

Lock-In Amplifier User Manual

Moku:Lab's lock-in amplifier supports dual-phase demodulation (XY/Rθ) from DC to 200 MHz, with more than 120 dB of dynamic reserve. It also features an integrated 2-channel oscilloscope and data logger, enabling you to observe signals at up to 500 MSa/s and log data at up to 1 MSa/s.





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

www.liquidinstruments.com

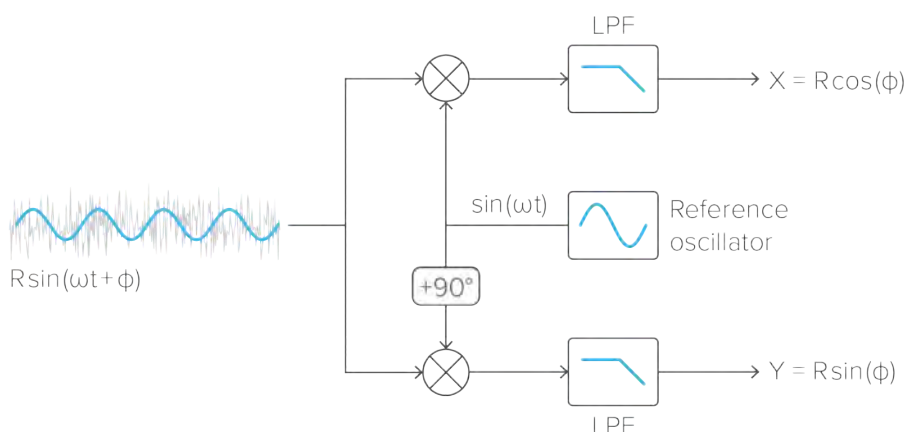


Introduction

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.

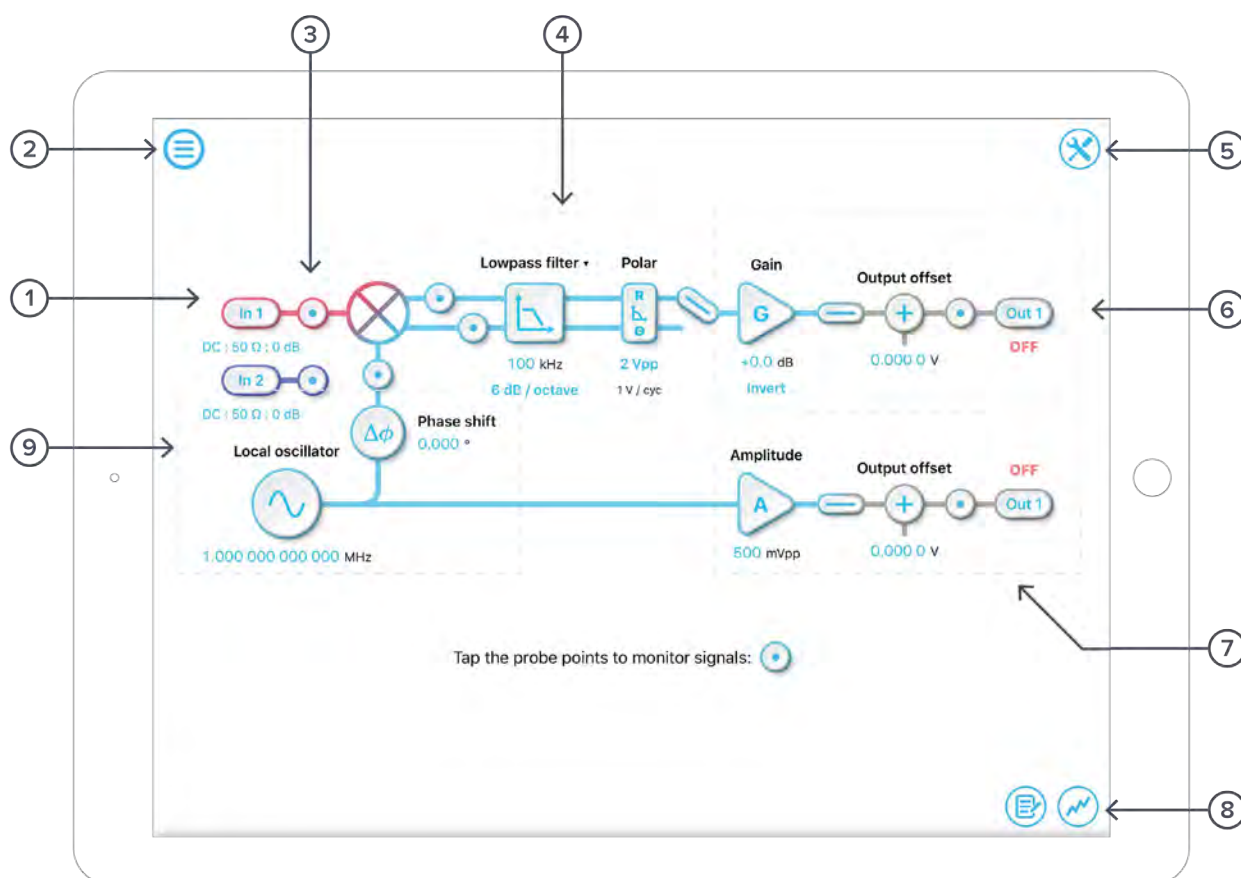
If the input and reference signals have the same frequency ω , then the down-shifted component will appear at DC and its phase will be equal to the difference between that of the input and reference signals, whereas the up-shifted component will appear at twice the input frequency with additive phase.

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

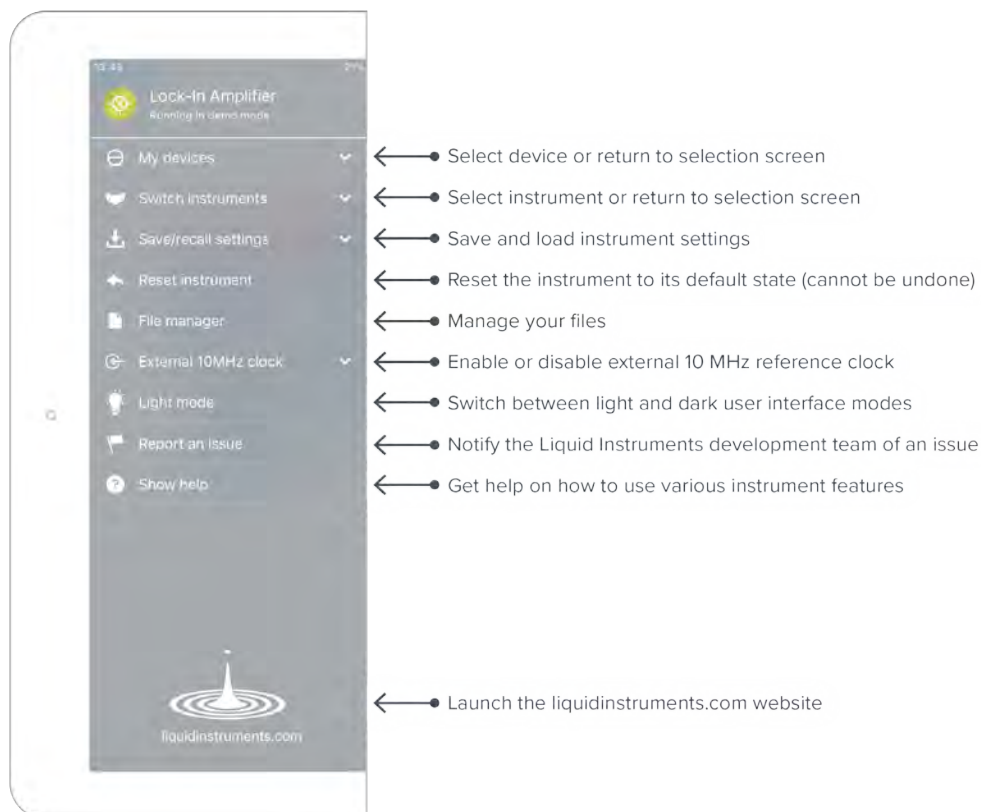


| ID | Description | ID | Description |
|----|-----------------------------|----|--------------------------|
| 1 | Input settings | 6 | Channel 1 output |
| 2 | Main menu | 7 | Channel 2 output |
| 3 | Probe point | 8 | Oscilloscope/Data logger |
| 4 | Filter settings | 9 | Reference oscillator |
| 5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



Main Menu

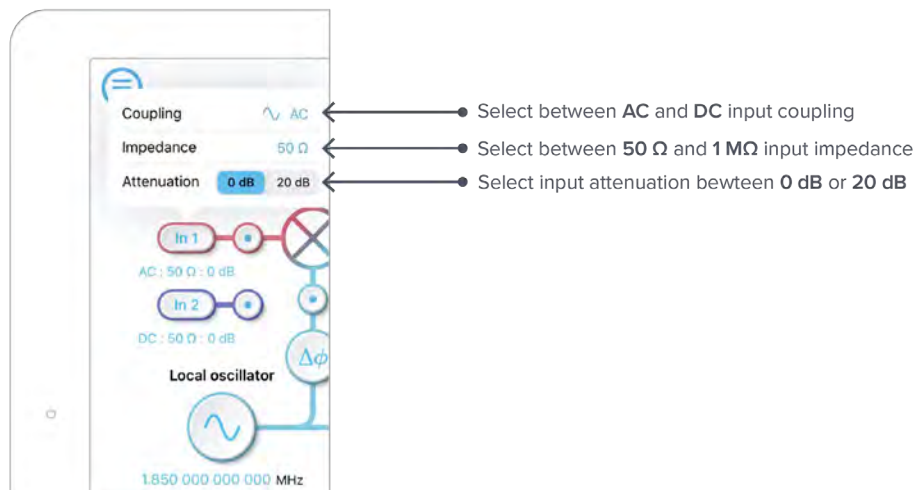
The **main menu** can be accessed by pressing the  icon, allowing you to:





Signal Input

Tap the **In 1** icon to configure the input settings for the signal input.

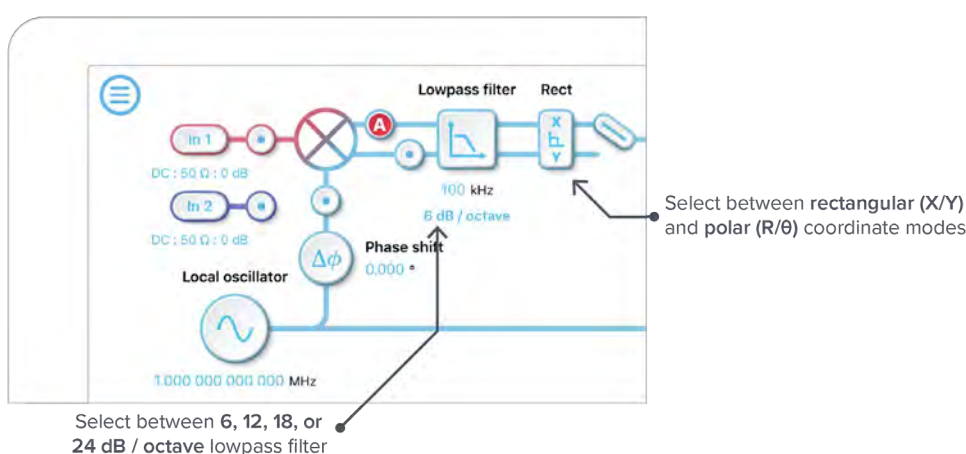




Dual-Phase Demodulator

Moku:Lab'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** lowpass 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 for external references configured in straight-through mode.




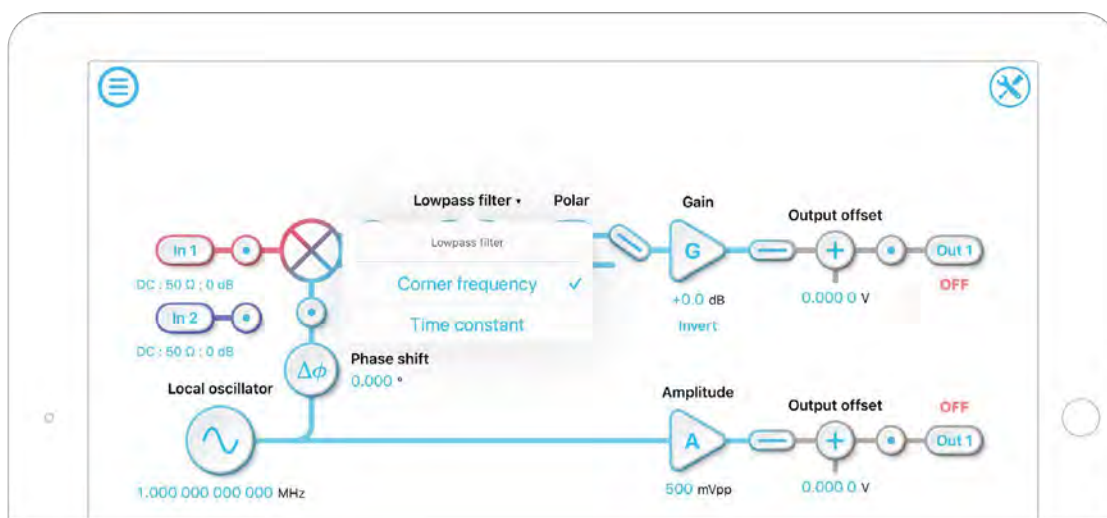
Filter Bandwidth and Time Constant

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

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

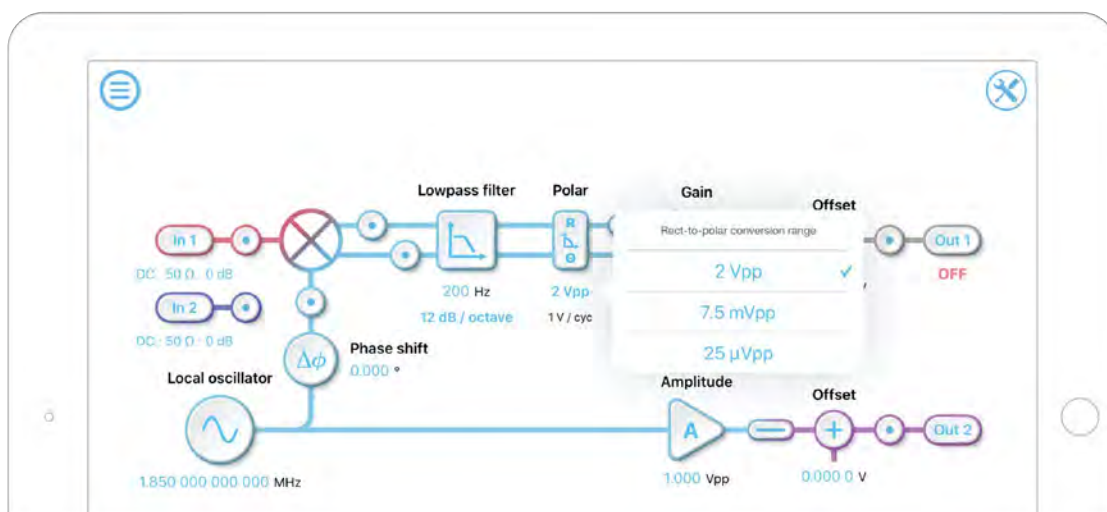


Tap the text above the  icon to switch between filter bandwidth or time constant representation.



