

Arbitrary Waveform Generator

Moku:Pro User Manual

Moku:Pro's Arbitrary Waveform Generator can generate custom waveforms with up to 65,536 points at update rates of up to 1 GS/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.





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Ensure Moku:Pro is fully updated. For the latest information:

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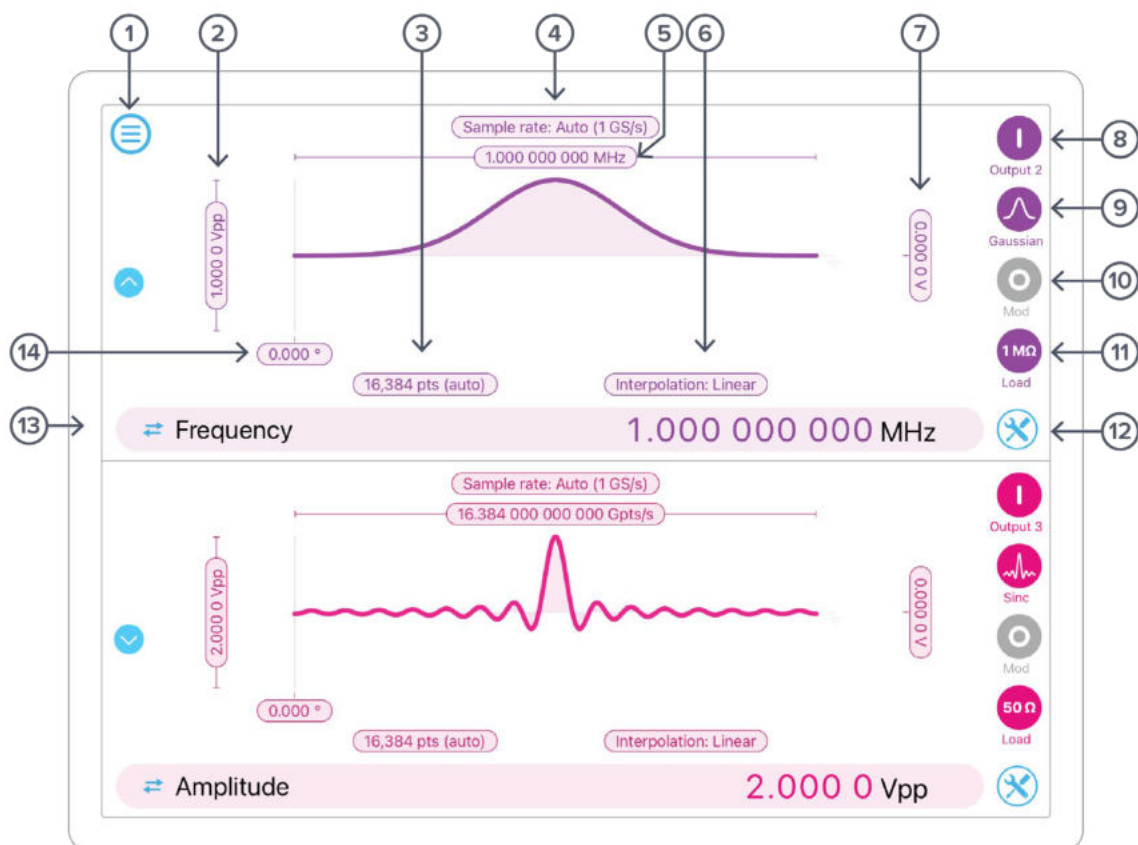
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User Interface

Moku:Pro is equipped with four outputs channels. You can tap the  or  icons to navigate between channels.



ID	Description	ID	Description
1	Main menu	8	Enable/disable output
2	Configure amplitude / high level	9	Configure waveform shape
3	Configure number of points	10	Enable/disable modulation
4	Configure sample rate	11	Configure the output load
5	Configure frequency / period / update rate	12	Configuration options*
6	Turn linear interpolation on or off	13	Switch between representations**
7	Configure offset	14	Configure phase

*Use this option to Sync phase, or copy settings from other outputs.

**Tap the amplitude, offset, frequency, or phase number to make it the active parameter. For amplitude and offset, click the swap button to switch between Vpp/offset or high/low level representations. For frequency, click the swap button to switch between frequency or period representations.



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Main Menu

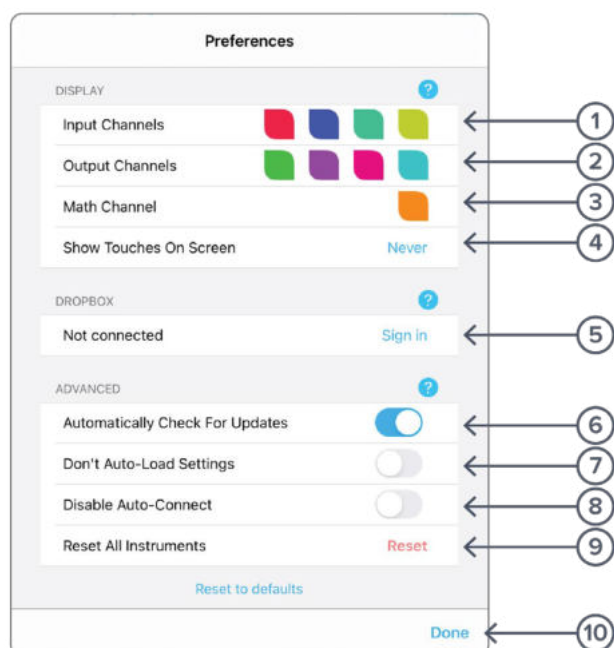
The **main menu** can be accessed by pressing the  icon, allowing you to:





Preferences

The preferences pane can be accessed via the main menu. In here, you can reassign the color representations for each channel, connect to Dropbox, etc. Throughout the manual, the default colors (shown in the figure below) are used to present instrument features.



ID Description

- | | |
|----|--|
| 1 | Tap to change the color associated with input channels. |
| 2 | Tap to change the color associated with output channels. |
| 3 | Tap to change the color associated with math channel. |
| 4 | Indicate touch points on the screen with circles. This can be useful for demonstrations. |
| 5 | Change the currently linked Dropbox account to which data can be uploaded. |
| 6 | Notify when a new version of the app is available. |
| 7 | Moku:Pro automatically saves instrument settings when exiting the app, and restores them again at launch. When disabled, all settings will be reset to defaults on launch. |
| 8 | Moku:Pro can remember the last used instrument and automatically reconnect to it at launch. When disabled, you will need to manually connect every time. |
| 9 | Reset all instruments to their default state. |
| 10 | Save and apply settings. |



Output Configuration

Enable / Disable Outputs

Enable the output of the selected channel by pressing the  icon

Disable the output of the selected channel by pressing the  icon

Load Impedance

Select between 50 Ω and 1 M Ω load impedance.

Selecting the correct load impedance

Moku:Pro's outputs have an impedance of 50 Ω . As such, voltages supplied to a 50 Ω load will be reduced by a factor of two due to the voltage divider formed by the closed circuit. Moku:Pro compensates for this voltage division into 50 Ω loads by doubling the output voltage that is displayed on the interface. A consequence of this is that the voltage measured across a high-impedance load will be *twice* the value displayed on the interface since the voltage division of the high-impedance circuit is comparably small.

Selecting a load impedance of 1 M Ω does not double the amplitude of the generated signal.



Output Modes

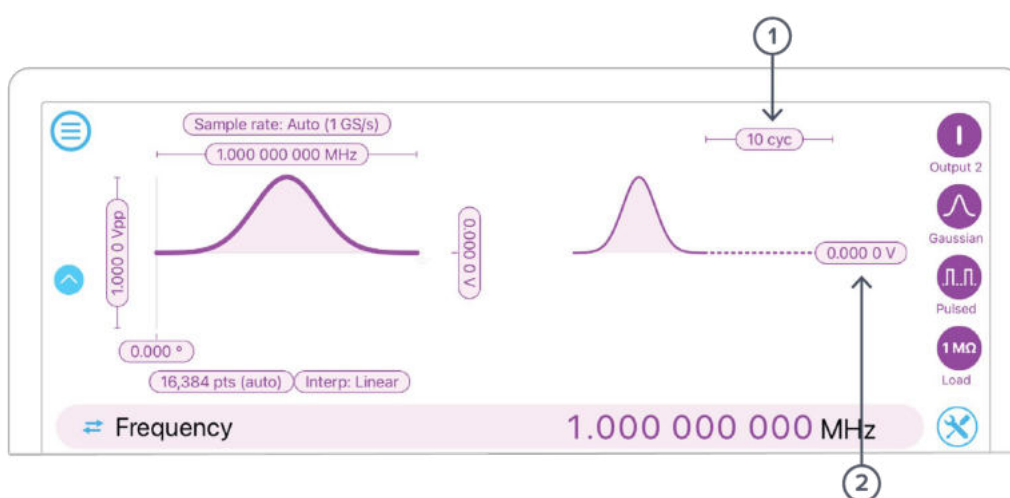
Moku:Pro's Arbitrary Waveform Generator supports two output modes: Normal and Pulsed.

Normal

In normal mode, the output waveform is repeated continuously with no dead time between cycles.

Pulsed

In pulsed mode, the output waveform can be configured to have up to $2^{18} = 262144$ cycles of dead time between each repetition of the arbitrary waveform.



ID	Parameter	Description
1	Dead cycles	The period of each cycle of dead time is equal to the selected period of the waveform.
2	Dead voltage	The dead time voltage can be configured to equal any DC value between the waveform's minimum and maximum voltages.



The screenshot displays the Keysight Oscilloscope GUI with two waveforms. The top waveform is a Gaussian pulse with a peak of 1.0000 V, a width of 1.000000000 MHz, and a phase of 0.000°. The bottom waveform is a burst of three cycles with a peak of 1.000000000 MHz, a width of 3 cycles, and a mode of N cycle. The frequency is set to 1.000000000 MHz. The trigger is set to Input 1, 1 MΩ, 4 Vpp, and 0.000 V. The load is set to 1 MΩ.

ID	Parameter	Description
1	Burst cycle count	N - Cycle mode only. The number of cycles to generate before re-arming.
2	Burst mode	N -Cycle or Start. The Start mode generates infinite loops of the waveform after the trigger event.
3	Trigger level	Set the voltage level to trigger at.
4	Input range	Set the input channel range.
5	Trigger source	Select between input 1 or 2.





Waveform Types

Generate one of five pre-set waveforms, a custom waveform from a file, or a waveform defined by a series of piece-wise mathematical equations.



Sine



Gaussian



Exp rise



Exp fall



Sinc



Cardiac



Equation



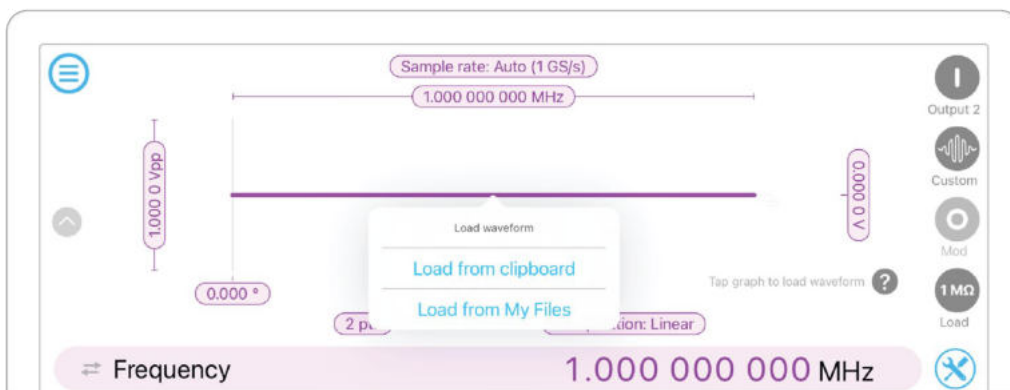
Custom



Custom

Uploading custom waveforms

- Tap the waveform preview to load the waveform
- Upload custom waveforms from comma- or newline-delimited text from the iPad's Clipboard, or My Files directory
- Up to 8192 points can be output at an update rate of 1 GS/s, up to 16384 points at 500 MS/s, up to 32768 points at 250 MS/s and up to 65536 points at 125 MS/s



Maximum recommended sampling rate

- The maximum safe frequency of the generated waveform is equal to the sampling rate divided by the number of points in the custom waveform
 - For example, the maximum safe frequency of a 1000-point waveform is $1 \text{ GS/s} / 1000 \text{ Samples} = 1 \text{ MHz}$
- Exceeding the maximum recommended frequency will result in some points being skipped

Amplitude scaling and interpolation




- The amplitude of custom waveforms will be normalized to the range [-1, +1] and then scaled to the desired amplitude and offset
- Select between linear and no interpolation



Equation

The **equation waveform type** enables you to design arbitrary waveforms using up to 32 piece-wise mathematical functions.



Equation editor

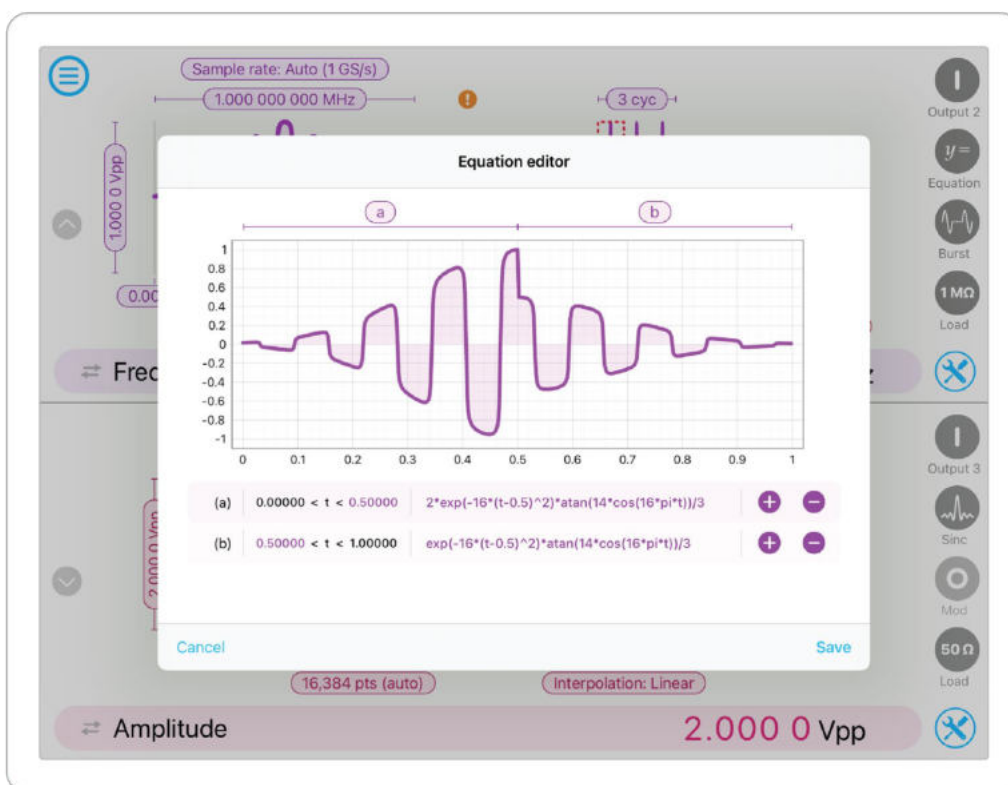
- The equation editor allows you to define arbitrary mathematical functions for each segment in the waveform
- Select from a range of common mathematical expressions including trigonometric, quadratic, exponential and logarithmic functions
- The variable **t** represents time in the range from 0 to 1 periods of the total waveform
- Access recently entered equations by pressing the  icon
- The validity of the entered equation is indicated by the  and  icons that appear to the right of the equation box





Waveform segments

- Add up to 32 waveform segments and define their time fractional time periods within a single period of the total waveform using the [Add segments...](#) button from the equation editor
- To add or remove segments, press the [Add / Remove](#) label and tap the  and  icons that appear to the left of the equations
- To modify the period of an individual segment, tap its **time segment** label and type in the desired end time for that period. The starting time for each segment is the end time for the previous segment





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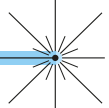
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Data Logger

Moku:Pro User Manual

Moku:Pro's Data Logger instrument records time series voltages from up to 4 channels at rates from 10 sample per second up to 1 MSa/s. The data can be logged to the onboard SSD storage.

The resulting logs can be shared to email or cloud services such as iCloud or DropBox.

Moku:Pro's Data Logger also includes an embedded 4-channel waveform generator.





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User Interface



ID	Button/icon	Description
1	Main menu	The main menu contains controls for switching instruments, switching devices, selecting device clock and user interface modes, and more. See Main Menu .
2	Autoscale	Toggle continuous autoscaling on/off.
3	Ref	Capture/clear a reference trace.
4	Time window	Overview of the logging time history. Drag bars to zoom/select different timescales/time windows.
5	Settings	Show/hide the settings.
6	Clear	Clear the trace history.
7	Signal display	Data traces are displayed in this area. By default, red represents channel 1, blue represents channel 2, teal represents channel 3, yellow green represents channel 4.
8	Bottom left	Double tap here to view entire log history.
9	Grid	Double tap on the grid to on-time autoscale.



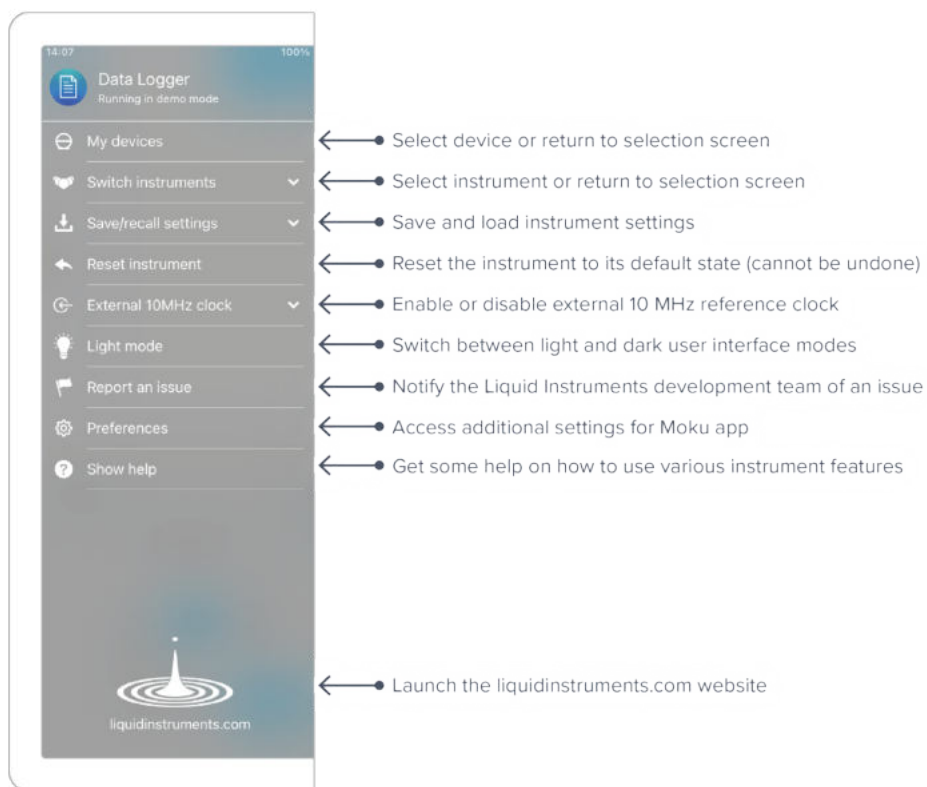
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Main Menu

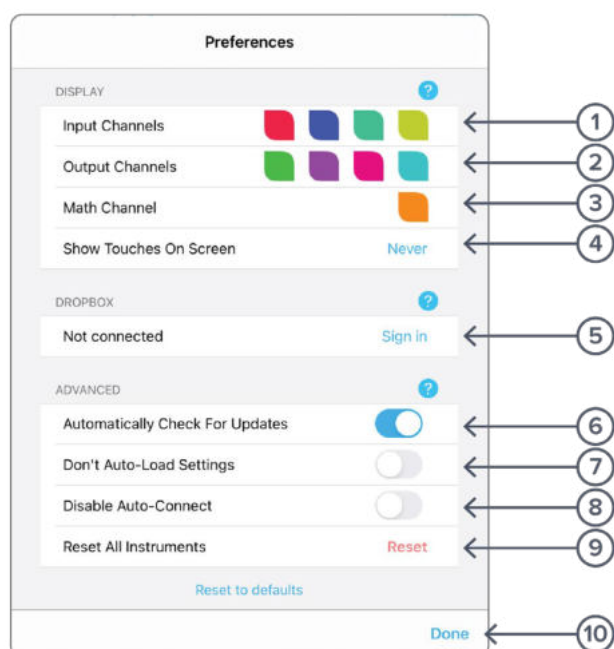
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Preferences

The preferences pane can be accessed via the main menu. In here, you can reassign the color representations for each channel, connect to Dropbox, etc. Throughout the manual, the default colors (shown in the figure below) are used to present instrument features.



ID Description

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2	Tap to change the color associated with output channels.
3	Tap to change the color associated with math channel.
4	Indicate touch points on the screen with circles. This can be useful for demonstrations.
5	Change the currently linked Dropbox account to which data can be uploaded.
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Data Logger control panel


Below the main Data Logger trace display is the control panel



ID	Button/icon	Description
1	Status	Logger status, either idle, aborted, waiting, or logging.
2	Share	The sharing button gives access to controls that allow you to save and share your data. See Saving and sharing data .
3	Memory	Displays the used and remaining memory available for logging.
4	Mode	Set acquisition mode as normal or precision.
5	Filename	Configure the prefix to be used on the data log filenames.
6	Comment	Text entered here will be saved in the file header.
7	Start/stop	Tap to start and top data logging.
8	Log format	Tap to select log format, CSV or LI binary format.
9	Duration	Tap to set log duration, up to 10,000 hrs, but limited to available memory.
10	Start	Tap to configure start delay, up to 240 hrs.
11	Acquisition rate	Tap to configure acquisition rate.



Sharing and saving data

Tap the share  button to access the file manager, allowing saving and sharing of the captured data logs. Dropbox, Mail, and iCloud service settings are configured in the iPad preferences.



ID	Button/icon	Description
1	All	Tap to select all files.
2	None	Tap to deselect all files.
3	Save options	Tap to share data files to “My Files” or any of these online services.



Settings

Acquisition

The acquisition sidebar configures the acquisition parameters of both input channels. The channel 1, channel 2, channel 3, channel 4, and acquisitions sub-panels may be dragged into the main display by tap/hold and dragging.



ID	Button	Description
1	Channels 1 settings	Channel 1 (red by default; configurable in main menu preferences), channel 2, channel 3, and channel 4 settings are configurable independently.
2	Coupling	Select AC or DC coupling.
3	Impedance	Select high 1 M Ω or 50 Ω input impedance.
4	Range	Range selects the input range as 400 mV, 4 V, or 40 V peak-to-peak.
5–8	Channel 2 settings	Configure channel 2 as described above for channel 1.
9	Acquisition settings	Configure acquisition settings.
10	Rate	Adjust the data acquisition rate.
11	Mode	Precision, normal.



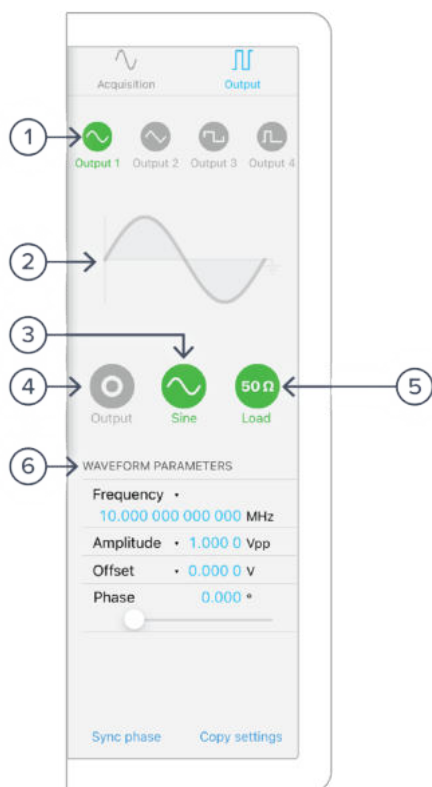
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Output

Moku:Pro's Data Logger has a built-in waveform generator capable of generating basic waveforms on the four output channels. For more complex waveforms, see Moku:Pro Waveform Generator and Arbitrary Waveform Generator.



ID	Button	Description
1	Configure channels	Tap to configure settings for channels 1 to 4. As illustrated, settings apply to channel 1.
2	Current waveform	Graphical representation of the selected waveform.
3	Waveform selection	Tap to choose between Sine, Square, Ramp, Pulse, or DC waveforms.
4	Enable	Tap to enable/disable channel output.
5	Load	Tap to select either 50 Ω or 1 M Ω output load.
6	Waveform parameters	Tap to configure the selected waveform parameters varying according the waveform type selected.



Instrument Reference

Moku:Pro's Data Logger is designed to be intuitive and straightforward to use.

Up to four channels of time-series voltages are recorded by Moku:Pro, for a specified duration, and at a specified rate.

Recording a Session

Recording data is done as follows:

1. Configure the channel(s) you wish to record using the acquisition sidebar. Ensure the voltage range, coupling, and impedance are all appropriate for your signals. Use the plotter window to ensure your signal is correctly connected and configured.
2. Configure the acquisition rate and acquisition mode, either normal or precision.
3. Set the recording duration and any comments you want to be saved with the file.
4. Optionally configure the waveform generator outputs.
5. Tap "record".

Channel Configuration

Each channel can be enabled or disabled, 400 mVpp, 4 Vpp, or 40 Vpp, AC or DC-coupled, and 50 Ω or 1 M Ω terminated.

Acquisition Parameters

The acquisition parameters refer to the logging rate and the down-sampling mode used to reduce Moku:Pro's native sampling rate to the logging rate.

The logging rate must be between 10 Sa/s and 1 MSa/s.

Acquisition mode may be either normal or precision. Normal mode down-samples by discarding points between those needed. This causes signals to alias; not desirable for most signals but can be useful for viewing frequency components outside the logging rate.

Precision mode down-samples by averaging, increasing precision and reducing noise. This mode is preferred for most applications.

File Types

The binary file format is proprietary to Moku:Pro and has been extensively optimized for speed and size. Using the binary format, Moku:Pro is able to reach very high logging rates and very low memory usage.

The binary file can be converted to other formats by the iPad app or the file converter software available from the Liquid Instruments website. This software can convert the binary file to CSV, MATLAB, or NPY formats for access in major scientific software.

Starting the Log

The red record button should be tapped to start.

The status indicator at the top of the control panel will display logging progress.



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The log will stop either when the specified duration has been reached, or when the user taps the record button again to abort.

Accessing your Data

Data logs can be shared to My Files, Dropbox, Mail, or iCloud services.

Embedded Waveform Generator

Moku:Pro's Data Logger integrates a simple waveform generator capable of providing Sine, Square, Ramp, Pulse, and DC waveforms on the output channels



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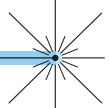
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Frequency Response Analyzer

Moku:Pro User Manual

Moku:Pro's Frequency Response Analyzer can be used to measure a system's frequency response from 10 mHz up to 250 MHz.

Frequency Response Analyzers are commonly used to measure the transfer functions of electrical, mechanical or optical systems by injecting a swept sinewave into the system and then comparing the output voltage to the input voltage. The resulting measurements of the system's magnitude and phase response can be used to optimise the closed-loop response of control systems, characterize resonant behaviour in non-linear systems, design filters, or measure the bandwidth of different electronic or optical components. Frequency Response Analyzers are quite simply an indispensable tool in any electronics and optics lab.





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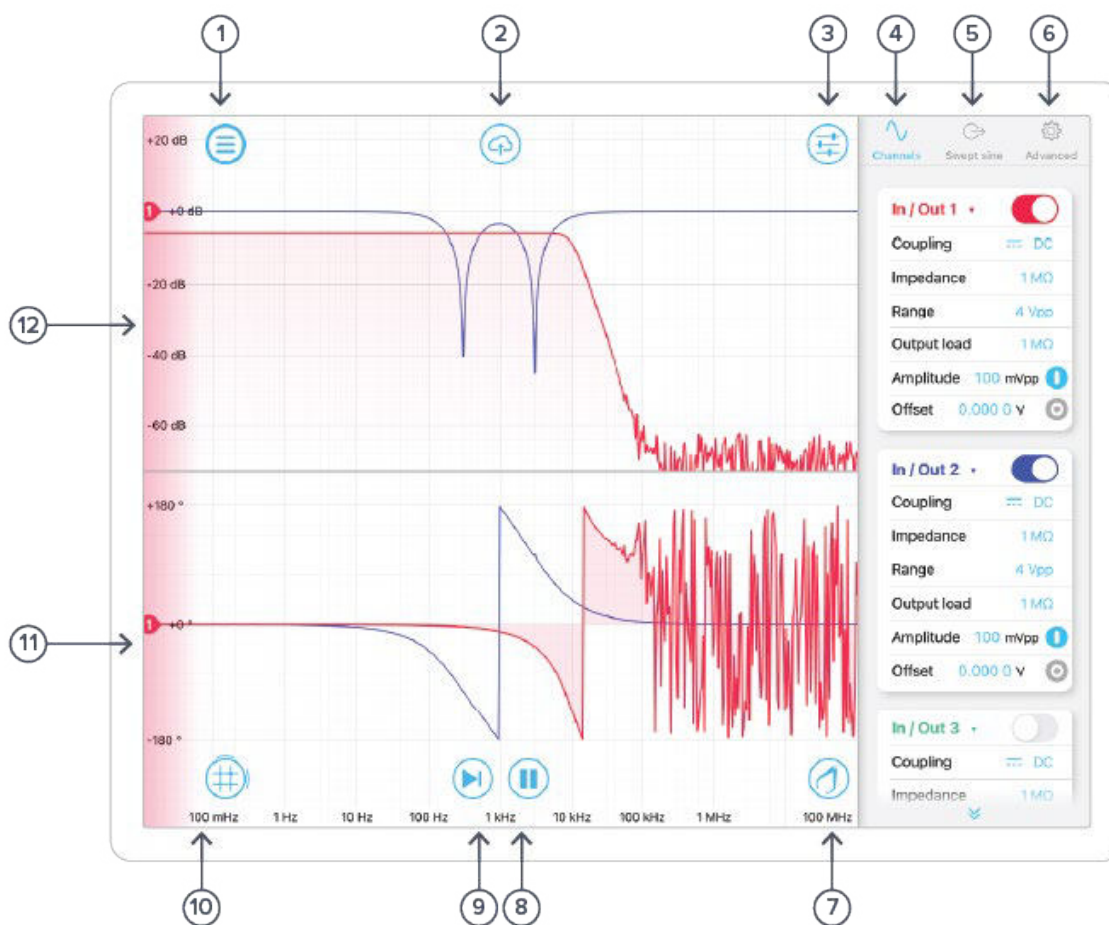
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User Interface

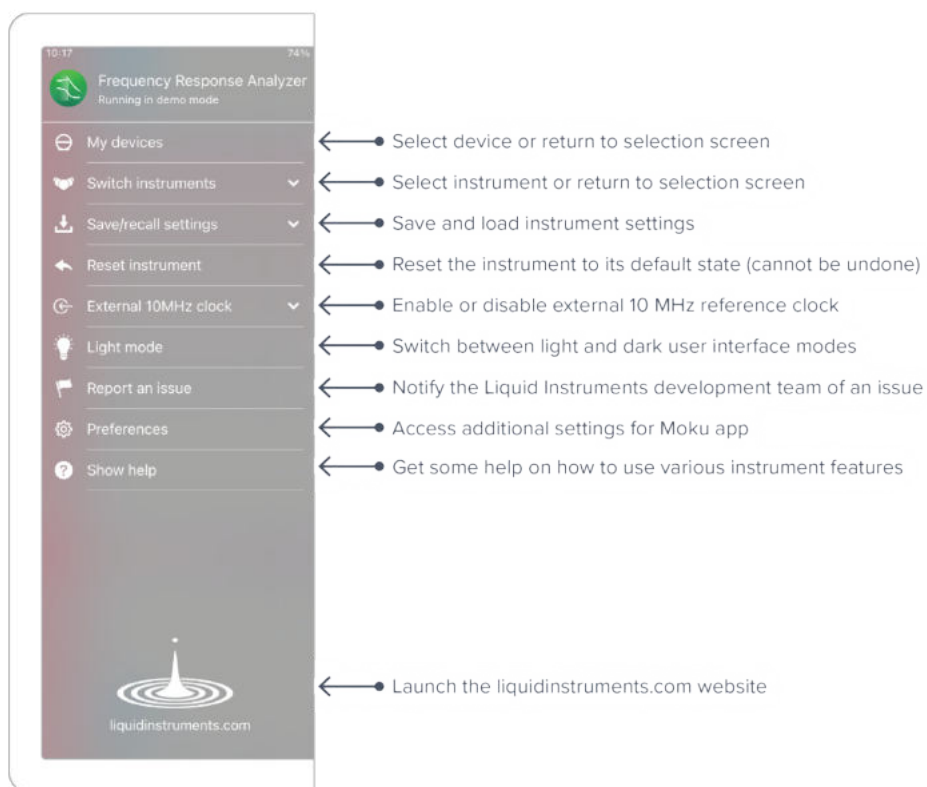


ID	Description	ID	Description
1	Main menu	7	Calibration tool
2	Export data	8	Sweep mode
3	Instrument configuration menu	9	Start / pause sweep
4	Channel settings	10	Cursors
5	Swept sine output settings	11	Phase plot
6	Advanced demodulation settings	12	Magnitude plot



Main Menu

The **main menu** can be accessed by pressing the  icon, allowing you to:



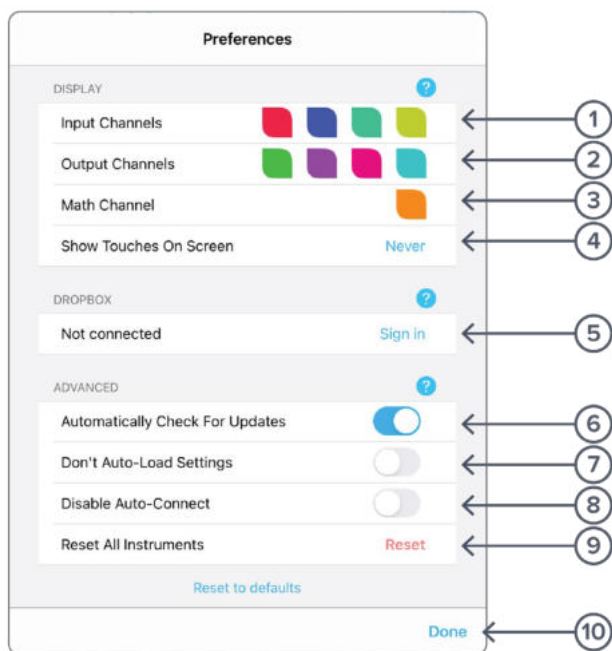
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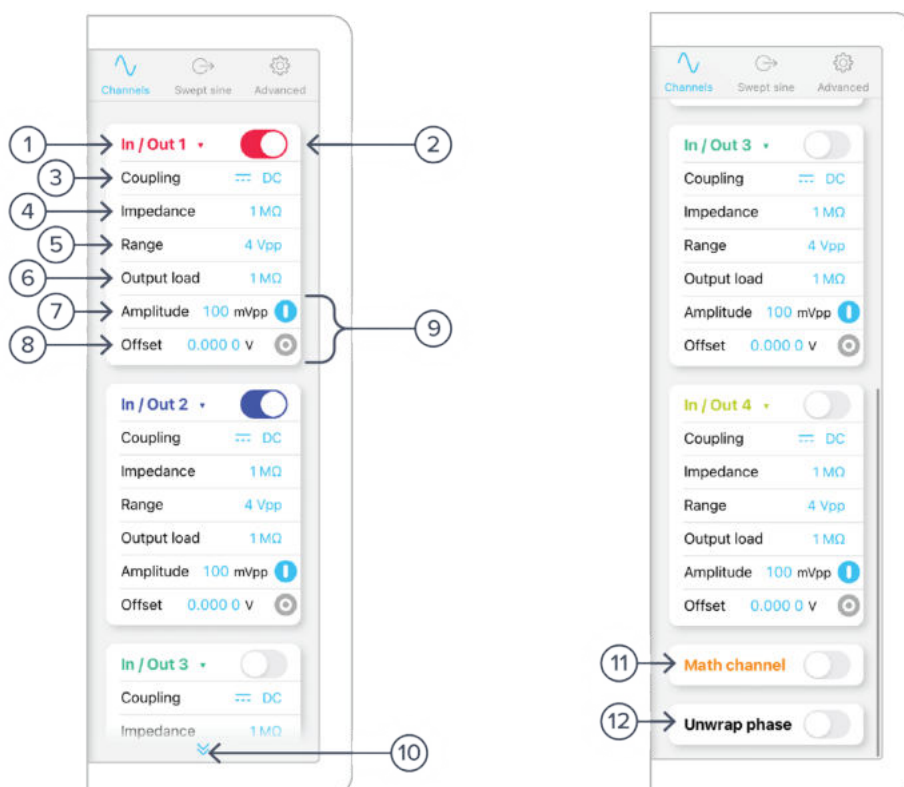
Instrument Configuration

The instrument configuration menu allows you to configure the Frequency Response Analyzer for your measurement, which will vary depending on the specific characteristics of the system under test.

Access the instrument configuration menu by pressing the  icon.

Channels

Additional settings can be accessed by scrolling up and down.



