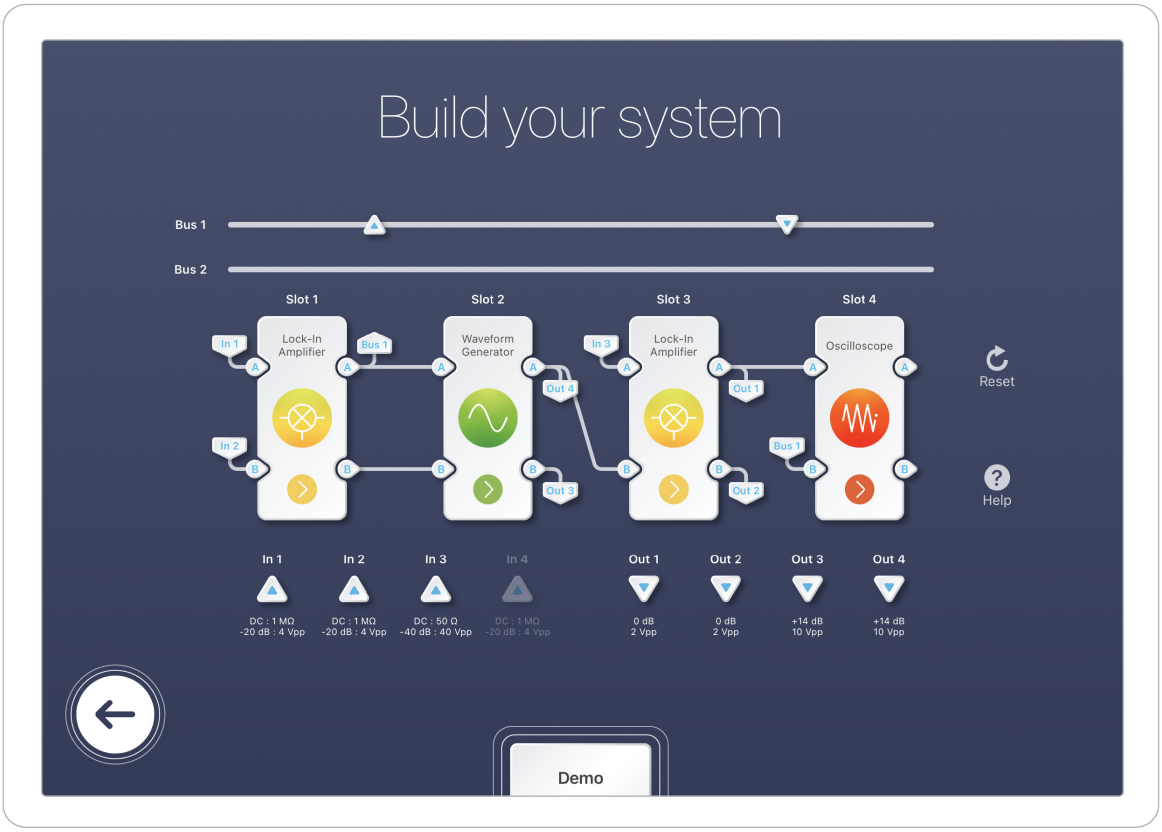
Applications

- System design
- Closed-loop control
- Noise filtering
- Signal amplification
- Filter design and evaluation

Moku:Pro Multi-Instrument Mode

Construct and reconfigure your test bench with a few touches

Moku:Pro multi-instrument mode allows users to place instruments in four virtual “slots”, dynamically adding or removing them to any of the slots. Each slot has access to the analog inputs and outputs, allowing you to run a suite of instruments on a single Moku:Pro. Instruments on chip are connected by a low-latency, real-time 30 Gb/s signal path and can be connected together to build sophisticated signal-processing pipelines. Connections to the analog inputs, analog outputs, and adjacent instruments are run-time configurable. Moku:Pro redefines flexibility for test instrumentation.



Deployable Instruments

- Arbitrary Waveform Generator
- Frequency Response Analyzer
- Lock-in Amplifier
- Oscilloscope
- PID Controller
- Spectrum Analyzer
- Waveform Generator

Hardware Highlights

- Exceptional low-frequency noise performance: 500 µV RMS noise
- 0.3 ppm stability onboard clock
- < 650 ns input to output latency

Analog Front-ends

Four Analog Inputs

- 10-bit and 18-bit ADCs with frequency-dependent blending
- 1.25 GSa/s sampling rate
- Input noise: 30 nV/√Hz at 100 Hz
- 300/600 MHz analog bandwidth
- AC or DC coupling, 50 Ω or 1 MΩ input impedance
- 400 mVpp, 4 Vpp, or 40 Vpp input range

Four Analog Outputs

- 16 bit, 1.25 GSa/s DACs
- 10 Vpp at < 100 MHz, 2 Vpp at < 500 MHz

Applications

- Automated test sequence
- System prototyping and simulation
- Closed loop control design
- Optical metrology and spectroscopy
- Control hub for optical, imaging, and other custom-made systems
- Quantum computing