Rect-to-polar Conversion Range

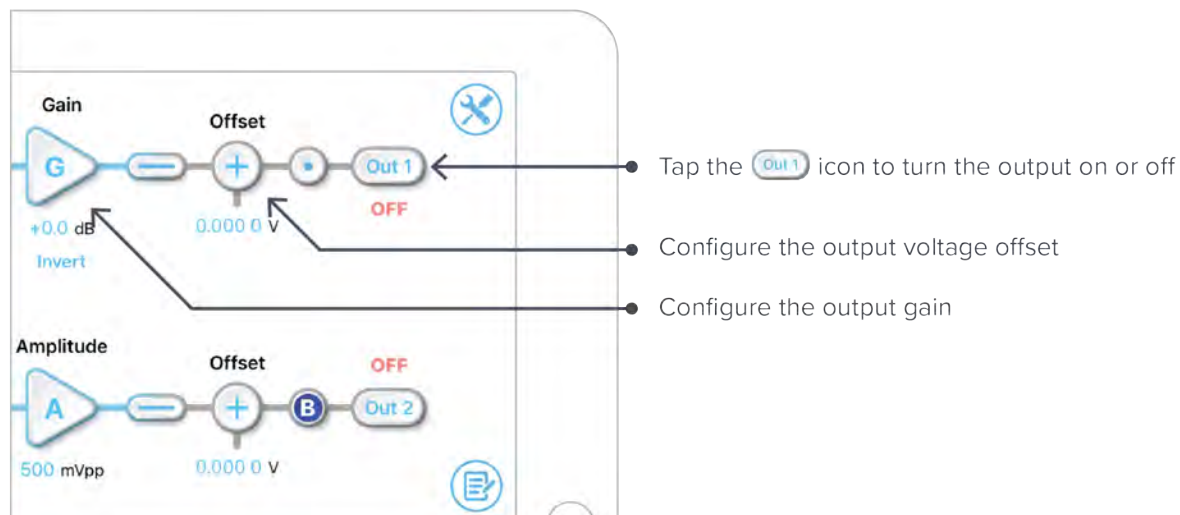
In polar mode, the rectangular-to-polar conversion range allows you to optimize the signal processing for best performance. Three ranges are available: 2 V_{pp}, 7.5 mV_{pp} and 25 μV_{pp}. Optimal performance is achieved by choosing the smallest range which can accommodate your signal without saturating.






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

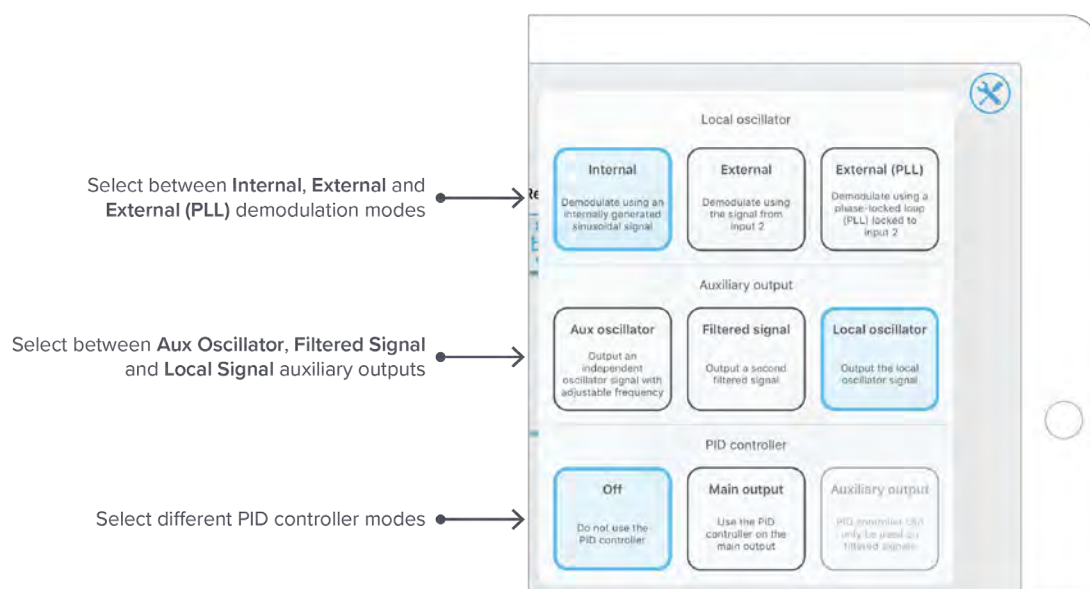




Advanced Configuration

The lock-in amplifier's digital signal processing layout can be rapidly re-configured to suit different applications by accessing the advanced configuration menu using the  icon at the top-right of the block diagram.

- Select between internal, external (straight-through), and external (phase-locked) demodulation references
- 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)
- Select whether to include a PID controller on 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:Lab's internal clock and thus shares the same time-base. The frequency range of the internal reference is 1 MHz to 200 MHz.

To measure the phase of the input signal relative to the reference Moku:Lab's time-base. This can be done in two ways:

1. Using the internal local oscillator to drive the external system
2. Phase-locking Moku:Lab to the external reference using the 10 MHz reference loop

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 mean 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.

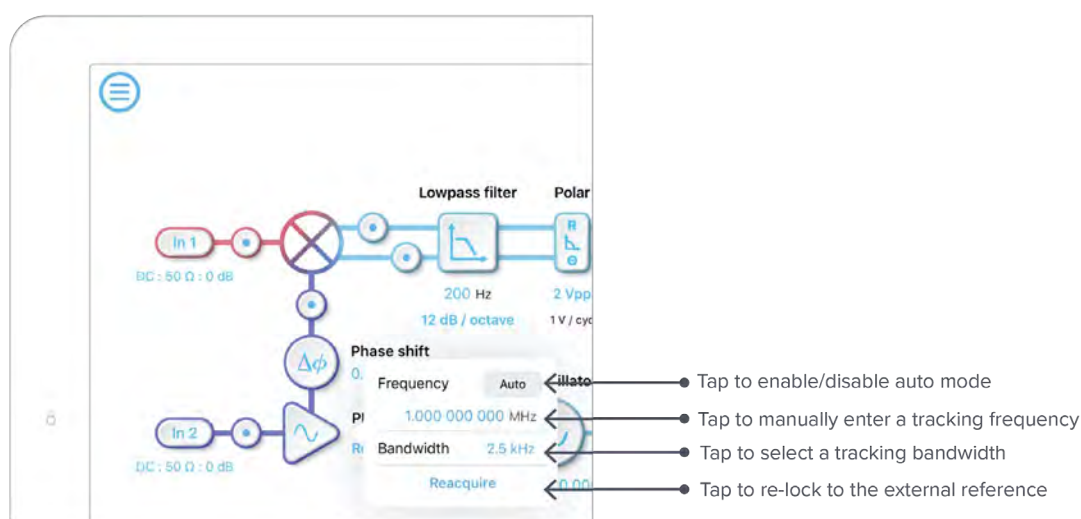


External (PLL)

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 and 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:Lab to share the same time-base 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 200 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.





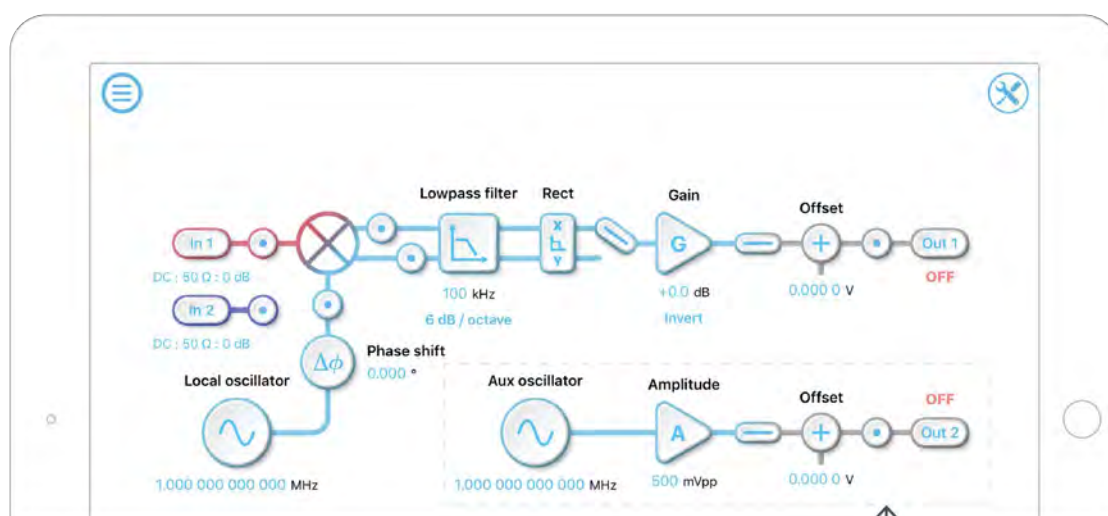
Auxiliary Output

Moku:Lab'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 200 MHz and the amplitude range (amplitude + offset) is $2 V_{pp}$ with 1 mV resolution.

The generated waveform shares the same time-base 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.



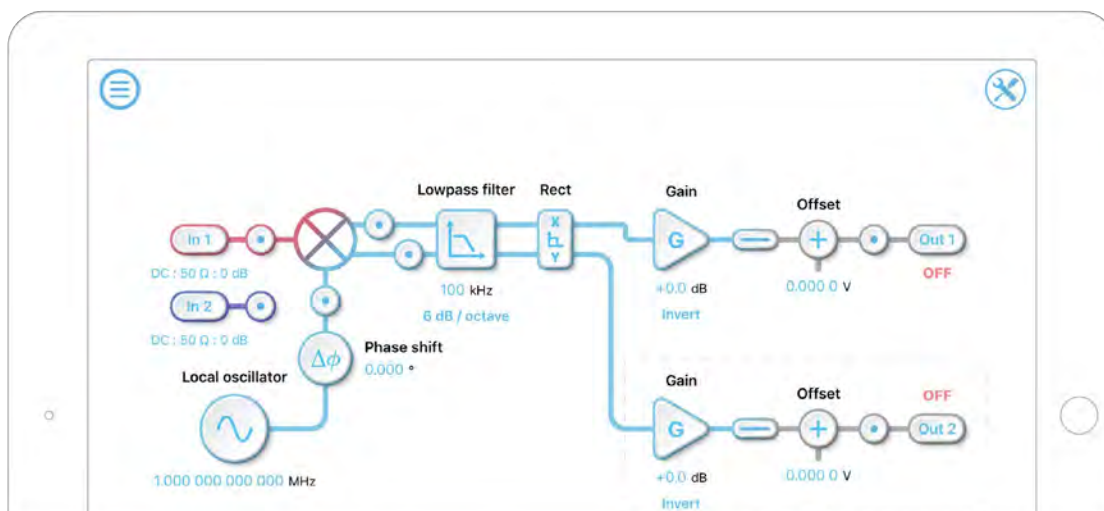
The **aux oscillator** auxiliary output mode allows you to generate a local oscillator signal with independent frequency, amplitude and vertical offset control



Filtered Signal

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

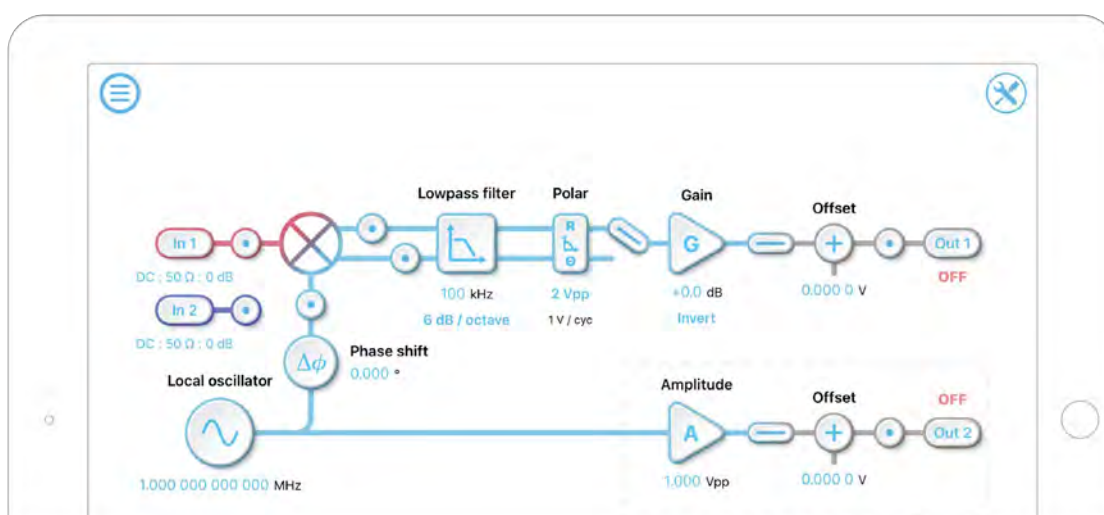
This mode can be used to record both in-phase and quadrature at the same time using probe points.



The **filtered signal** auxiliary output mode generates a second voltage signal proportional to the second lowpass 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:Lab'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.

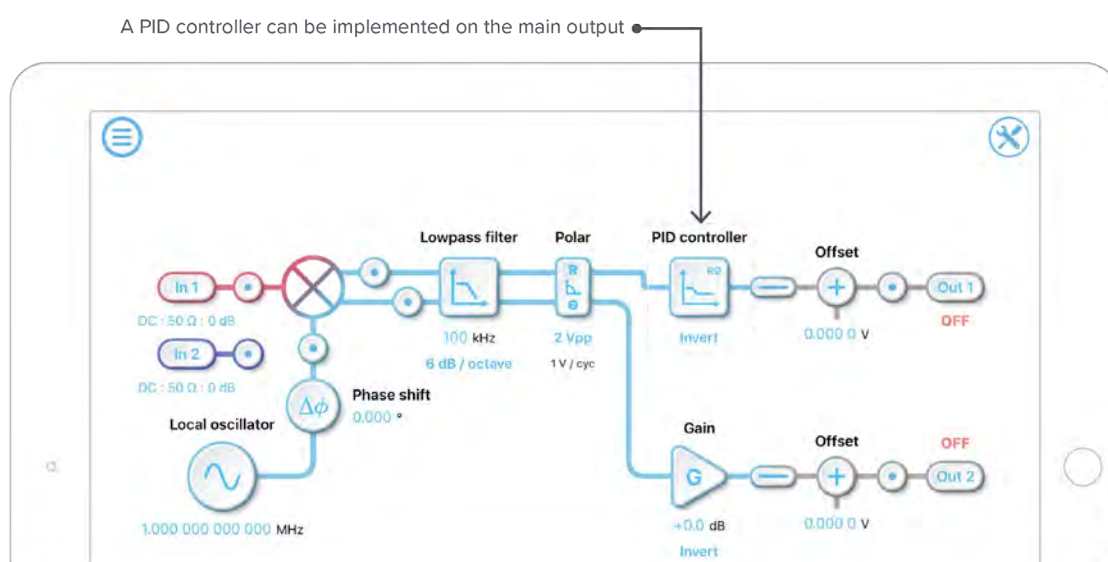
Note: The lock-in amplifier can only implement a single PID controller at a time. This means that when the instrument's auxiliary output is configured to generate a voltage signal proportional to the Y or θ , the PID controller can be used on *either* X/R or Y/θ , but not both.