ID	Description	ID	Description
1	Select to display In1 or In1/Out1	7	Swept sine amplitude
2	Toggle channel on/off	8	Swept sine offset
3	Select AC or DC coupling	9	Turn on/off amplitude and/or offset
4	Select 1 M Ω or 50 Ω input impedance	10	Access additional settings
5	Select input range 400 mV, 4 V or 40 V peak-to-peak	11	Enable/disable Math channel
6	Select 1 M Ω or 50 Ω output load	12	Unwrap/wrap phase



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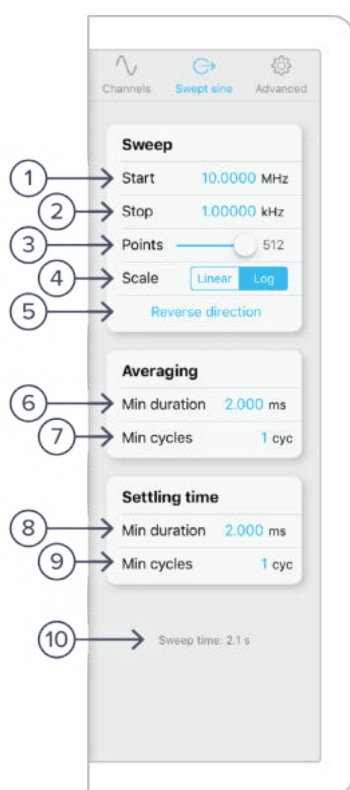
Math channel

- Select between addition, subtraction, multiplication and division of two channels.
- Compare transfer functions of channel 1, 2, 3, and 4 by configuring them identically.

Unwrap phase

- Phase is measured as a modulo of 2π . Enabling unwrapping will display an estimate of the total accumulated phase of the system.

Swept Sine



ID	Description	ID	Description
1	Configure sweep start frequency	6	Configure minimum averaging time
2	Configure sweep stop frequency	7	Configure minimum averaging cycles
3	Select number of sweep points	8	Configure minimum settling time
4	Select Linear or Log scale	9	Configure minimum setting cycles
5	Reverse direction of sweep	10	Total sweep time based upon selected parameters



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Sweep points

- Increasing the number of points in the sweep increases frequency resolution of the measurement allowing narrower features to be detected over a wider frequency range but will increase the total measurement duration.

Sweep scale

- Select whether or not the discrete points in the swept sine output are spaced linearly or logarithmically. Logarithmic sweeps provide greater measurement resolution at lower frequencies.

Averaging

- Measurements at each point in the frequency sweep are averaged to improve accuracy and precision. You can configure the period over which each measurement is averaged in order to control signal-to-noise ratio. Longer averaging times result in higher SNRs, allowing small features to be detected with greater precision. Shorter averaging times result in lower SNR measurements but the reduce total sweep time.
- The total averaging time is determined based on the **minimum duration** and **minimum number of cycles** over which each point in the sweep is averaged. Moku:Pro's Frequency Reference Analyzer averages for the greater of the two values rounded up to the nearest number of integer cycles in order to avoid spectral leakage.

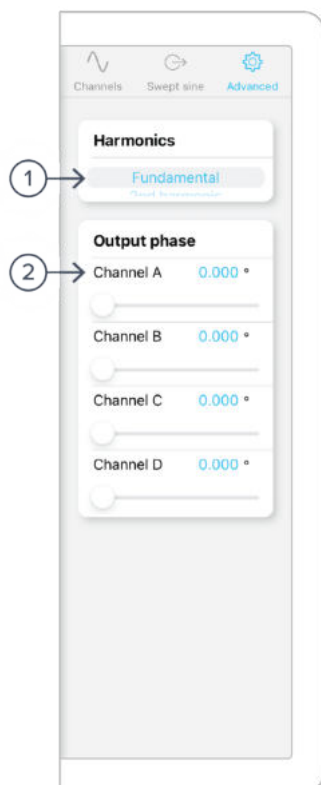
Settling time

- The settling time determines how long the Frequency Reference Analyzer waits before performing measurements at each frequency in the sweep. Settling time is important when characterizing resonant systems with high Q-factors in order to allow excitations to 'settle' between measurements. It can also be used to account for transmission delays in cables. When interrogating a non-resonant system, the settling time should be set to equal the total propagation delay through the system.
- The total settling time is determined based on the **minimum duration** and **minimum number of cycles** over which the instrument will wait before beginning a measurement at each frequency in the sweep. The Frequency Reference Analyzer will wait for the greater effective duration of the two settings before beginning a measurement at each point in the sweep.





Advanced



ID	Description	ID	Description
1	Select a harmonic to measure the frequency response of the swept sine	2	Adjust output phase for each channel

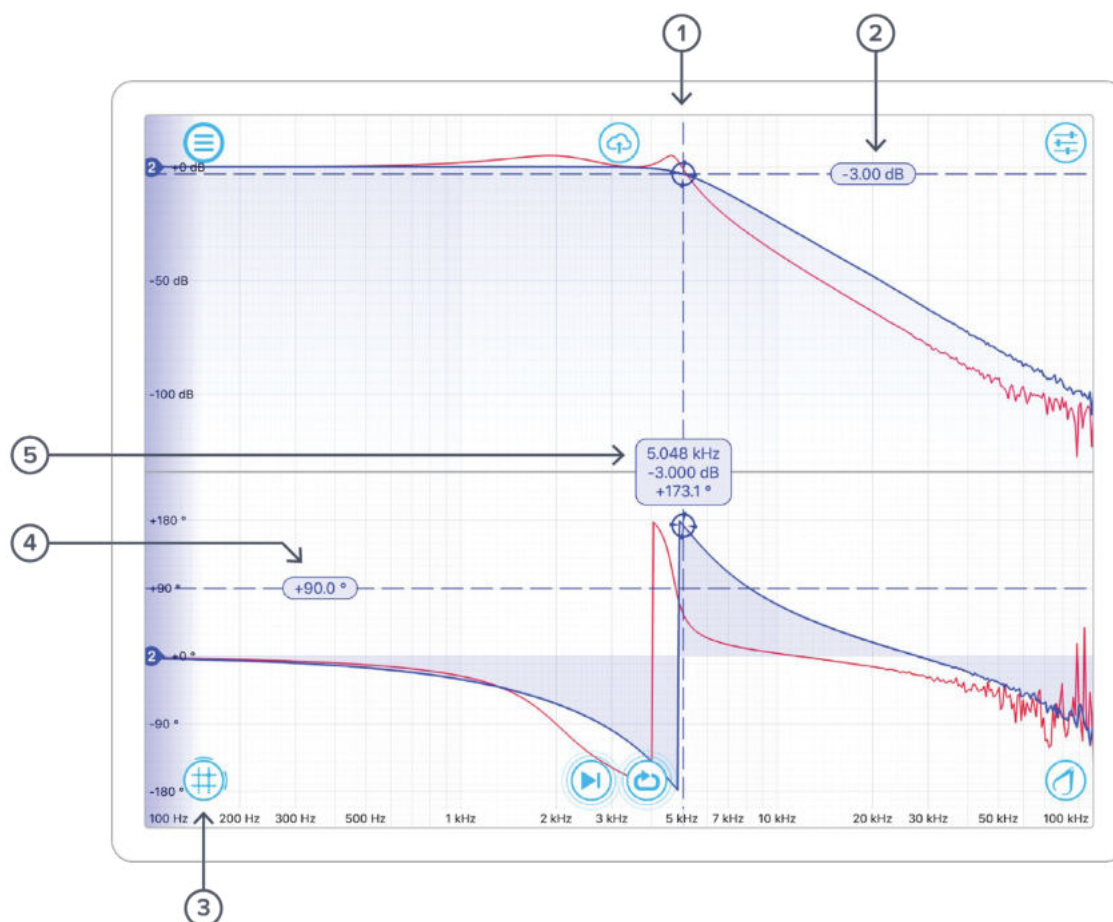


Cursors



Magnitude and phase cursors can be added to the Frequency Response plot by pressing the button.

Tip: Magnitude and phase cursors can be moved between the two plots by dragging them vertically across the horizontal divider.




ID	Cursor item	Description
1	Frequency cursor	Drag to adjust frequency, tap and hold to hide channel
2	Amplitude cursor	Drag to adjust tap to set magnitude manually & other options
3	Create cursor	Tap to create, or drag up or drag right for magnitude/frequency cursor
4	Phase cursor	Drag to adjust, tap to set phase manually & other options
5	Cursor label	Label depicting frequency, amplitude and phase of cursor. Drag to adjust. Tap to manually adjust or remove




ID	Description	ID	Description
1	Cursor action buttons	4	Add phase cursor
2	Remove all cursors	5	Add magnitude cursor
3	Add frequency cursor		


Magnitude cursors

Magnitude cursors can be added to the Magnitude plot by tapping the  icon and selecting 'Add magnitude cursor'. A magnitude cursor can also be created by dragging your finger up from the cursor icon and then repositioning it on the magnitude plot.


Phase cursors

Phase cursors can be added to the Phase plot by tapping the  icon and selecting 'Add phase cursor'. A phase cursor can also be created by dragging your finger up from the cursor icon and then repositioning it on the phase plot.

Frequency cursors

Up to five frequency cursors can be added to the Frequency plot by tapping the  icon and selecting 'Add frequency cursor'. Frequency cursors can also be created by dragging your finger to the right from the cursor icon.

Removing cursors

All active cursors can be removed from the Frequency and Phase plots by tapping the  icon and selecting 'Remove all cursors'. Individual cursors can be removed by tapping their label and pressing 'Remove'.



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Sweep modes



Single

Tapping the  icon will enable single sweep mode, which will pause the swept sine source at the end of the next full sweep. The swept sine signal will be turned off after the sweep completes and displayed data will not be updated.

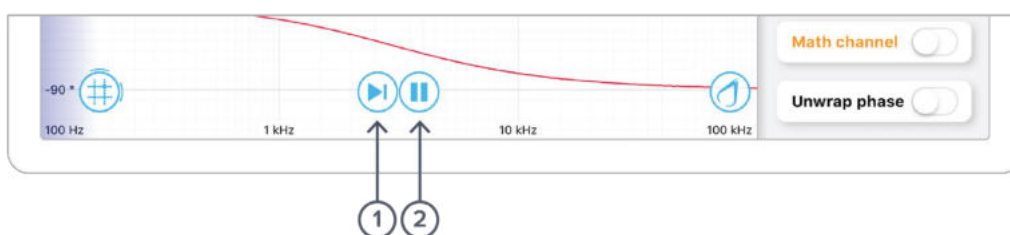
Continuous

Tapping the  icon will enable continuous sweep mode, which will perform a new measurement as soon as the previous one has finished. This mode is commonly used to monitor systems with transfer functions that may change over time (e.g., control loops).

Pause / Restart

Tapping the  icon will immediately pause the current sweep. While paused, you can zoom in on features for more details, but no new data will be captured. Pressing the  icon will also pause capture.


Tapping the  or  icons will restart the sweep.

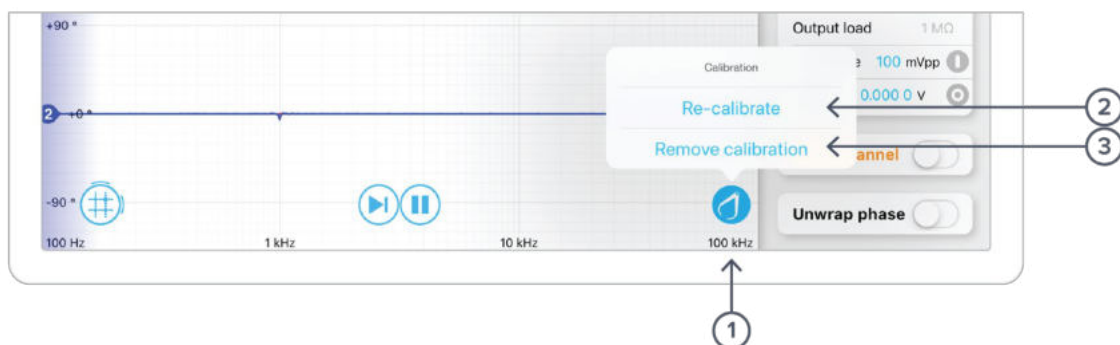


ID	Description	ID	Description
1	Start single sweep	2	Stop sweep




Calibration

Moku:Pro's Frequency Reference Analyzer features a calibration tool  that can be used to normalize subsequent measurements. Calibration is useful when compensating for cables delays and comparing different devices under test.



ID	Description	ID	Description
1	Calibrate menu	3	Remove calibration
2	Recalibrate		

Tapping the  icon will bring up the calibration menu. **Re-calibrate** will replace the current calibration trace with a new one. **Remove calibration** will erase all stored calibration settings and cannot be undone.

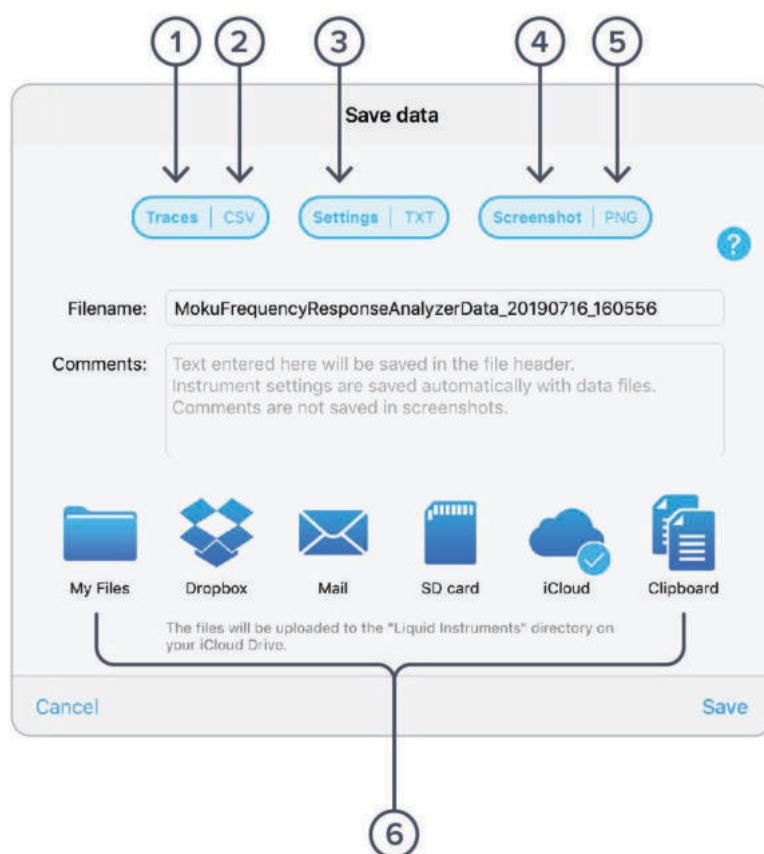


Exporting Data

Measurement traces and screenshots can be uploaded to My Files (iOS 11 or later), Dropbox, E-mail, SD card, iCloud, Clipboard (screenshot is not copied to the clipboard).

The frequency analyser instruments settings can also be exported for future reference.

To export a measurement trace, press the  icon at the top of the Frequency response plot.



ID	Button	Description
1	Traces data	Select to enable saving of Trace data
2	Traces format	Tap to select CSV or MATLAB format
3	Settings data	Select to save instrument settings
4	Screenshot capture	Select to capture screenshot
5	Screenshot format	Tap to select JPG or PNG screenshot format
6	Saved data destination	Select data destination



Ensure Moku:Pro is fully updated. For the latest information:

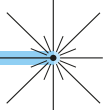
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Lock-in Amplifier

Moku:Pro User Manual

Moku:Pro's Lock-in Amplifier supports dual-phase demodulation (XY/Rθ) from DC up to 600 MHz, with more than 120 dB of dynamic reserve. It also features an integrated 4-channel oscilloscope and data logger, enabling you to observe signals at a rate of up to 1.25 GSa/s and log data up to 1 MSa/s.





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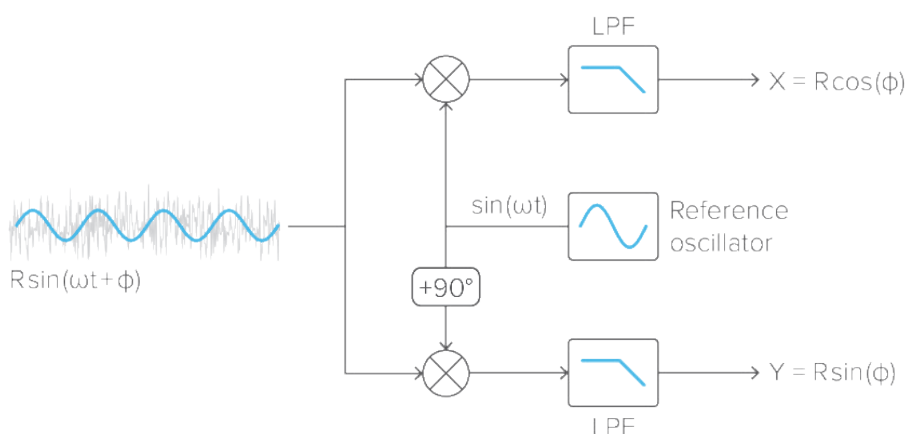


Introduction

Lock-in amplifiers are extremely versatile instruments used primarily to recover the magnitude and phase of weak oscillating signals in the presence of overwhelming noise. They are used in a vast range of applications including atomic physics, radio-frequency engineering, materials science, precision laser metrology, and many more.

Principle of Operation

Lock-in amplifiers work by demodulating an input signal $R \sin(\omega t + \phi)$ with a reference signal $\sin(\omega t)$.



The demodulation process produces two spectral components: an *up-shifted* signal with a frequency equal to the *sum* of the input and reference signals, and a *down-shifted* signal with a frequency equal to the *difference* of the input and reference signals.

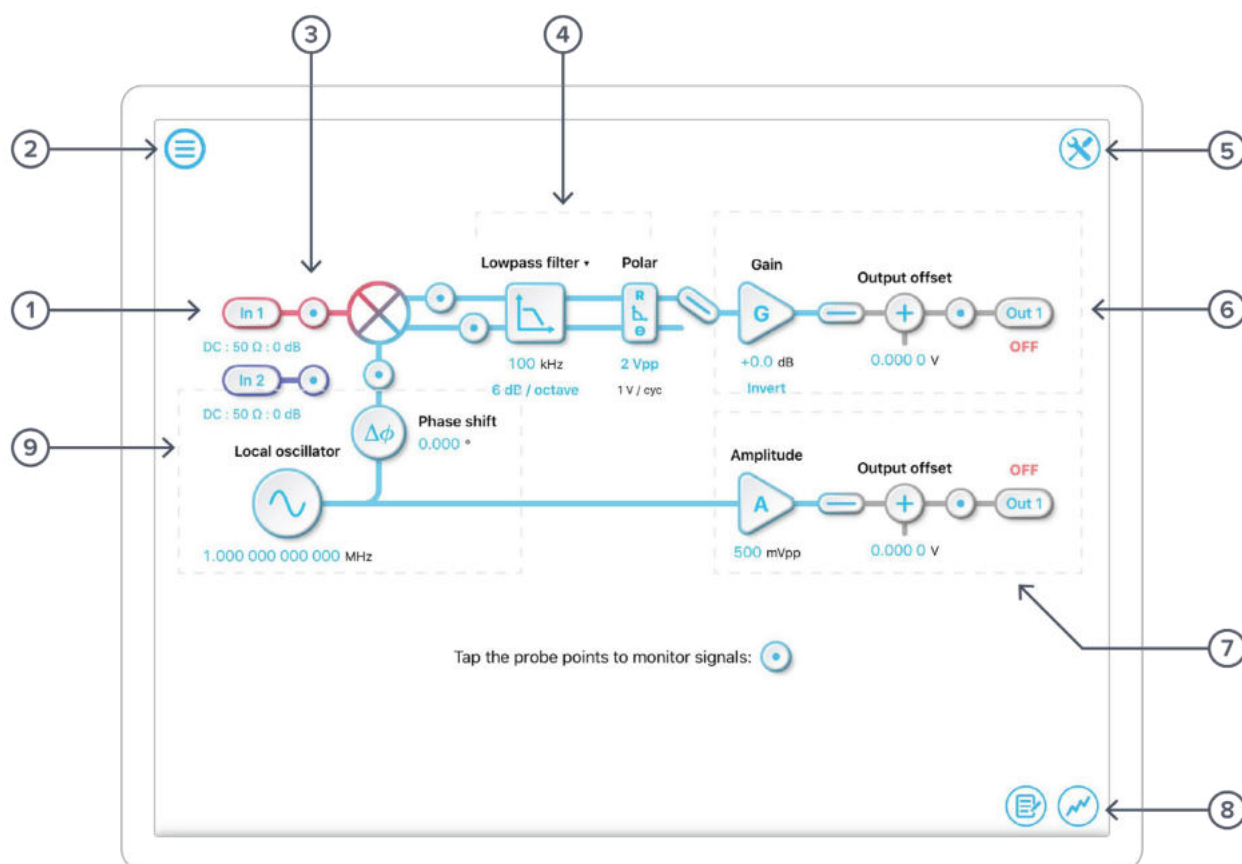
If the input and reference signals have the same frequency ω , then the down-shifted component will appear at DC and its phase will be equal to the difference between that of the input and reference signals, whereas the up-shifted component will appear at twice the input frequency with additive phase.

A low pass filter is used to attenuate the up-mixed signal and to suppress noise, the output of which is proportional to the amplitude of the input signal scaled by the cosine of the phase difference: $R \cos(\phi)$. In order to reconstruct the magnitude and phase of the input signal, it is necessary to demodulate it with two orthogonal references, sine and cosine, to produce in-phase (X) and quadrature (Y) components relative to the reference. This process is referred to as dual-phase demodulation and is a standard feature of all modern lock-in amplifiers.

With X and Y, the magnitude R and phase ϕ can be calculated as $R = \sqrt{X^2 + Y^2}$ and $\phi = \tan^{-1}(Y/X)$.



User Interface



ID	Description	ID	Description
1	Input settings	6	Channel 1 output
2	Main menu	7	Channel 2 output
3	Probe point	8	Oscilloscope/Data logger
4	Filter settings	9	Reference oscillator
5	Advanced configuration menu		



Main Menu

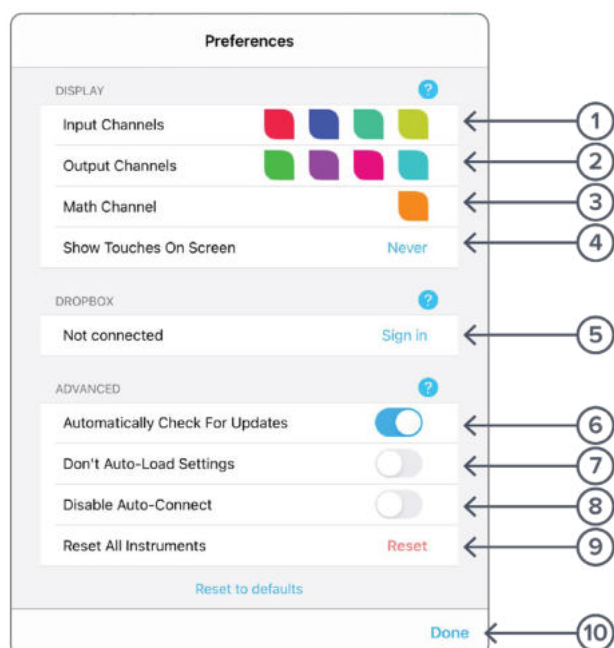
The **main menu** can be accessed by pressing the  icon, allowing you to:





Preferences

The preferences pane can be accessed via the main menu. In here, you can reassign the color representations for each channel, connect to Dropbox, etc. Throughout this manual, the default colors (shown in the figure below) are used to present instrument features.



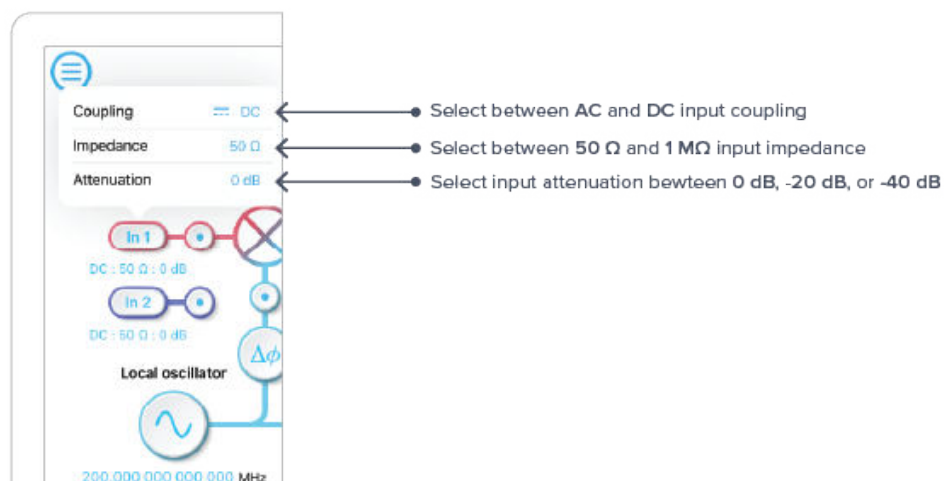
ID Description

- | | |
|----|--|
| 1 | Tap to change the color associated with input channels. |
| 2 | Tap to change the color associated with output channels. |
| 3 | Tap to change the color associated with math channel. |
| 4 | Indicate touch points on the screen with circles. This can be useful for demonstrations. |
| 5 | Change the currently linked Dropbox account to which data can be uploaded. |
| 6 | Notify when a new version of the app is available. |
| 7 | Moku:Pro automatically saves instrument settings when exiting the app, and restores them again at launch. When disabled, all settings will be reset to defaults on launch. |
| 8 | Moku:Pro can remember the last used instrument and automatically reconnect to it at launch. When disabled, you will need to manually connect every time. |
| 9 | Reset all instruments to their default state. |
| 10 | Save and apply settings. |



Signal Input

Tap the  icon to configure the input settings for the signal input.



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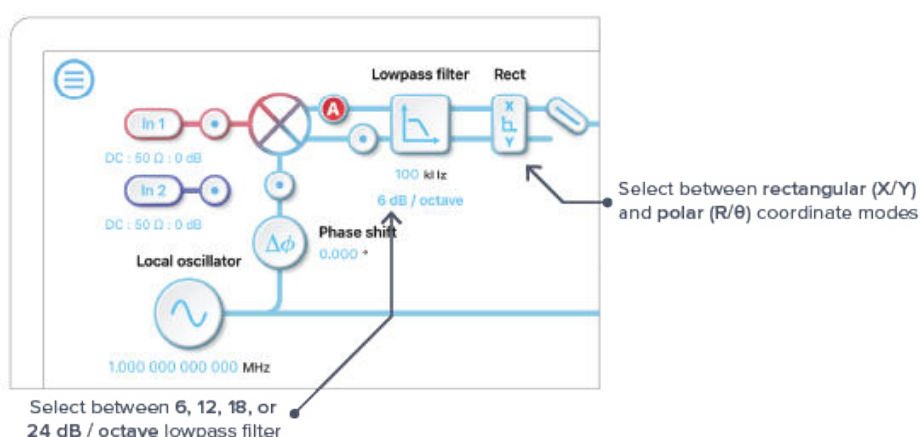
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Dual-Phase Demodulator

Moku:Pro's Lock-in Amplifier features a dual-phase demodulator with cascaded single pole low pass filters to attenuate the second harmonic and suppress noise in the in-phase and quadrature components.

- Select between **6, 12, 18, or 24 dB / octave** low pass filter slopes.
- Select between **rectangular (X/Y)** and **polar (R/θ)** coordinate modes.
- View the demodulated in-phase and quadrature signals prior to the low pass filters using probe points.
- Select which demodulated signal to route to the output. Note: your options depend on how the Lock-in Amplifier is configured.



Rectangular (or Cartesian) coordinate mode measures the input signal with respect to a specific quadrature of the reference signal. When combined with a PID controller, Cartesian mode can be used to perform laser frequency stabilization.

Polar coordinate mode measures the amplitude and phase of the input signal with respect to the reference signal. Polar mode is not available when using external references in straight-through mode.



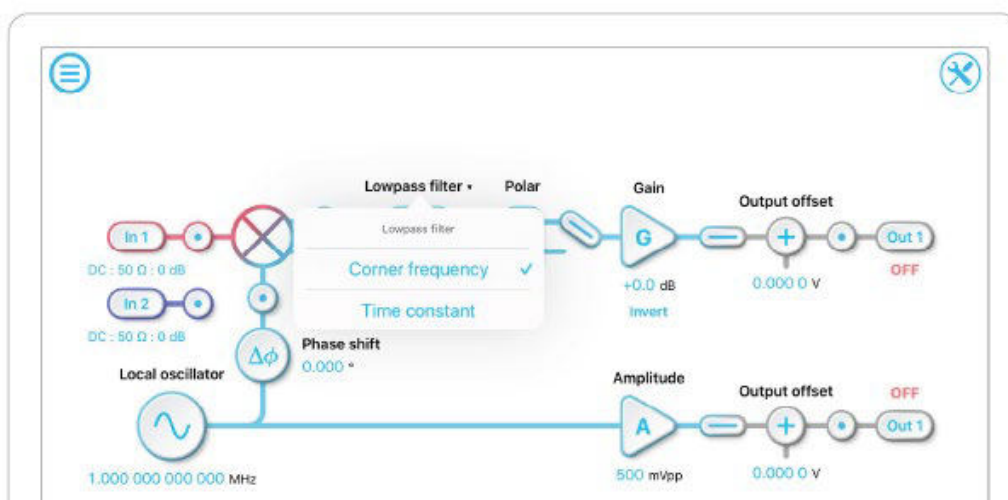
Filter Bandwidth and Time Constant

The filter bandwidth and time constant are equivalent representations for the width of the filter passband. They can be converted using the following equation:

$$\text{Time Constant} = \frac{1}{2\pi \times \text{Filter Bandwidth}}$$



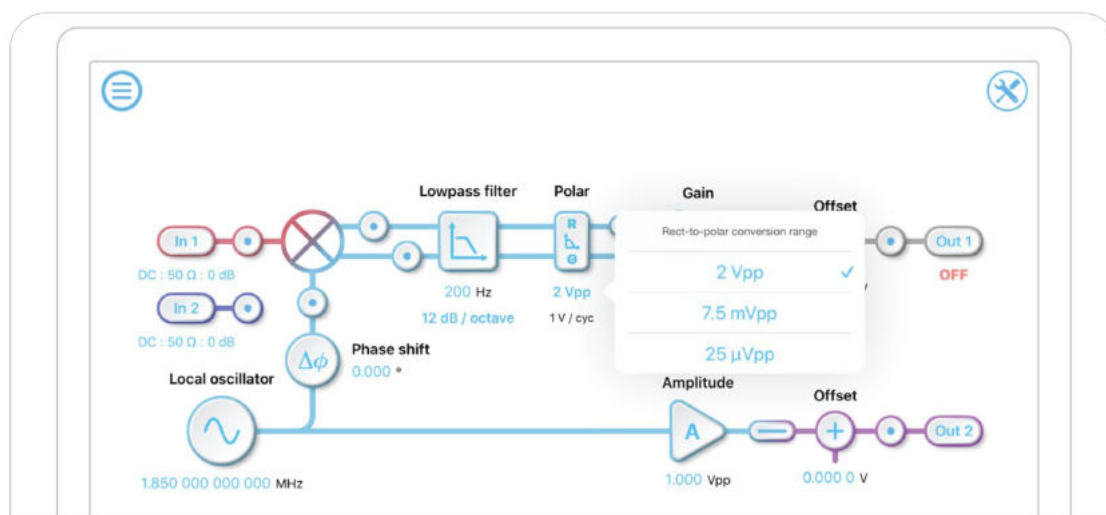
Tap the text above the icon to switch between filter bandwidth or time constant representation.





Rect-to-Polar Conversion Range

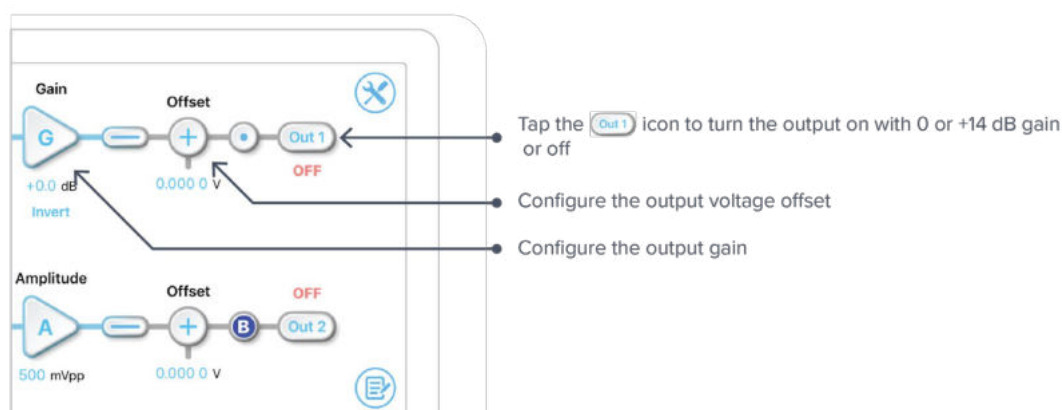
In polar mode, the rectangular-to-polar conversion range allows you to select the signal processing range for optimized system performance. Three ranges are available: 2 V_{pp}, 7.5 mV_{pp} and 25 μV_{pp}. The smallest range which can accommodate your signal without saturating should be used. For example, if the measured signal has an amplitude of 1 mV_{pp}, the 7.5 mV would be the most suitable range; if a signal has an amplitude of 1 V_{pp}, the 2 V_{pp} range would be the most suitable range.






Outputs

Configure the gain / amplitude and voltage offset of the two output channels. Enable / disable either output channel by tapping the **Out 1** and **Out 2** icons. View the signal at the output of each channel using the probe points

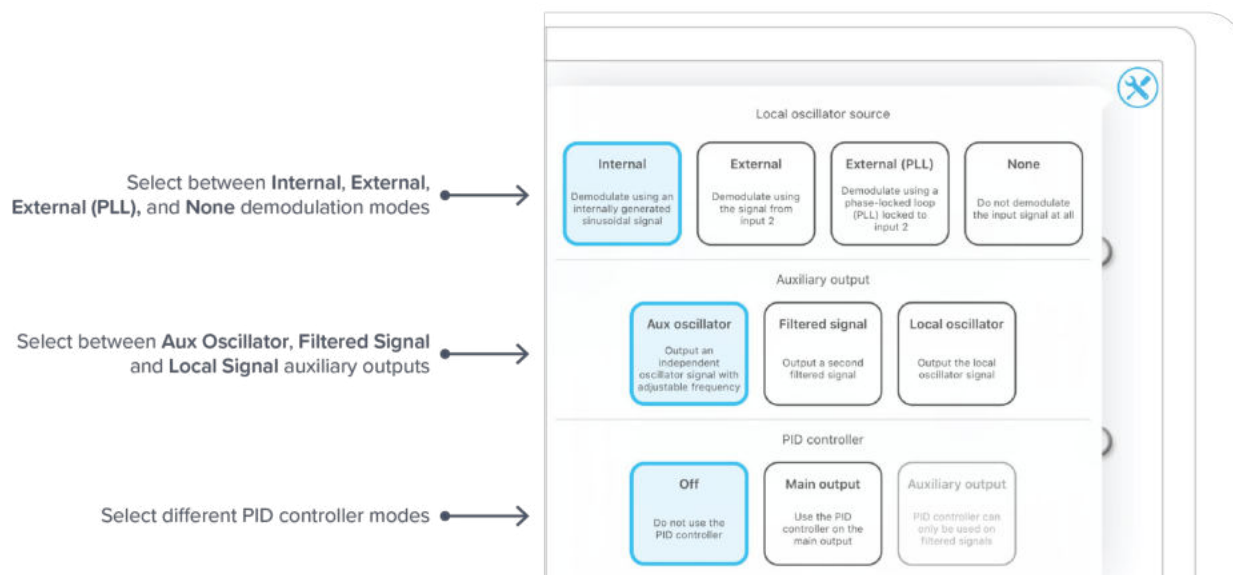




Advanced Configuration

The Lock-in Amplifier's digital signal processing layout can be rapidly re-configured to suit different applications. Access the advanced configuration menu using the  icon at the top right of the interface.

- Select between internal, external (straight-through), or external (phase-locked) demodulation references. Alternatively, you can bypass the demodulation by selecting “none”.
- Configure the auxiliary output to generate an independent aux oscillator with adjustable frequency and amplitude, the second output from the demodulator (e.g., generate voltage signals proportional to R and θ from outputs 1 and 2 respectively), or the local oscillator (available in internal demodulation mode only).
- A PID controller can be added to the main output (channel 1) or the auxiliary output (only available when generating a second filtered signal from the auxiliary output).





Demodulation

The demodulation mode determines which reference signal is used to demodulate the input signal.

Internal

The input signal can be demodulated with an internally generated reference signal. This *local oscillator* is derived from Moku:Pro's internal clock and thus shares the same timebase. The frequency range of the internal reference is 1 mHz to 600 MHz.

There are two ways to measure the phase of the input signal relative to the reference using Moku:Pro's timebase:

1. Using the internal local oscillator to drive the external system.
2. Phase-locking Moku:Pro to the external reference using the 10 MHz reference loop at the back of the device.

External (direct)

The input signal can be demodulated by a direct external reference, permitting the use of non-sinusoidal demodulation of the input signal. This can be used to measure correlation or to recover specific components of complex input signals.

The arbitrary nature of direct external reference signals means that they cannot be used to perform dual-phase (orthogonal) demodulation of the input signal. This prevents external (direct) demodulation mode from being used to measure Y , R , and θ since only one quadrature can be interrogated.