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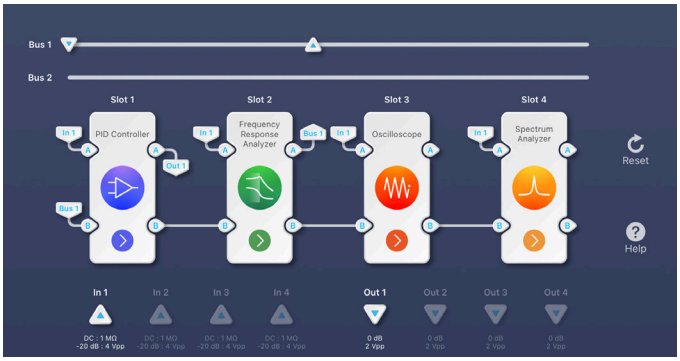
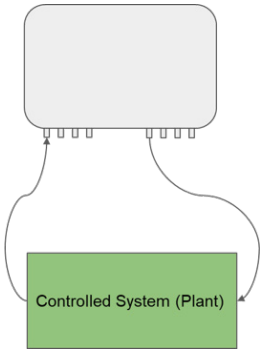
Application Highlights

Low-latency closed-loop control design and characterization

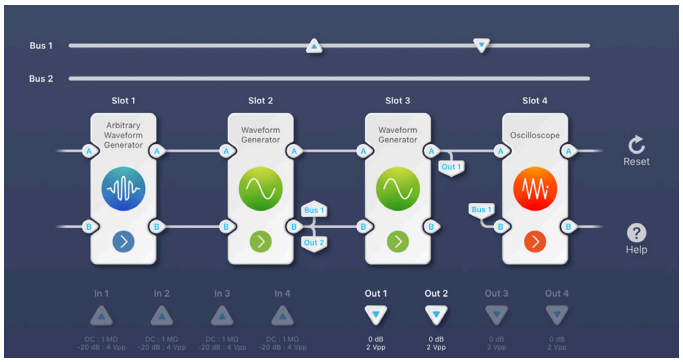
Moku:Pro's PID controller provides a sub-µs input to output delay, it is ideal for high-speed closed-loop controller applications. The controller's transfer function and impulse response can be observed and measured in real time by adding a Frequency Response Analyzer using the multi-instrument mode. The system's response can also be measured in both time and frequency domains using the Oscilloscope and Spectrum Analyzer. Any adjustments in the controller are reflected in real-time in the monitoring instruments.

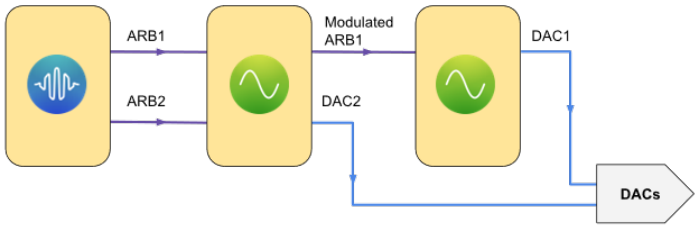




Generate signals with arbitrary modulation

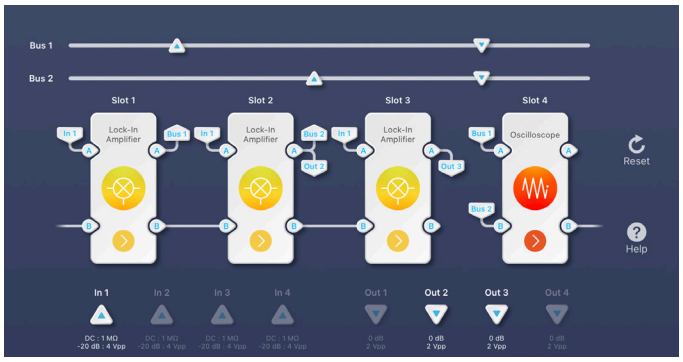
Combining the Arbitrary Waveform Generator with multiple Waveform Generators to output high stability complex signals. Arbitrary waveforms can be connected to the input of the Waveform Generators as the modulation source. Frequency, phase, and amplitude modulation can also be added to the signal. This removes the look-up table calculations and provides better controls over the modulation and output signal. An Oscilloscope or Spectrum Analyzer can also be added to one of the slots to measure the signals.

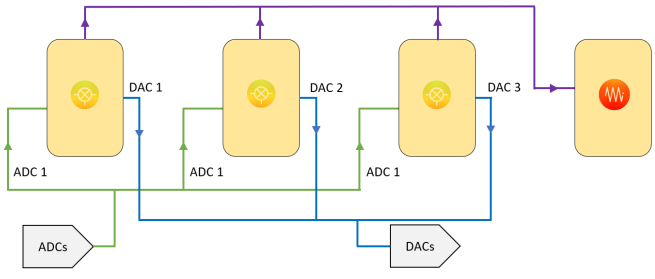




Multi-demodulator Lock-in Amplifier

Moku:Pro's multi-instrument mode allows up to four Lock-in Amplifiers to run simultaneously. Each of the Lock-in Amplifiers can demodulate the signal at the fundamental, second, or higher harmonics. Measured R/θ or X/Y components from each of the Lock-in Amplifiers can also be compared in the Oscilloscope in the final instrument slot or driven to the analog outputs.





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