Off

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

Main Output

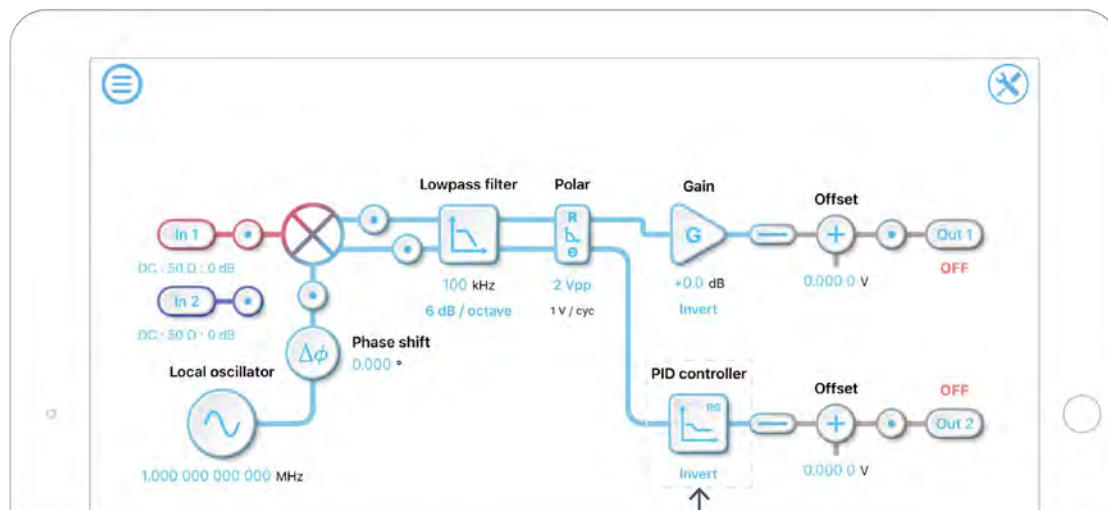
Adds a PID controller to the main output.





Auxiliary Output

Adds a PID controller to the auxiliary output.



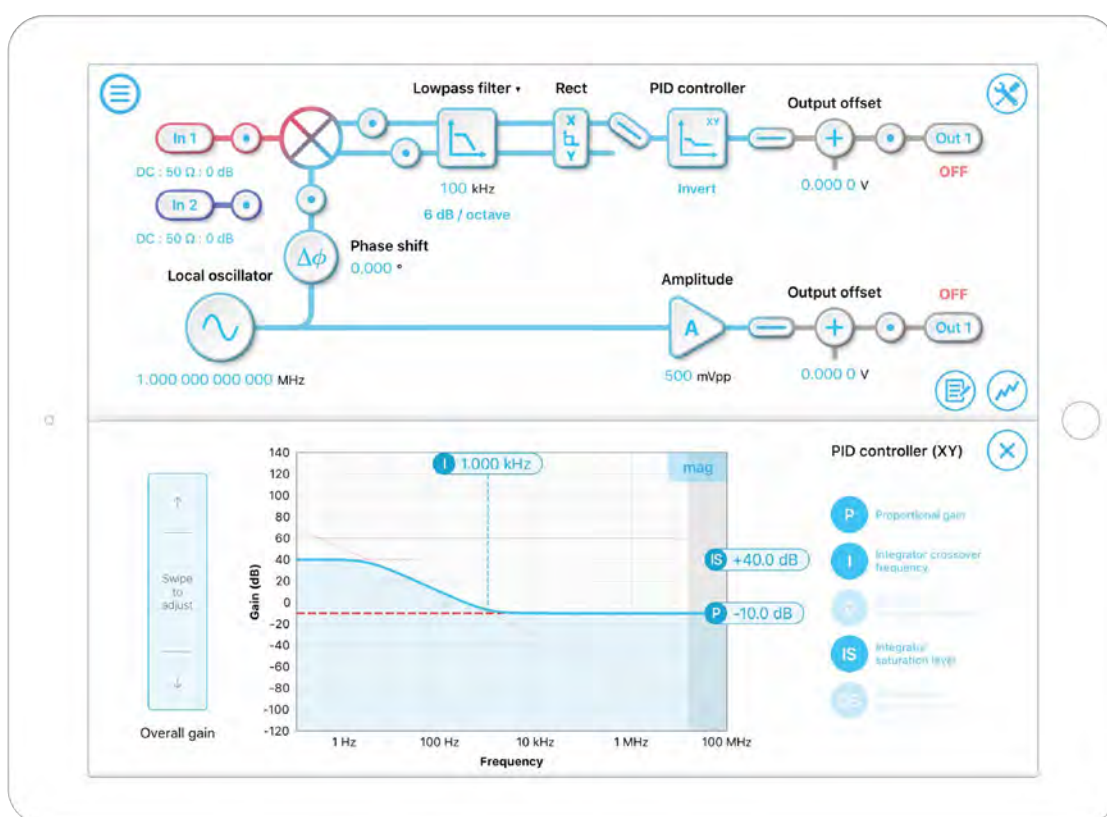
A PID controller can be implemented on the auxiliary output



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.

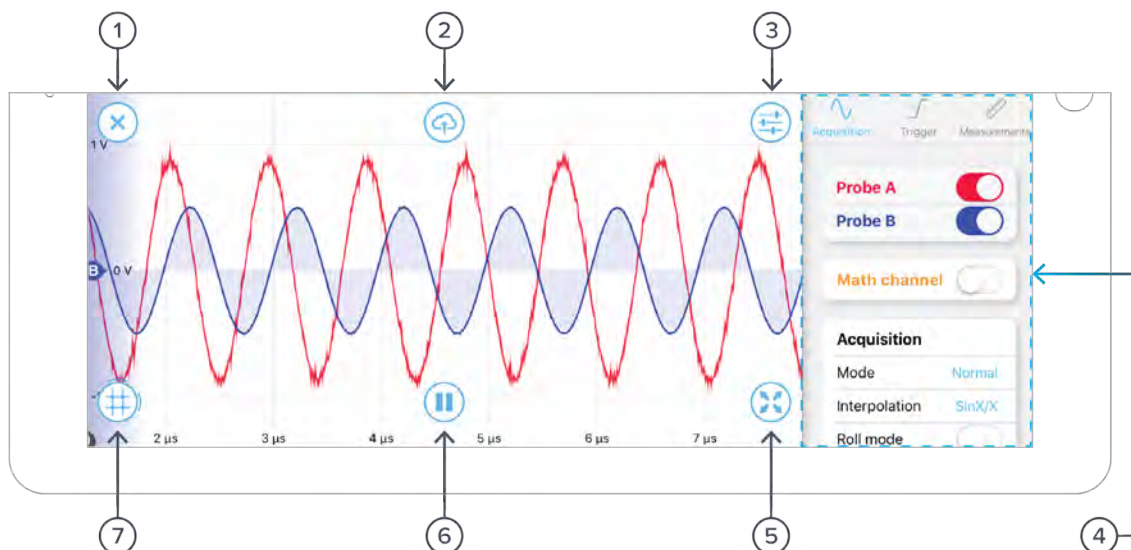
The gain of each control stage can be adjusted using touch gestures on the iPad interface. The following example shows a proportional plus integral controller with a unity gain crossover frequency at 1 kHz. It is possible to maintain this crossover frequency with the proportional gain by using the **Overall 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:Lab's PID Controller Manual.





Oscilloscope

Moku:Lab's Lock-In Amplifier includes a built-in oscilloscope, enabling you to observe and record data of up to two signals in the lock-in amplifier's signal processing chain at a time. More details about the oscilloscope can be found in Moku:Lab Oscilloscope Manual.



| ID | Description |
|----|---|
| 1 | Close oscilloscope graph |
| 2 | Upload saved data |
| 3 | Open / close the measurement configuration menu |
| 4 | Measurement configuration menu |
| 5 | Enter full screen mode |
| 6 | Pause the current trace |
| 7 | Add cursors to the oscilloscope window |

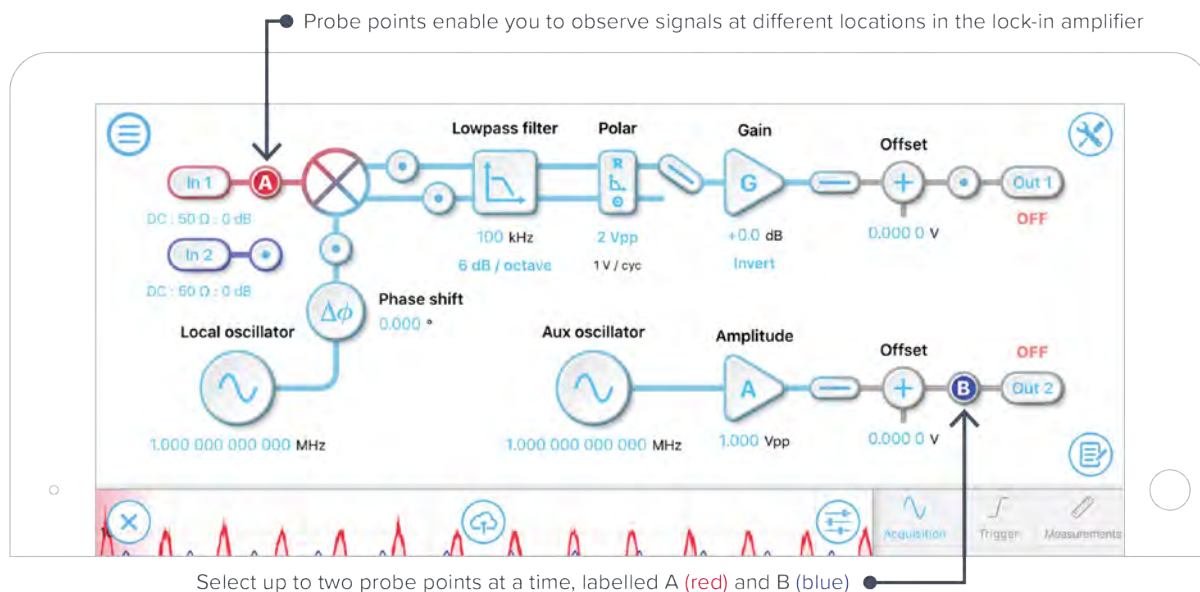
The oscilloscope will appear automatically when a probe point  is activated.

You can hide the oscilloscope by pressing the  icon and reveal it by pressing the  icon.



Probe Points

Add probe points  to view signals at different locations in the digital signal processing chain.



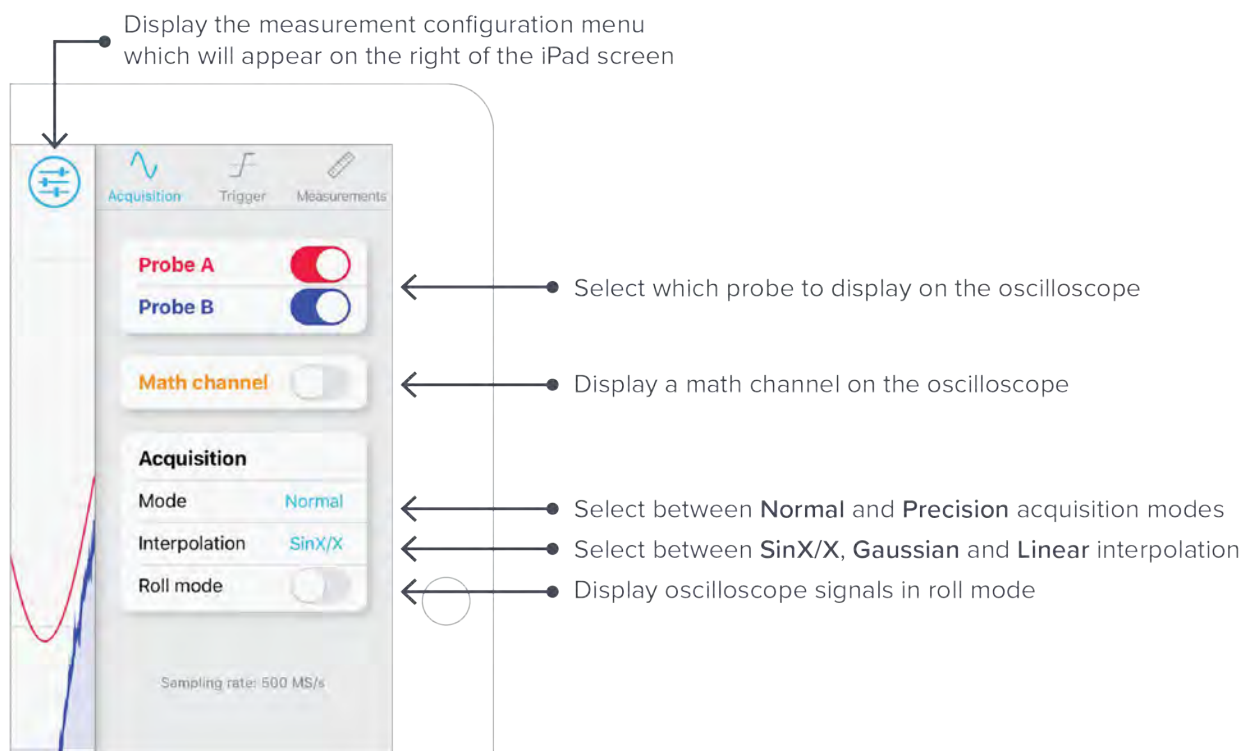


Measurement Configuration

The measurement configuration menu allows you to configure the oscilloscope's acquisition, trigger, and measurement settings.

Access the measurement configuration menu by pressing the  icon.