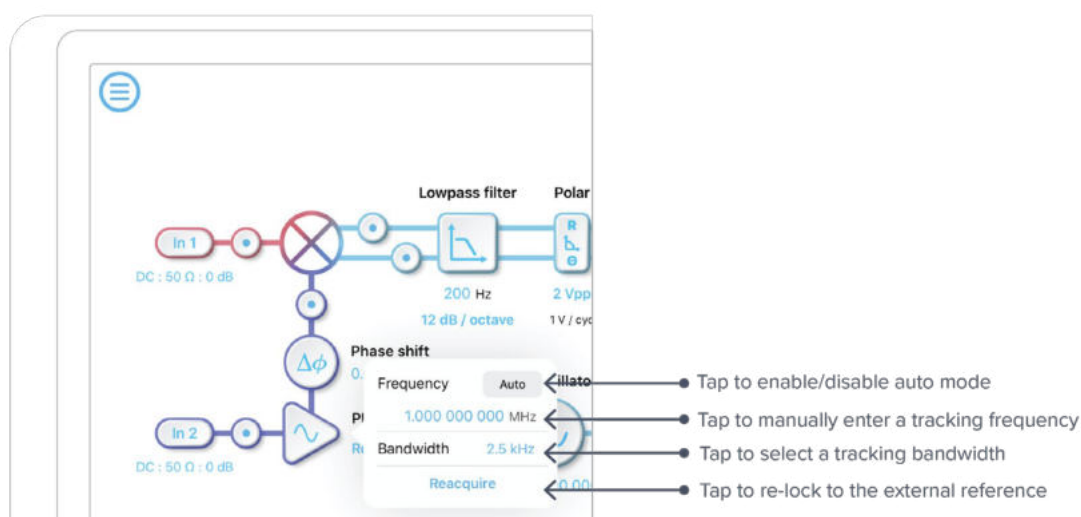


External (PLL)

Dual-phase demodulation of the input signal with an external reference can be performed using phase-locked external reference mode, which constructs two orthogonal reference signals phase-locked to the external reference. This mode uses a digitally implemented phase-locked loop to track the phase of the external reference with a user selectable bandwidth, allowing it to generate phase-locked in-phase and quadrature sinusoids at the same frequency, with adjustable phase.

External (PLL) mode enables the Lock-in Amplifier to recover information in all quadratures (X/Y and R/ θ) without requiring Moku:Pro to share the same timebase as the external system.

The phase-locked loop will automatically lock to the strongest harmonic of the external reference in the range of 500 kHz to 400 MHz in the auto mode. Tracking frequencies between 500 kHz and 10 kHz can be manually entered. The reacquire button can be used to re-lock to the external reference.



None

The demodulation step can be bypassed by selecting “none”. This enables modulation-free locking techniques such as DC locking, fringe-side locking, and tilt locking.



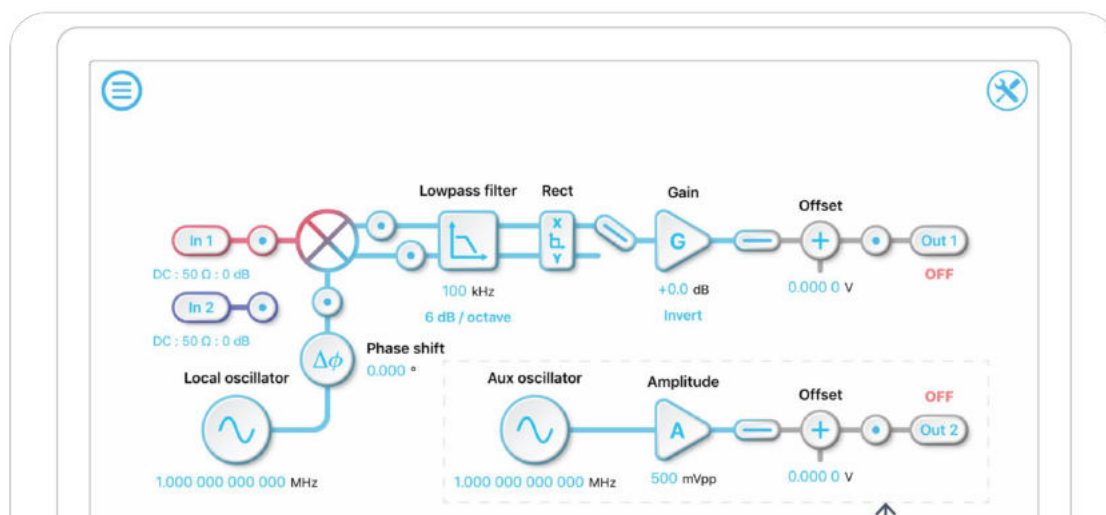
Auxiliary Output

Moku:Pro's second output can be configured to generate an additional auxiliary voltage signal.

Aux Oscillator

Aux oscillator mode allows you to generate a sinusoidal signal with independently configurable frequency, amplitude, and voltage offset. The frequency can be adjusted from 1 mHz to 400 MHz and the amplitude range (amplitude + offset) is $2 V_{pp}$ with 1 mV resolution.

The generated waveform shares the same timebase as the rest of the instrument. When used with internal demodulation, this mode can be used to stimulate a system at one frequency and demodulate at a different frequency, for example in wavelength modulation spectroscopy where it is necessary to demodulate harmonics of the input signal.



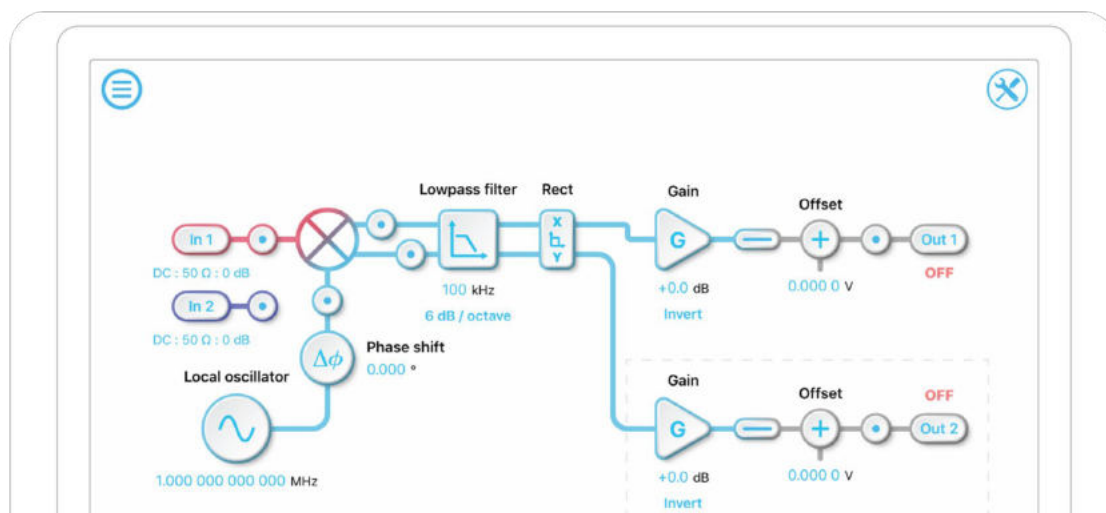
The **aux oscillator** auxiliary output mode allows you to generate a local oscillator signal with independent frequency, amplitude, and vertical offset control



Filtered Signal

The second output of the dual-phase demodulator can be routed to Moku:Pro's second output channel to produce a voltage signal proportional to Y or θ .

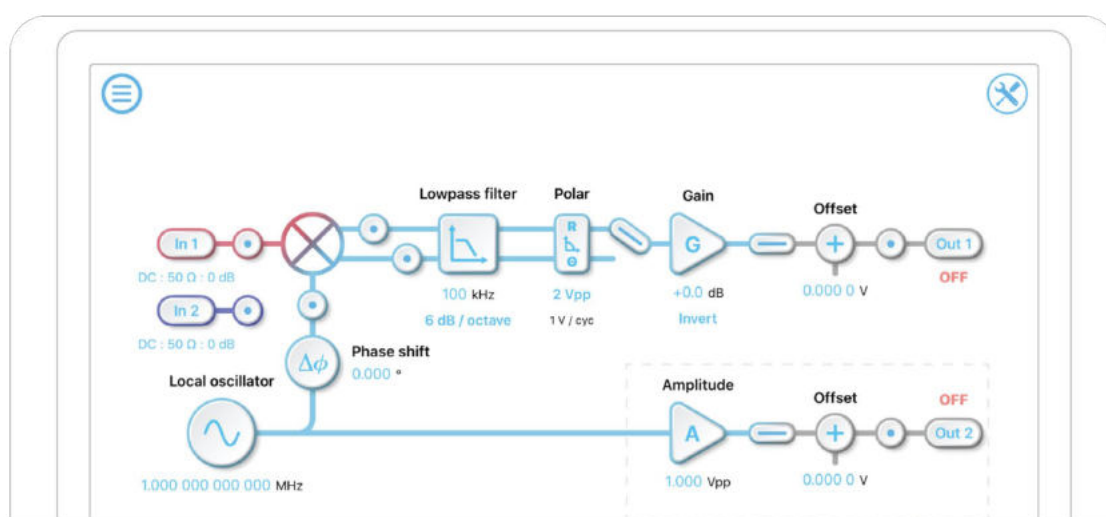
This mode can be used to record both in-phase and quadrature at the same time using probe points.



The **filtered signal** auxiliary output mode generates a second voltage signal proportional to the second low pass filtered output of the demodulator

Local Oscillator

The internal reference used to demodulate the input signal can be used to generate a sinusoidal waveform at the same frequency with configurable amplitude and voltage offset.



The **local oscillator** auxiliary output mode will generate a local oscillator at the same frequency as the demodulation waveform with full amplitude and vertical offset control



PID Controller

Moku:Pro's Lock-In Amplifier can be used to control an external system by acting as both a sensor and controller using a dedicated PID controller. The PID controller's frequency dependent gain can be easily configured to satisfy the stability requirements of the control system.

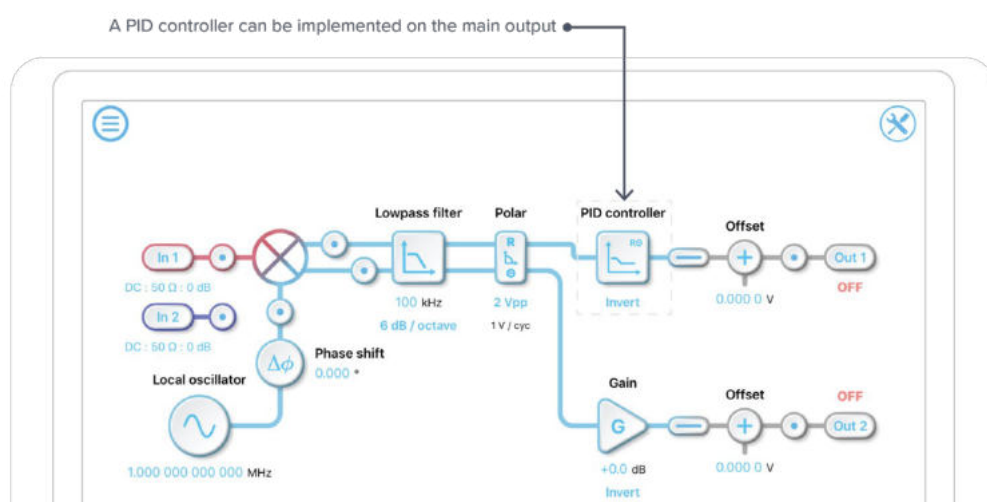
Note: The Lock-in Amplifier can only implement a single PID controller at a time. This means that when the instrument's auxiliary output is configured to generate a voltage signal proportional to the Y or θ , the PID controller can be used on *either* X/R or Y/θ , but not both.

Off

Turns off the full PID controller. A flat gain can still be configured.

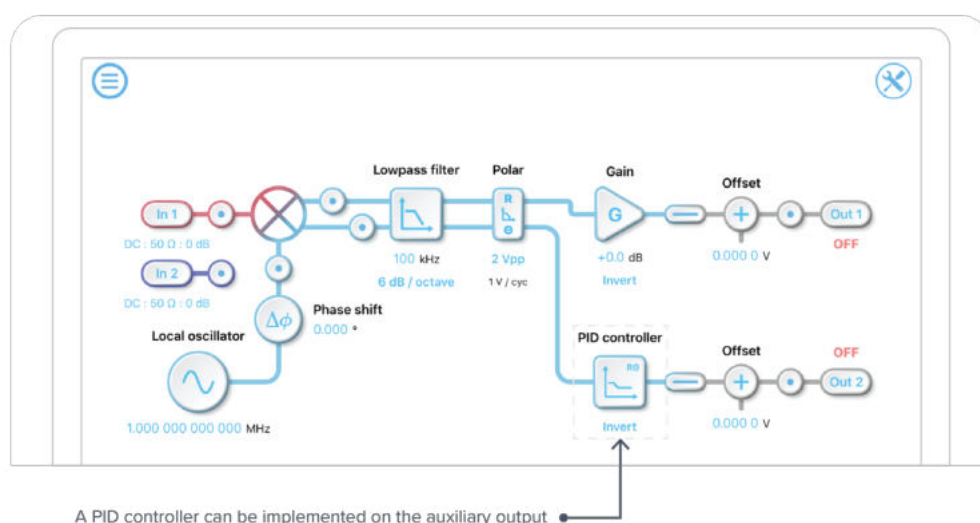
Main Output

Adds a PID controller to the main output.



Auxiliary Output

Adds a PID controller to the auxiliary output.



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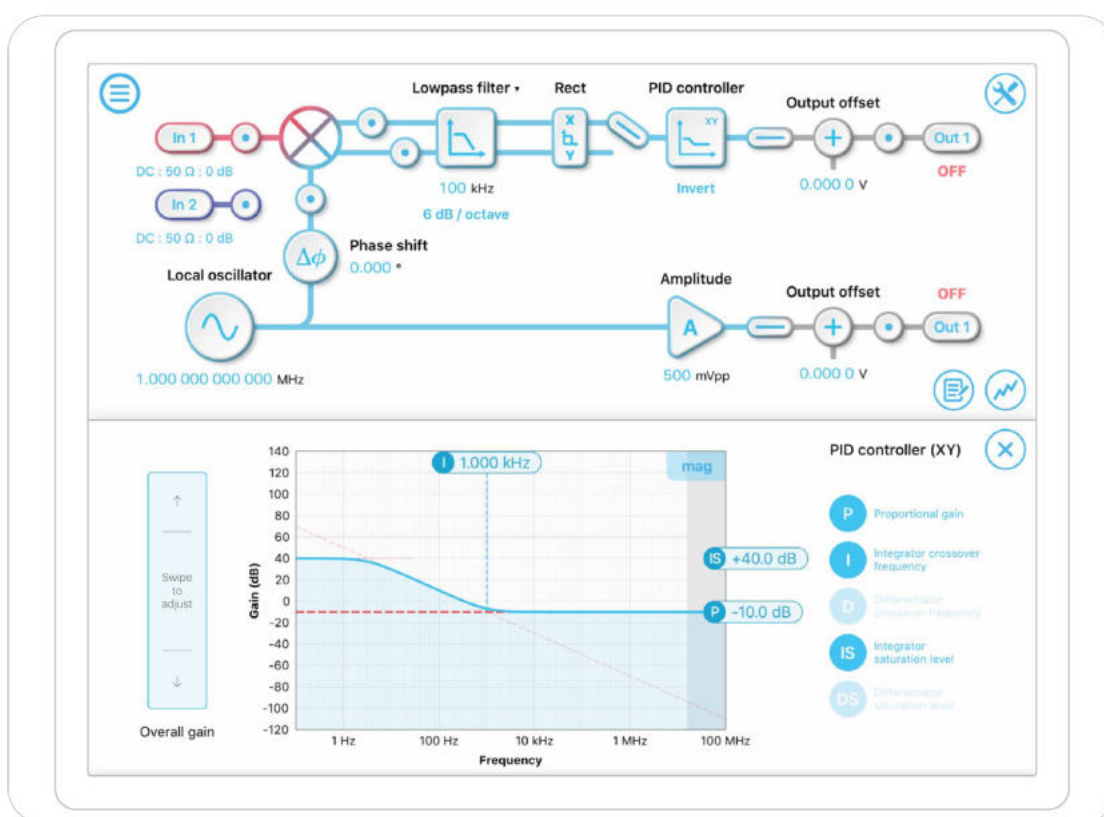
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PID Controller


The PID controller provides full control over proportional, integral, and derivative gain profiles with saturation levels available for the integral and derivative controllers. The PID's transfer function is updated in real-time.

The gain of each control stage can be adjusted individually. The following example shows a proportional-plus-integral controller with a unity gain crossover frequency at 1 kHz. It is possible to maintain this crossover frequency with the proportional gain by using the **overall gain** control on the left, which will shift the entire gain profile up and down. More details about the PID controller can be found in Moku:Pro's PID Controller Manual.

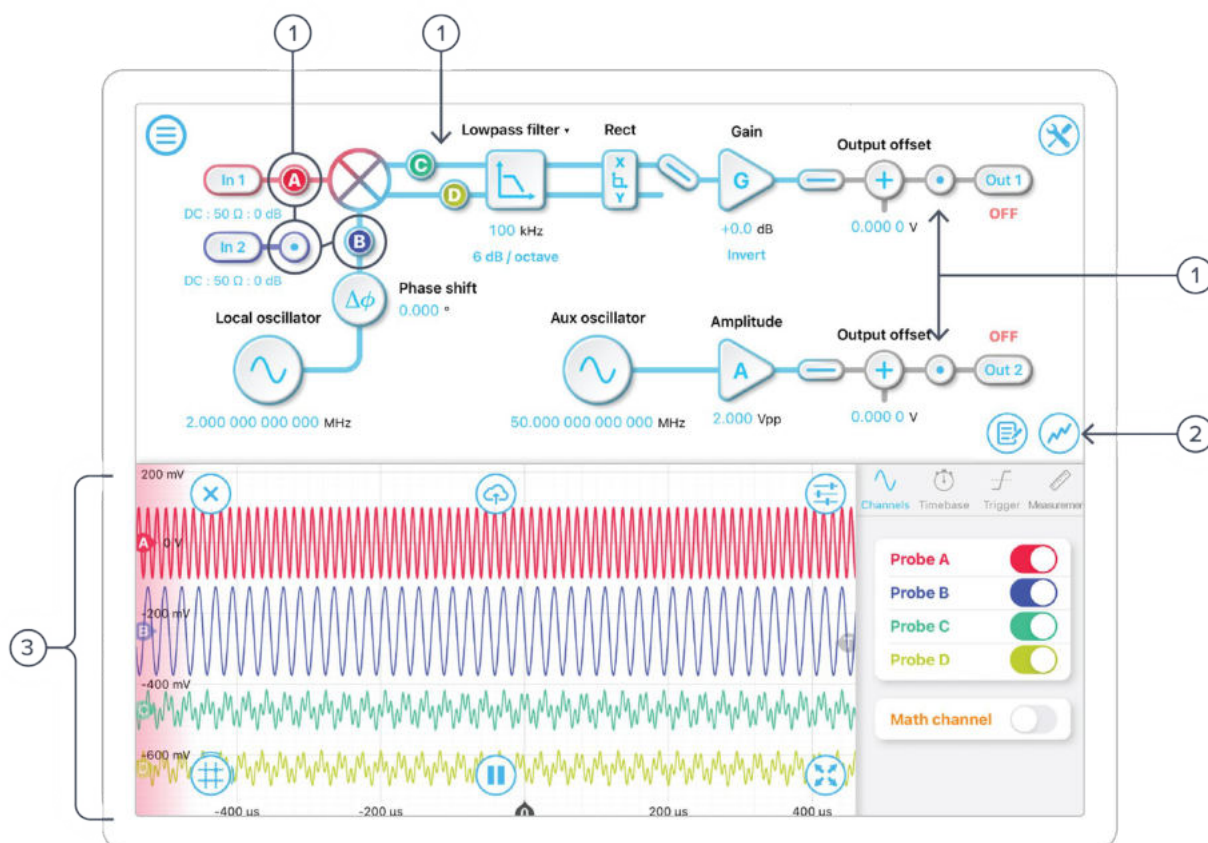




Probe Points

Moku:Pro's lock-in amplifier has an integrated oscilloscope and data logger that can be used to probe the signal at various stages of the demodulation process. The probe points can be added by tapping the  icon. Up to four probe points can be added to monitor or log data.

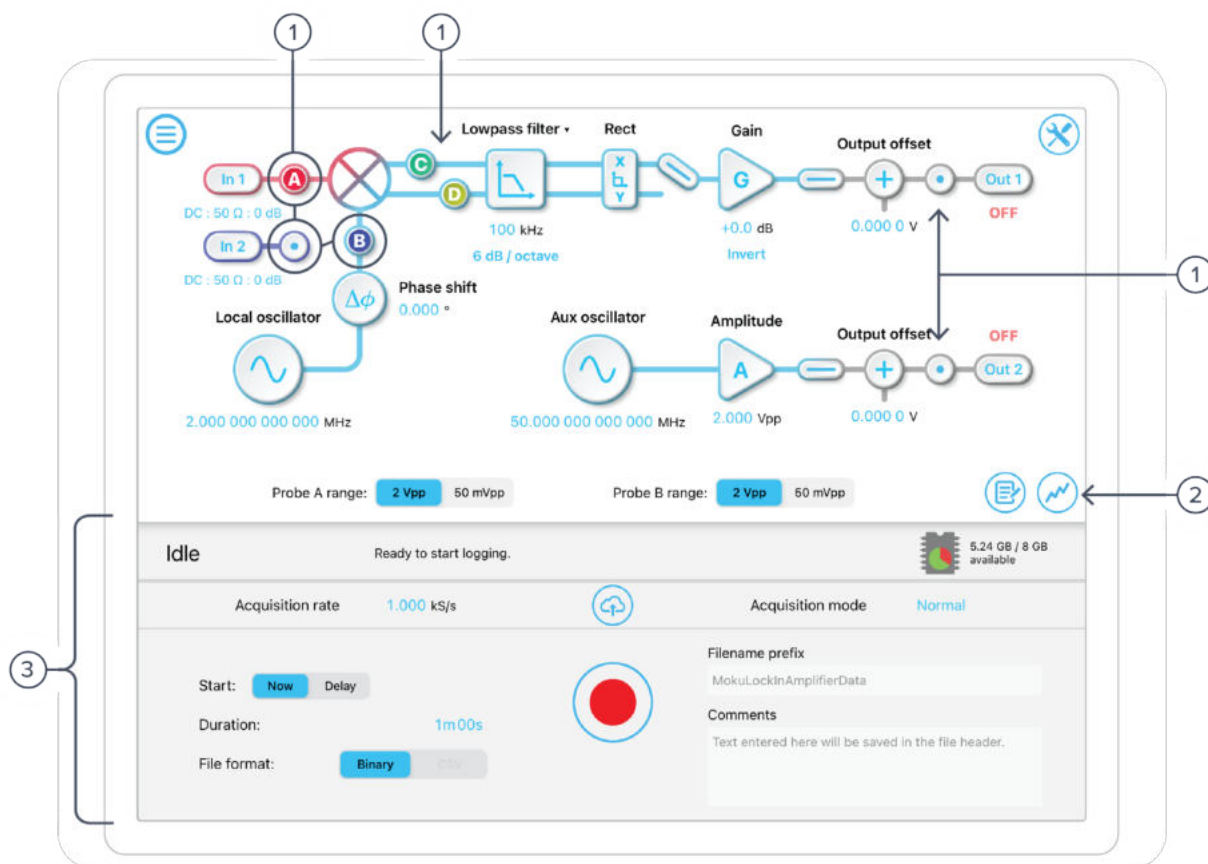
Oscilloscope



ID	Parameter	Description
1	Probe points	Tap to place the probe point. You can enable up to four probe points at a time.
2	Oscilloscope/data logger toggle	Toggle between built-in oscilloscope or data logger.
3	Oscilloscope	Refer to the Moku:Pro's Oscilloscope manual for the details.



Data Logger



ID	Parameter	Description
1	Probe points	Tap to place the probe point. You can enable up to four probe points at a time.
2	Oscilloscope/data logger toggle	Toggle between built-in oscilloscope or data logger.
3	Data Logger	Refer to the Moku:Pro's Data Logger manual for the details.



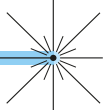
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Oscilloscope

Moku:Pro User Manual

Moku:Pro's Oscilloscope features four highspeed, ultra-low noise input channels with up to 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 full dynamic range. The built-in four-channel waveform generators are capable of producing waveforms with a maximum bandwidth of 500 MHz.





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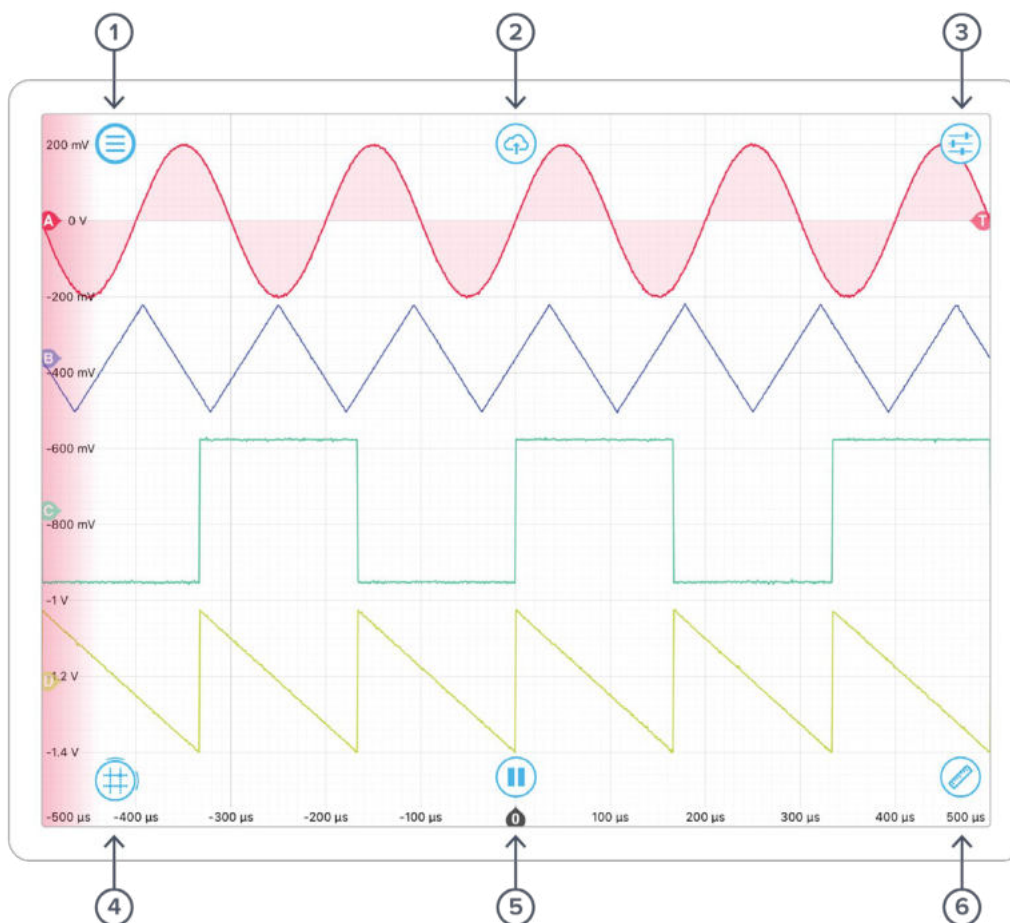
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User Interface

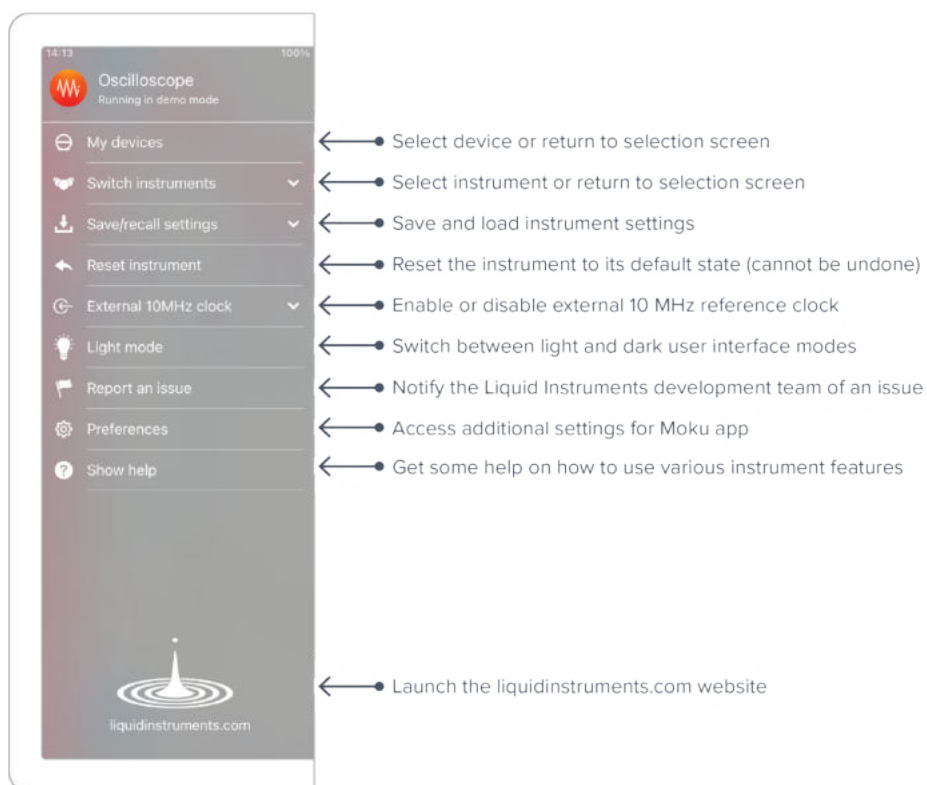


ID	Button	Description
1	Main menu	The main menu contains controls for switching instruments, switching devices, selecting device clock and user interface modes, and more. See Main Menu
2	Share	The sharing button gives access to controls that allow you to save and share your data. See Saving and sharing data
3	Controls	Reveals or hides the control drawer, giving access to all instrument settings. Also available by swiping in from/out to the right-hand side of the screen.
4	Cursors	Tapping brings up the cursor menu, from which you may add or remove cursors. Dragging up/right from this button will quickly create a voltage/time cursor respectively.
5	Play/pause	Pauses or resumes data capture. While paused, you can zoom in on features for more detail, but no new data will be captured. Pressing the “Share” button will also pause capture and must be resumed from this button.
6	Measurements	Reveals or hides the measurements drawer. Also available by swiping up from/down to the bottom of the screen. See Making Measurements



Main Menu

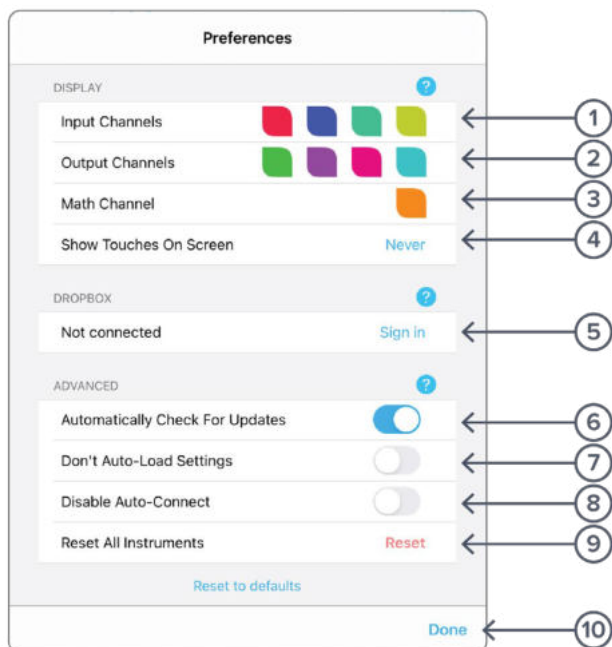
The **main menu** can be accessed by pressing the  icon, allowing you to:





Preferences

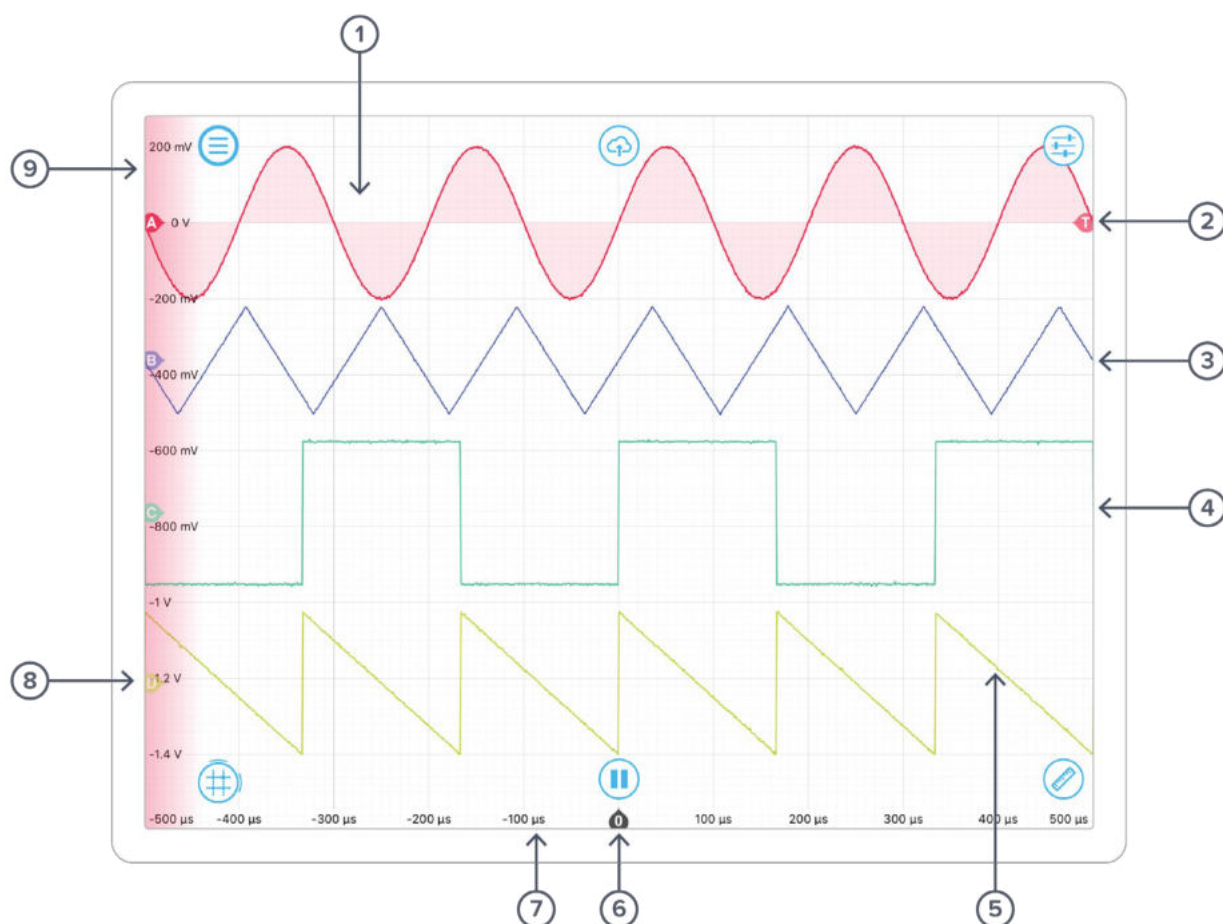
The preferences pane can be accessed via the main menu. In here, you can reassign the color representations for each channel, connect to Dropbox, etc. Throughout the manual, the default colors (shown in the figure below) are used to present instrument features.



ID	Description
1	Tap to change the color associated with input channels.
2	Tap to change the color associated with output channels.
3	Tap to change the color associated with math channel.
4	Indicate touch points on the screen with circles. This can be useful for demonstrations.
5	Change the currently linked Dropbox account to which data can be uploaded.
6	Notify when a new version of the app is available.
7	Moku:Pro automatically saves instrument settings when exiting the app, and restores them again at launch. When disabled, all settings will be reset to defaults on launch.
8	Moku:Pro can remember the last used instrument and automatically reconnect to it at launch. When disabled, you will need to manually connect every time.
9	Reset all instruments to their default state.
10	Save and apply settings.



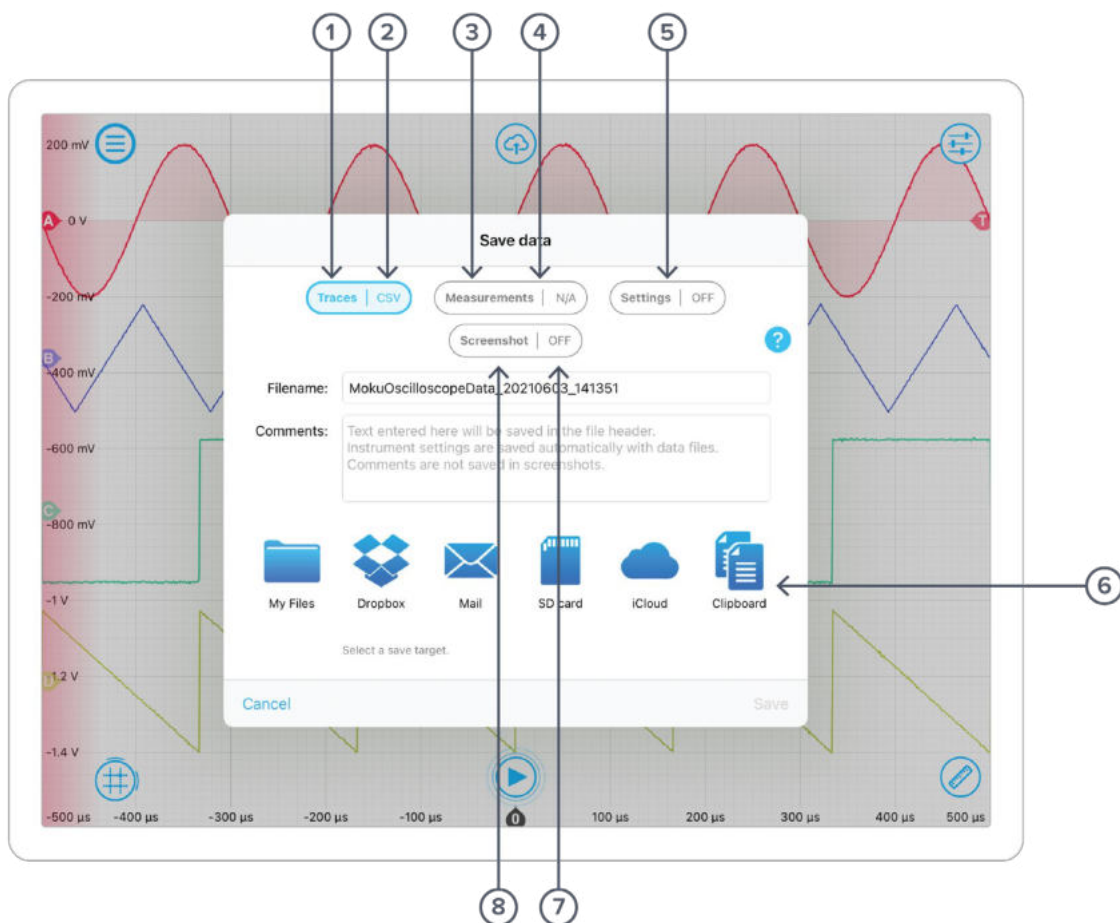
Axes and Traces



ID	Button	Description
1	Channel A Trace	The time/voltage trace for channel A. When channel A is active, the trace will have a light fill to the zero-volt level (as shown).
2	Trigger Level Mark	Marks the trigger threshold level. Shown against whichever trace is currently set for triggering (if any). Drag to set level or tap for more options. See Navigating your Signal .
3	Channel B Trace	The time/voltage trace for channel B.
4	Channel C Trace	The time/voltage trace for channel C.
5	Channel D Trace	The time/voltage trace for channel D.
6	Time Origin Mark	Marks the “zero second” point on the time scale. This will be the trigger point if the Oscilloscope has triggered, otherwise is undefined.
7	Time Axis	Shows the time scale for both channels (the channels always share a time scale).
8	Origin Mark	Marks the “zero volt” level for channel D. Each channel has its own corresponding origin mark.
9	Voltage Axis	Shows the voltage scale for the active channel. The active channel is selected by tapping on the waveform and is indicated by the shading of the voltage axis and the trace itself.