Acquisition



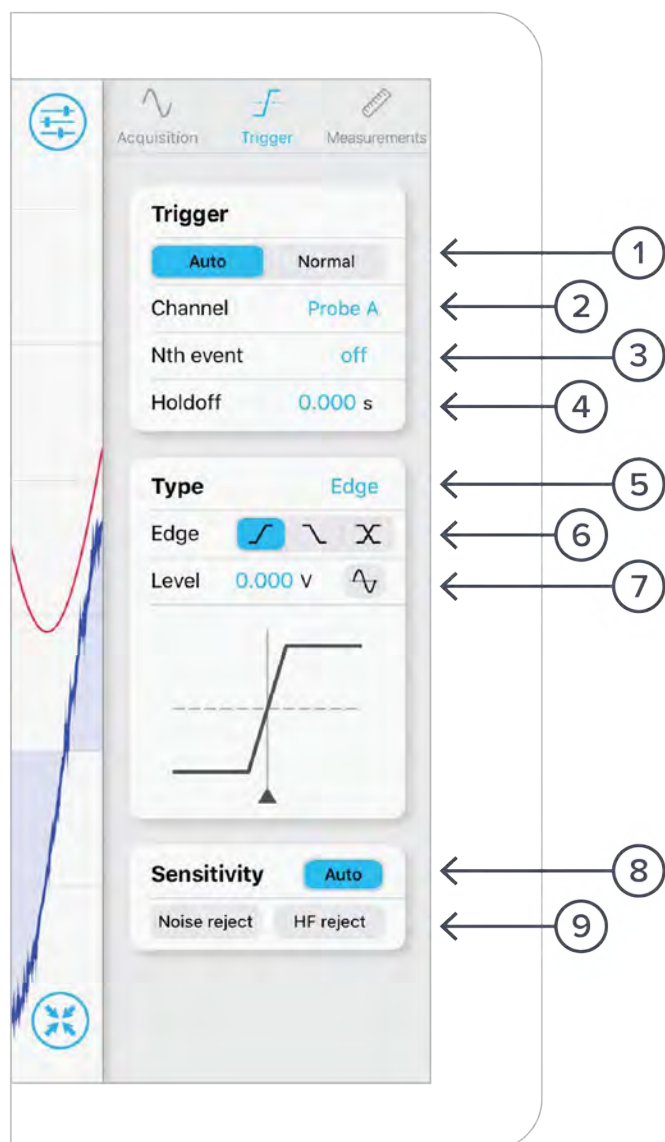
| ID | Description |
|----|---|
| 1 | Display the oscilloscope measurement menu which will appear on the right of the iPad screen |
| 2 | Select which probe to display on the oscilloscope |
| 3 | Display a math channel on the oscilloscope |
| 4 | Select between Normal and Precision acquisition modes* |
| 5 | Select between SinX/X , Gaussian and Linear interpolation |
| 6 | Enable or disable the roll mode |

***Normal** mode down-samples by discarding points between those needed. **Precision** mode down-samples by averaging, increasing precision and reducing noise.



Trigger

Tip: Quickly adjust trigger settings by tapping the trigger marker 

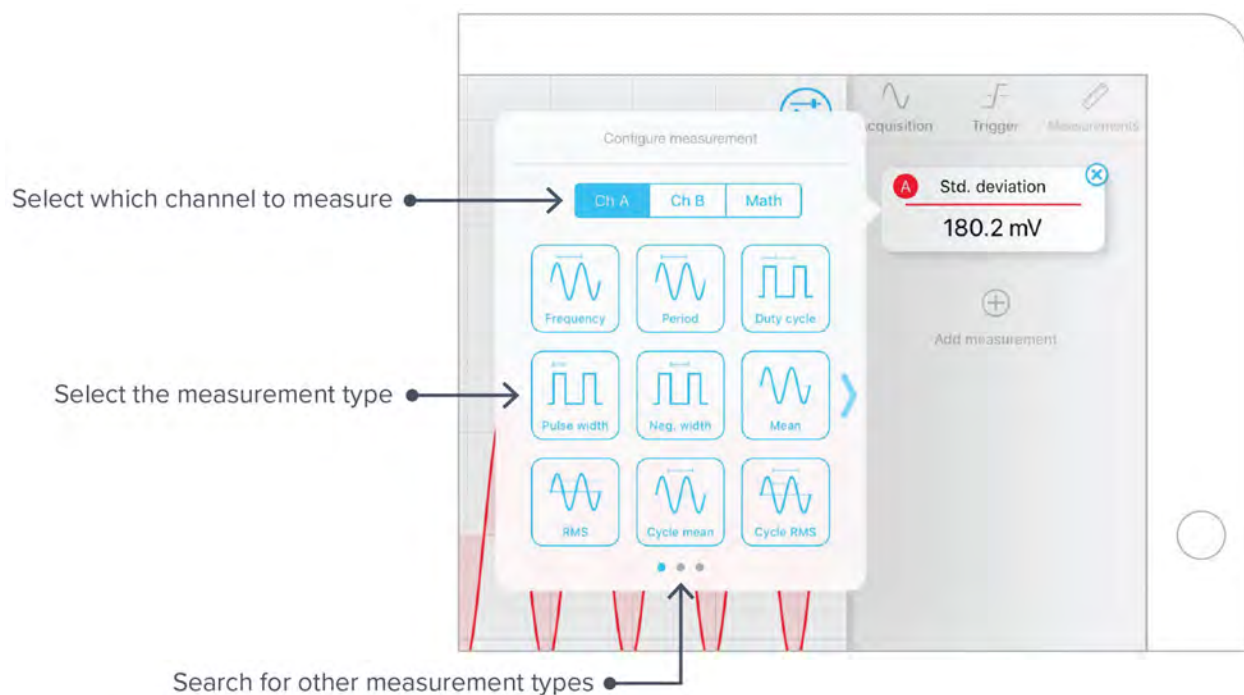
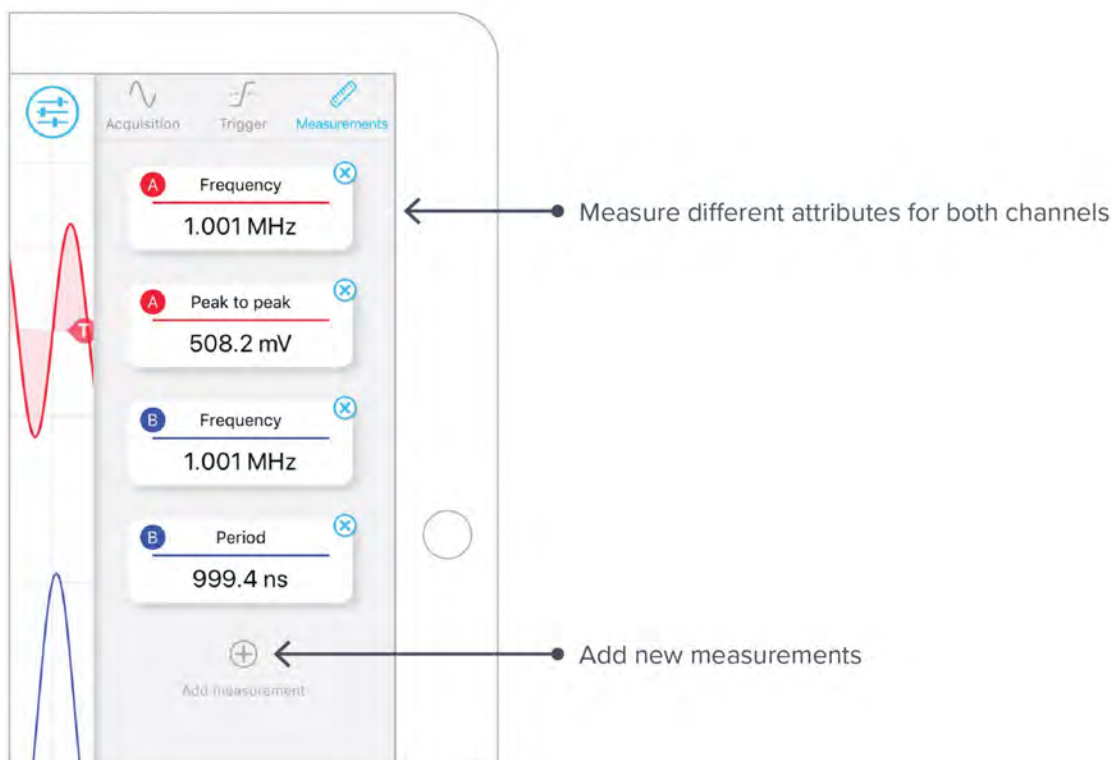


| ID | Description |
|----|--|
| 1 | Select between Auto and Normal trigger mode |
| 2 | Select which channel to trigger on |
| 3 | Configure Nth event triggering mode |
| 4 | Set the trigger's holdoff time (0 to 10 seconds) |
| 5 | Select between Edge and Pulse trigger types |
| 6 | Configure the desired behaviour of the trigger |
| 7 | Set the trigger level |
| 8 | Select Auto or Manual trigger sensitivity |
| 9 | Activate Noise Reject or High Frequency Reject |




Measurements

The measurements menu  allows you to measure up to seven attributes at a time across both input channels and the math channel.







Cursors

Voltage and Time cursors can be added to the measurement trace by pressing the  icon.



Tip: Quickly add voltage cursors by dragging your finger up from the cursor icon. Add time cursors by dragging your finger to the right, away from the icon.

Play / Pause

The measurement trace can be paused at any time by pressing the  button. This allows you to closely inspect features in the most recently captured trace. No new measurement data will be displayed until the measurement is resumed by pressing the  icon.


Pressing the “Share” button will also pause capture and must be resumed from this button.

Full Screen Mode

Press the  icon to enter full screen mode. Exit full screen mode by pressing .

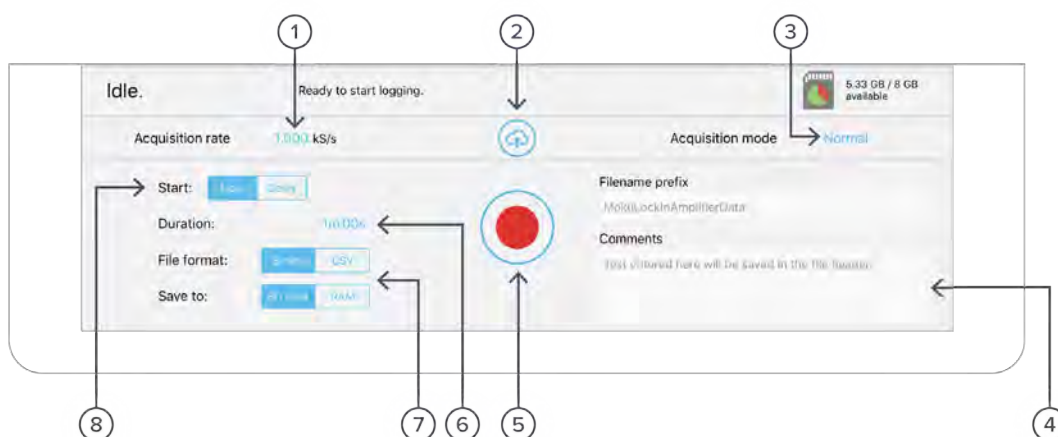


Data Acquisition

Acquire data from up to two probe points at a time at a maximum sampling rate of 500 kS/s for two channels and 1 MS/s for one channel. To access the data acquisition menu, press the  icon. More details about the data logger can be found in Moku:Lab's Data Logger Manual.

Data can be acquired in one of two acquisition modes, Normal and Precision. Precision mode filters channel data according to the selected acquisition rate, increasing vertical resolution and attenuating aliased harmonics.

- Data can be saved to SD card or RAM with binary *.li or comma separated value *.csv file formats
- Files saved to RAM will be lost when Moku:Lab is powered down or reset
- Files saved with binary *.li format can be converted to *.csv or *.mat using Liquid Instruments' file conversion software (<https://github.com/liquidinstruments/lireader>)
- Record data for up to 10,000 hours, and delay the start of a measurement for up to 10,000 hours
- Start a measurement by pressing the red circle



| ID | Description |
|----|---|
| 1 | Select the sampling rate at which your measurement is recorded |
| 2 | Upload saved data |
| 3 | Select between Normal and Precision acquisition modes |
| 4 | Add comments to your measurement |
| 5 | Record a new measurement |
| 6 | Configure measurement duration |
| 7 | Select the file format and destination of the recorded measurement data |
| 8 | Configure when to begin recording data |

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



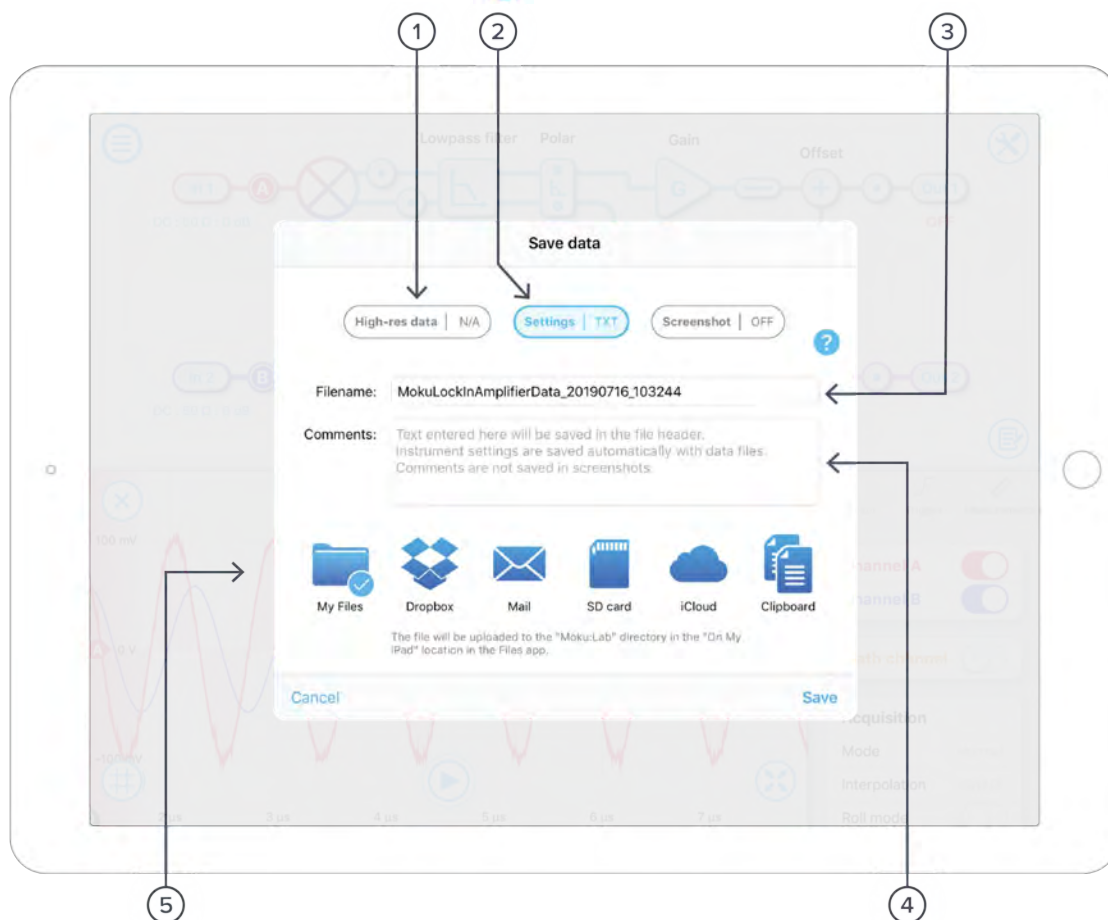
Exporting Data

Export data by pressing the  icon.

Measurement Traces

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

To export a measurement trace, press the  icon on the oscilloscope.