Saving and sharing data



The **save data** options can be accessed by pressing the  icon, allowing you to:

ID	Button	Description
1	Traces data	Select to enable saving of trace data
2	Traces format	Tap to select CSV or MATLAB format
3	Measurements trends	Select to enable saving of measurement trends, if a measurements trends drawer is open
4	Measurement trends format	Tap to select CSV or MATLAB format
5	Settings	Save Oscilloscope settings to a file, enables user to quickly setup the Oscilloscope in a known state
6	Save data destination	Select data destination: DropBox, Email, iCloud, or Clipboard
7	Screenshot format	Select PNG or JPG for screenshot
8	Screenshot	Select to save screenshot



Settings and controls

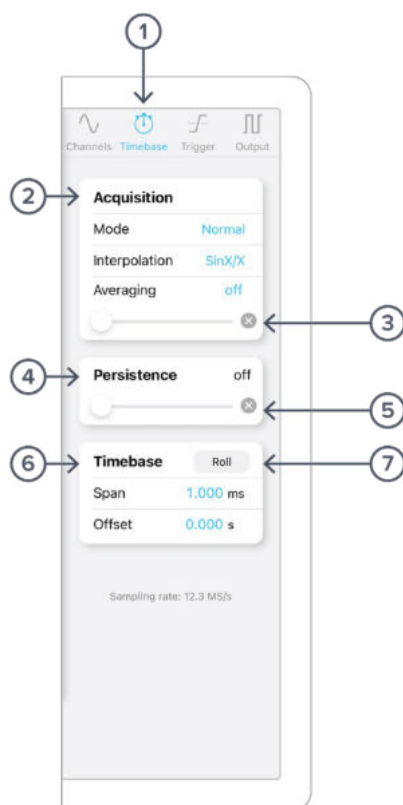
Channel Control Pane



ID	Button	Description
1	Channels Control Pane Selector	Reveals the channels control pane in the controls drawer. Can also be revealed by swiping right from the timebase control pane.
2	Channel A	Toggles channel A on/off
3	Channel A source	Changes Data Source for channel A.
4	Channel A Controls	Coupling: Toggles between DC/AC coupling Impedance: Toggles between 1 M Ω and 50 Ω impedance Probe: Specifies the probe attenuation, if such an attenuating probe is connected.
5	Math Channel On/Off	Toggles the math channel on/off
6	Math Channel Control Pane	(Operation): Selects the mathematical operation to perform on the data. Tap the operation symbol and/or channel letters to change behavior.



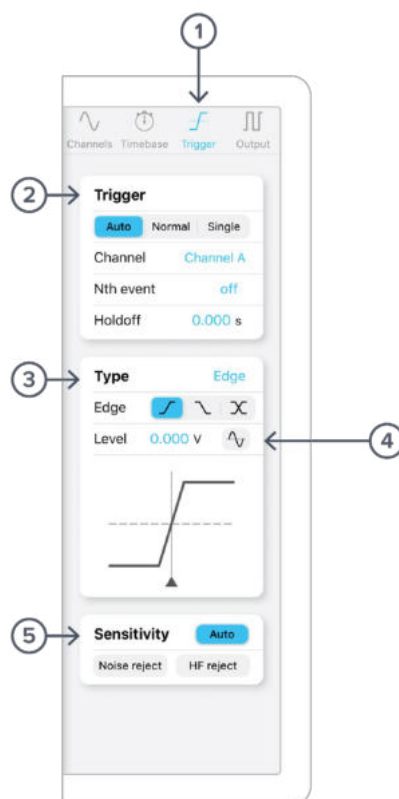
Timebase Control Pane



ID	Button	Description
1	Timebase Control Pane Selector	Reveals the timebase control pane in the controls drawer. Also revealed by swiping left from the channels pane or right from the trigger pane.
2	Acquisition Control Pane	Mode: Changes acquisition mode between normal and precision. See Acquisition Modes and Sampling Interpolation: Changes the on-screen interpolation mode. See Display Options Averaging: Displays on screen an average trace taken from this many consecutive waveforms.
3	Averaging Reset	Tap to reset averaging
4	Persistence Control	Keeps a history of the last number of waveforms on the screen.
5	Persistence Reset	Resets the on-screen persistence
6	Timebase Scale Pane	Scale: Horizontal screen scale. Changes dynamically when pinch-zooming a trace or can be entered manually by tapping. Offset: Horizontal trigger point offset. Changes dynamically when horizontally-dragging a trace or can be set manually by tapping.
7	Roll-mode Toggle	Toggles between roll and sweep modes. See Display Options



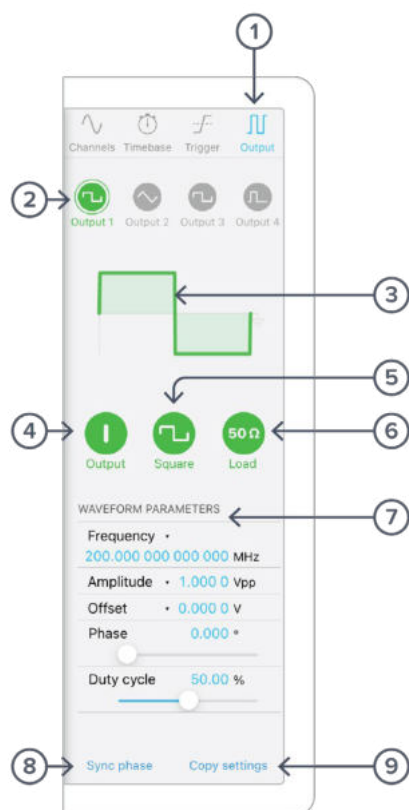
Trigger Control Pane



ID	Button	Description
1	Trigger Control Pane Selector	Reveals the trigger control pane in the controls drawer. Can also be revealed by swiping left from the timebase pane or right from the output pane.
2	Trigger Settings Pane	<p>(Mode): Switches between auto, normal and single trigger modes. See Navigating your Signal</p> <p>Channel: Select the source for the trigger circuit. This can be one of the Oscilloscope channels, Moku:Pro inputs, Moku:Pro outputs, or external trigger input independent of what is displayed on the screen.</p> <p>Nth event : Select up to 65,535 trigger events before actually triggering the Oscilloscope</p> <p>HoldOff : Select a time to holdoff Oscilloscope trigger post trigger event</p>
3	Trigger type	Select between edge and pulse triggering with selectable levels, edge types and pulse widths
4	Trigger zero	One touch to set trigger level to 0 V
5	Sensitivity	Configure auto or manual hysteresis for noise rejection. Configure HF reject to enable a low pass filter on the trigger circuit, giving better noise immunity but with a short delay between the trigger event and detection.



Output Control Pane



The output pane of the Oscilloscope allows for generation of various waveforms on Moku:Pro's output channels.

ID	Button	Description
1	Output Control Panel Selector	Reveals the output control pane in the controls drawer. Can also be revealed by swiping left from the trigger pane
2	Output 1 select	Select output 1, 2, 3, or 4.
3	Waveform Preview	Shows a preview of the waveform to be generated
4	Output enable	Toggles the output enable of the selected channel
5	Waveform select	Selects the waveform type to generate
6	Output load select	Selects the output load

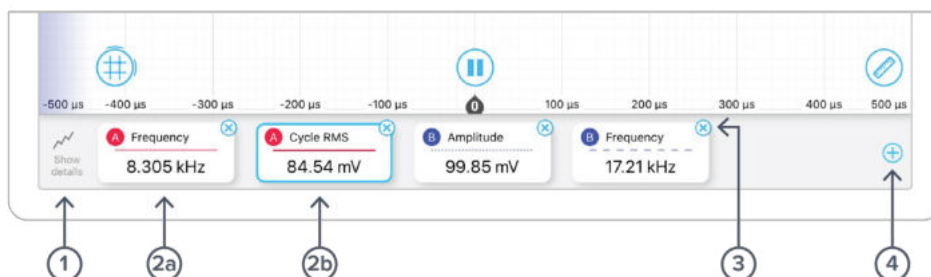


7	Waveform Parameters	<p>The parameters available in this pane vary for different waveform types. For more information on these parameters, refer to Using the Built-in Waveform Generator.</p> <p>Amplitude, Frequency: Basic waveform parameters.</p> <p>Offset: DC value to add to the output. Note that setting this non-zero may restrict the maximum amplitude.</p> <p>Phase: Phase offset of the waveform with respect to the Moku:Pro's internal clock (and therefore the other output channel). This is not relative to any input signal characteristic.</p> <p>Symmetry: For ramp wave, the ratio between rising and falling edge times.</p> <p>Pulse Width: For pulse wave, the high-time of the pulse (limited by the frequency).</p> <p>Edge Time: For pulse wave, the rise and fall time of the pulse edges. Can be manipulated to provide triangle pulses and other waveforms.</p> <p>DC Level: For DC wave, the constant voltage to output.</p>
8	Sync phase	Synchronizes phase with the other channel
9	Copy settings	Copies all waveform settings from one channel to the other

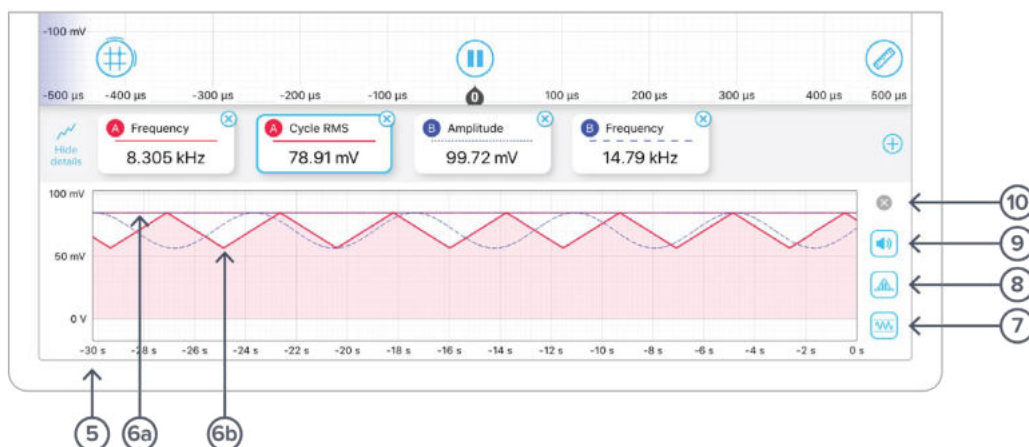


Measurements drawer

Tap the ruler icon to open the measurements drawer. See [Making Measurements](#) for detailed definitions and explanation of the many measurement options.



Show details reveals the measurements trend graph.

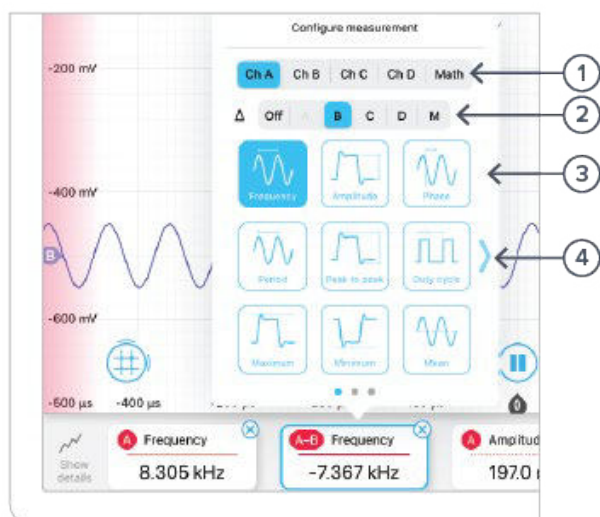


ID	Button	Description
1	Show/Hide Trends	Tap to reveal/hide the measurement trend draw. May also be revealed by swiping up/down on the measurement bar.
2a,b	Measurement Tablets	Measurement results color-coded to the source channel. Line style is matched to the trend window. Tap to change measurement.
3	Remove Measurement	Remove this measurement.
4	Add Measurement	Add new measurement to the currently active channel.
5	Trend History Length	Tap to change trend history length from 30s to 300s,
6a,b	Trend plot	Solid and dashed plots representing trends of the respective measurements.
7	Autoscale	Scale the vertical axis of the history plot.
8	Statistics	Switch to statistics view of the measurements.
9	Audio	Enable audible representation of selected measurement. This can be very helpful when working on an experimental adjustment when you do not have immediate sight of the oscilloscope
10	Close	Close the measurements details



Configure measurement

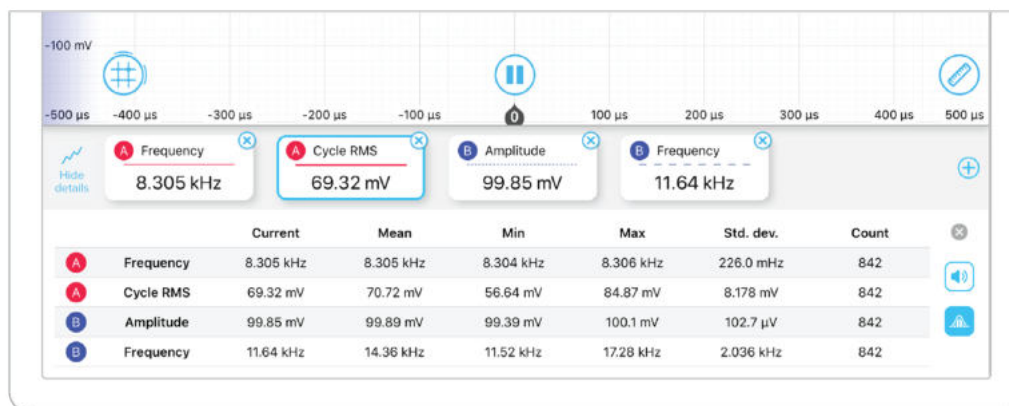
Tap any measurement tab to configure the measurement



ID	Button	Description
1	Channel selection	Select channel A, B, C, D, or Math for measurement.
2	Delta measurement	Select a delta measurement. The screenshot shows frequency difference between channels, together with measurements of channel A amplitude and frequency.
3	Measurement	See Making Measurements for full details
4	Next tab	Select next tab of measurements.



Measurements drawer with detailed statistics



Cursors button

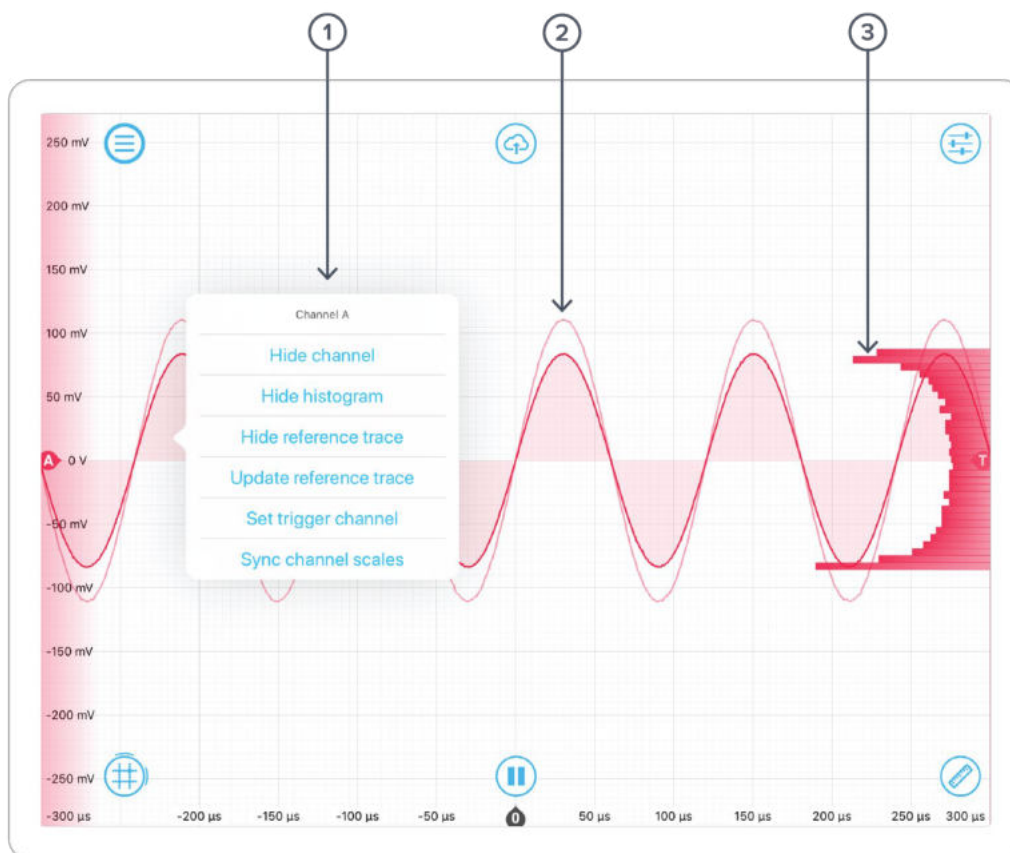


The cursor button allows time and voltage cursors to be readily displayed. Drag up from the cursor button to create a voltage cursor. Drag right from the cursor button to create a time cursor.

Tapping the cursor button allows all cursors to be removed while tapping individual cursors allows specific time or voltage levels and configuration as a reference.



Trace Context menu



ID	Button	Description
1	Trace Context Menu	<p>Long-press on the trace to reveal:</p> <p>Hide Channel: Removes channel trace from the screen.</p> <p>Show/Hide Histogram: Histogram shows the count of points at a particular voltage value for that waveform.</p> <p>Show/Hide/Update Reference Trace: Reference trace takes a snapshot of the channel trace at the time the reference is created. The reference trace is displayed in the active channel's color with transparency.'</p> <p>Set Trigger channel: Set trigger to channel selected channel</p> <p>Sync channel scale: Make scale of all visible channels the same as the selected channel scale.</p>
2	Reference Trace	An example reference trace for channel A.
3	Histogram	An example histogram for channel A.



Instrument Reference

Configuring Inputs

Input Impedance

Moku:Pro's inputs have a selectable impedance of either 1 M Ω or 50 Ω . This is effectively the resistance from the signal line to ground. For high-frequency measurements, it is important that Moku:Pro's impedance matches that of the device under measurement. If the impedance is mismatched, some signal power will reflect off Moku:Pro's input, thus interfering with the measurement.

The input impedance also forms a resistive divider with the signal's source impedance, reducing the apparent voltage. The ratio should be a half; however, the impedances have a tolerance that may affect the accuracy of the measurement.

High-impedance mode (1 M Ω) is used where Moku:Pro is observing a signal that is externally-terminated (e.g. between two high-speed devices), or where absolute voltage measurement accuracy is required and the signal is low-enough frequency that reflections from the measurement equipment do not significantly interfere with the original signal.

High-impedance is the default setting for many oscilloscopes that are not targeted at RF frequencies, while 50 Ω is most common for RF devices and signal generators.

Gain Ranges

Moku:Pro contains a front-end attenuator that divides the signal by 10x or 100x increasing the range of voltages that can be measured. In Moku:Pro's Oscilloscope, this attenuator is automatically activated whenever the screen includes voltages outside of the range ± 0.5 volts; that is, whenever you zoom out or scroll up/down to reveal voltages outside of this range.

Further input voltage range can be achieved by using an attenuating probe. A "10x" probe is common in test and measurement, meaning the probe will present 1/10th of the input voltage to Moku:Pro. To correct for this on the Oscilloscope's voltage scale, the probe factor can be entered on the channels tab.

Overvoltage Protection

Moku:Pro's input will disconnect automatically when the input voltage on the BNC connector exceeds its limit. At this time, the Oscilloscope will show a flat line at zero volts.

If you're having trouble viewing your signal, ensure the signal is within this range, e.g. by using an attenuating probe.



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Coupling

Moku:Pro includes a switchable AC/DC coupling circuit on each input. This is activated from the channels tab.

For most applications, DC-coupled is the preferred option; this does not filter or modify the signal in any way.

AC-coupled acts as a high pass filter, removing the DC component of the incoming signal (and attenuating other components with a frequency below the coupling corner). This is useful when you're looking for a small signal on top of a large DC offset. Doing so can give better precision than simply scrolling the trace up the screen, as it may avoid Moku:Pro activating its internal attenuator (see [Gain Ranges](#)).

Navigating your Signal

Trace Selection

Moku:Pro's Oscilloscope can display up to four signal traces, plus a math trace. Each signal trace may either be the analog input (default) or a preview of the analog output if the waveform generator is active.

To turn a trace on and off, tap the slider on that trace's box on the channels tab.

Triggering

The triggering circuit of the Oscilloscope allows you to indicate what kind of signal event you're interested in. This event will then be aligned to the "zero second" mark of the time axis. Common events that can be triggered are simply times when the signal rises or falls past a particular voltage. These are "rising edge" and "falling edge" triggers respectively, and the voltage past which the signal must move is called the "trigger level".

Data to be displayed before the trigger point (negative values on the time axis) is called "pre-trigger" data and data after, "post-trigger" data. Moku:Pro's Oscilloscope can record and display a maximum of 16,384 points of pre-trigger data but as many as 2^{32} points of post-trigger. In practice, this limits the distance that you may scroll to the left and right.

In the Oscilloscope, the trigger level is set from the trigger tab, or by dragging the trigger marker on the screen. Other trigger parameters such as the event to be triggered upon and the channel to be monitored are also on this tab.



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Trigger Modes

Trigger modes describe how the Oscilloscope responds to several trigger events. The options are “Auto”, “Normal”, and “Single” triggering.

“Normal” trigger mode will only trigger, and therefore update the display, when a trigger event is detected. This is very useful if you genuinely only care about the signal around the trigger event, but you cannot view the signal in real-time without a stream of triggers (e.g. for a DC signal or while setting up the trigger in the first place).

“Auto” trigger mode acts like “Normal”; however if no trigger event has been detected in a short while, it will generate a fake event, causing the display to update. The delay from a real trigger to a fake one is longer than that between fake events, so the signal can be viewed in real-time without triggers while still giving time to view events around a trigger if one does arrive.

“Single” trigger simply captures the first trigger event then stops acquisition until the user starts it again. This is useful when you need time to study your signal in detail or to capture a specific signal event for sharing or saving.

Trigger Filtering

Often a signal will be noisy and setting a simple trigger event such as “rising edge” may cause a trigger event due to noise rather than due to the underlying signal. Moku:Pro’s Oscilloscope has two features to help reliably trigger on noisy data: noise reject and high-frequency (HF) reject.

Noise reject adds a small amount of hysteresis to the trigger event. This stops the trigger firing several times as noise repeatedly crosses the trigger threshold; the rising and falling events happen at different levels.

High-frequency (HF) reject passes the trigger signal through a low pass filter before looking for the trigger event. This smooths out the noise, allowing the trigger circuit to observe just the underlying signal. The trade-off is that this filter introduces some delay in the signal, offsetting the trigger event from the actual data.

Pan and Zoom

The signal on the Oscilloscope will always align a trigger event to the “zero second” mark on the time axis (including fake trigger events injected in auto-trigger mode). To move the signal and view different times and voltages, the Oscilloscope provides a number of gestures:

Single-finger drag: Move the signal left and right (different times) and up and down (different voltage offsets).

Two-finger pinch: Zoom the signal in and out in time and/or voltage (horizontal and vertical pinch respectively).

Two-finger drag: Quickly zoom the signal in and out in time and/or voltage, maintaining current voltage and time offsets. This mode is good for changing scales by orders of magnitude without repeatedly pinch-zooming.

Screen Update Modes

As you zoom out, you will come to a point where the displayed time span is longer than the time between screen updates. In this case, the Oscilloscope will enter one of two update modes: sweep or roll.



Sweep Mode

Sweep mode is the default if roll is not active. In sweep mode, the screen will only update once a trigger event is received. At this time, all the currently-captured data (all the data before the trigger point) will be updated on the screen at once. New data will be shown on the screen as it arrives, with the new data progressively “sweeping” across the screen.

This mode is useful when you still require trigger events despite the low data rate.

Roll Mode

If roll mode is active, trigger events are completely ignored. Instead, all new data is displayed on the screen in real time with the most recent data on the right of screen. This causes the trace to roll from right to left continuously.

Use this mode if you want to view all your data in real time and no longer care about aligning the data by trigger.

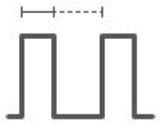





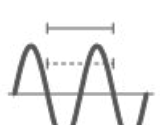


Making Measurements

Automatic Measurements







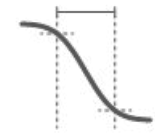
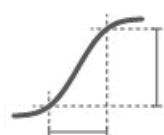
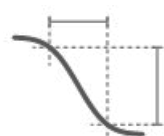
The Oscilloscope can automatically make a number of measurements on your data in real time. To open the measurements pane, swipe up from the bottom or tap the ruler icon. Add a new measurement by tapping the plus button or configure an existing measurement by tapping the measurement itself. The available measurements are described below.

Name (unit)	Icon	Description
Frequency (Hz)		Frequency of the signal as determined by the time between rising or falling edges.
Phase		Phase of strongest frequency component with respect to a perfect sine wave.
Period (s)		Time between pairs of rising or falling edges.


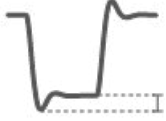
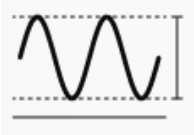


Duty Cycle (%)		Ratio of the time spent above the median to that spent below it.
Pulse Width (s)		Time the signal spends above the median.
Negative Width (s)		Time the signal spends below the median.
Mean (V)		Average value of the signal
RMS (V)		Root-Mean-Square value of the signal
Cycle Mean (V)		Average value of the signal, discounting partial cycles at the beginning and end of the frame.
Cycle RMS (V)		Root-Mean-Square value of the signal, discounting partial cycles at the beginning and edge of the frame.
Standard Deviation (V)		Mathematical description of the spread of the points in the signal
Peak to Peak (V)		Difference between the highest and lowest voltage in the signal.



Amplitude (V)		Difference between the high- and low-level voltage, excluding over- and undershoot.
Maximum (V)		Highest voltage in the signal
Minimum (V)		Lowest voltage in the signal
High Level (V)		Highest voltage in the signal, excluding overshoot.
Low Level (V)		Lowest voltage in the signal, excluding undershoot
Rise Time (s)		Time taken for the signal to transition from 10% to 90% of the way from minimum to maximum.
Fall Time (s)		Time taken for the signal to transition from 90% to 10% from maximum to minimum.
Rise Rate (V/s)		Rate at which the signal transitions from 10% to 90% of the way from minimum to maximum
Fall Rate (V/s)		Rate at which the signal transitions from 90% to 10% of the way from minimum to maximum



Overshoot (V)		Distance the signal shoots above the maximum level before settling
Undershoot (V)		Distance the signal shoots below minimum level before settling
Fringe visibility (%)		Measurement of interference

Measurement Trends

The Oscilloscope can keep a time-history of any of the above measurements and graph the trends in those measurements.

To reveal the measurement trends tray, swipe up from the measurements tray or tap the “Show Trends” button on the left of that tray. The history of all configured trends will be shown. This window doesn’t define a Y-axis, it’s designed to provide trend information only, not precise readouts of prior measurements.

To configure the length of the history, tap the left-most time value on the X-axis (which is highlighted blue). The range is from 30 seconds to 300 seconds.

Manual Measurements

Measurements of voltage and time between points can also be made manually by placing cursors. A cursor can measure either voltage or time and is linked to a specific channel.

To place a cursor, tap the cursor icon in the bottom-left, or touch and drag out from this icon. Dragging up will give a voltage cursor on the current channel, dragging right will give a time cursor. To remove a single cursor, tap that cursor’s readout box to reveal its cursor menu and select “remove”. To remove all cursors, tap the cursor icon in the bottom-left and select “remove all cursors”.

Voltage Cursors

By default, a voltage cursor will stay at the location you drag it to and display the voltage at that level. Tap the cursor to reveal the cursor menu, from which you can lock the cursor on to specific aspects of the signal; current maximum or minimum, or all-time maximum or minimum (max/min hold).

If you have multiple voltage cursors, one can be set as the reference cursor from its cursor menu. If there is a reference cursor, then all other cursor voltages will be displayed with respect to this reference.



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Time Cursors

A time cursor must be placed at a specific location and cannot be locked to a signal. It will display the time at which it is placed, relative to the trigger point (see Triggering above).

When two cursors are placed, the difference between them is automatically displayed towards the bottom of the screen, as is the frequency corresponding to this period.

If more than two cursors are placed, one can be selected as the reference cursor and all other time and frequency measurements will then be shown with respect to that. Like voltage cursors, setting a reference is done by tapping the cursor's reading to reveal its cursor menu, and selecting "reference".

Acquisition Modes and Sampling

The Oscilloscope processes data in two stages. First, data is acquired from the analogue-to-digital converters (ADCs), down-sampled, and stored in memory. From there, the data is aligned relative to the trigger point and displayed on the screen.

Both of these operations require down- or up-sampling of the data (reducing or increasing the total number of data points) and the method for doing this can provide increased precision and different aliasing behaviour.

Acquisition Modes

The acquisition mode refers to the process of capturing the data and storing it in Moku:Pro's internal memory. This is always down-sampled.

Normal Mode: Extra data is simply removed from the memory (direct down-sampled). For example, the ADC is running at 1.25 GSPS and the selected time span on the Moku oscilloscope requires 1MSPS, then 1249 out of 1250 points will be ignored.

This causes the signal to alias and doesn't increase the precision of the measurement. It does however provide a view-able signal at all timespans and all input frequencies.

Precision Mode: Extra data is averaged to the memory (decimation). For example, if the ADC is running at 1.25 GSa/s and the selected time span on the Oscilloscope requires 1 MSa/s, then 1250 consecutive samples will be averaged to produce one data point in the memory.

This increases precision and prevents aliasing, however if you have the wrong time span selected for the signal then all points can average to zero (or close to it), making it appear like no signal is present.

A common workflow would be to use normal mode to find the signal and align it as you want, then switch to precision mode to improve the signal quality for measurement.

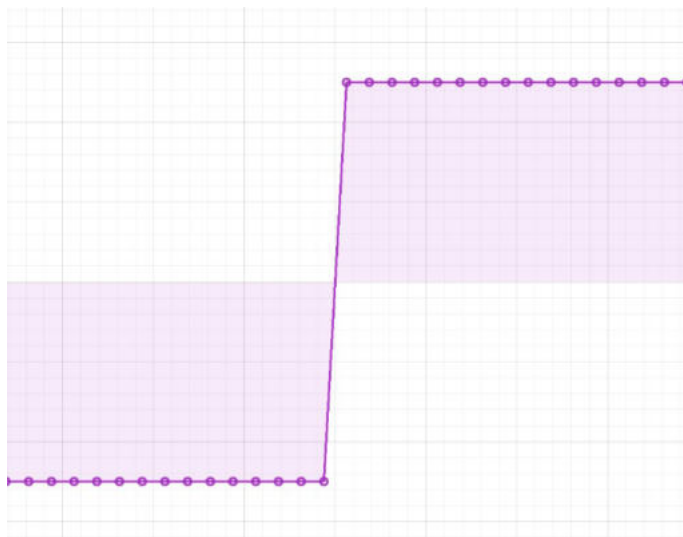




Interpolation Modes

Once the data is in the memory, it needs to be displayed on the screen. This may be down-sampling or up-sampling, depending on zoom level. Down-sampling is done by Cubic Spline Interpolation and cannot be configured by the user. Up-sampling mode can be selected and is one of Linear, Sin X/X or Gaussian.

Linear



Linear interpolation does not perform any up-sampling. For display, it marks each point in the original data set and draws a straight line between them. This is “ugly” but doesn’t “invent” any new data points.

Sin X/X

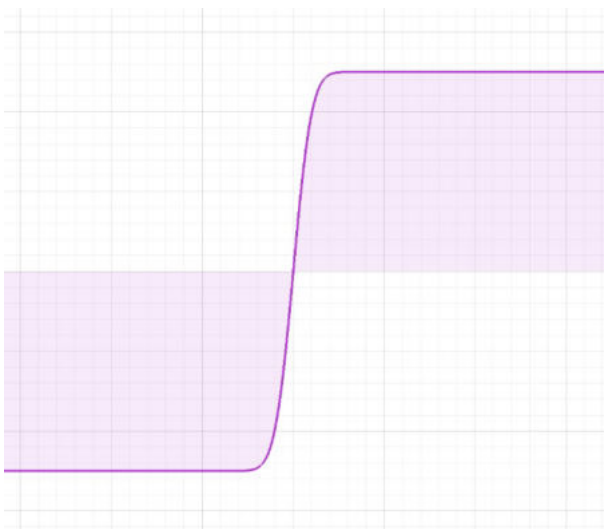


Also called “Sinc” interpolation, this mode preserves the frequency characteristics of the signal. In the time domain though, it can appear that there is over- or under-shoot that is not in fact present in the signal.

Use Sin X/X if your signal is sine-like; it doesn’t include significant frequency components that have been removed by filtering or decimation.



Gaussian



Gaussian interpolation “smooths” the signal out, preserving the visual characteristics of the signal at the expense of frequency information.

Use this mode if your signal is square-like; it contains harmonics or other signal elements that have been removed by filtering or decimation.

Display Options

When displaying data in the screen, the Oscilloscope can provide waveform averaging to reduce noise and persistence to catch brief events. Averaging and persistence are not exported with either channel or high-res data, see [Saving and Sharing Data](#).

Averaging

Drag the slider to average the given number of waveforms on the screen. If the signal is strictly repetitive then this can give you improved precision and noise performance. If not, this mode should not be used.

Persistence

Drag the slider to keep the given number of old waveforms on the screen, fading out. Dragging the slider all the way right will set infinite persistence, in which waveforms are never erased from the screen.

Persistence is useful for capturing events that would otherwise only be on the screen for one frame.



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Math Operations

The Oscilloscope can perform real time math operations on the incoming data and display it as a third channel. This math channel is different from the measurements above; measurements can be configured to be performed on the math channel rather than on a physical input channel.

Operation	Symbol	Description
Addition	+	Sum of two channels.
Subtraction	-	Difference of two channels.
Multiplication	x	Product of two channels. The two channels can be the same, giving a squaring of the signal values.
Division	÷	Ratio of two channels.
XY	XY	Plots a trace whose horizontal axis is not time, but the voltage of the selected channel.
Integral	∫	Discrete time-integral (running sum) of the trace
Derivative	d / dt	Discrete time-derivative (pointwise difference) of the trace
FFT	FFT	Fast Fourier Transform of a trace, giving the frequency domain representation. This mode is complex and described in more detail below.
Min Hold	Min hold	Minimum hold
Max Hold	Max hold	Maximum hold
User entered function	f()	A user-defined math function



FFT Function




The FFT math channel gives the user the frequency-domain representation of the input data. This can be useful for quickly checking parameters in that domain. In general, the user should quickly switch to Moku:Pro's Spectrum Analyzer instead, gaining access to advanced features that drastically improve the quality of the measurement.

Limitations of the FFT function of the Oscilloscope include:

- The FFT is subject to aliasing, depending on acquisition mode. Moku:Pro's Spectrum Analyzer instrument has an advanced DSP anti-aliasing chain, minimizing the effect of unwanted signals.
- The FFT is not windowed. The Spectrum Analyzer provides a range of different windows for minimizing harmonics and spurs, improving amplitude accuracy, and so on.
- The FFT has a fixed frequency resolution set by the time span. The Spectrum Analyzer has a fully-configurable Resolution Bandwidth (RBW).
- The FFT has its span completely defined by the time span. The Spectrum Analyzer can have any span, providing much more detail around the signal of interest.



Using the Built-in Waveform Generator

The Oscilloscope has a built-in waveform generator. This resembles Moku:Pro's Waveform Generator instrument, but without modulation and sweep properties.

Waveform	Symbol	Description
Sine	 Sine	Sinusoid. Configurable parameters are: <ul style="list-style-type: none">• Frequency• Amplitude (peak-to-peak)• Offset• Phase (relative to the other channel)
Square	 Square	Square wave, variable duty cycle, low jitter. Configurable parameters are: <ul style="list-style-type: none">• Frequency• Amplitude (peak-to-peak)• Offset• Phase (relative to the other channel)• Duty cycle
Ramp	 Ramp	Ramp, generalized sawtooth wave. Configurable parameters are: <ul style="list-style-type: none">• Frequency• Amplitude (peak-to-peak)• Offset• Phase (relative to the other channel)• Symmetry (ratio of rising- to falling-edge of the ramp; symmetries of 0% or 100% are sawtooth waves).