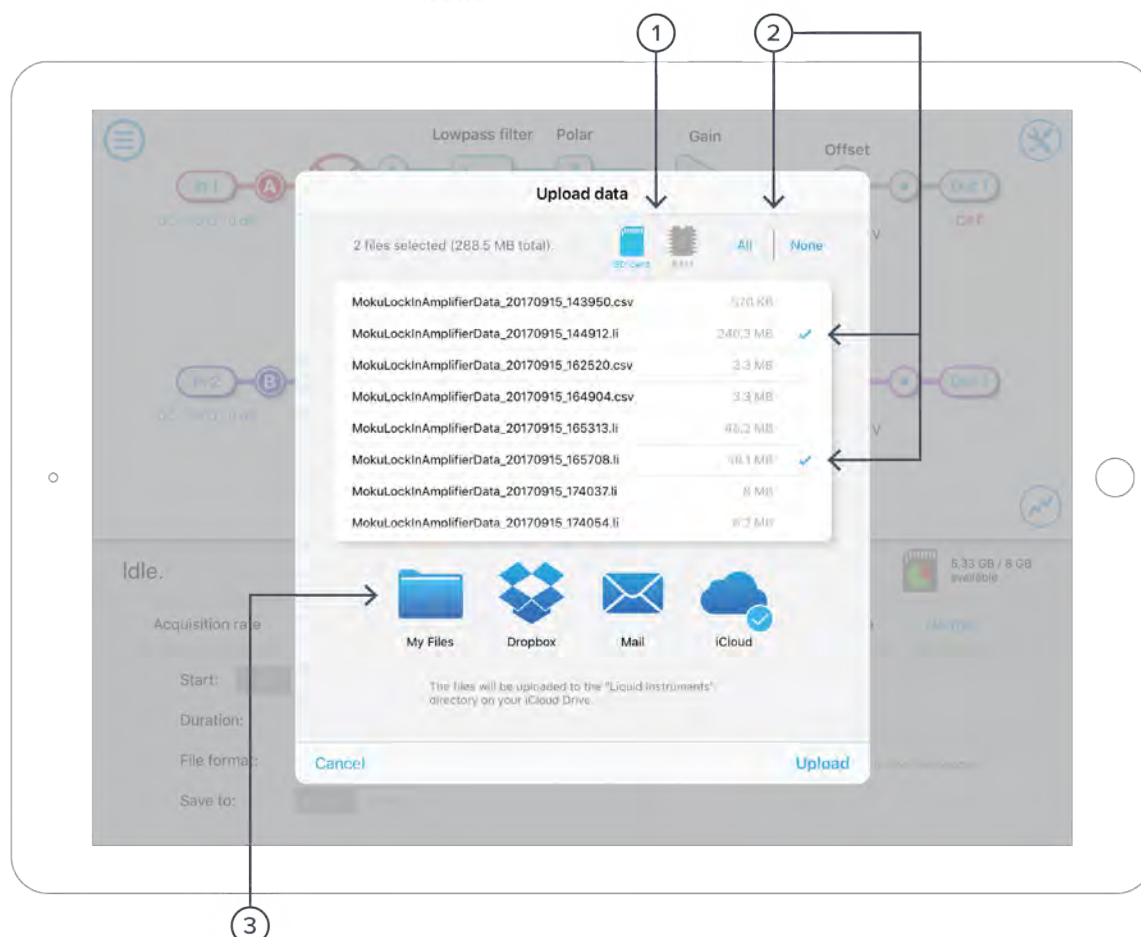
| ID | Description |
|----|---|
| 1 | Select the data you'd like to save |
| 2 | Tap to save the instrument settings |
| 3 | Change the filename |
| 4 | Add comments to your file |
| 5 | Select the destination for your data. Note: cloud storage will require you to sign in |



Acquired data

Data that has been acquired to SD card or RAM can be uploaded to My Files (iOS 11 or later), Dropbox, E-mail, and iCloud.

To export acquired data, press the  icon in the data logger.



| ID | Description |
|----|---|
| 1 | Select whether to upload your data from SD card or RAM |
| 2 | Select which files to upload |
| 3 | Select the destination for your data. Note: cloud storage will require you to sign in |

SD card

- Upload files to SD card by inserting a compatible FAT32 formatted drive into Moku:Lab's SD card slot, located on the rear of the device next to the power connector.

Dropbox

- Upload files to Dropbox by logging in to your account with Moku:Lab iPad app.



Example Measurement Configurations

Measure magnitude and phase with respect to an external reference

To measure the magnitude and phase of the input signal with respect to an external reference:

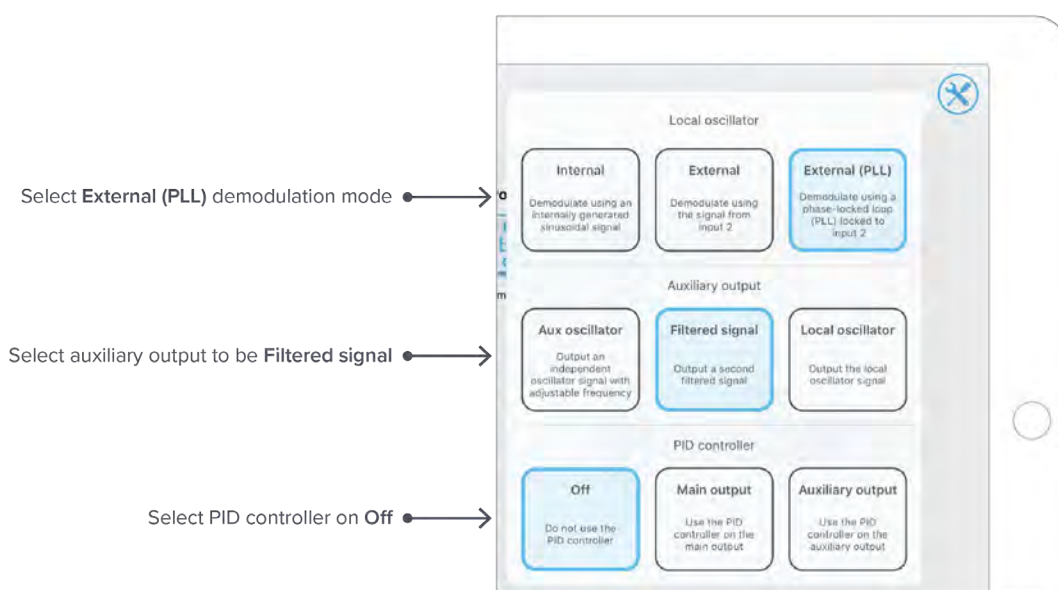
1. Configure the input coupling, impedance and gain to suit your measurement 

2. Set the demodulation mode to **Polar**



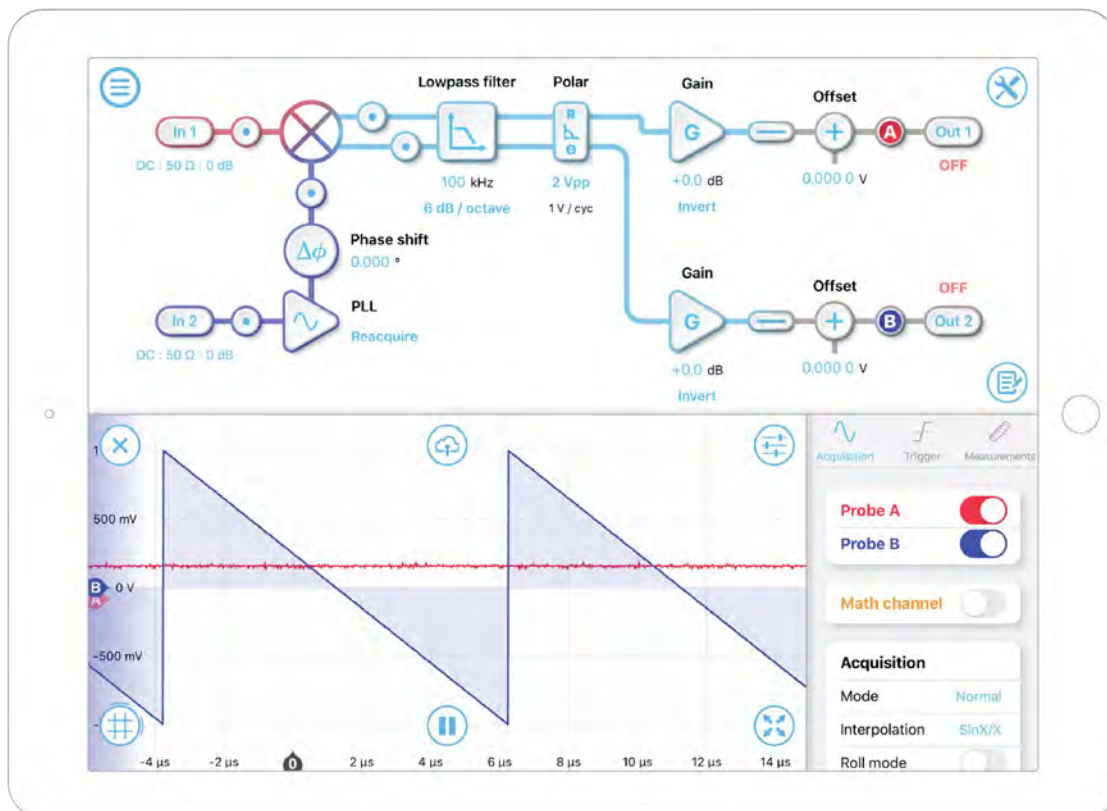
Access the Advanced Configuration Menu  and

3. Set demodulation to **External (PLL)**
4. Set auxiliary output to **Filtered signal**
5. Set PID controller to **Off**

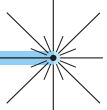




6. Place probe points at the two outputs. View the time-series magnitude and phase data using the lock-in amplifier's built-in oscilloscope.



7. Tune the gain values in each arm to balance precision and measurement range.



Arbitrary Waveform Generator User Manual

Moku:Lab'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.



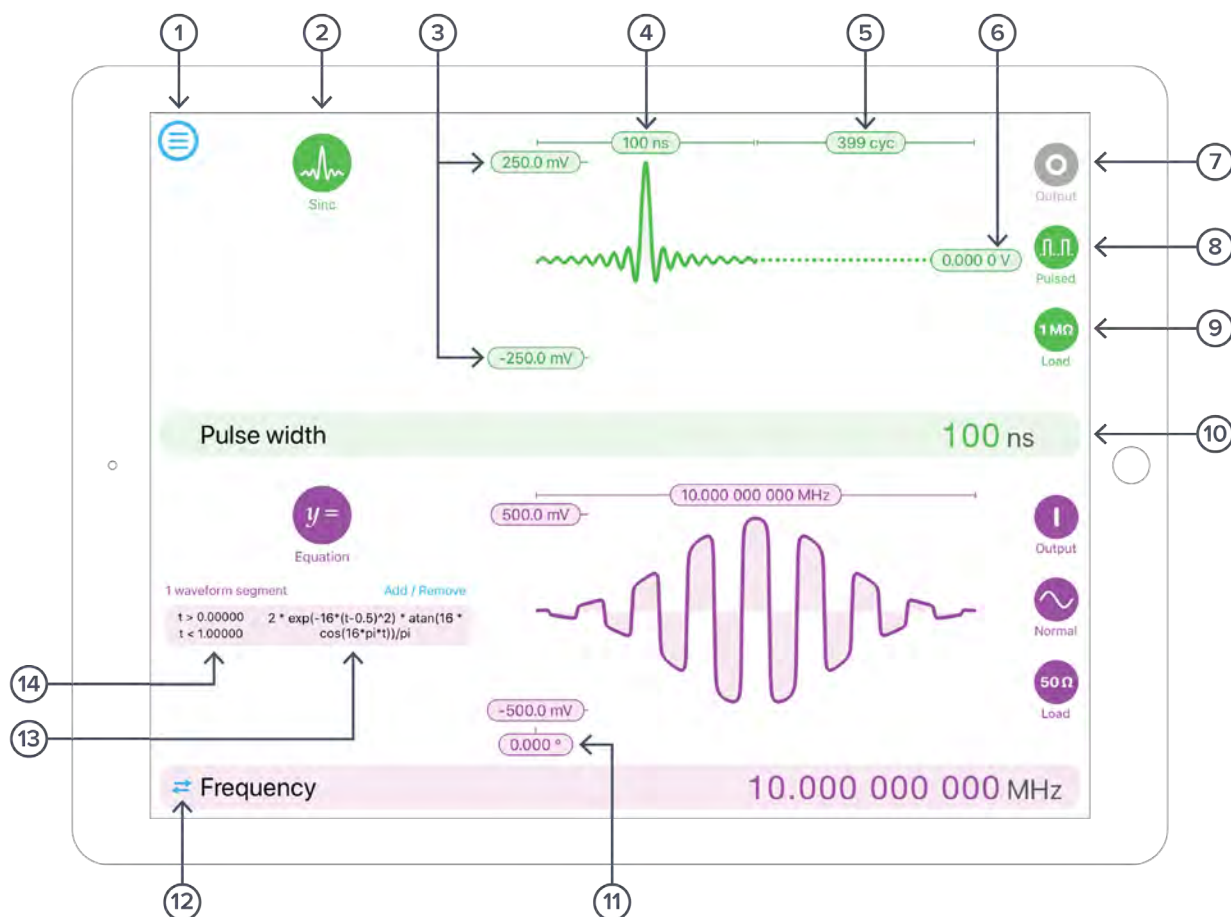


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| Amplitude scaling and interpolation | 7 |
| Equation | 8 |
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| Equation editor | 9 |



User Interface

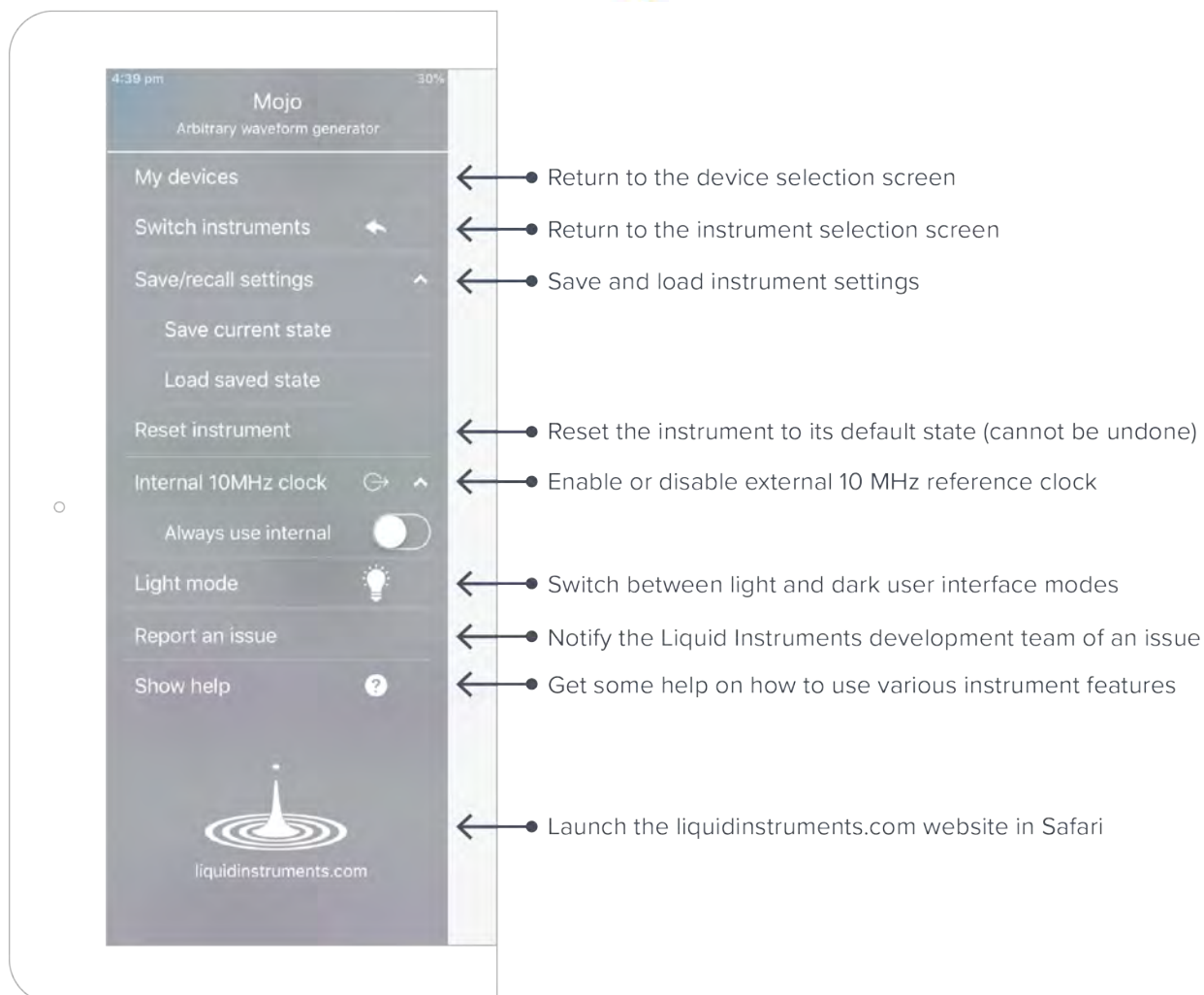


| ID | Description | ID | Description |
|----|--|----|-------------------------------------|
| 1 | Main menu | 8 | Waveform mode (Normal, Pulsed) |
| 2 | Waveform shape | 9 | Load impedance (50 Ω / 1 MΩ) |
| 3 | Configure amplitude | 10 | Configured parameter display |
| 4 | Configure pulse width / period / frequency | 11 | Configure phase (normal mode) |
| 5 | Configure dead time (pulsed mode) | 12 | Switch between frequency and period |
| 6 | Configure dead time voltage (pulsed mode) | 13 | Configure mathematical equations |
| 7 | Enable / disable output | 14 | Configure equation time segments |



Main Menu

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





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:Lab'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:Lab 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:Lab'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.

- The period of each cycle of dead time is equal to the selected period of the waveform
- The dead time voltage can be configured to equal any DC value between the waveform's minimum and maximum voltages

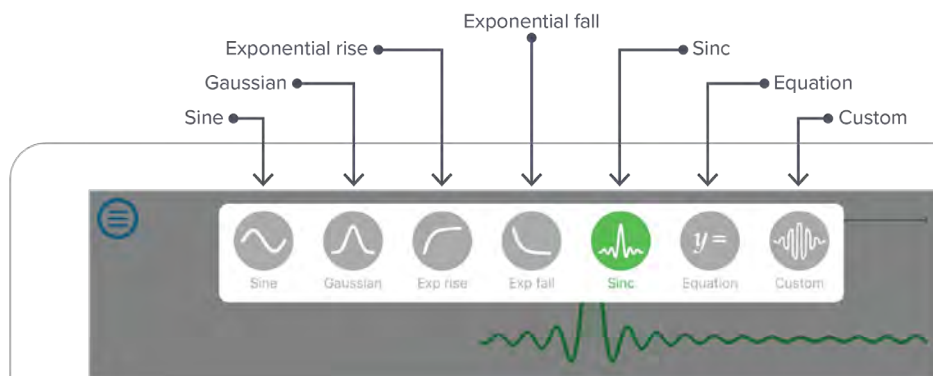
Phase Synchronization

The phase of the two outputs can be synchronised by selecting the phase configuration label (in Normal mode) and then tapping **Sync with Ch 1** or **Sync with Ch 2** depending on which channel you would like to synchronise to.



Waveform Types

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





Custom

Uploading custom waveforms

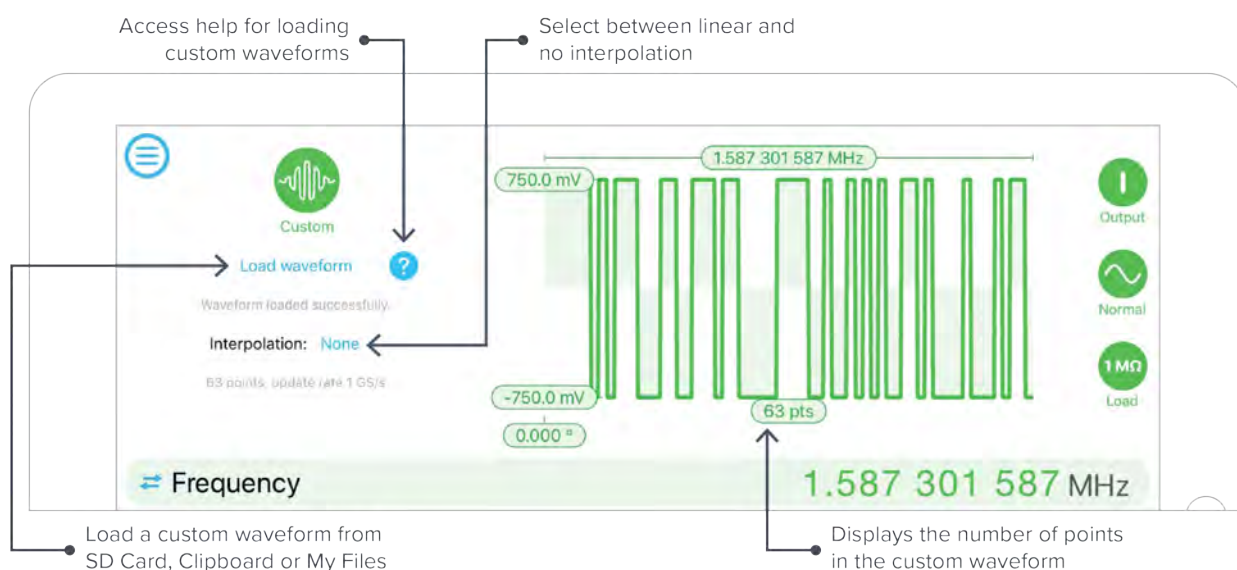
- Upload custom waveforms from comma- or newline-delimited text from SD card or the iPad's Clipboard and My Files directory
- Up to 8192 points can be output at an update rate of 1 GS/s, up to 16384 points at 500 MS/s, up to 32768 points at 250 MS/s and up to 65536 points at 125 MS/s

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



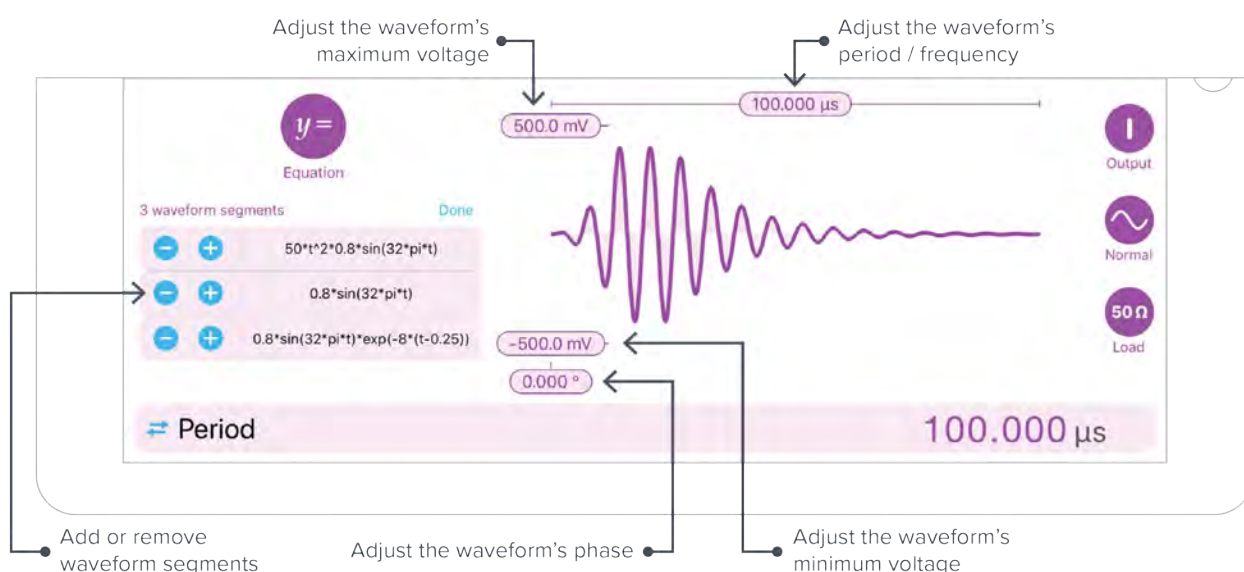
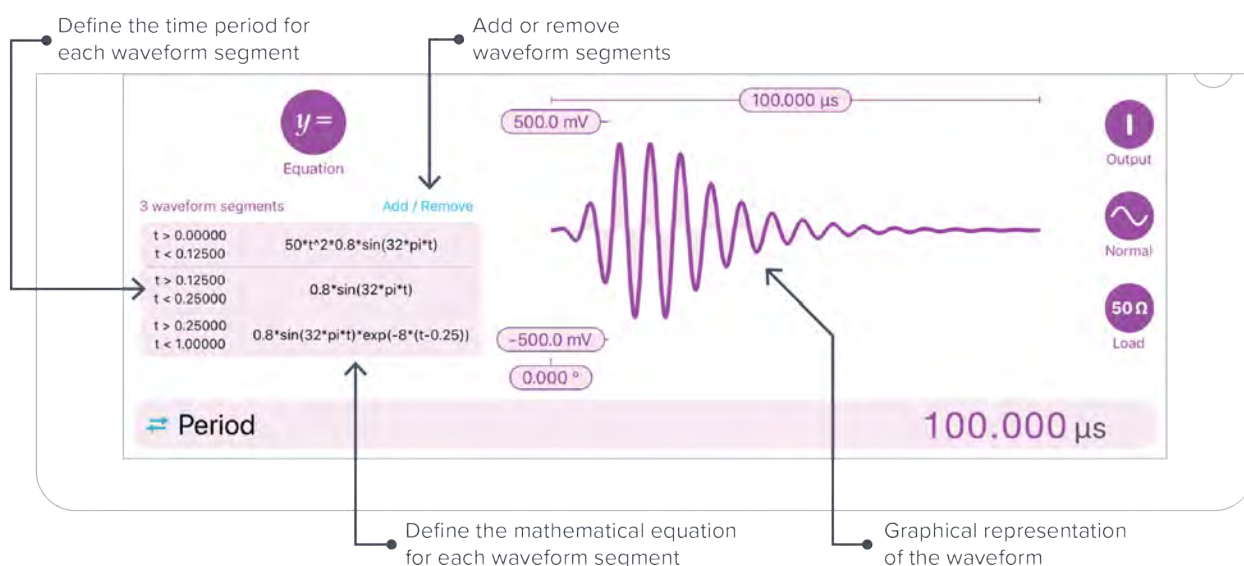


Equation

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




Waveform segments

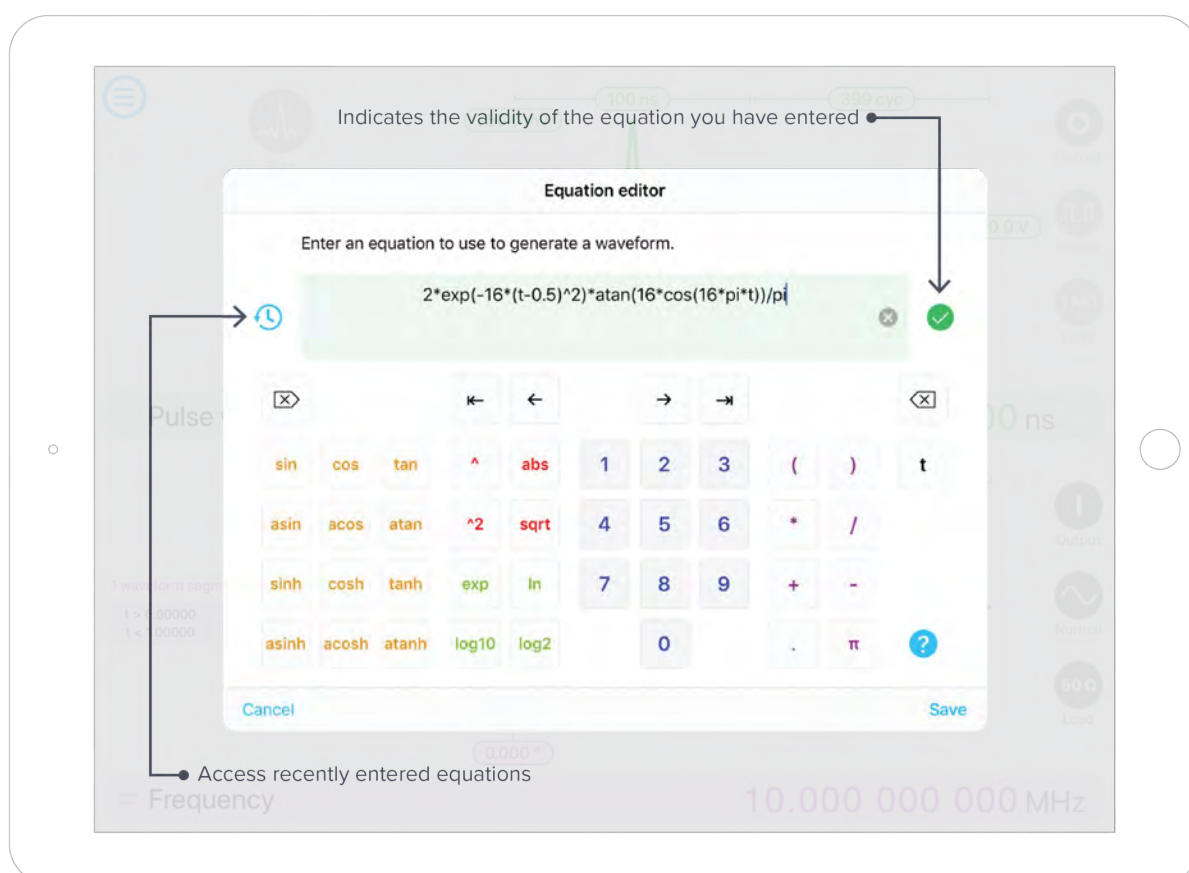
- Add up to 32 waveform segments and define their time fractional time periods within a single period of the total waveform
- To add or remove segments, press the **Add / Remove** label and tap the **+** and **-** icons that appear to the left of the equations
- To modify the period of an individual 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

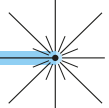




Equation editor

- 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





Oscilloscope User Manual

Moku:Lab's Oscilloscope instrument can be used to observe, analyse, measure and record signals over time on 2 channels, with an analogue bandwidth of 200 MHz and sampling to 500 MS/s.