Pulse		Square wave, configurable edge times, worse jitter than Square option above. Configurable parameters are: <ul style="list-style-type: none">• Frequency• Amplitude (peak-to-peak)• Offset• Phase (relative to the other channel)• Pulse width (high-time of the waveform)• Edge time (time taken to transition from the low- to high-level and vice-versa, limiting slew rate).
DC		Fixed DC output voltage. Configurable parameters are: <ul style="list-style-type: none">• DC Level (voltage to output)

Saving and Sharing Data

The Oscilloscope can save different data to multiple locations. For full details regarding available locations and set up, see the [Saving and sharing data](#) section of this manual.

Data Types

Oscilloscope data can be saved through the “save data” icon in the center-top. The following options are available, corresponding to the two different phases of data acquisition above:

Channel Data: The data as viewed on the screen, including cubic down-sampling and interpolation.

High-res Data: The data directly from Moku:Pro’s internal memory, no interpolation or cubic down-sampling. The data saved in this way is exactly and only data that has been acquired (either by direct down-sampling or decimation depending on acquisition mode above).

In addition to the data itself, the Oscilloscope can save:

Measurement Trends: A CSV file containing the history of the measurements made by the Oscilloscope. See Measurement Trends above.

Settings: A file containing the current settings of the Oscilloscope instrument.

Screenshot: An image of the current screen, including traces and scales. This does not save the view of any settings tabs or the on-screen icons.



Ensure Moku:Pro is fully updated. For the latest information:

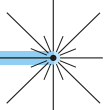
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Phasemeter

Moku:Pro User Manual

Moku:Pro's Phasemeter measures phase with up to 6 μ radian precision for input signals oscillating between 1 kHz and 400 MHz. Using a digitally implemented phase-locked loop architecture, it provides exceptional dynamic range and precision far exceeding the capabilities of conventional lock-in amplifiers and frequency counters. The Moku:Pro's Phasemeter is ideal for applications demanding precise measurements of phase or frequency, including precision metrology and heterodyne interferometry, channel characterisation in communication networks, clock recovery and signal reconditioning for digital communication systems, and laser frequency stabilization.





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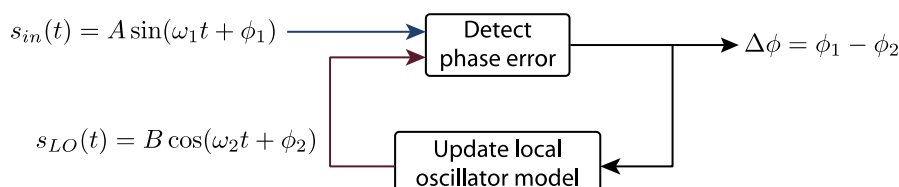
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Introduction

How does it work?

Moku:Pro's Phasemeter measures phase using a digitally implemented phase-locked loop, which uses feedback control to continuously update the phase of a local oscillator to equal that of the input signal.



The instantaneous phase error between the input signal and local oscillator is detected via demodulation using a digital multiplier and low-pass filter, almost identical in principle to a lock-in amplifier. The detected phase error is then passed through a PID controller to generate a feedback control signal to continuously update the phase of the local oscillator. The phase of the input signal relative to the local oscillator is measured by keeping a record of every change made to the phase of the local oscillator.

Why use a Phasemeter?

Digitally implemented phase-locked loops have extremely high dynamic range, allowing them to continuously measure phase over millions of cycles with a sensitivity of better than 6 micro-radians. This is particularly important for applications where the phase is expected to drift over many wavelengths within the measurement time, but still require extremely high measurement precision.

Heterodyne interferometry

One key application of phasemeters is in heterodyne interferometry, where displacement information is stored within the phase of a beat-note produced by interfering two electric fields with slightly different frequencies at a photodetector. Laser heterodyne interferometers are typically used to measure tiny displacements on the order of a fraction of the laser wavelength.

At a laser wavelength of 1064 nano-meters, Moku:Pro's phasemeter is capable of measuring displacements with pico-meter sensitivity (i.e., *one millionth* of the wavelength of the laser). It is not uncommon, however, for heterodyne interferometers to experience displacements on the order of many thousands of wavelengths due to path-length contraction and expansion caused by shock, vibrations and changes in temperature. And depending on their optical configuration, heterodyne interferometers can also be extremely susceptible to laser frequency noise which typically appears as large, random excursions in phase at low frequencies.

The ability to measure phase with high dynamic range is therefore crucial in heterodyne interferometry.

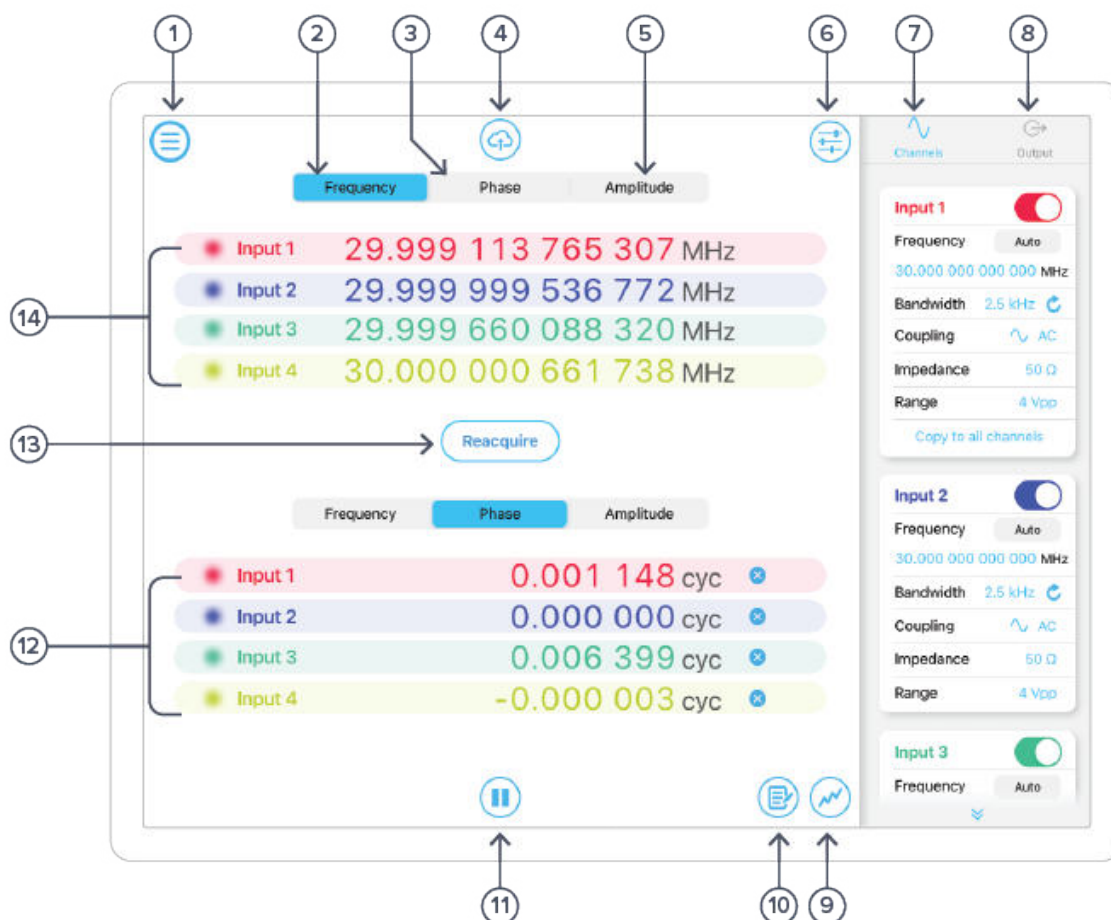


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User Interface

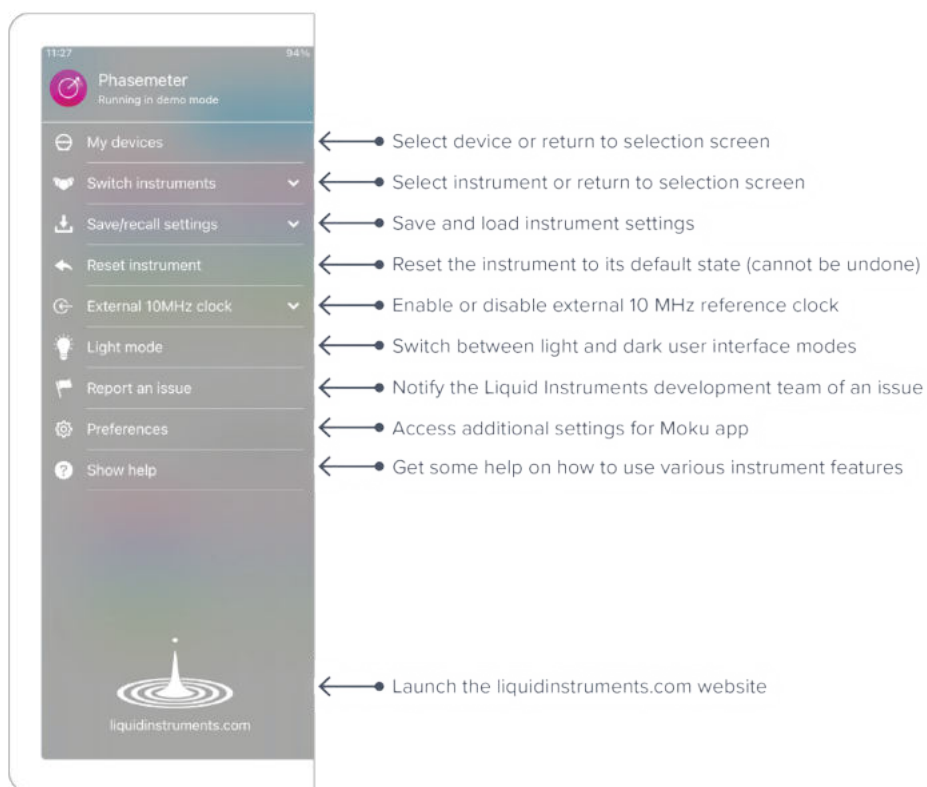


ID	Description	ID	Description
1	Main menu	8	Output settings
2	Display frequency data	9	Data visualization
3	Display phase data	10	Data logger
4	Export data	11	Start / pause measurement
5	Display amplitude data	12	Channel data display area 2
6	Instrument configuration menu	13	Reacquire button
7	Channel settings	14	Channel data display area 1



Main Menu

The **main menu** can be accessed by pressing the  icon, allowing you to:





Channel Configuration

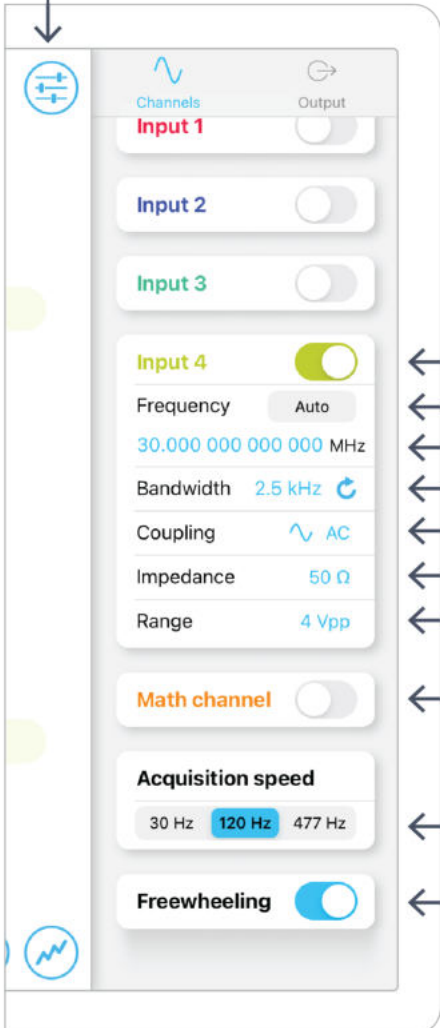
The **channel configuration menu** allows you to configure the Phasemeter's channel settings and outputs.

Access the measurement configuration menu by tapping the  icon.

Moku:Pro is equipped with four input channels. You can swipe up and down to access different inputs. In this section, we will use input 4 as an example.

Channels

● Show / hide the measurement configuration menu



The screenshot shows the 'Channels' configuration menu. At the top, there are tabs for 'Channels' and 'Output'. Below these are four input channels, each with a toggle switch. 'Input 4' is currently selected and active. Below 'Input 4', there are several settings: 'Frequency' (set to 30.000 000 000 000 MHz), 'Bandwidth' (set to 2.5 kHz), 'Coupling' (set to AC), 'Impedance' (set to 50 Ω), and 'Range' (set to 4 V_{pp}). Below these are 'Math channel' (toggle), 'Acquisition speed' (set to 120 Hz), and 'Freewheeling' (toggle). Arrows point from text labels to specific settings in the menu.

- Activate / deactivate channel 4
- Enable **auto-acquisition** mode
- Configure the **acquisition frequency** of the phasemeter
- Select the **bandwidth** of the phasemeter
- Select between **AC** and **DC** coupling
- Select between **50 Ω** and **1 M Ω** input impedance
- Select between **0.4 V_{pp}**, **4 V_{pp}**, **40 V_{pp}** input range
- Enable / disable **Math channel**
- Select the data **acquisition speed**
- Enable / disable **freewheeling**



Acquisition frequency

- The phasemeter will attempt to track frequencies around the specified acquisition frequency.
- If you know the frequency of the tone you'd like to measure, you can set it manually by tapping the blue number below the Frequency label.
- If you do not know the frequency of the tone you'd like to measure, you can enable auto-acquisition mode. This will automatically search for and track the highest magnitude tone between 500 kHz and 400 MHz.

Note: Auto-acquisition does not work reliably for tones below 500 kHz.

Bandwidth

- The Moku:Pro's Phasemeter will reliably measure the phase of an input signal up to the specified bandwidth.
- Select between 10 Hz, 40 Hz, 150 Hz, 600 Hz, 2.5 kHz and 10 kHz bandwidth settings.
- **Note:** The selected bandwidth should not exceed one fifth of the acquisition frequency.

Input voltage range

- Select an appropriate input voltage range to avoid harmonic distortion caused by clipping.
- Input sensitivity is 10 times lower at 4 V_{pp} input voltage range, and 100 times lower at 40 V_{pp}. If the amplitude of the input signal is lower than 400 mV_{pp}, use the 400 mV_{pp} input voltage range setting.

Acquisition speed

- Acquisition speed specifies the sampling rate at which phase, frequency and amplitude data is saved to file or streamed over a network.

Math channel

- Use the math channel to measure differences between any two input channels

Freewheeling

- When freewheeling mode is enabled, the phasemeter will continue to 'freewheel' at a constant frequency when the input signal is too weak to track reliably. The phasemeter will resume tracking the phase of the input signal when its amplitude returns to a reliable level
- The freewheeling frequency is determined by averaging the previous two seconds of continuous, uninterrupted frequency data
- Freewheeling mode is useful in applications where the amplitude of the input signal is expected to fluctuate significantly. For example, freewheeling is useful in free-space optical communications systems where the phasemeter can be used to perform clock recovery in the presence of strong atmospheric turbulence



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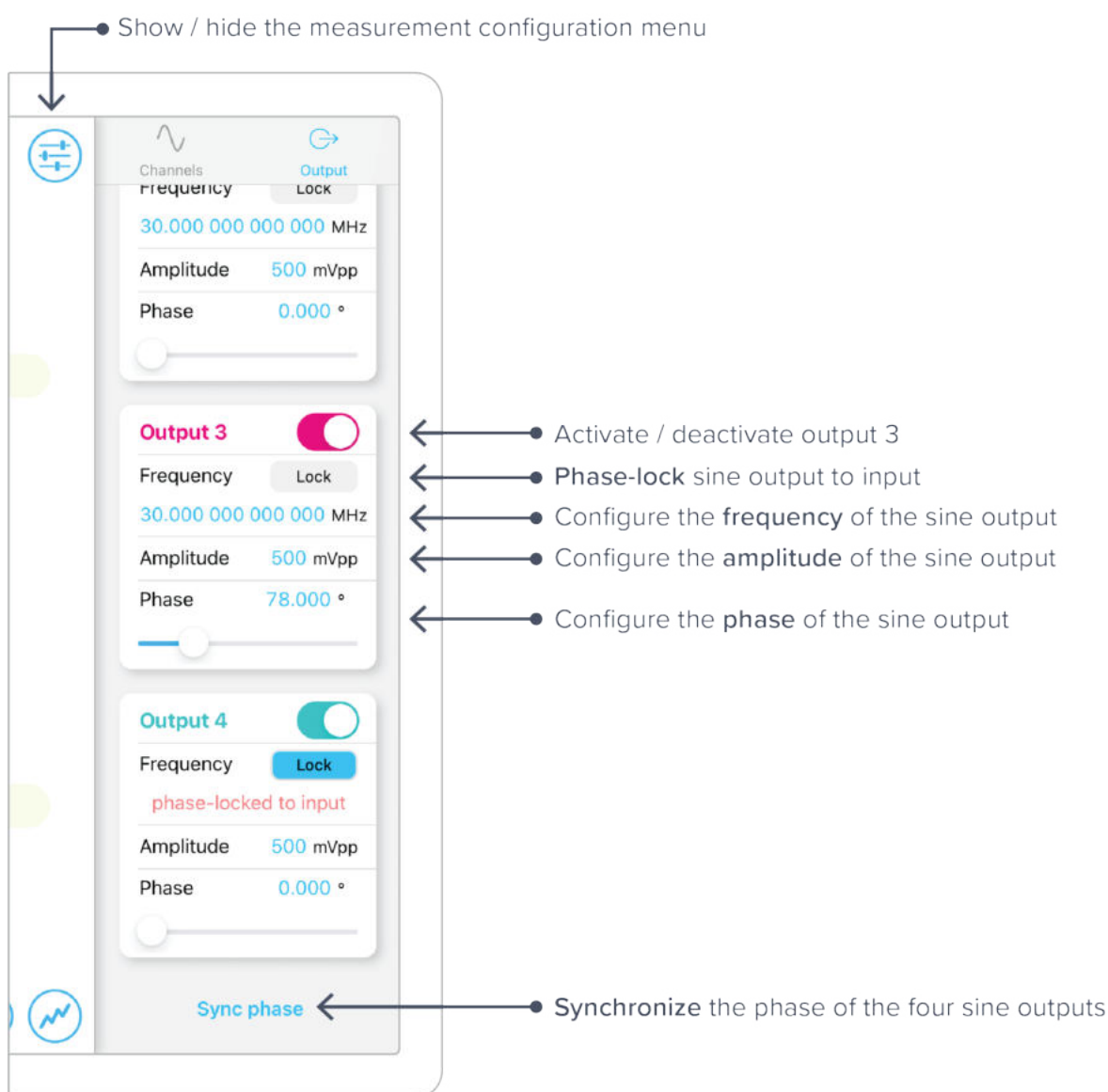
Outputs

The Phasemeter features four sine generators with manual control over amplitude, frequency and phase. The outputs can also be phase-locked to their corresponding input channel whilst maintaining the full range of control over amplitude and phase.

The phase of all outputs can be synchronized by tapping the **Sync phase** button at the bottom of the tab.

Phase-locked output

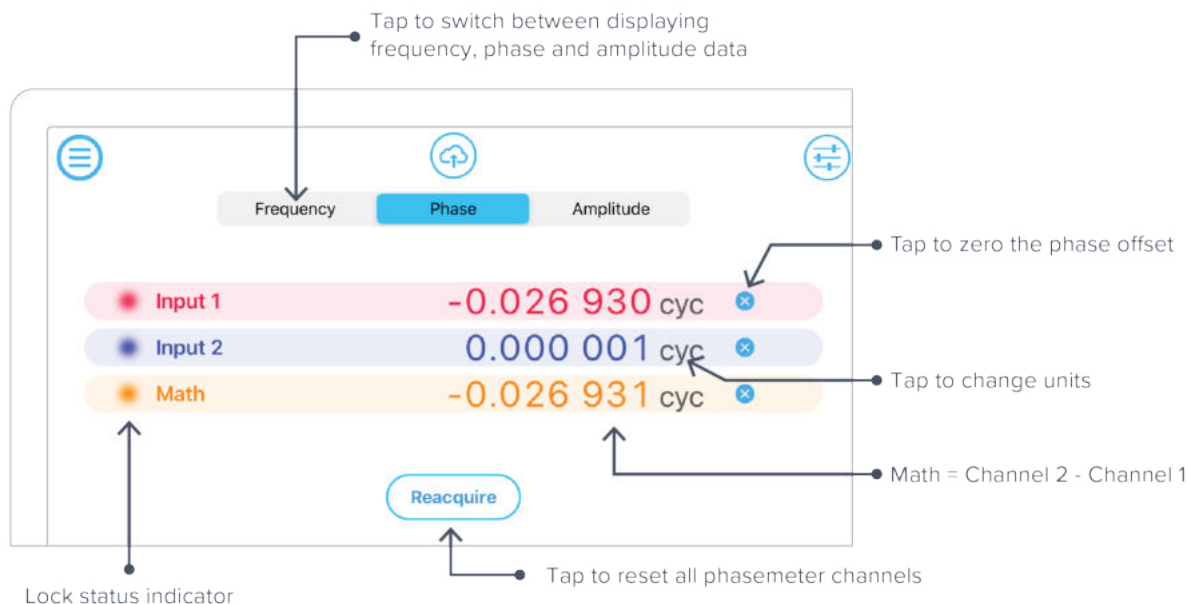
- Generate an output tone with the same frequency and phase of the input signal.
- The amplitude and phase of the generated tone remains configurable.





Measurement Data

Moku:Pro is equipped with four input channels. In this section, we will use channel 1, channel 2, and the math channel to demonstrate.




Measurement tabs

Frequency

- The Frequency measurement tab displays the input signal's frequency in Hertz (Hz).

Phase

- The Phase measurement tab displays the input signal's phase in units of cycles (cyc), radians (rad) or degrees (deg).
- Tap the gray 'units' text to switch between the available units.
- Zero the phase offset by tapping the  icon on the right-hand side of the display. Zeroing the phase offset of the Math channel will zero the phase offset between Math channels.

Amplitude

- The Amplitude measurement tab displays the input signal's amplitude in units of Volts RMS (V_{rms}), Volts peak-to-peak (V_{pp}) or Decibels (dB).
- Tap the gray 'units' text to switch between the available units.



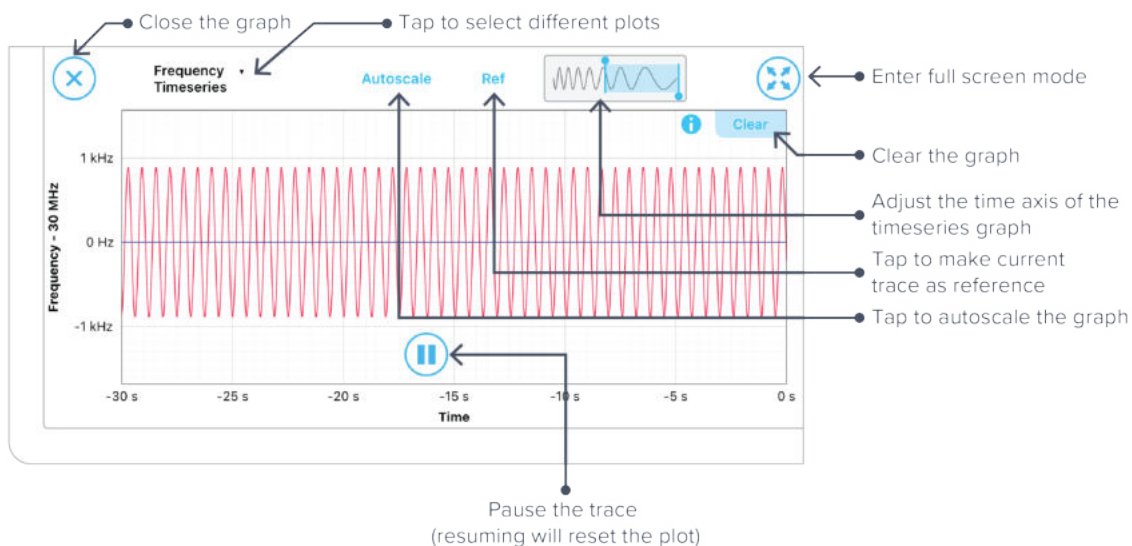
Reacquisition

- Tap the **Reacquire** button to reset both phasemeter channels simultaneously.
- All channels are reset at the same time to maintain synchronization.
- If a channel loses phase lock, the text on the corresponding row will be grayed out.



Data Visualization

The data visualization panel can be accessed by tapping the  icon at the bottom right corner of the interface, allowing you to display measurement data for enabled channels in a variety of formats and over different time and frequency scales.





Plot Types

Frequency, Phase and Amplitude data can be displayed in different formats, including timeseries, power spectral density, amplitude spectral density, coherence, Rayleigh spectrum and Allan deviation. All plot types can be auto-scaled.

Timeseries

- Timeseries data can be viewed over time spans ranging from 0.5 seconds to 600 seconds.
- Adjust timescale and span using pinch gestures anywhere on the graph.
- Set the start and end times of the span manually using the slide rule located above the graph.

Power spectral density

- Power spectral density describes a signal's distribution of power at different frequencies.
- The units of power spectral density are proportional to $\text{amplitude}^2/\text{Hz}$ (e.g., $\text{cycles}^2/\text{Hz}$).

Amplitude spectral density

- Amplitude spectral density provides a measure of a signal's amplitude at different frequencies.
- The units of amplitude spectral density are proportional to $\text{amplitude}/\sqrt{\text{Hz}}$ (e.g., $\text{cycles}/\sqrt{\text{Hz}}$).
- Amplitude spectral density is equal to the square root of the power spectral density.

Coherence

- Spectral coherence is a unitless statistic used to measure the similarity between two signals.


Allan deviation

- Allan deviation is a unitless measure of stability, typically used to quantify the stability of clocks and other oscillators.
- Allan deviation is equal to the square-root of the Allan variance.
- An Allan deviation of 2×10^{-6} at an averaging time of $\tau = 1$ seconds can be interpreted as there being an RMS error between two measurements one second apart of 2×10^{-6} cycles.

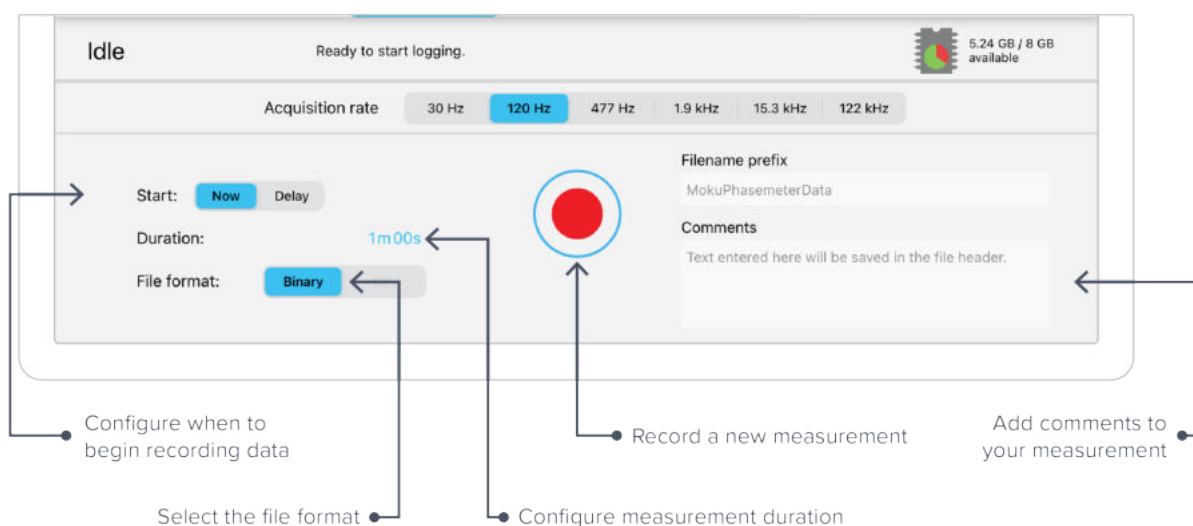




Data Acquisition

The Moku:Pro's Phasemeter can acquire data at a maximum **acquisition speed** of 15.3 kSa/s for two or more channels and 122 kSa/s for one channel. To access the data acquisition menu, press the  icon.

- Data can be saved to the SSD as *.li file
- Files saved with binary *.li format can be converted to *.csv or *.mat using Liquid Instruments file conversion software.
- Record data for up to 10,000 hours and delay the start of a logging session for up to 240 hours.
- Start a measurement by pressing the red circle.



Note: As a precaution, you will be warned about switching instruments while a data logging session is taking place.



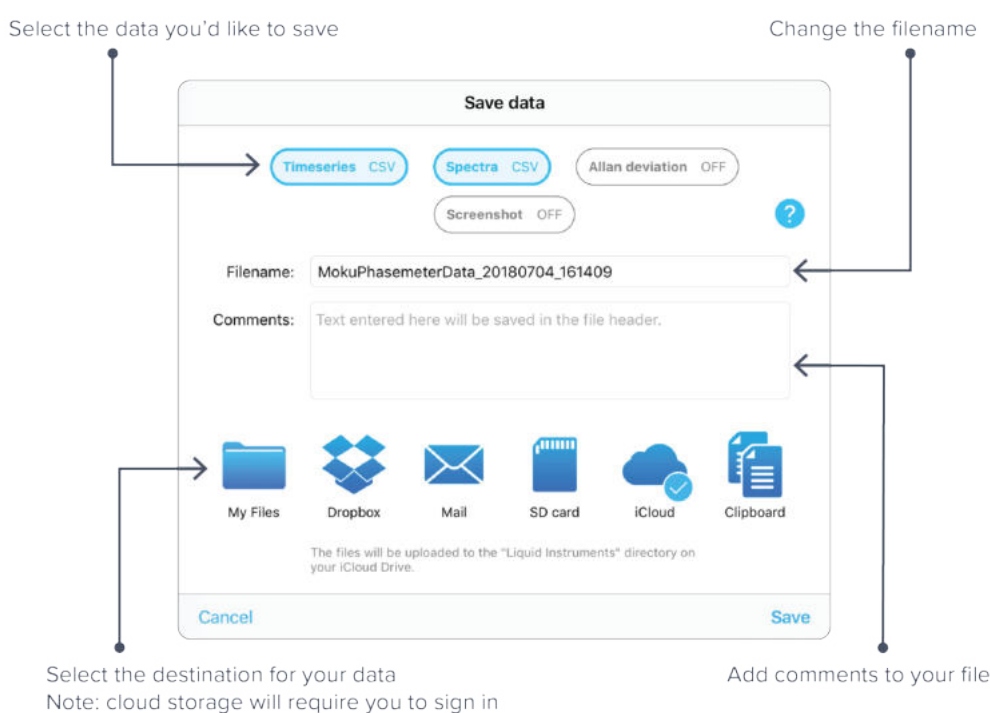
Exporting Data

Export data by pressing the  icon at the top of the interface.

Live Data

Measurement data can be uploaded to My Files (iOS 11 or later), Dropbox, E-mail, iCloud, Clipboard (screenshot is not copied to the clipboard).

To export a live data, tap the  icon and select the 'Live Data' option.

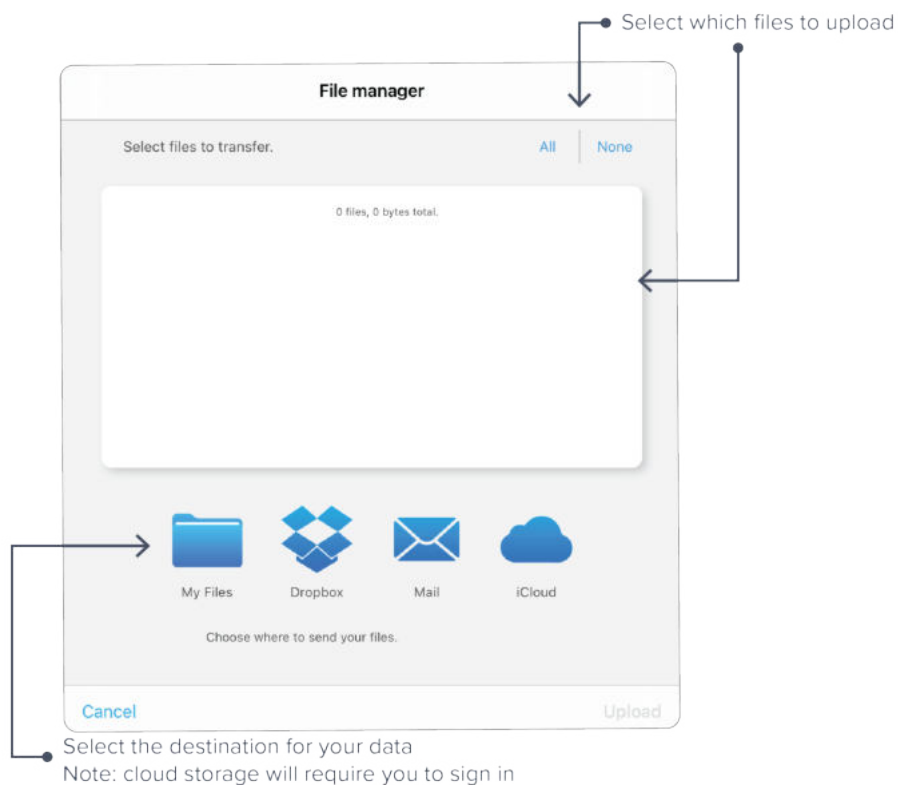




Logged data

Data that has been acquired to Moku:Pro's SSD can be uploaded to My Files (iOS 11 or later), Dropbox, E-mail, and iCloud.

To export logged data, press the  icon and select the 'Logged data' option.






Example Measurement Configurations

Measure the relative phase of two signals


To measure the phase of one signal with respect to another:

1. Connect the two signals to the Moku:Pro's input 1 and 2.
2. Enable the math channel and set it to measure the difference between input 1 and 2.
3. Configure the two input channels for your measurement setup.
 - a. The Acquisition speed and Bandwidth settings limit the range of frequencies within which you can observe changes in magnitude and phase. For example, to observe features up to 200 Hz, set the Bandwidth to be at least 600 Hz and the acquisition rate to be at least 488 Hz.

Note: When measuring the relative frequency, phase and amplitude of two signals, it's often useful to configure both channels identically to maximise the rejection of common sources of error and noise in the Delta measurement.

4. When both channels have been configured, tap the **Reacquire** button to synchronously reset both phasemeter channels.
5. View the data in the frequency and time domains by tapping the  icon. Double-tap the graph to automatically scale the vertical axis, and adjust the horizontal axis using the slider located above the graph or by using pinch gestures.

Tip: Tap the 'Clear' button at the top right of the graph every time you reacquire to discard transient data which can sometimes corrupt the quality of the graph.

6. To record data, tap the  icon and configure the data logger as required for the measurement.

Note: If the Moku:Pro's internal clock is not synchronized to that of the device generating the input signals, you can expect the measured phase for channels 1 and 2 to 'ramp' linearly over time.

The reason this occurs is because phase is the integral of frequency, which means that any DC frequency error between the Moku:Pro's internal clock and that of the external source will cause the measured phase to grow at a rate proportional to the frequency difference between the two devices.

As long as the two input signals are generated by the same source, the frequency error will be common to both phase measurements and will be cancelled out in the Delta phase measurement.



Ensure Moku:Pro is fully updated. For the latest information:

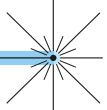
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PID Controller

Moku:Pro User Manual

Moku:Pro's PID (Proportional-Integrator-Differentiator) Controller features four fully real-time configurable PID controllers with a closed-loop bandwidth >100 kHz. 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.