Oscilloscopes are the most essential item of test equipment in any electronics lab and the Moku:Lab's user interface makes control and setup of the oscilloscope very efficient.

Additionally, there are a wide range of measurements available together with a computed maths channel. Data or signal captures can be easily shared via email, DropBox or iCloud directly from the Moku:Lab





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Introduction

The oscilloscope is an essential item of equipment in almost all engineering laboratories. Moku:Lab implements an oscilloscope as one of 12 high quality instruments.

Moku:Lab's Oscilloscope is a precision yet versatile instrument with a modern, touch based and intuitive interface. The tablet-based interface operates wirelessly and this enables the engineer or technician to operate the oscilloscope fully, while free to move about the working environment.

Extensive measurements are readily available from the touch interface. Data, screenshots and logs can be readily captured to email or cloud-based services for rapid sharing and evaluation.

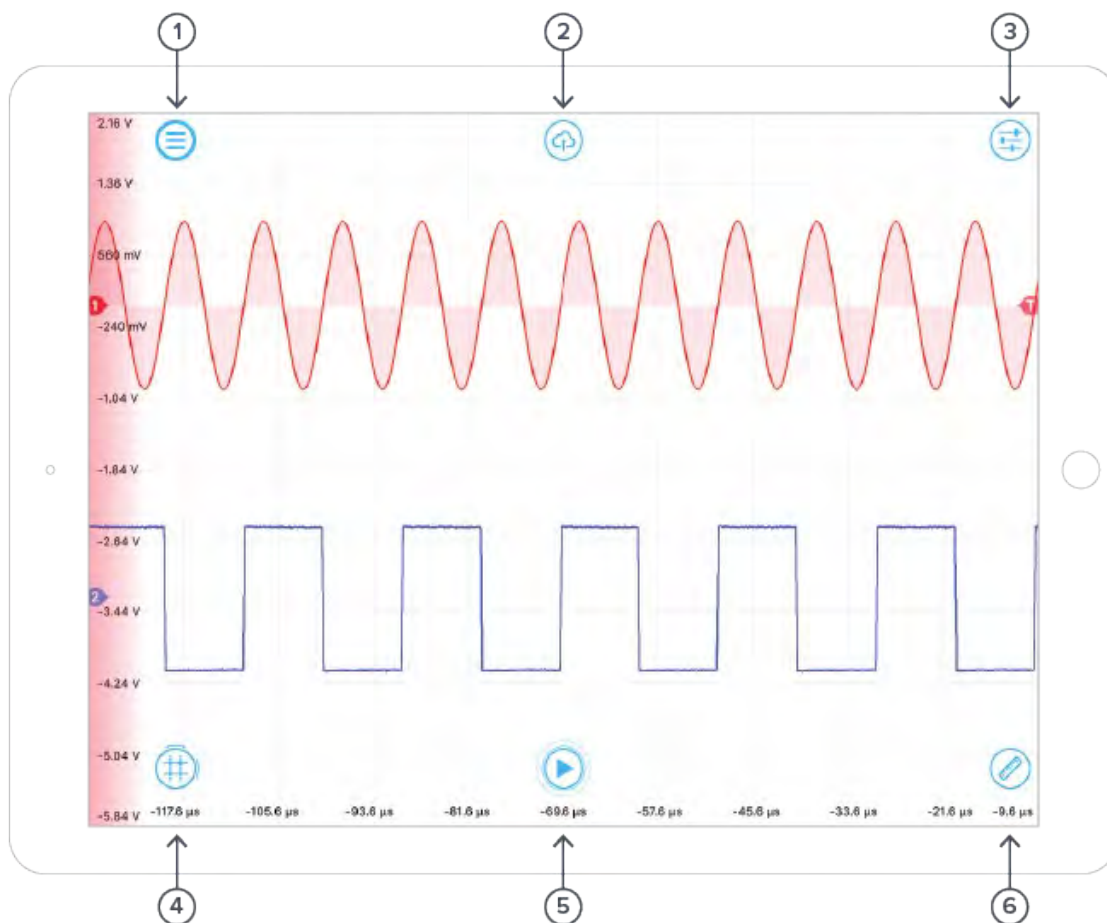
Moku:Lab's Oscilloscope also has Python, LabView and MATLAB interfacing capabilities.

MokuLab's Oscilloscope can be reconfigured nearly instantaneously to be one of:

- Oscilloscope
- Spectrum Analyzer
- Phasemeter
- Laser Lock Box
- Bode Analyzer
- FIR Filter Builder
- Digital Filter Box
- Waveform Generator
- Arbitrary Waveform Generator
- PID Controller
- Data Logger
- Lock in Amplifier



User Interface Quick Reference

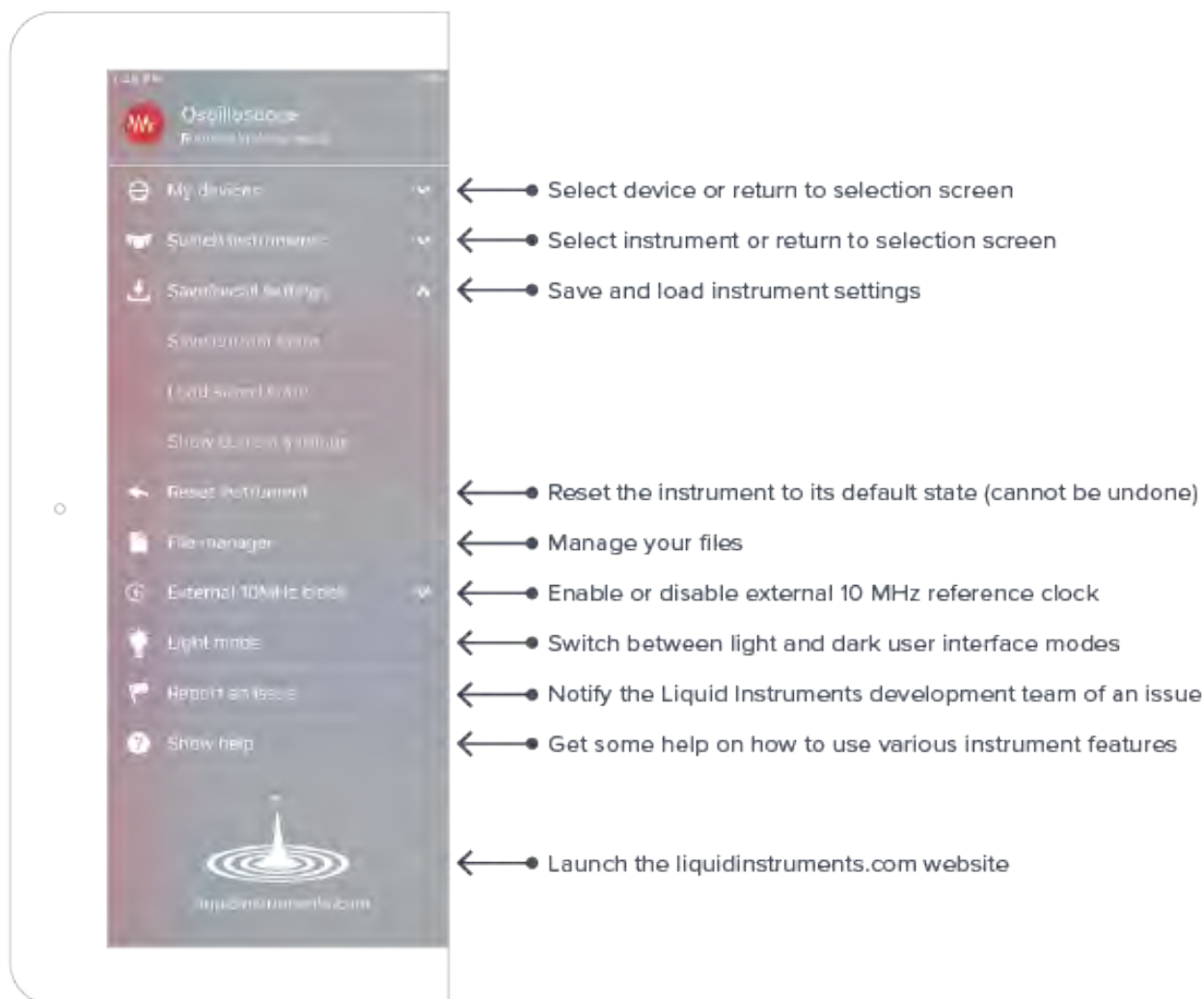


| ID | Button | Description |
|----|--------------|--|
| 1 | Main menu | The main menu contains controls for switching instruments, switching devices, selecting device clock and user interface modes and more. See Main Menu |
| 2 | Share | The sharing button gives access to controls that allow you to 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 |



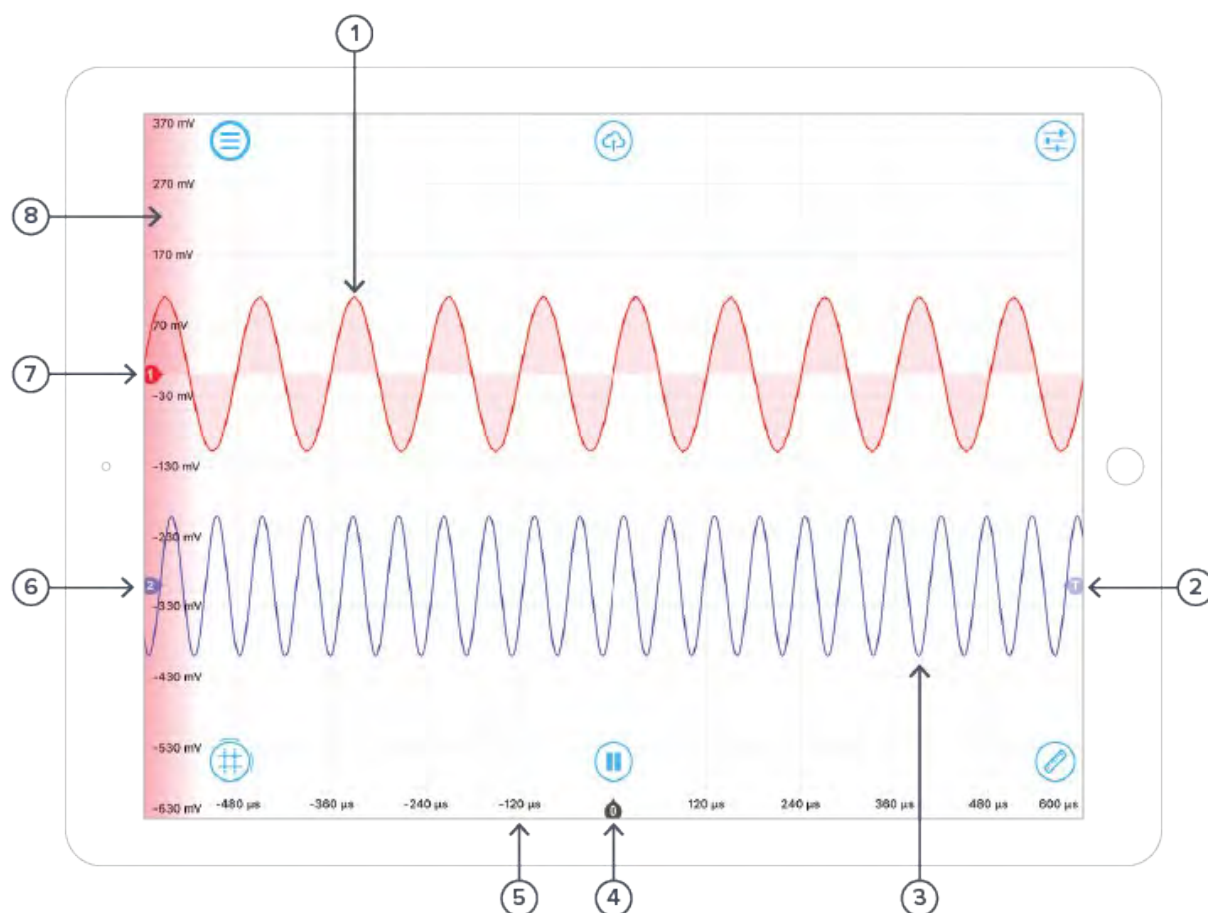
Main Menu

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





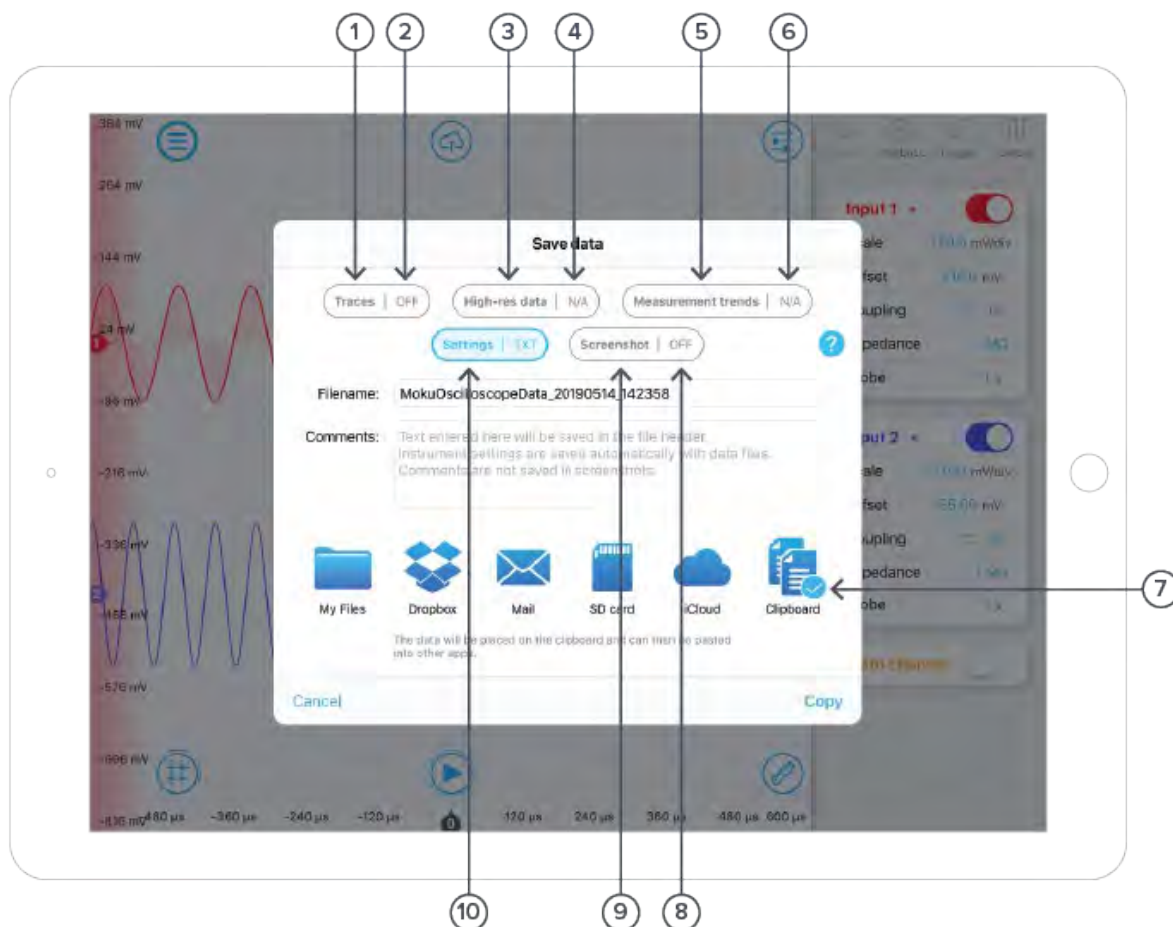
Axes and Traces



| ID | Button | Description |
|----|-----------------------|---|
| 1 | Channel 1 Trace | The Time/Voltage trace for Channel 1. When channel 1 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 either). Drag to set level or tap for more options. See Navigating your Signal |
| 3 | Channel 2 Trace | The Time/Voltage trace for Channel 2. When channel 2 is active, the trace will have a light fill to the zero-volt level (not shown above). |
| 4 | 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. |
| 5 | Time Axis | Shows the time scale for both channels (the channels always share a time scale). |
| 6 | Channel 2 Origin Mark | Marks the “zero volt” level for channel 2 |
| 7 | Channel 1 Origin Mark | Marks the “zero volt” level for channel 1 |
| 8 | 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