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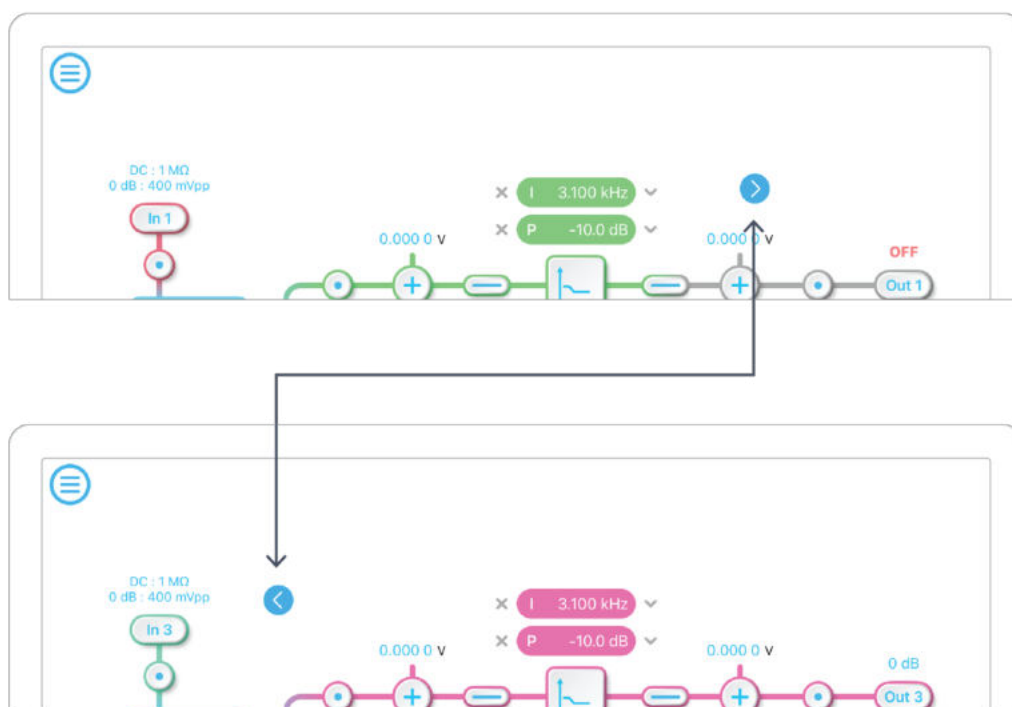
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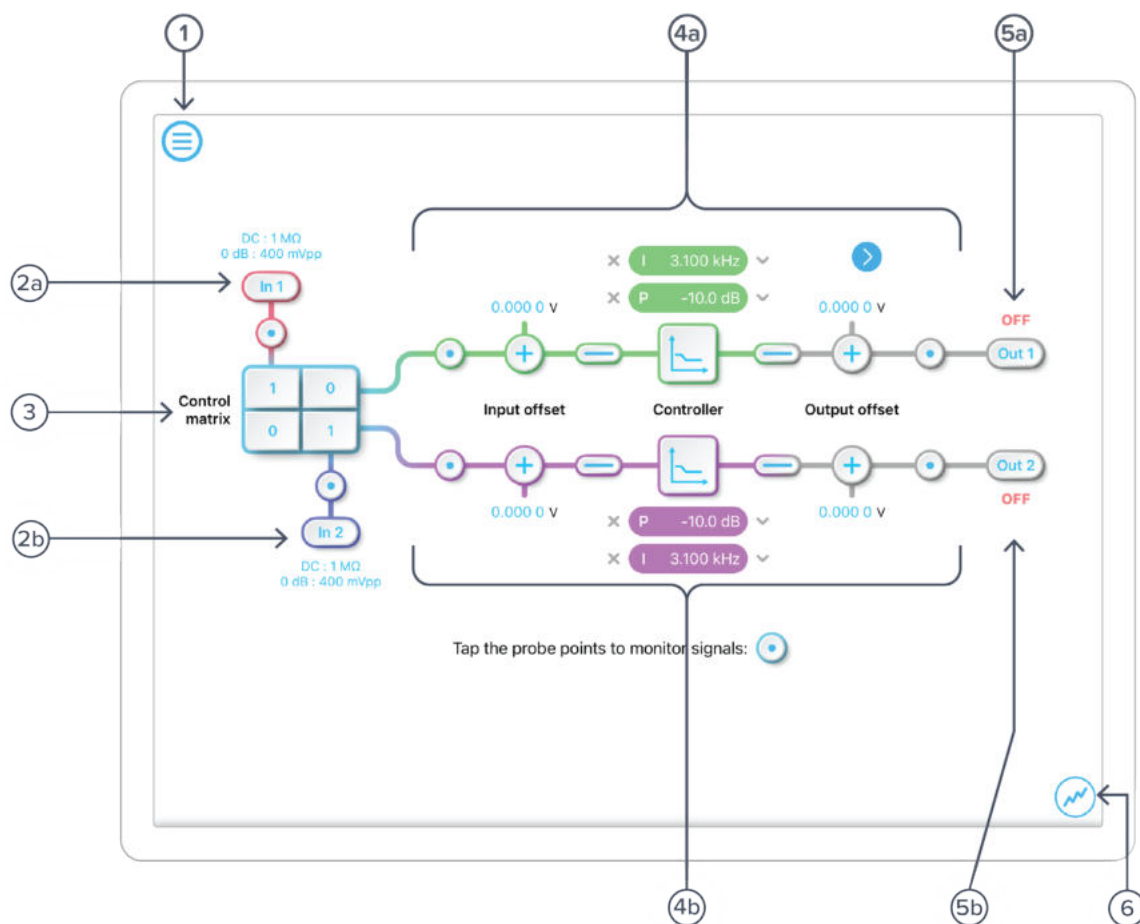
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User Interface

Moku:Pro is equipped with four inputs, four outputs, and four PID controllers. Two control matrices are used to create two multiple-input and multiple-output (MIMO) in groups for PID 1 & 2, and PID 3 & 4. You can tap the  or  icons to switch between MIMO group 1 and 2. MIMO group 1 (inputs 1 and 2, PID 1 and 2, Output 1 and 2) is used throughout this manual. The settings for MIMO group 2 are similar to MIMO group 1.





ID Description

1	Main menu
2a	Input configuration for Channel 1
2b	Input configuration for Channel 2
3	Control matrix
4a	Configuration for PID Controller 1
4b	Configuration for PID Controller 2
5a	Output switch for Channel 1
5b	Output switch for Channel 2
6	Enable the oscilloscope



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Main Menu

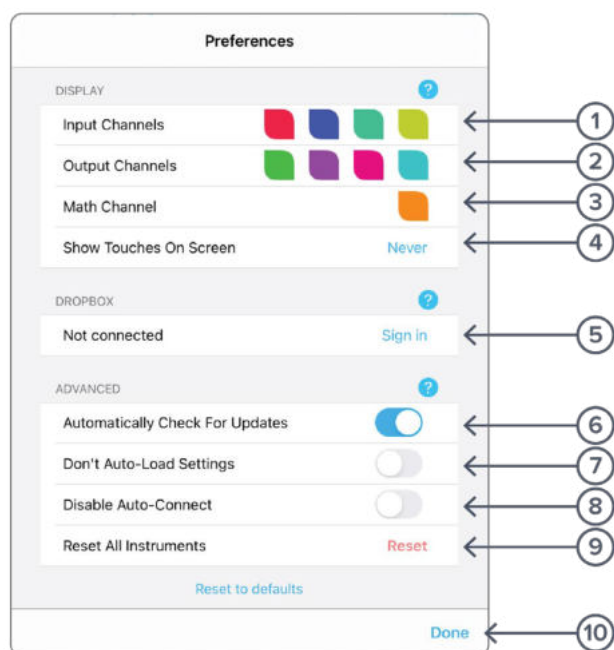
The **main menu** can be accessed by pressing the  icon, allowing you to:





Preferences

The preferences pane can be accessed via the main menu. In here, you can reassign the color representations for each channel, connect to Dropbox, etc. Throughout the manual, the default colors (shown in the figure below) are used to present instrument features.



ID Description

- | | |
|----|--|
| 1 | Tap to change the color associated with input channels. |
| 2 | Tap to change the color associated with output channels. |
| 3 | Tap to change the color associated with math channel. |
| 4 | Indicate touch points on the screen with circles. This can be useful for demonstrations. |
| 5 | Change the currently linked Dropbox account to which data can be uploaded. |
| 6 | Notify when a new version of the app is available. |
| 7 | Moku:Pro automatically saves instrument settings when exiting the app, and restores them again at launch. When disabled, all settings will be reset to defaults on launch. |
| 8 | Moku:Pro can remember the last used instrument and automatically reconnect to it at launch. When disabled, you will need to manually connect every time. |
| 9 | Reset all instruments to their default state. |
| 10 | Save and apply settings. |



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Input Configuration

The **input configuration** can be accessed by tapping the **In 1** or **In 2** icon, allowing you to adjust the coupling, impedance and input range for each input channel.



Details about the probe points can be found in the [Probe Points](#) section.



Control Matrix

The **control matrix** combines, rescales, and redistributes the input signal to the two independent PID controllers. The output vector is the product of the control matrix multiplied by the input vector.

$$\begin{bmatrix} \text{Path1} \\ \text{Path2} \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \times \begin{bmatrix} \text{In1} \\ \text{In2} \end{bmatrix}$$

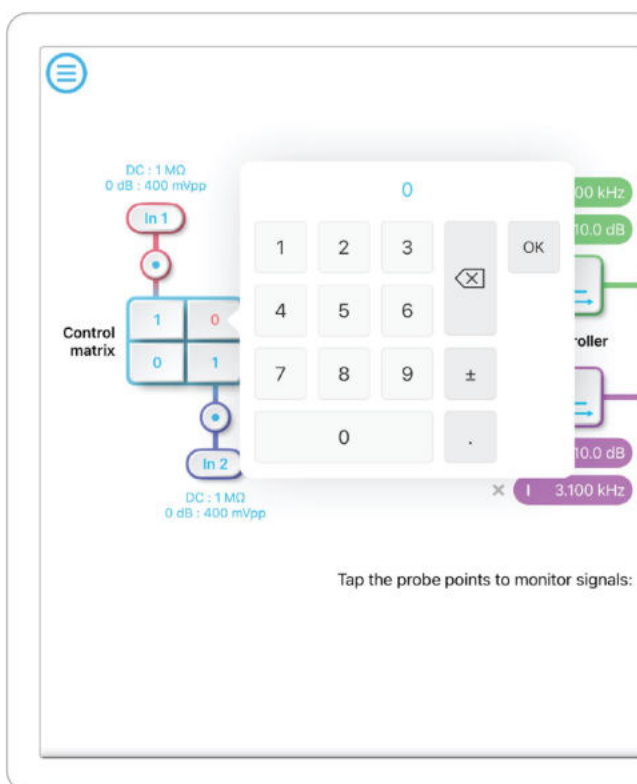
where

$$\text{Path1} = a \times \text{In1} + b \times \text{In2}$$

$$\text{Path2} = c \times \text{In1} + d \times \text{In2}$$

For example, a control matrix of $\begin{bmatrix} 1 & 1 \\ 0 & 2 \end{bmatrix}$ equally combines the **Input 1** and **Input 2** to the top **Path1** (PID Controller 1); multiplies **Input 2** by a factor of two, and then sends it to the bottom **Path2** (PID Controller 2).

The value of each element in the control matrix can be set between -20 to +20 with 0.1 increments when the absolute value is less than 10, or 1 increment when the absolute value is between 10 and 20. Tap the element to adjust the value.

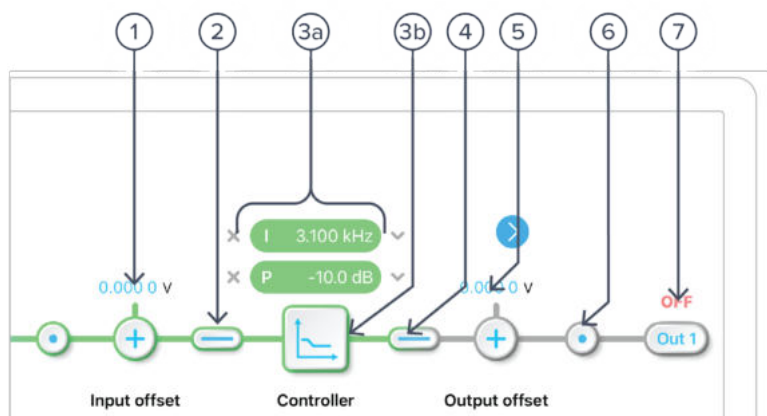




PID Controller

The four independent, fully real-time configurable PID controller are grouped into two MIMO groups. MIMO group 1 is shown here. In MIMO group 1, PID controller 1 and 2 follow the control matrix in the block diagram, represented in green and purple, respectively. The settings for all controller paths are the same.

User Interface



ID	Parameter	Description
1	Input offset	Tap to adjust the input offset (-1 to +1 V).
2	Input switch	Tap to zero the input signal.
3a	Quick PID control	Tap to enable/disable controllers and adjust the parameters. Not available in advanced mode.
3b	Controller view	Tap to open full controller view.
4	Output switch	Tap to zero the output signal.
5	Output offset	Tap to adjust the output offset (-1 to +1 V).
6	Output probe	Tap to enable/disable the output probe point. See Probe Points section for details.
7	Moku:Pro output switch	Tap to disable or enable DAC output with 0 dB or 14 dB gain.

Input / Output Switches



Closed/Enable



Open/disable



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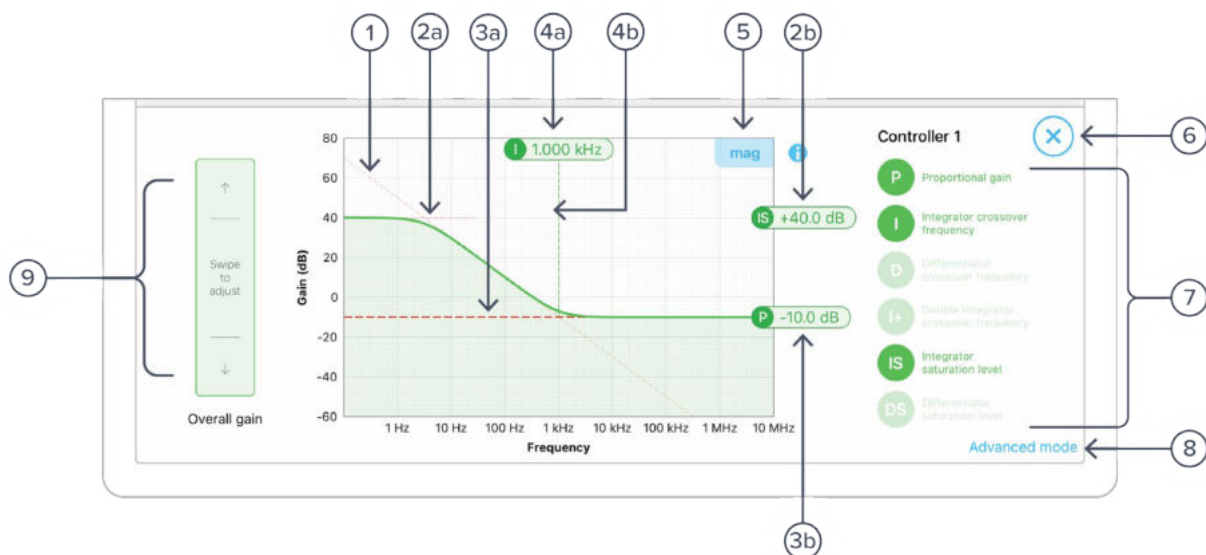
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Controller (Basic Mode)

Controller Interface

Tap the  icon to open the full controller view.

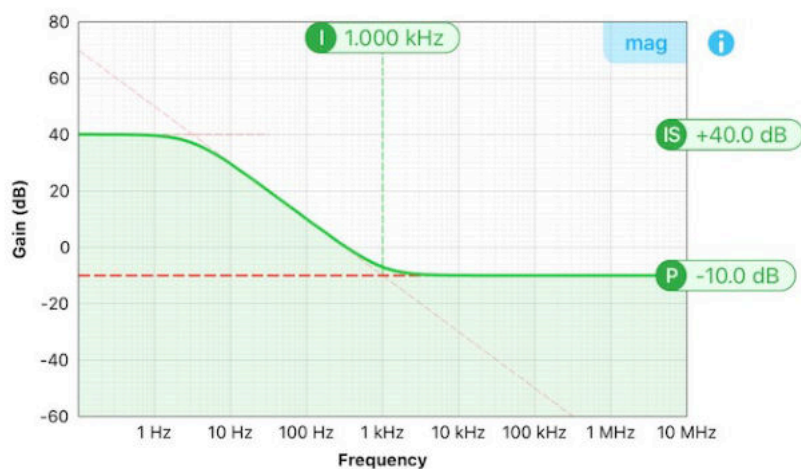


ID	Parameter	Description
1	Design cursor 1	Cursor for Integrator (I) setting.
2a	Design cursor 2	Cursor for Integrator Saturation (IS) level.
2b	Cursor 2 reading	Reading for IS level. Drag to adjust the gain.
3a	Design cursor 3	Cursor for Proportional (P) gain.
3b	Cursor 3 reading	Reading of the P gain.
4a	Cursor 4 reading	Reading for I crossover frequency. Drag to adjust the gain.
4b	Design cursor 4	Cursor for I crossover frequency.
5	Display toggle	Toggle between magnitude and phase response curve.
6	Close controller view	Tap to close the full controller view.
7	PID control switches	Turn on/off individual controller.
8	Advanced mode	Tap to switch to the advanced mode.
9	Overall gain slider	Swipe to adjust overall gain of the controller.



PID Response Plot

The PID Response Plot provides an interactive representation (gain as a function of frequency) of the controller.



The green/purple solid curve represents the active response curve for PID Controller 1 and 2, respectively.

The green/purple dashed vertical lines (④) represent the cursors crossover frequencies, and/or unity gain frequencies for PID Controller 1 and 2, respectively.

The red dashed lines (① and ②) represent the cursors for each controller.

The bold red dashed line (③) represents the cursor for actively selected parameter.

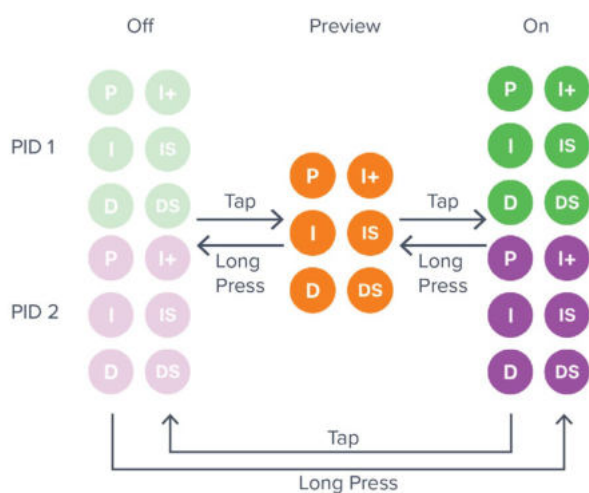


PID Paths

There are in total six switch buttons for the controller paths in area ⑥. The function of each button can be found below:

ID	Description	ID	Description
P	Proportional gain	I+	Double integrator crossover frequency
I	Integrator crossover frequency	IS	Integrator saturation level
D	Differentiator	DS	Differentiator saturation level

Each button has three states: off, preview, and on. Tap the buttons to circle these states. Long press the buttons to go reverse order.





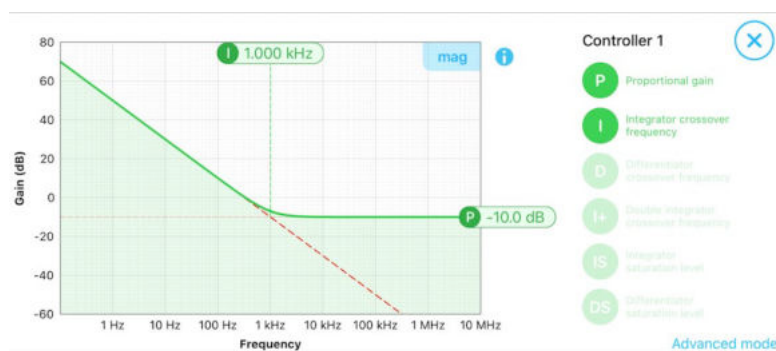
PID Path Preview

PID path preview allows the user to preview and adjust the settings on the PID response plot before engaging.

Preview



Engaged



List of Configurable Parameters in Basic Mode

Parameters	Range
Overall gain	± 60 dB
Proportional gain	± 60 dB
Integrator crossover frequency	3.125 Hz to 312.5 kHz
Differentiator crossover frequency	31.25 Hz to 3.125 MHz
Integrator saturation level	± 60 dB or limited by the crossover frequency/proportional gain
Differentiator saturation level	± 60 dB or limited by the crossover frequency/proportional gain



Controller (Advanced Mode)

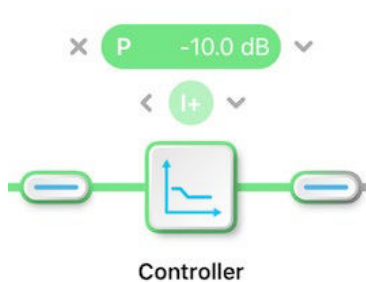
In **Advanced Mode**, users can build fully customized controllers with two independent sections (A and B), and six adjustable parameters in each section. Tap the **Advanced Mode** button in the full controller view to switch to the **Advanced Mode**.



ID	Parameter	Description
1	Display toggle	Toggle between magnitude and phase response curve.
2	Close controller view	Tap to close the full controller view.
3a	Section A pane	Tap to select and configure Section A.
3b	Section B pane	Tap to select and configure Section B.
4	Section A Switch	Master switch for Section A.
5	Overall gain	Tap to adjust the overall gain.
6	Proportional panel	Tap the switch to enable/disable proportional path. Tap the number to adjust the gain.
7	Integrator panel	Tap the switch to enable/disable integrator path. Tap the number to adjust the gain.
8	Differentiator panel	Tap the switch to enable/disable differential path. Tap the number to adjust the gain.
9	Additional Settings	
	Integrator corner frequency	Tap to set the frequency of the integrator corner.
	Differentiator corner frequency	Tap to set the frequency of the differentiator corner.
10	Basic mode	Tap to switch to the basic mode.

Quick PID Control

This panel allows user quickly to view, enable, disable, and adjust the PID controller without open the controller interface. It is only available in basic PID mode.



Tap the  icon to disable active controller path.


Tap the  icon to select the controller to adjust.

Tap the faded icon (i.e. ) to enable the path.

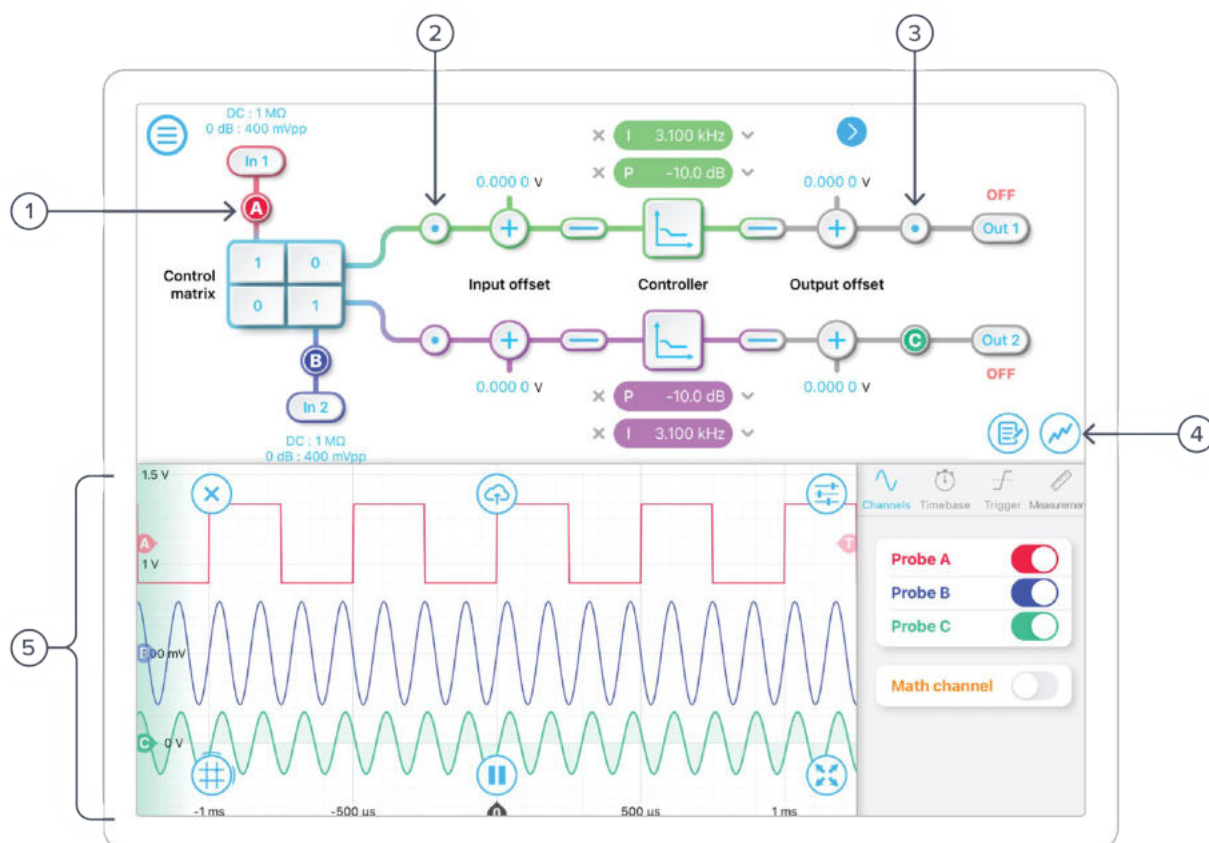
Tap the active controller path icon (i.e. ) to enter the value. Hold and slide to adjust the value.



Probe Points

Moku:Pro's PID controller has an integrated oscilloscope and data logger that can be used to probe the signal at the input, pre-PID, and output stages. The probe points can be added by tapping the  icon.

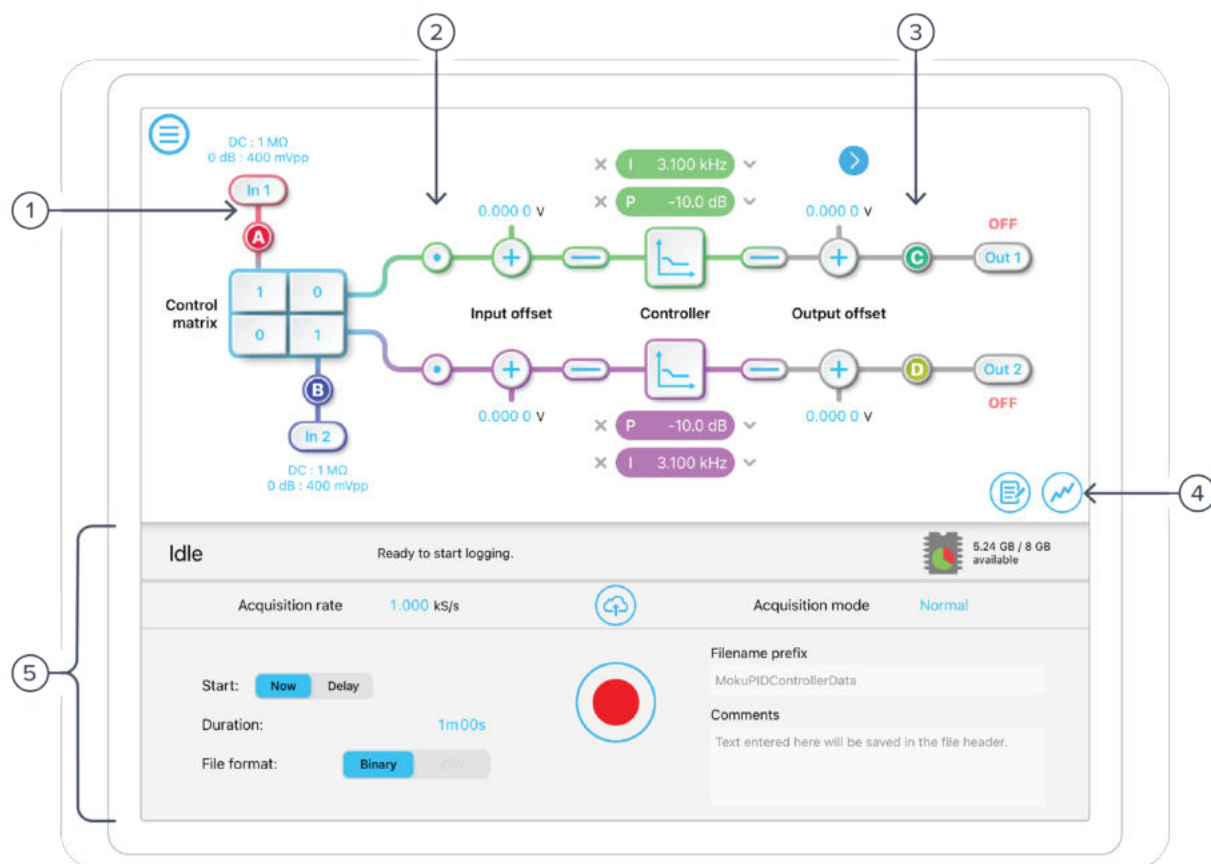
Oscilloscope



ID	Parameter	Description
1	Input probe point	Tap to place the probe point at input.
2	Pre-PID probe point	Tap to place the probe after the control matrix.
3	Output probe point	Tap to place the probe at output.
4	Oscilloscope/data logger toggle	Toggle between built-in oscilloscope or data logger.
5	Oscilloscope	Refer to the Moku:Pro's Oscilloscope manual for the details.



Data Logger



ID	Parameter	Description
1	Input probe point	Tap to place the probe point at input.
2	Pre-PID probe point	Tap to place the probe after the control matrix.
3	Output probe point	Tap to place the probe at output.
4	Oscilloscope/data logger toggle	Toggle between built-in oscilloscope or data logger.
5	Data Logger	Refer to the Moku:Pro's Data Logger manual for the details.



Ensure Moku:Pro is fully updated. For the latest information:

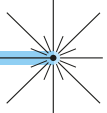
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Spectrum Analyzer

Moku:Pro User Manual

Moku:Pro's Spectrum Analyzer allows you to observe input signals in the frequency domain between DC and 400 MHz. View four channels of data simultaneously with a resolution bandwidth as low as 2.2 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 500 MHz.





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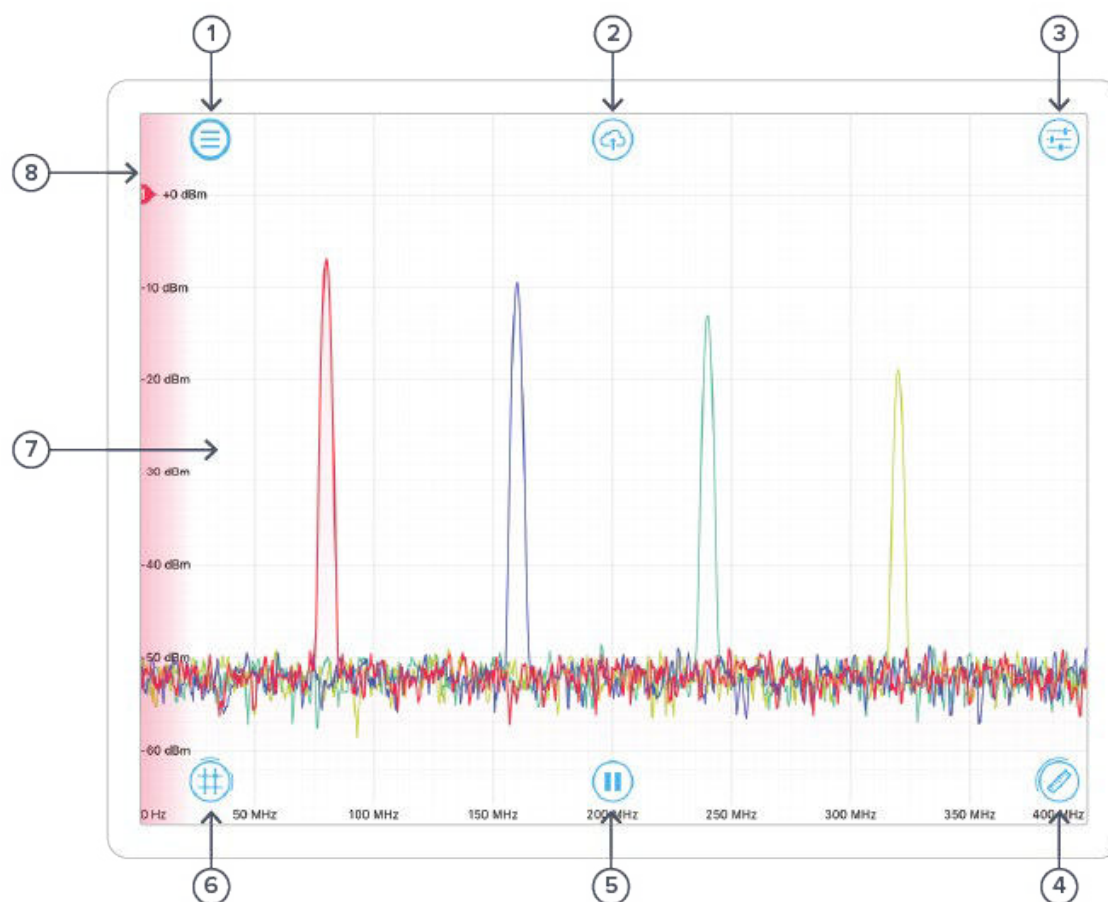


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User Interface



ID	Description	ID	Description
1	Main menu	5	Play/Pause
2	Save data	6	Cursors
3	Controls	7	Signal display area
4	Measurements	8	Reference position indicator



Main Menu

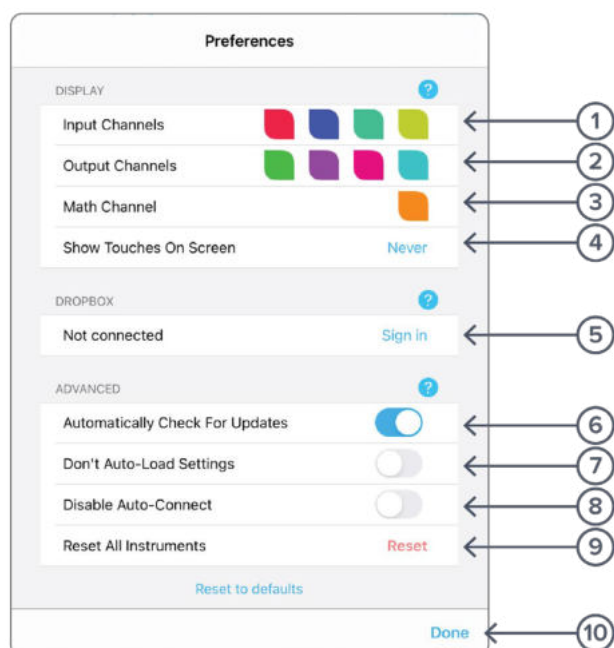
The **main menu** can be accessed by pressing the  icon, allowing you to:





Preferences

The preferences pane can be accessed via the main menu. In here, you can reassign the color representations for each channel, connect to Dropbox, etc. Throughout the manual, the default colors (shown in the figure below) are used to present instrument features.



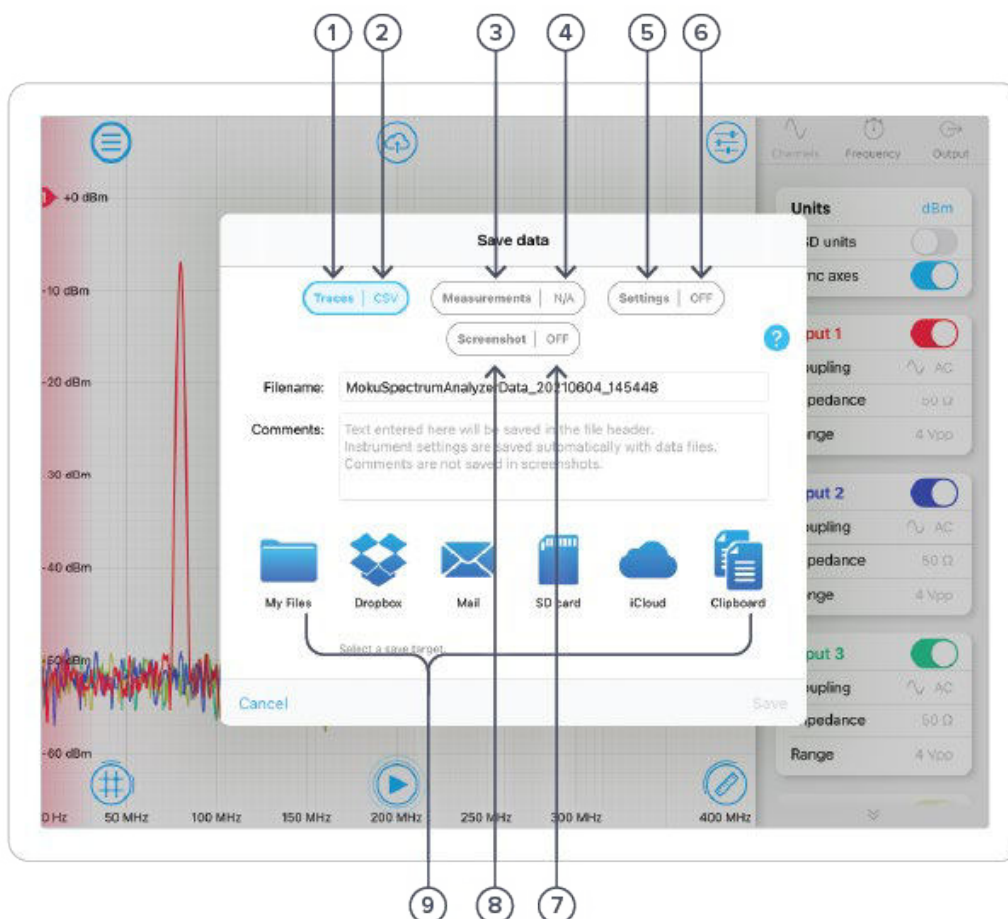
ID Description

- | | |
|----|--|
| 1 | Tap to change the color associated with input channels. |
| 2 | Tap to change the color associated with output channels. |
| 3 | Tap to change the color associated with math channel. |
| 4 | Indicate touch points on the screen with circles. This can be useful for demonstrations. |
| 5 | Change the currently linked Dropbox account to which data can be uploaded. |
| 6 | Notify when a new version of the app is available. |
| 7 | Moku:Pro automatically saves instrument settings when exiting the app, and restores them again at launch. When disabled, all settings will be reset to defaults on launch. |
| 8 | Moku:Pro can remember the last used instrument and automatically reconnect to it at launch. When disabled, you will need to manually connect every time. |
| 9 | Reset all instruments to their default state. |
| 10 | Save and apply settings. |



Save data

The **save data** options can be accessed by pressing the  icon, allowing you to:



ID Description

- | ID | Description |
|----|---|
| 1 | Tap to save data from all visible traces. |
| 2 | Tap to change the save format (CSV or MAT). |
| 3 | Tap to save measurement trends when the measurement tile is visible and at least one measurement is active. |
| 4 | Tap to change the save format (CSV or MAT). |
| 5 | Tap to save the current instrument's settings to a text file. Note that settings are saved automatically in the header of data files. |
| 6 | Tap to change the save format (TXT only). |
| 7 | Tap to change the save format (PNG or JPG). |
| 8 | Tap to save the iPad screen as an image. |
| 9 | Tap on any of these options for saving your files. |




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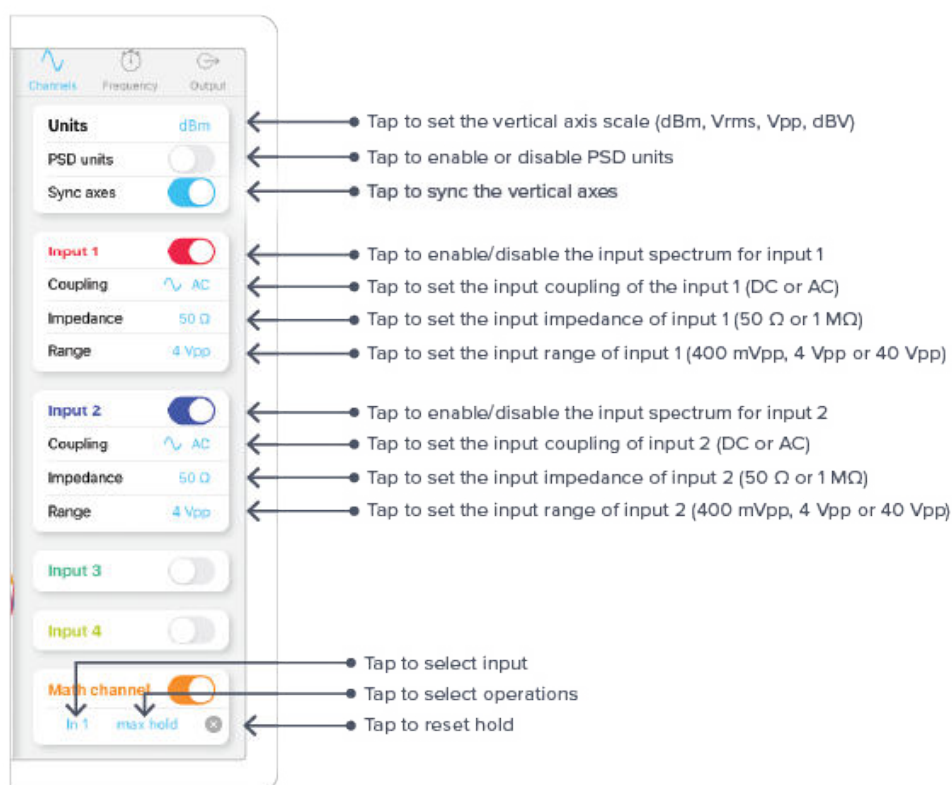


Controls

The **controls** options can be accessed by pressing the  icon, allowing you to reveal or hide the control drawer, giving you access to all instrument settings. This menu is also available by swiping in from to the right-hand side of the screen. The controls drawer gives you access to channels, frequency, and output settings.

Channels

The **channels** pane allows you to change the input settings for each input channel, adjust the input range, impedance, and coupling, and enable/disable the math channel. Additional settings are available when math channel is enabled.

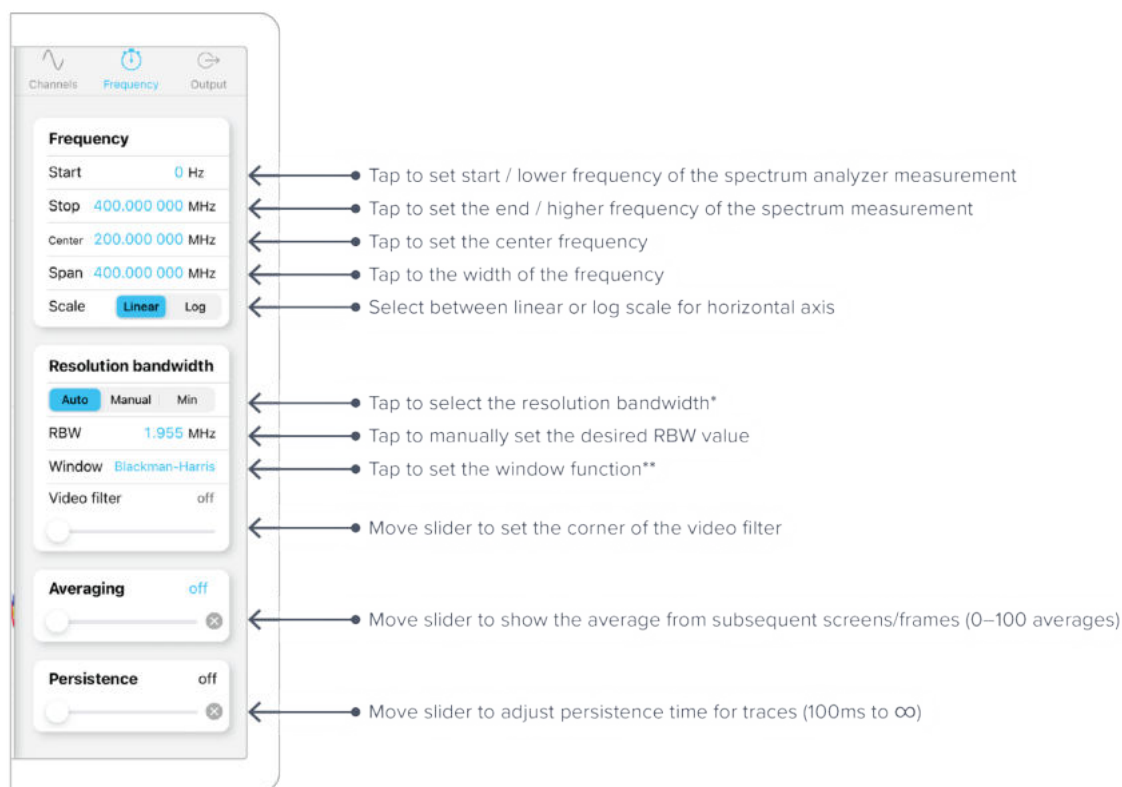


Four operations are currently supported by Moku:Pro's Spectrum Analyzer: +, \times , min hold, and max hold.



Frequency

The **frequency** pane allows you to change parameters related to the frequency domain (horizontal axis), including frequency span, resolution bandwidth, and video bandwidth.



Note that [Start, Stop] and [Center, Span] in the frequency panel are equivalent representations of the measured frequency range. Moku:Pro will automatically update the other pair if one is changed.

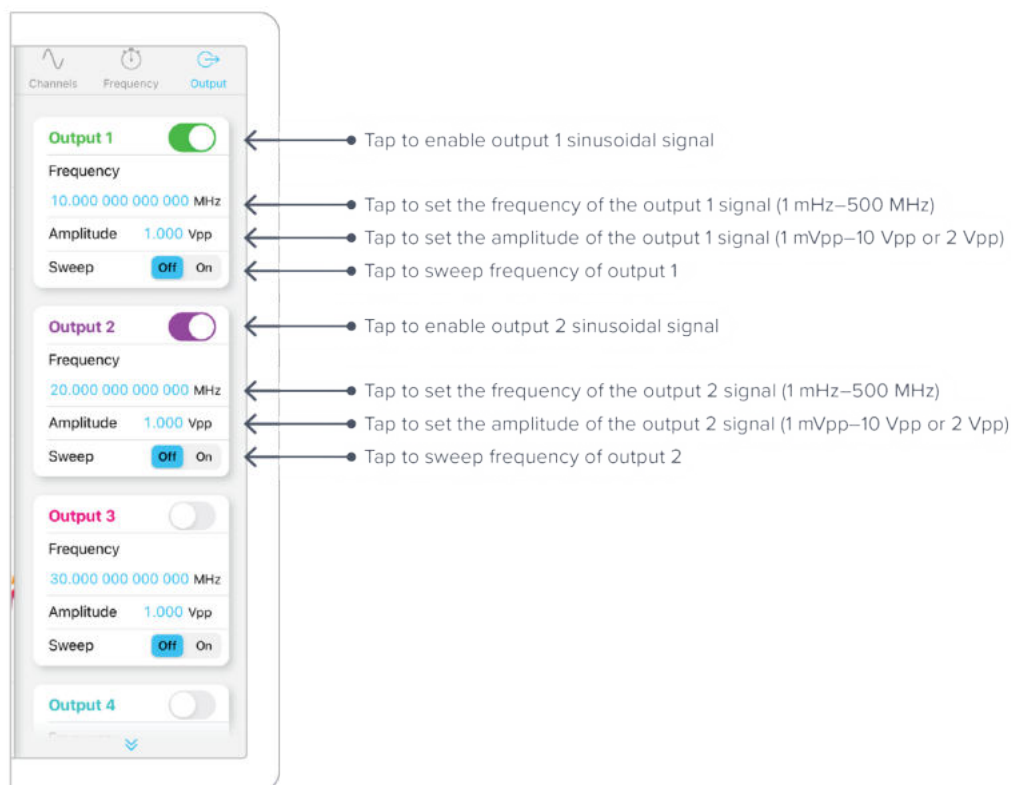
* Auto: determines the best resolution based on the span; Manual: manually set the resolution bandwidth of the spectrum analyzer; Min: uses the smallest RBW available.

** Available options: Blackman-Harris, Flat top, Hanning, and None.



Output

The **output** pane allows you to configure the integrated sine wave generator for the Spectrum Analyzer.



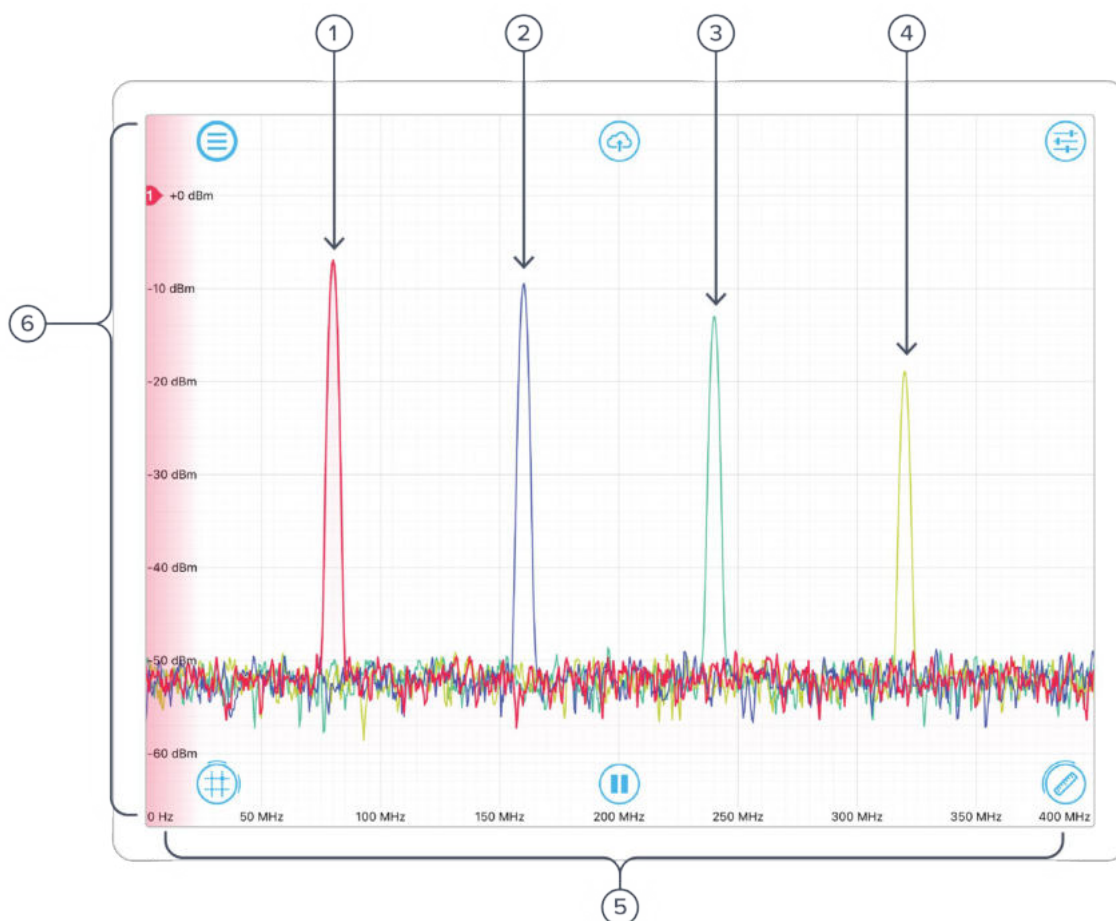
The maximum output amplitude depends on the output frequency. It is 10 Vpp for 100 MHz and below, and 2 Vpp for 100 MHz to 500 MHz.



Display

User Interface

This area is intended to display the spectrum of input and math channels, where the horizontal axis is the measured frequency range and the vertical axis is the power or power spectral density (PSD) in linear or log scales.



ID Description

- | ID | Description |
|----|---|
| 1 | Spectrum for input channel 1. |
| 2 | Spectrum for input channel 2. |
| 3 | Spectrum for input channel 3. |
| 4 | Spectrum for input channel 4. |
| 5 | Frequency axis: shows the frequency scale for all channels. |
| 6 | Power axis: shows the power scale for the active channel. * |

The scales of both axes can be adjusted with pinching gestures.

* The shaded color near the vertical axis indicates the active channel. By default, red represents channel 1, blue represents channel 2, teal represents channel 3, yellow green represents channel 4, and orange represents the math channel.



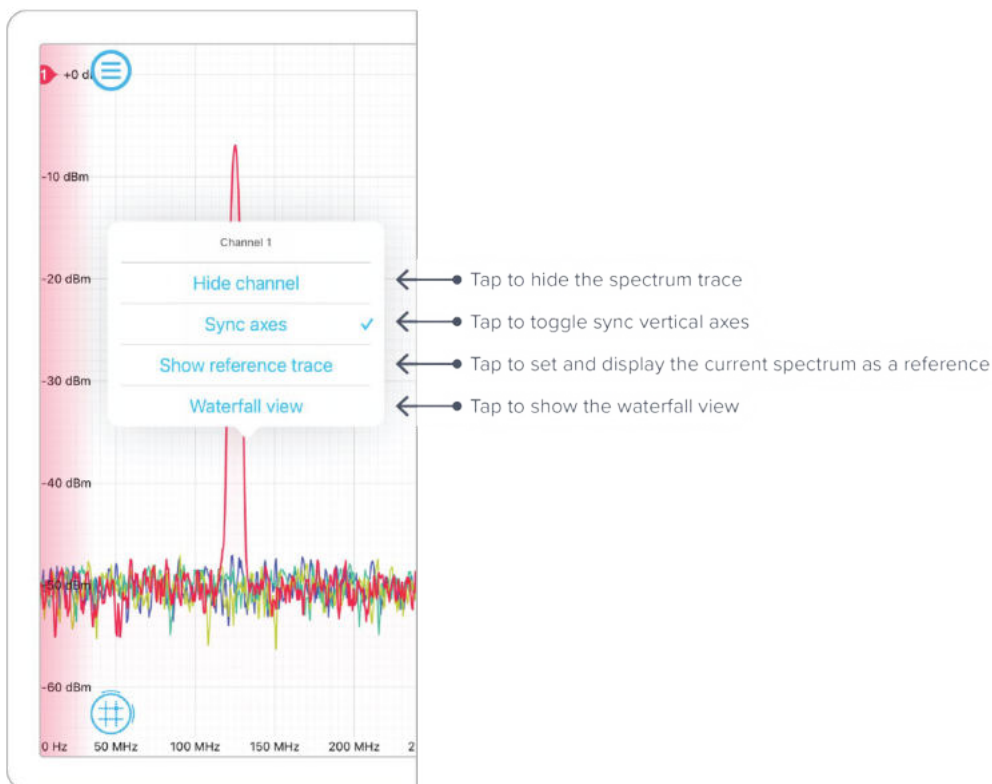
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Spectrum Trace

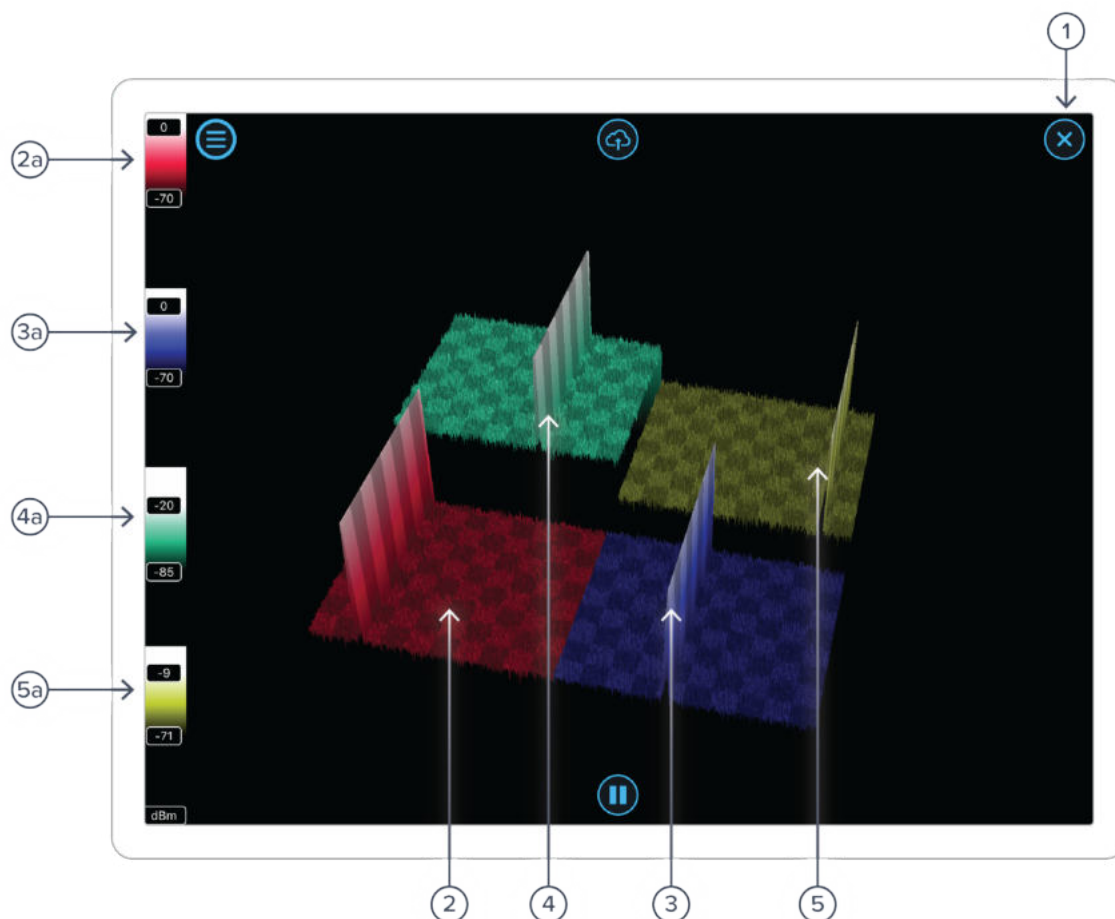
Press and hold the spectrum trace to reveal additional viewing options:





Waterfall View

Use the waterfall view to visualize the spectrum variation over time. Use finger gestures to adjust the scales and viewing angle.



ID Description

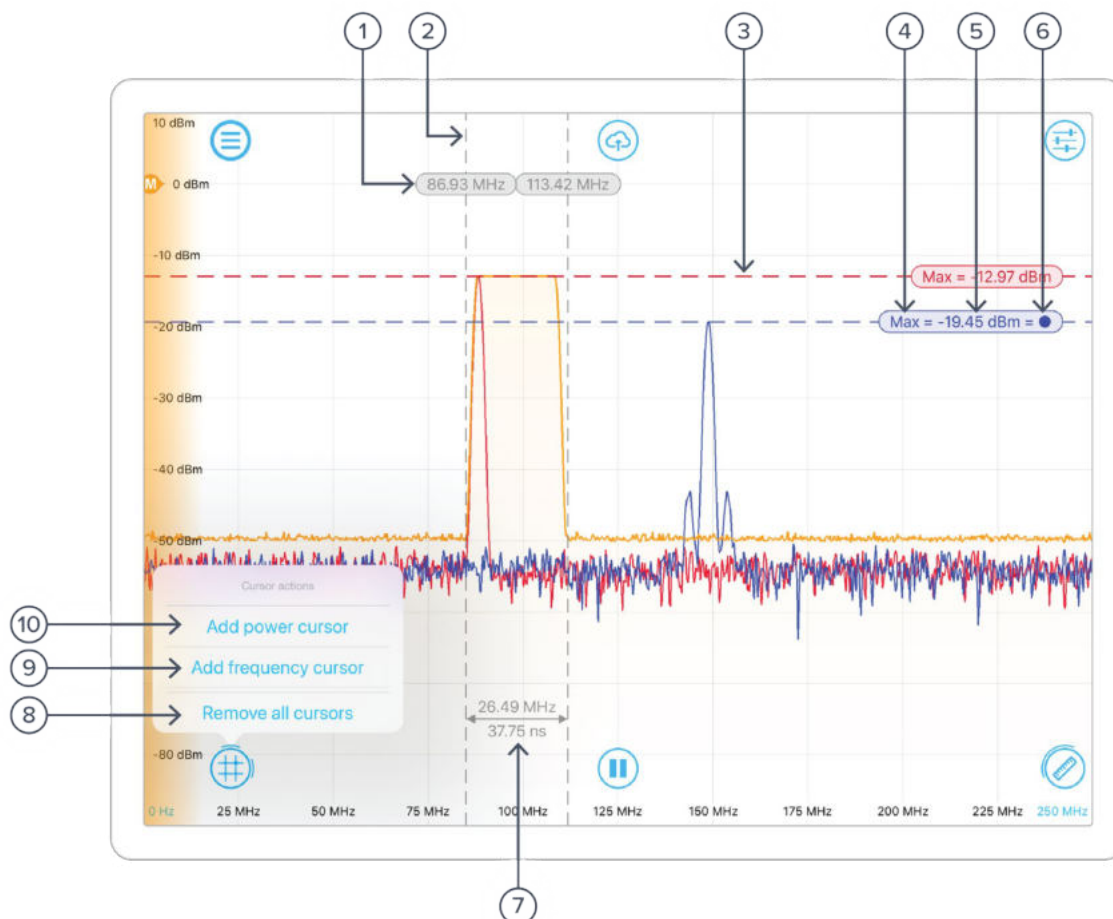
- | | |
|----|----------------------------------|
| 1 | Tap to close the waterfall view. |
| 2 | Waterfall view for input 1. |
| 2a | Color scale for input 1. |
| 3 | Waterfall view for input 2. |
| 3a | Color scale for input 2. |
| 4 | Waterfall view for input 3. |
| 4a | Color scale for input 3. |
| 5 | Waterfall view for input 4. |
| 5a | Color scale for input 4. |



Cursors

The **cursors** can be accessed by pressing the  icon, allowing you to add power or frequency cursors on the display.

User Interface



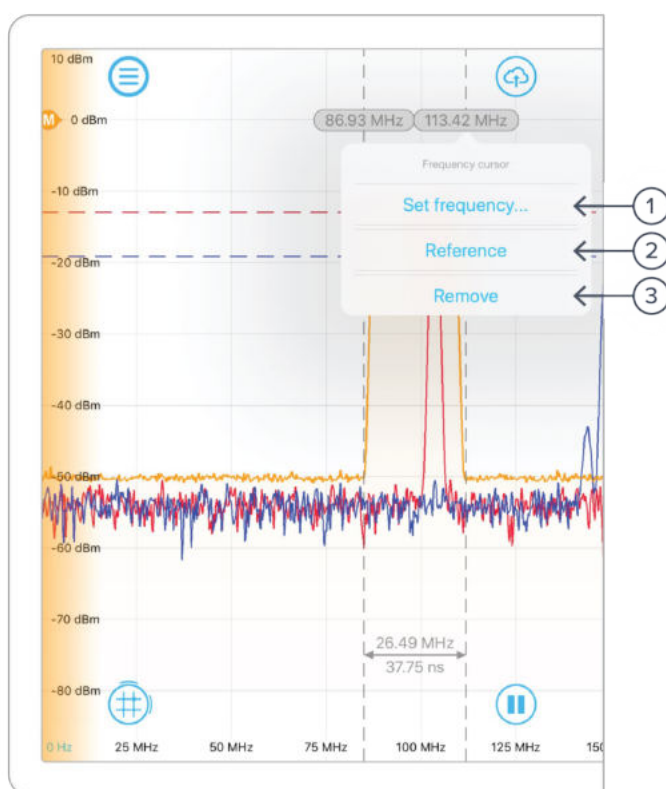
ID	Parameter	Description
1	Frequency reading	Tap to reveal frequency cursor options.
2	Frequency cursor	Drag left or right to set positions.
3	Power cursor	Drag up or down to set positions. Color represents the channel of the measurement.
4	Cursor function	Indicates the current cursor function (max, min, max hold, etc).
5	Amplitude reading	Tap to reveal amplitude cursor options.
6	Reference indicator	Indicates the cursor is set as reference.
7	Frequency difference	Represents the frequency difference between two cursors. This will show up automatically when you have two frequency cursors placed.



ID	Parameter	Description
8	Remove all cursors	Tap to remove all power and frequency cursors.
9	Add frequency cursor	Tap to add a cursor measuring horizontal position.
10	Add power cursor	Tap to add a cursor measuring vertical position.

Frequency Cursor

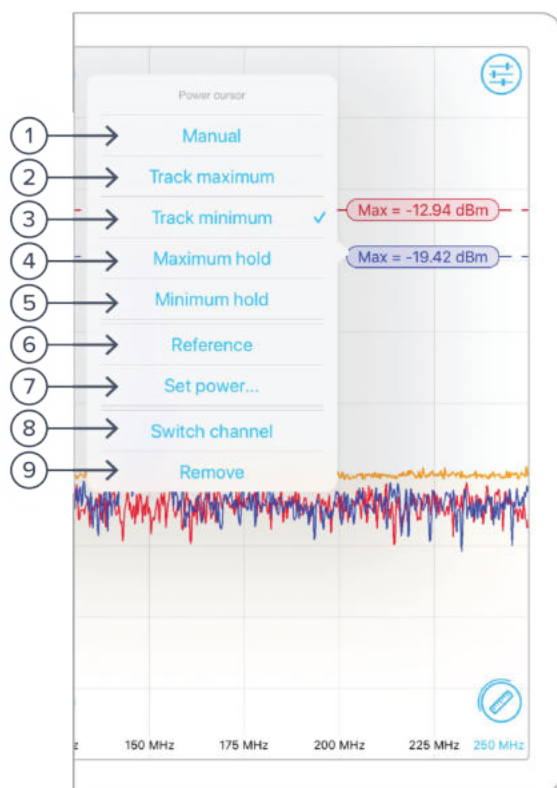
Tap the cursor reading to reveal additional frequency cursor options:



ID	Parameter	Description
1	Set frequency	Tap to position the cursor at the frequency selected.
2	Reference	Tap to set the cursor to act as a horizontal reference value. When this option is selected all other cursors will display the difference between the cursor and the reference cursor's value.
3	Remove	Tap to remove the cursor from display.




Power Cursor



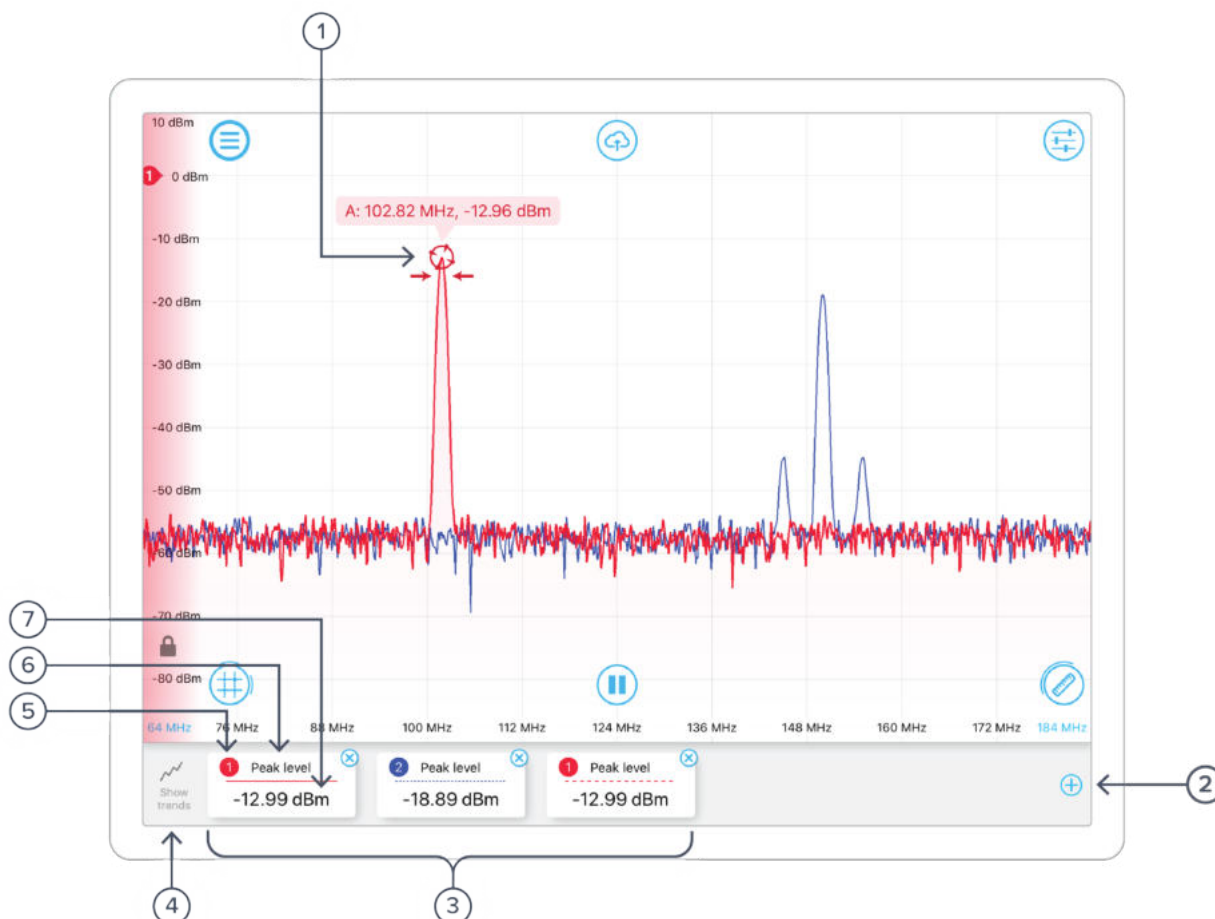
ID	Parameter	Description
1	Manual	Tap to manually set the vertical position of the cursor.
2	Track maximum	Tap to set the cursor to track the maximum power/amplitude.
3	Track minimum	Tap to set the cursor to track the minimum power/amplitude.
4	Maximum hold	Tap to set the cursor to the maximum power/amplitude of previous traces.
5	Minimum hold	Tap to set the cursor to the minimum power/amplitude of previous traces.
6	Reference	Tap to set the cursor to act as a vertical reference value. When this option is selected, all other cursors will display the difference between the cursor and the reference cursor's value.
7	Set power	Tap to set amplitude cursor at specific amplitude.
8	Switch channel	Tap to change the channel that the cursor measures.
9	Remove	Tap to remove the selected cursor.



Measurements

The **measurements** can be accessed by pressing the  icon, allowing you to add/remove measurements to probe a spectra's peak level, peak frequency, power, etc. The measurement function operates on a per channel or per markers basis.

User Interface



ID Description


- | ID | Description |
|----|--|
| 1 | Measurement marker, tap to reveal additional options. |
| 2 | Tap to add measurements. |
| 3 | List of current measurement cards, tap to reveal additional options. |
| 4 | Tap to show measurements trends. |
| 5 | Source channel. |
| 6 | Measurement type. |
| 7 | Measurement reading. |

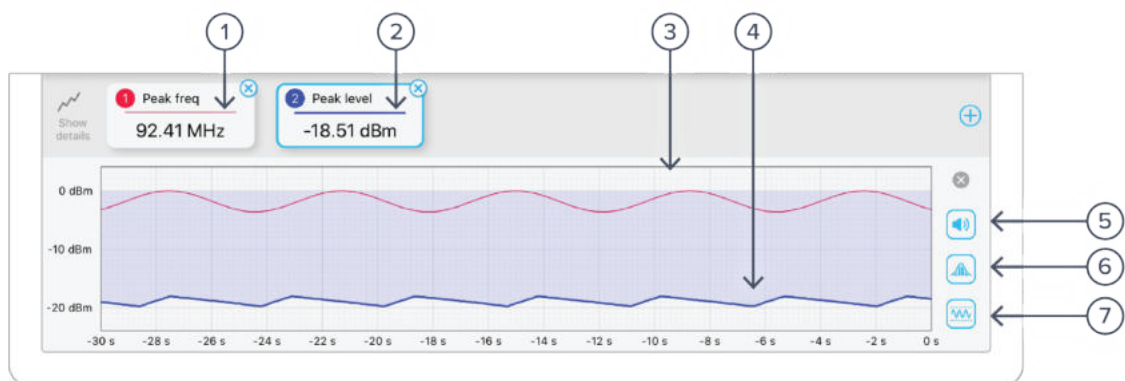


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Note that measurement markers can be added by dragging the measurement icon  to snap on the input signal. In addition, a plot of measurements vs. time can be accessed by tapping the “show trends” button.



ID Description

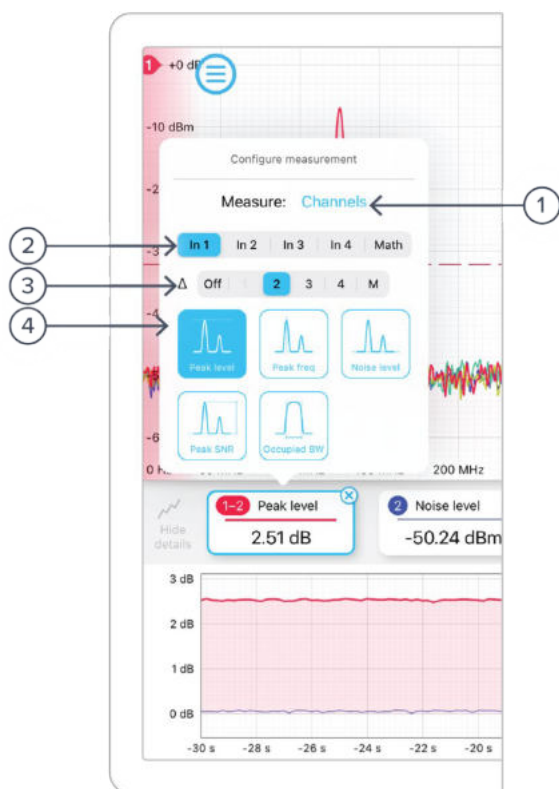
- | | |
|---|--|
| 1 | Trend line style for tile 1. |
| 2 | Trend line style for tile 2. |
| 3 | Trend line for tile 1. |
| 4 | Trend line for tile 2. |
| 5 | Tap to enable/disable audio. |
| 6 | Tap to enable/disable statistics. |
| 7 | Tap to enable/disable adjusted Y-axis scale. |



Measurement Tile Options

Measurement tile options can be revealed by simply tapping the tile. Users can select to measure peak level, peak frequency, noise level, peak signal-to-noise ratio (peak SNR), and occupied bandwidth (occupied BW) of a selected channel/marker.

Options for measurements from channels

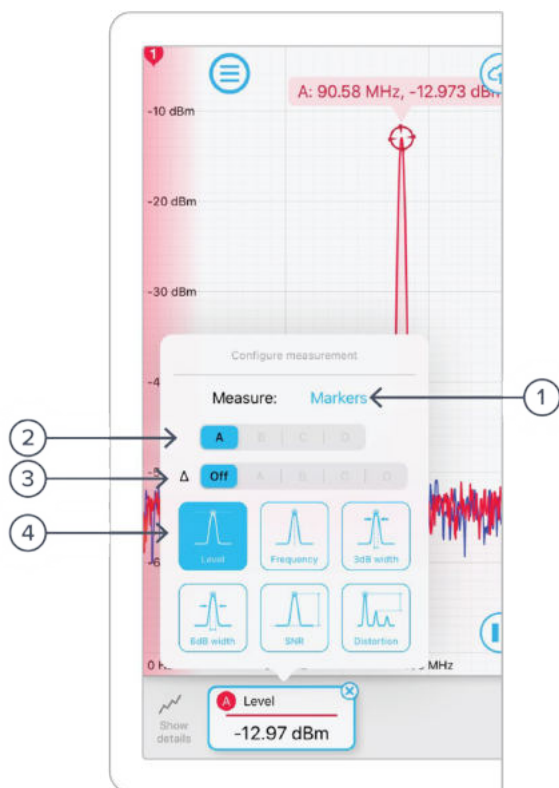


ID Description

- | ID | Description |
|----|---|
| 1 | Tap to switch to measurements from markers. |
| 2 | Tap to select measurement source. |
| 3 | Tap to measure the difference channels |
| 4 | Tap to select measurement type. |



Options for measurements from markers



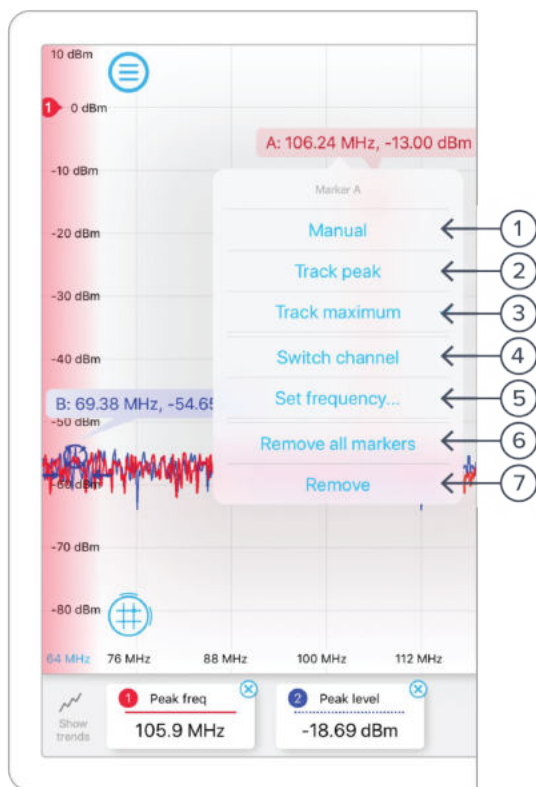
ID Description

- | ID | Description |
|----|--|
| 1 | Tap to switch to measurements from channel. |
| 2 | Tap to select measurement source. |
| 3 | Tap to measure the difference between markers. |
| 4 | Tap to select measurement type. |



Measurement Marker Options

Measurement marker options can be revealed by simply tapping the markers. Users can select to set the marker to track the peak, track the maximum, and other options.



ID	Parameter	Description
1	Manual	Tap to set marker position manually.
2	Track peak	Tap to set marker to the frequency of the closest peak / spur.
3	Track maximum	Tap to set marker to the frequency of the maximum power. The marker is updated in real-time.
4	Switch channel	Tap to switch the channel that the marker measures.
5	Set frequency	Tap to set the marker to measure the amplitude of a particular frequency.
6	Remove all markers	Tap to remove all active markers.
7	Remove	Tap to remove currently selected marker.



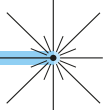
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Waveform Generator

Moku:Pro User Manual

Moku:Pro's Waveform Generator is designed to generate common signals with high accuracy and configurability across four independent output channels. The outputs are precisely adjustable for frequency, phase and amplitude. Further, the outputs may be modulated with a variety of internally generated or external signals and there are flexible, programmable triggers.





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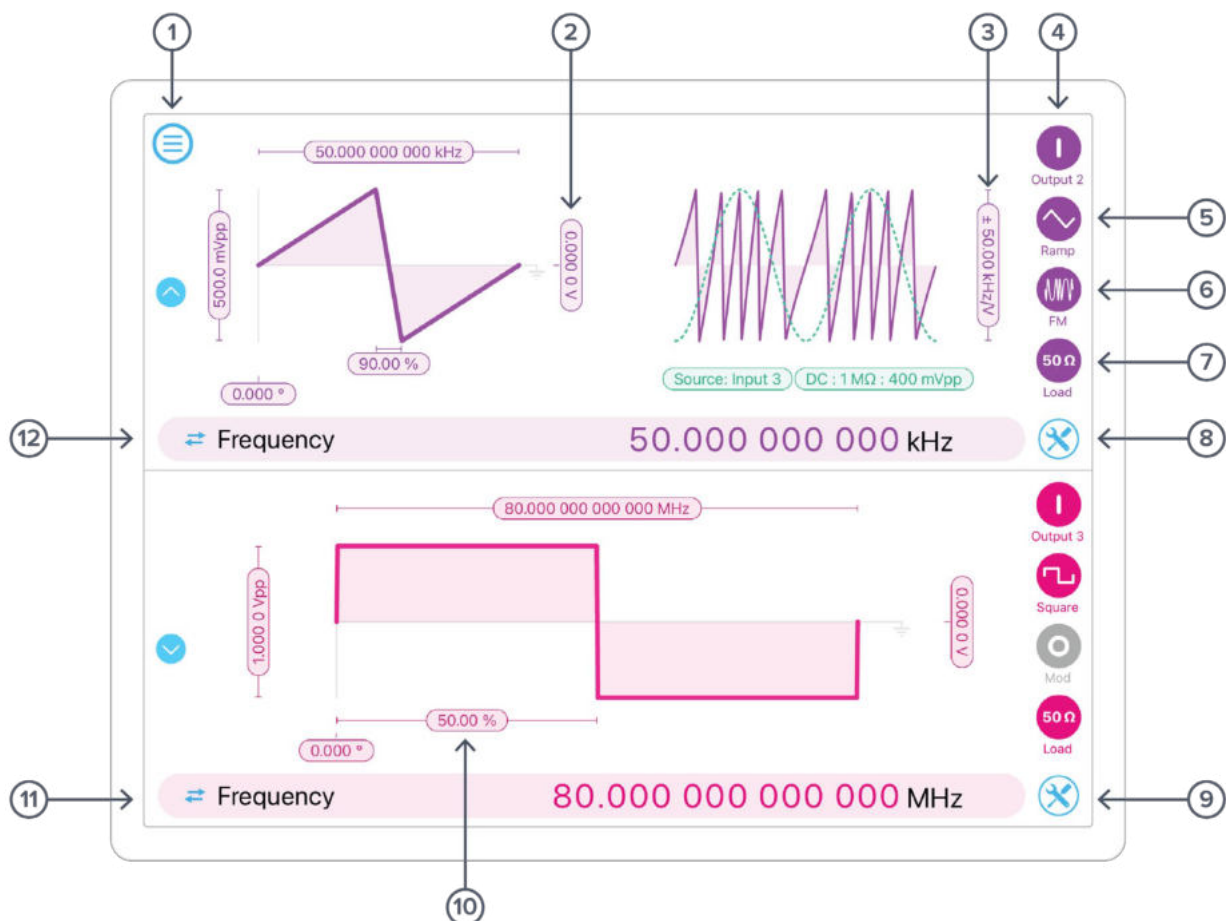
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User Interface

Moku:Pro is equipped with four outputs channels. You can tap the or icons to navigate between channels.

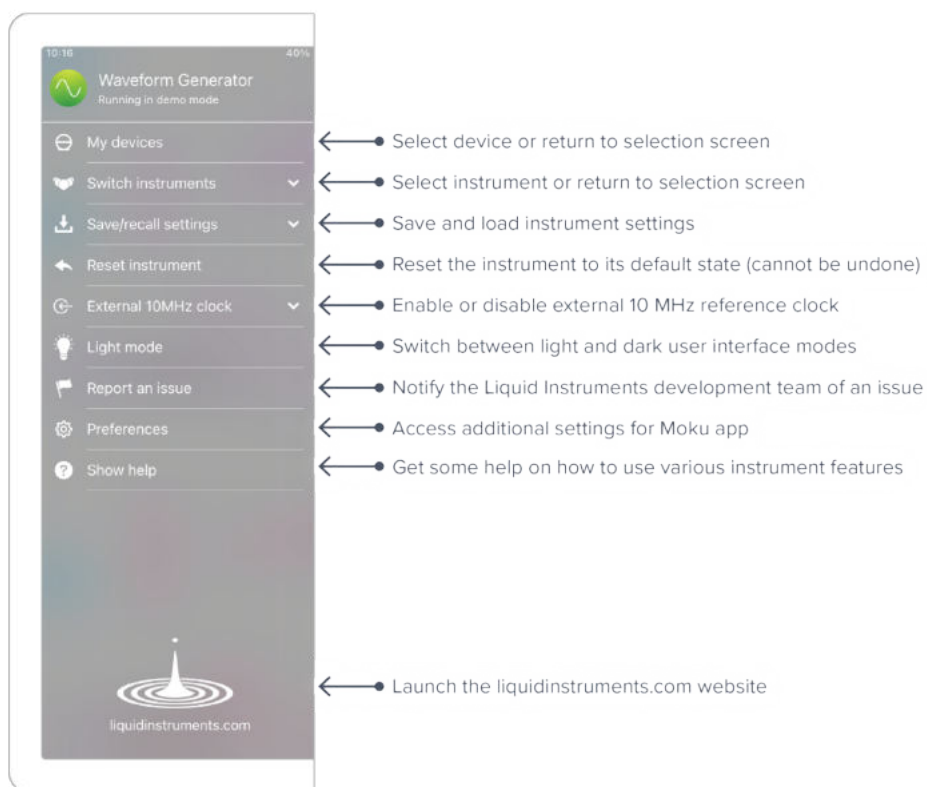


ID	Description	ID	Description
1	Main menu	7	Configure output load (50 Ω or 1 MΩ)
2	Configure offset	8	Settings (Ch 2)
3	Configure modulation depth	9	Settings (Ch 3)
4	Enable / disable output	10	Configure square duty cycle
5	Waveform shape	11	Switch between frequency and period
6	Configure modulation	12	Switch between frequency and period



Main Menu

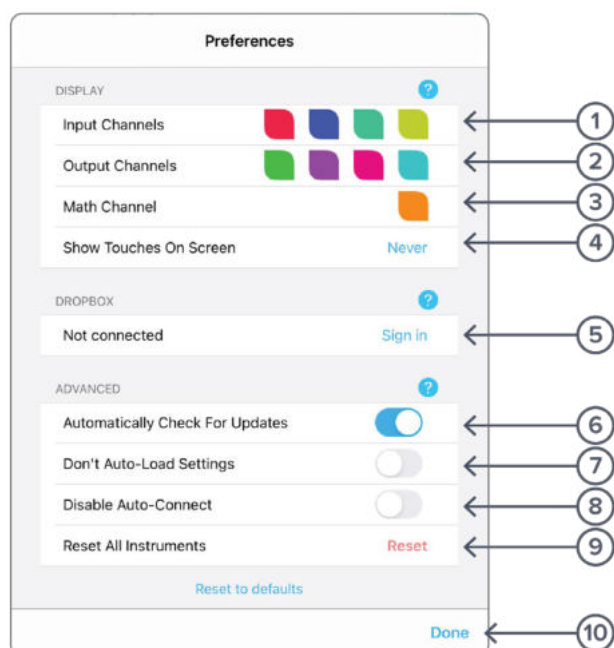
The main menu can be accessed by pressing the  icon, allowing you to:





Preferences

The preferences pane can be accessed via the main menu. In here, you can reassign the color representations for each channel, connect to Dropbox, etc. Throughout the manual, the default colors (shown in the figure below) are used to present instrument features.



ID Description

- | | |
|----|--|
| 1 | Tap to change the color associated with input channels. |
| 2 | Tap to change the color associated with output channels. |
| 3 | Tap to change the color associated with math channel. |
| 4 | Indicate touch points on the screen with circles. This can be useful for demonstrations. |
| 5 | Change the currently linked Dropbox account to which data can be uploaded. |
| 6 | Notify when a new version of the app is available. |
| 7 | Moku:Pro automatically saves instrument settings when exiting the app, and restores them again at launch. When disabled, all settings will be reset to defaults on launch. |
| 8 | Moku:Pro can remember the last used instrument and automatically reconnect to it at launch. When disabled, you will need to manually connect every time. |
| 9 | Reset all instruments to their default state. |
| 10 | Save and apply settings. |




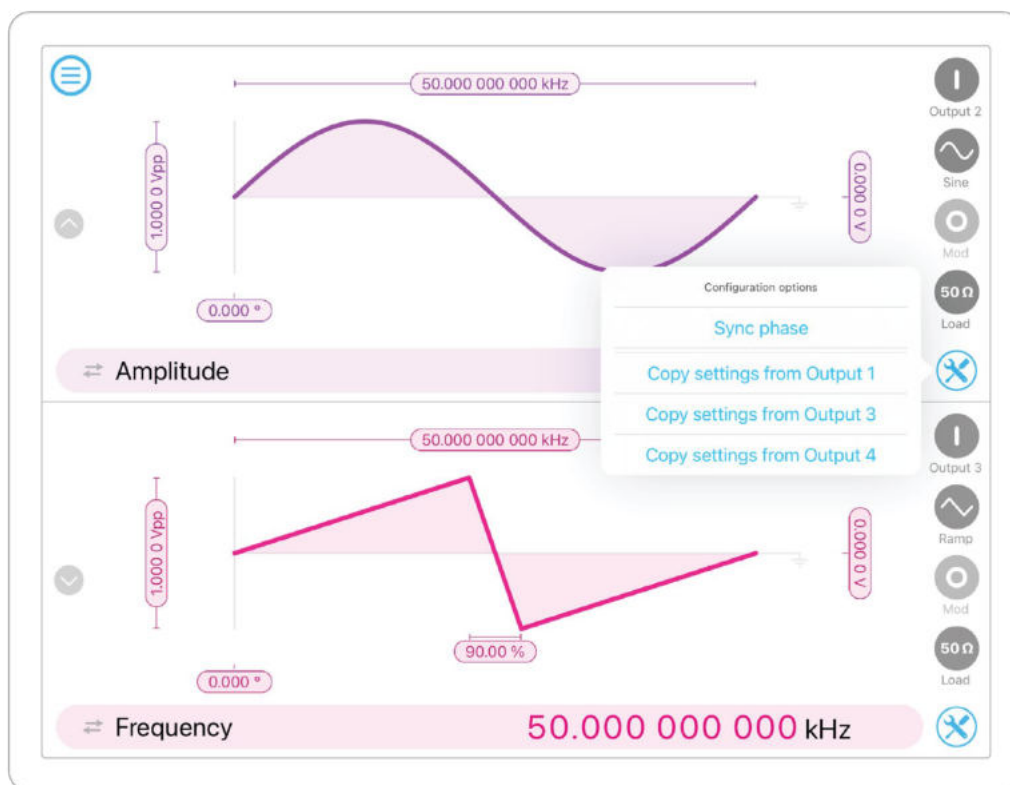
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Settings

The settings menu can be accessed by tapping the  icon, allowing the settings on other channels to be instantly applied to channel this channel. The output phase can be synced by tapping [sync phase](#).





Output Configuration

Enable / Disable Outputs



shows the output channel is disabled, tap to enable



shows the output channel is enabled, tap to disable

Impedance

Moku:Pro's outputs have an impedance of $50\ \Omega$. As such, voltages supplied to a $50\ \Omega$ load will be reduced by a factor of two due to the voltage divider formed by the closed circuit. Changing the load impedance on the user interface does not affect the actual output voltage. Instead, it scales the voltage displayed on the screen corresponding to the output load.

Waveform types

Each channel can be set to generate one of five predefined waveforms.



Sine



Square



Ramp



Pulse



DC

Each of Sine, Square and Ramp can be configured for Frequency, Amplitude, Offset and Phase.

The Square wave is low jitter and symmetric (50% duty cycle by default)

The Ramp type has a variable symmetry setting, while the Pulse provides a highly configurable square wave with variable duty and slew rate.

The DC setting provides an accurate and stable voltage reference.

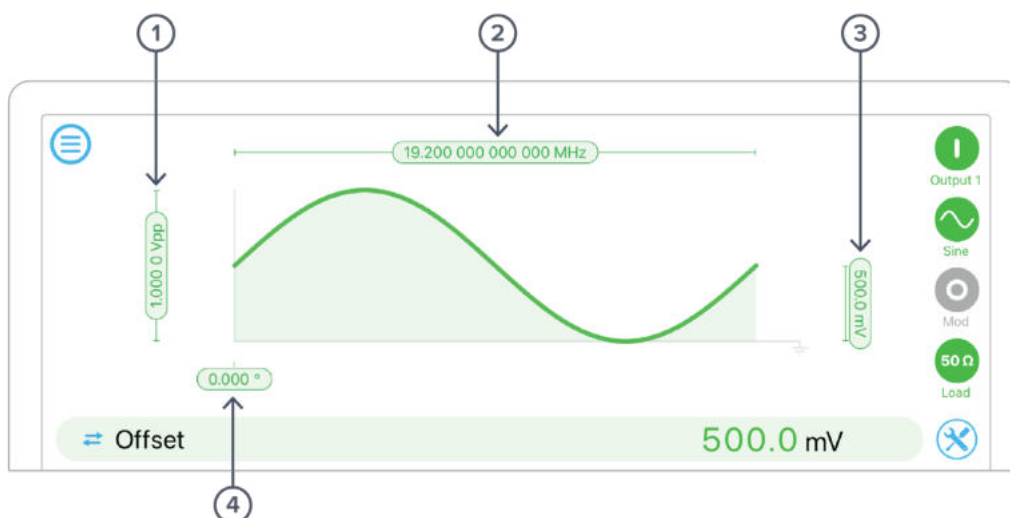


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Sine Wave

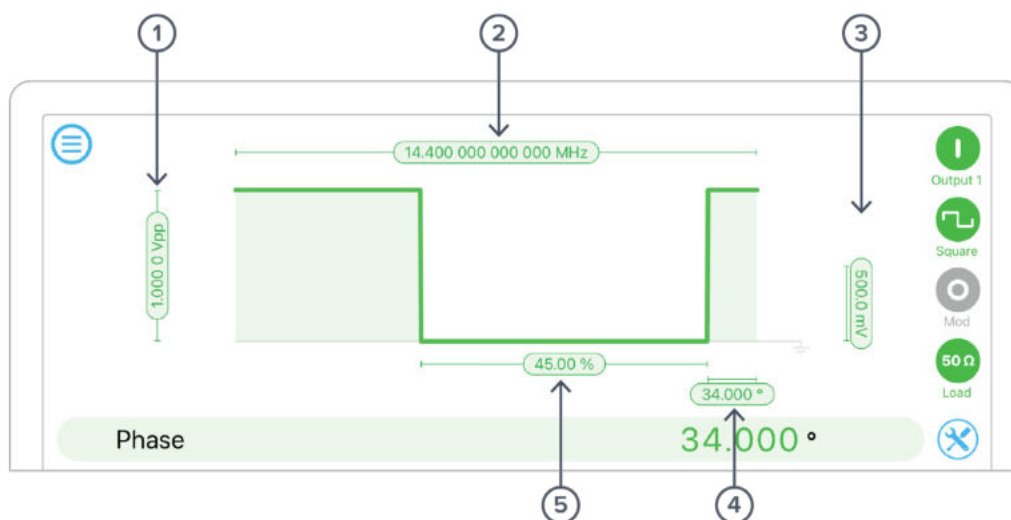


ID	Description	ID	Description
1	Amplitude (High Level)	3	Offset (Low Level)
2	Signal Frequency (Period)	4	Phase

Tap Parameter Settings pill or bar to change. Parameter bar can show different representations of many parameters; these alternative representations are shown in brackets and revealed in the UI by tapping the 'left right' icon.



Square Wave

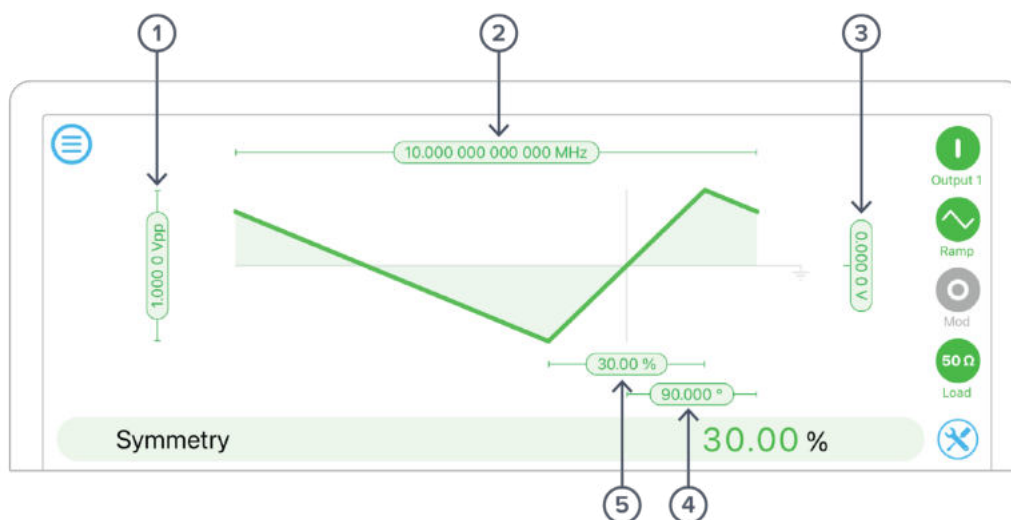


ID	Description	ID	Description
1	Amplitude (High Level)	4	Phase
2	Signal Frequency (Period)	5	Duty Cycle
3	Offset (Low Level)		

Tap Parameter Settings pill or bar to change. Parameter bar can show different representations of many parameters; these alternative representations are shown in brackets and revealed in the UI by tapping the 'left right' icon.



Ramp Wave

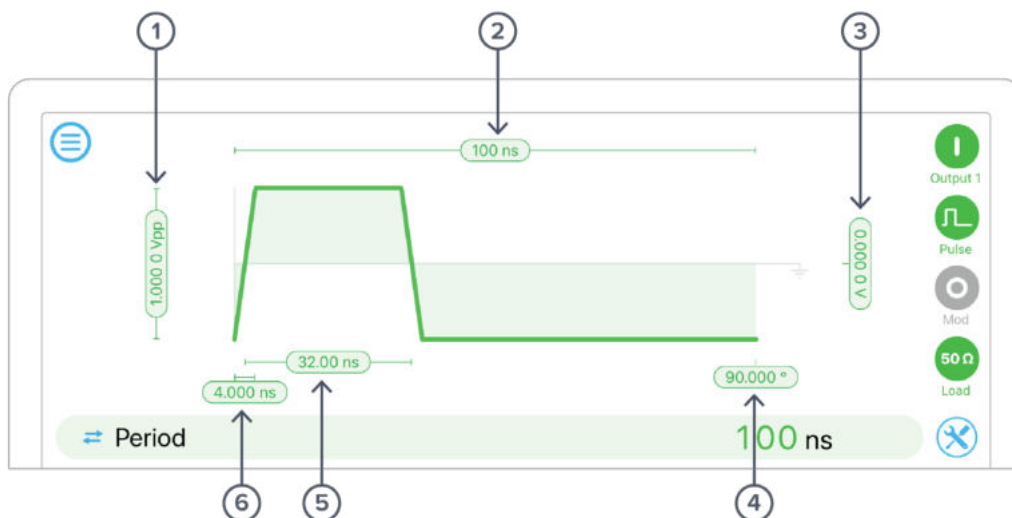


ID	Description	ID	Description
1	Amplitude (High Level)	4	Phase
2	Signal Frequency (Period)	5	Symmetry
3	Offset (Low Level)		

Tap Parameter Settings pill or bar to change. Parameter bar can show different representations of many parameters; these alternative representations are shown in brackets and revealed in the UI by tapping the 'left right' icon.



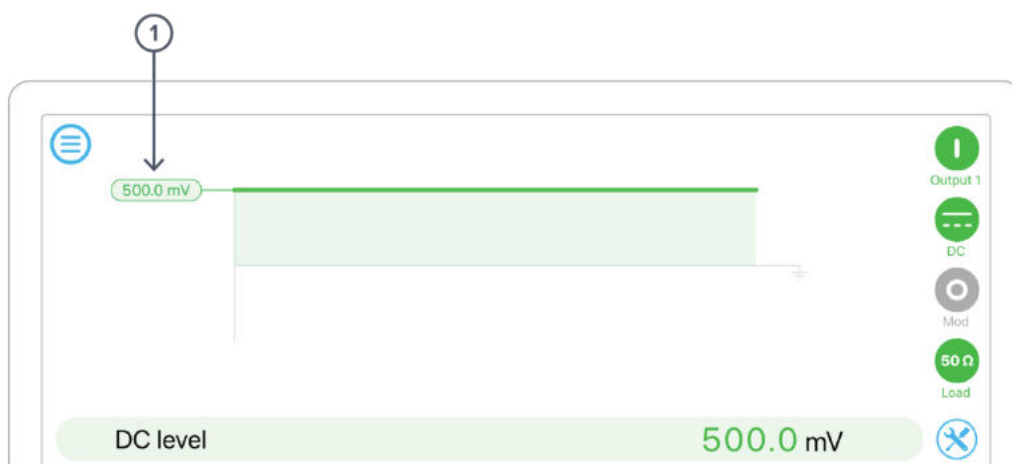
Pulse Wave



ID	Description	ID	Description
1	Amplitude (High Level)	4	Phase
2	Signal Frequency (Period)	5	Pulse Width
3	Offset (Low Level)	6	Edge time

Tap Parameter Settings pill or bar to change. Parameter bar can show different representations of many parameters; these alternative representations are shown in brackets and revealed in the UI by tapping the 'left right' icon.

DC wave



ID	Description
1	DC level

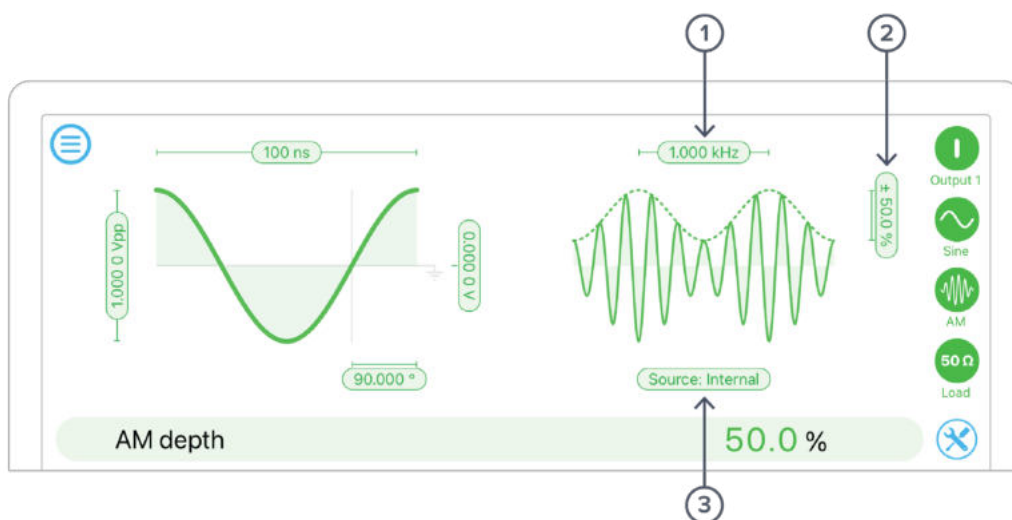
Tap Parameter Settings pill or bar to change.



Modulation types

Moku:Pro's Waveform Generator supports a variety of modulations. Modulation is available on all waveforms except DC. Ramp waveforms can only be amplitude modulated; but all other waveforms can be Amplitude, Frequency or Phase modulated and can be continuous or triggered in burst or sweep modes.

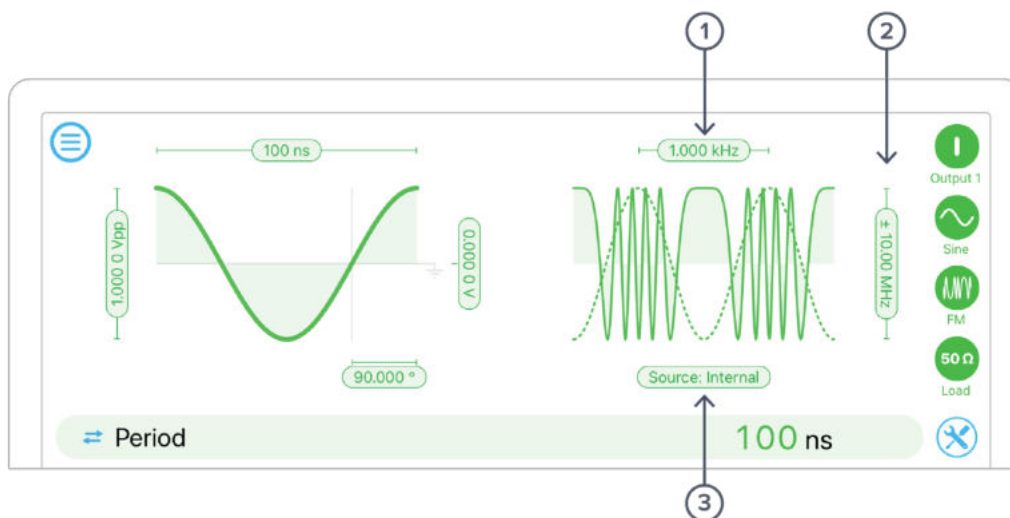
Amplitude modulation



ID	Parameter	Description
1	Frequency	Only for “Internal” modulation; the frequency of the sine wave being used for modulation.
2	AM Depth	Fractional depth of modulation. 100% depth will reduce the signal amplitude to zero for a full-range negative modulation signal
3	Modulation Source	The modulation source can be a Moku:Pro input; the another Moku:Pro output or “internal”, an internally-generated sinewave.



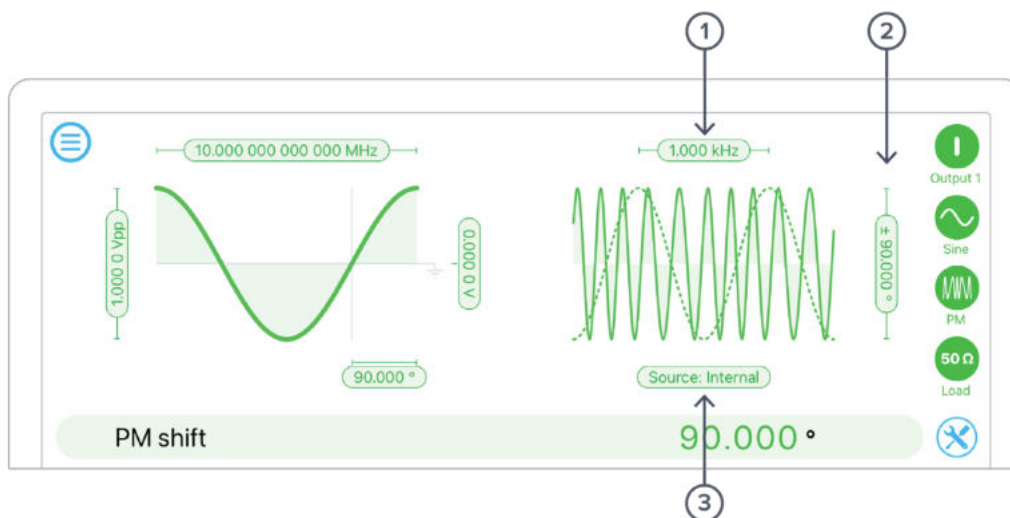
Frequency modulation



ID	Parameter	Description
1	Frequency	Only for “Internal” modulation; the frequency of the sine wave being used for modulation.
2	FM Deviation	Full-range frequency deviation. A full-range input signal will vary the output frequency by this amount.
3	Modulation Source	The modulation source can be a Moku:Pro input; the another Moku:Pro output or “internal”, an internally-generated sinewave.



Phase modulation



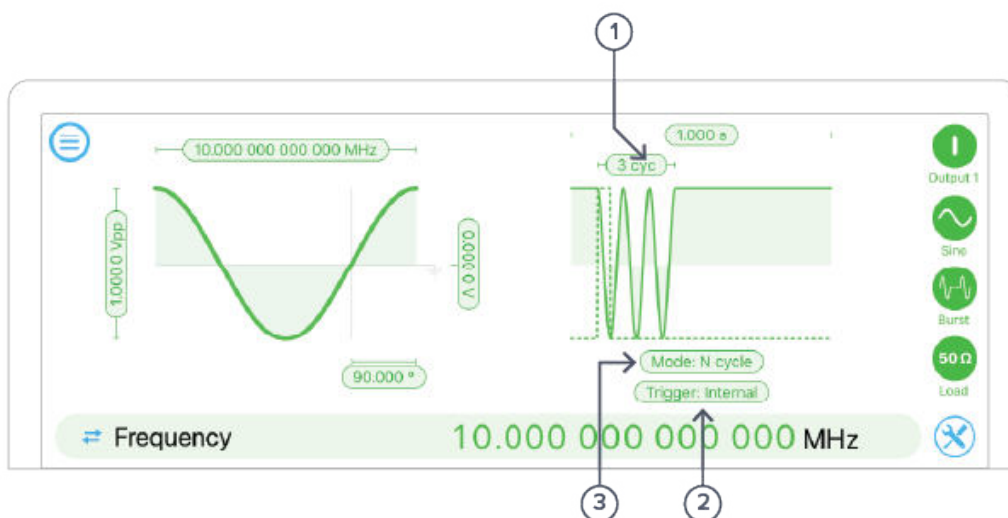
ID	Parameter	Description
1	Frequency	Only for “Internal” modulation; the frequency of the sine wave being used for modulation.
2	Depth	Full-range phase deviation. A full-range input signal will vary the output phase by this amount.
3	Modulation Source	The modulation source can be a Moku:Pro input; the another Moku:Pro output or a “internal”, internally-generated sinewave.



Triggered modulation modes

Sine, Square and Pulse waves can be triggered from an external source. The behaviour upon receipt of the trigger signal varies according to mode.

Burst



ID	Parameter	Description
1	Cycle count	N - Cycle mode only. The number of cycles to generate.
2	Trigger source	One of: Internal: Trigger automatically at the defined rate External: Trigger event on from rear-panel external trigger input Input: Trigger from associated input channel, at given voltage Output: Trigger from another output channel, at given voltage
3	Mode	One of: Gated: Continue to generate the output signal while ever the trigger event is asserted (level-triggered) Start: Begin generation of the waveform on trigger, continue indefinitely. N Cycle: Upon receipt of trigger signal, generate this many cycles of the waveform then re-arm.



Instrument Reference

Waveform Types

The Moku:Pro's waveform generator is programmed to generate one of five different signals, each with optional modulation.

Sine Wave

The Sine wave is the simplest dynamic signal in the Moku:Pro. It features extremely low harmonic distortion; it's very close to a pure single frequency.

The Sine wave can be modulated by all available modulation types. Moreover, it forms the basis of the "Internal" selectable modulation source, providing a modulating waveform regardless of whether any channel of the Moku:Pro is currently outputting a Sine wave.

Square Wave

The Square wave is a low-jitter waveform with fixed 50% duty cycle and high slew rates. The high analogue bandwidth of the Moku:Pro gives very sharp rise and fall times, highly desirable in many applications. If you require slew-rate limits or variable duty cycle in your application, see Pulse Wave below.

Ramp Wave

The Ramp wave consists of linear ramps from low level to high and back again. The ratio between the time spent rising and the overall period is referred to as the symmetry. If you require configurable dwell times at the high or low levels but common rise and fall times, you may use the Pulse Wave with large edge times.

Pulse Wave

The Pulse wave is like the Square wave but has configurable duty cycle and edge times (rise and fall time). The trade-off is that at high frequency, Pulse has slightly worse edge jitter behaviour compared to the Square wave.

DC

Provides a high precision, fixed reference voltage at the output. Note that the outputs are always 50Ω terminated.

Waveform Parameters

Amplitude

Applicable To: Sine, Square, Ramp, Pulse

Amplitude is specified as a Peak-to-Peak value; that is, the high level minus the low level. If you wish to specify the high and low levels explicitly, tap the Amplitude pill then the Toggle Arrows in the parameter bar; or just tap the Amplitude label in the Settings Drawer to toggle between the two representations.



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Frequency

Applicable To: Sine, Square, Ramp, Pulse

Specified in Hertz. Can also be represented as period in seconds by tapping the Frequency label in the Settings Drawer, or the Toggle Arrows in the parameter bar.

Offset

Applicable To: Sine, Square, Ramp, Pulse

Average value of the Sine wave over time. The alternative representation of this parameter is Low Level, which combined with High Level also specifies Amplitude.

Phase

Applicable To: Sine, Square, Ramp, Pulse

Defines the phase of the waveform with respect to the Moku:Pro's internal reference. By tapping the "Sync Phase" button in the Settings Drawer, this phase also becomes relative to another output channel.

Symmetry

Applicable To: Ramp

Ratio, in percent, between the time spent on the rising edge and the overall period. In the limit of 0% and 100% symmetry, the ramp wave becomes a sawtooth (zero¹ rise and fall times respectively).

Pulse Width

Applicable To: Pulse

Positive width of the pulse. Any specified Edge Time is split equally between the Pulse Width and the rest of the cycle; that is, duty cycle is preserved when altering Edge Time.

Edge Time

Applicable To: Pulse

Time taken to transition from low level to high and vice-versa. This limits the slew rate of the signal which can be advantageous in some applications. Edge Time is split between high and low time equally, preserving duty cycle.

¹ The minimum rise and fall time of the Moku:Pro is actually 2ns not zero, which means in practice that the output can never achieve exactly 0% or 100% symmetry, even if specified.



DC Level

Applicable To: DC

Fixed voltage to output.

Modulation Types and Trigger Modes

Modulation Sources

Each modulation type can be driven by one of three sources.

Internal

Modulation is driven by an internally-generated sine wave of configurable frequency. The amplitude of this wave is “full range”, in that it will modulate to the depth specified when configuring the modulation type.

Input

Modulation for a given channel is driven by the corresponding analogue input (i.e. Output 1 can only be modulated from Input 1, Output 2 from Input 2, Output 3 from Input 3, Output 4 from Input 4). The depth is specified *per volt* on the input.

Output

Modulation for a given channel is driven by the another analog output (i.e. Output 1 is modulated by the waveform on Output 3). This allows the user to doubly-modulate a signal by modulating a signal on one channel, then using that signal to modulate the opposite channel. This can be useful for example when you wish to generate an “ideal” modulated signal on one channel, but then perturb the phase, frequency or amplitude in order to test a system’s response.

Trigger Sources

Burst and Sweep modes depend on the detection of a trigger event. There are three possible sources for this event.

Internal

The trigger event is generated automatically at a given rate (specified period).

External

A rising edge on the back-panel External Trigger Input is used as the trigger source. For trigger level and precision characteristics, refer to the Moku:Pro Technical Specifications available at www.liquidinstruments.com.

Input

The corresponding analog input is monitored for a rising edge past the specified voltage. Output 1 can only be triggered from Input 1; Output 2 from Input 2, Output 3 from Input 3, Output 4 from Input 4.



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Output

The other analog outputs are monitored for a rising edge past the specified voltage. Combined with the fact that that opposite output can in turn be modulated from a variety of sources, this provides extremely flexible control of the trigger period (included for example changing period based on an external voltage).

Amplitude Modulation

Applicable To: Sine, Square, Ramp, Pulse

Amplitude modulation will change the amplitude of the generated signal proportionally to the modulation input. The actual proportion changed is called the modulation depth, the units of which depend on the modulation source (see discussion of sources above).

Frequency Modulation

Applicable To: Sine, Square, Pulse

Frequency modulation will change the frequency of the generated signal proportionally to the modulation input. The change in frequency caused by a given input is called the modulation depth and has units of Hertz or Hertz per Volt depending on the modulation source used.

Phase Modulation

Applicable To: Sine, Square, Pulse

Phase modulation will change the phase of the generated signal proportionally to the modulation input. The change in frequency caused by a given input is called the modulation depth and has units of Degrees or Degrees per Volt depending on the modulation source used.

Burst Mode

Applicable To: Sine, Square, Pulse

In burst mode, a trigger event causes the given output to begin generating its configured waveform. Burst requires you to specify a sub-mode that defines if or when the generation ends.

N-Cycle: The waveform will stop being generated after the specified number of cycles, at which time it will re-arm and become ready to receive a new trigger.

Gated: The waveform will continue to be generated while-ever the trigger signal is high (level-triggered).

Start: The waveform generation begins on a trigger signal but will continue indefinitely.

Sweep Mode

Applicable To: Sine, Square, Pulse

Sweep mode provides a frequency modulation of the input waveform, where the modulation waveform is a ramp wave that begins generation on the detection of a trigger signal. That is, when a trigger is detected, waveform generation will begin at the Start frequency and sweep (or “chirp”) to the End frequency over a given duration.

Sweep mode has three configurable parameters:



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Start Frequency: Initial frequency of the output waveform, immediately on detection of a trigger. Note that in sweep mode, the waveform itself cannot have a frequency set independently; its frequency parameters are completely defined by the sweep.

End Frequency: Final frequency of the output waveform, *duration* sections after the trigger has been detected.

Duration: The time taken to sweep from Start to End frequency. Upon completion of the sweep, the sweep circuit will re-arm and be ready to receive a new trigger input.



Ensure Moku:Pro is fully updated. For the latest information:

www.liquidinstruments.com



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