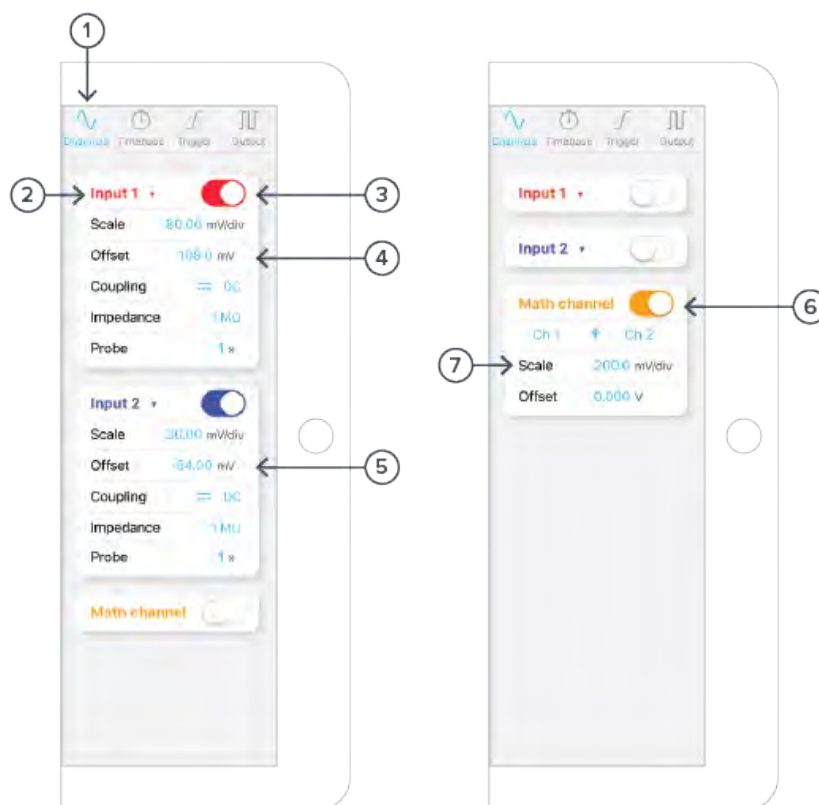
The **save data** options can be accessed by pressing the  icon, allowing you to:

| ID | Button | Description |
|----|---------------------------|---|
| 1 | Traces data | Select to enable saving of Trace data |
| 2 | Traces format | Tap to select CSV or MATLAB format |
| 3 | Hi-res data | Select to enable saving of Hi-res data |
| 4 | Hi-res format | Tap to select CSV or MATLAB format |
| 5 | Measurements trends | Select to enable saving of Measurement trends, if a measurements trends drawer is open |
| 6 | Measurement trends format | Tap to select CSV or MATLAB format |
| 7 | Save data destination | Select data destination. DropBox, Email or iCloud |
| 8 | Screenshot format | Select PNG or JPG for screenshot |
| 9 | Screenshot | Select to save screenshot |
| 10 | Settings | Save oscilloscope settings to a file, enables user to quickly setup the oscilloscope in a known state |



Settings and controls

Channel Control Pane

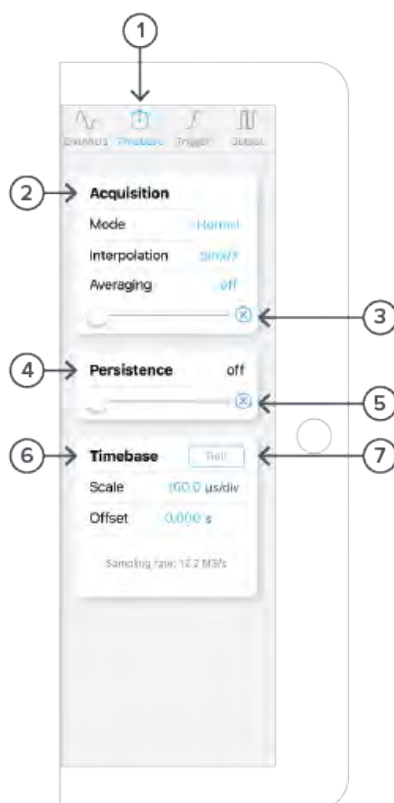


| ID | Button | Description |
|----|--------------------------------|--|
| 1 | Channels Control Pane Selector | Reveals the Channels Control Pane in the Controls Drawer. Can also be revealed by swiping right from the Timebase Control Pane. |
| 2 | Channel 1 Data Source | Changes Data Source for Channel 1. The default is to view data from Input 1, but also may be used to preview Waveform Generator data from Output 1. See Using the Built-in Waveform Generator |
| 3 | Channel 1 On/Off | Toggles Channel 1 On/Off |
| 4 | Channel 1 Control Pane | <p>Scale: The voltage scale. Changes dynamically when pinch-zooming the trace or can be entered manually by tapping.</p> <p>Offset: The vertical offset of the Channel 1 trace. Changes dynamically when vertically-dragging the trace or can be entered manually by tapping.</p> <p>Coupling: Toggles between DC/AC coupling</p> <p>Impedance: Toggles between 1MΩ and 50Ω impedance</p> <p>Probe: Specifies the probe attenuation, if such an attenuating probe is connected.</p> |



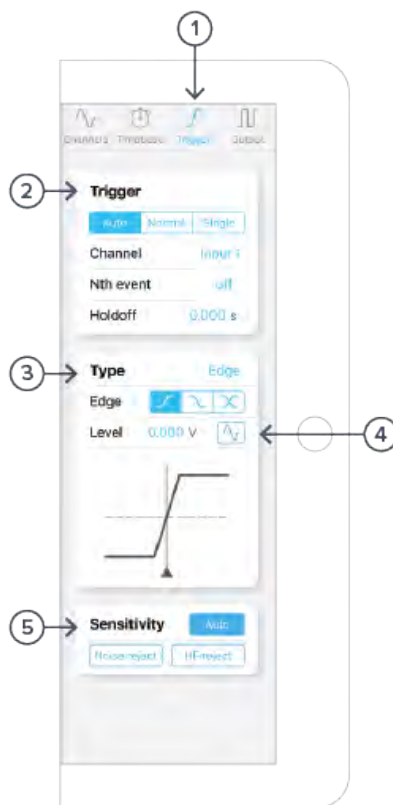
| | | |
|---|---------------------------|--|
| 5 | Channel 2 Control Pane | Provides control for Channel 2. As explained above for channel 1. |
| 6 | Math Channel On/Off | Toggles the Math Channel on/off |
| 7 | Math Channel Control Pane | <p>(Operation): Selects the Mathematical operation to perform on the data. Tap the operation symbol and/or Channel numbers to change behaviour. See Math Operations</p> <p>Scale: Vertical scale for the Math channel. Changes dynamically when pinch-zooming the Math trace or can be set manually by tapping. Units for this setting change depending on the operation.</p> <p>Offset: Vertical offset for the Math channel. Changes dynamically when vertically-dragging the Math trace or can be set manually by tapping. Units for this setting change depending on the operation.</p> |

Timebase Control Pane



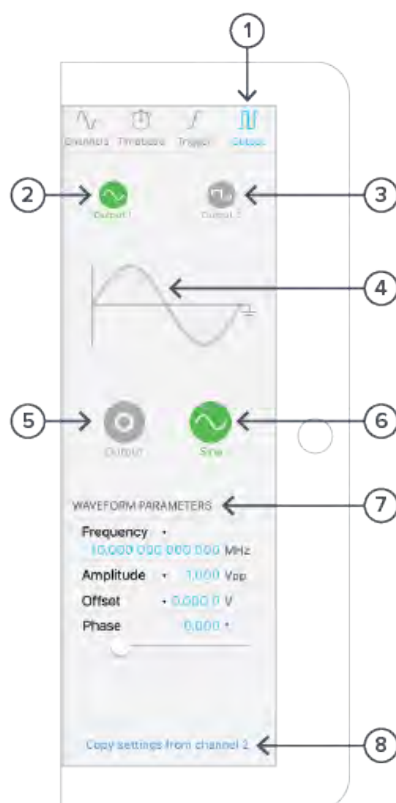
| ID | Button | Description |
|----|--------------------------------|---|
| 1 | Timebase Control Pane Selector | Reveals the Timebase Control Pane in the Controls Drawer. Also revealed by swiping left from the Channels Pane or right from the Output Pane. |
| 2 | Acquisition Control Pane | <p>Mode: Changes acquisition mode between Normal and Precision. See Acquisition Modes and Sampling</p> <p>Interpolation: Changes the on-screen Interpolation mode. See Display Options</p> <p>Averaging: Displays on screen an average trace taken from this many consecutive waveforms.</p> |
| 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 | <p>Scale: Horizontal screen scale. Changes dynamically when pinch-zooming a trace or can be entered manually by tapping.</p> <p>Offset: Horizontal trigger point offset. Changes dynamically when horizontally-dragging a trace or can be set manually by tapping.</p> |
| 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 device inputs, outputs or external trigger input independent of what is displayed on the screen.</p> <p>Nth event : Select up to 65535 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 the Moku's output channels.

| ID | Button | Description |
|----|-------------------------------|--|
| 1 | Output Control Panel Selector | Reveals the Output Control Pane in the Controls Drawer |
| 2 | Output 1 select | Select output 1 |
| 3 | Output 2 select | Select output 2 |
| 4 | Waveform Preview | Shows a preview of the waveform to be generated |
| 5 | Output enable | Toggles the output enable of the selected channel |
| 6 | Waveform Select | Selects the waveform type to generate |



| | | |
|---|---------------------|--|
| 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:Lab'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 | Duplicate Settings | Copies all waveform settings from one channel to the other |

Measurements drawer

See [Making Measurements](#) for detailed definitions and explanation of the many measurement options.



| 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 colour-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 |
| 5a | Trend History Length | Tap to change trend history length |
| 6 | Trend plot | Solid and dashed plots representing trends of the respective measurements |



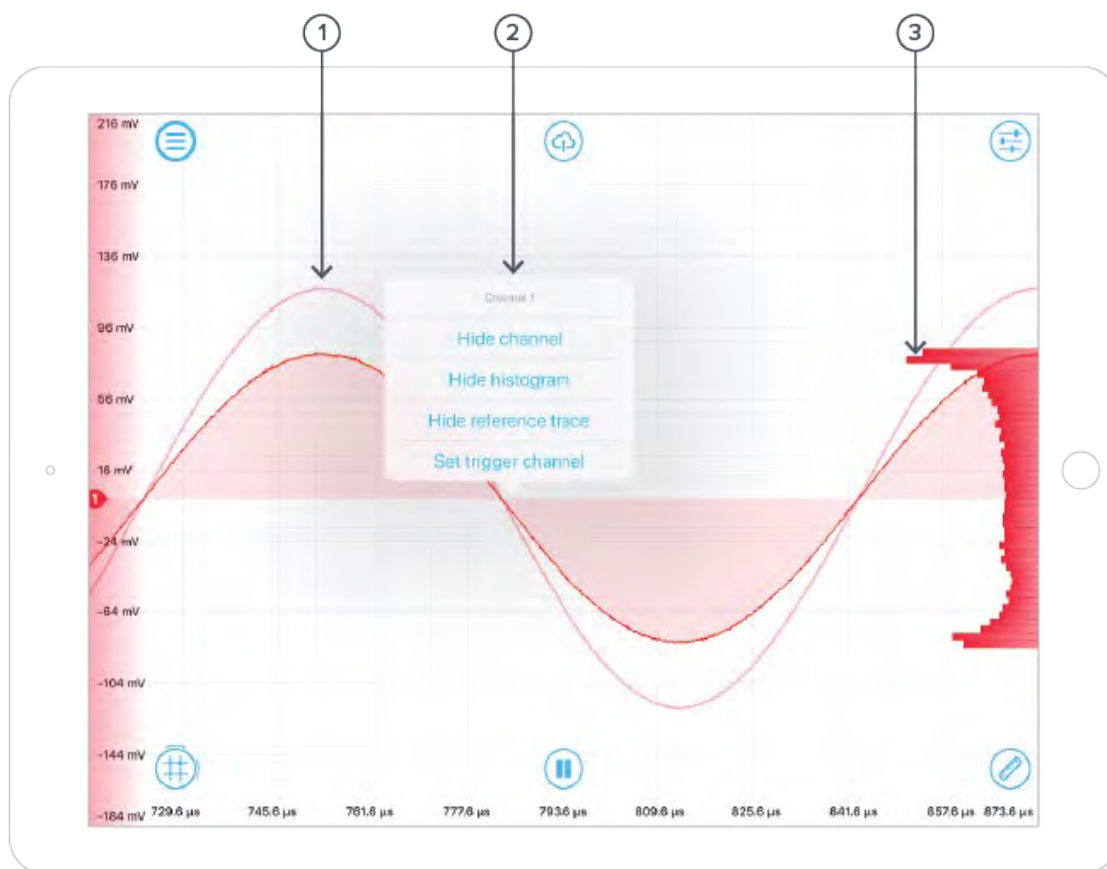
Cursors button



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 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 channels' colour with transparency</p> |
| 2 | Reference Trace | An example reference trace for Channel 1 |
| 3 | Histogram | An example histogram for Channel 1 |



Instrument Reference

Configuring Inputs

Input Impedance

The Moku's inputs have a selectable impedance of either $1\text{M}\Omega$ or 50Ω . This is effectively the resistance from the signal line to ground. For high-frequency measurements, it is important that the Moku's impedance matches that of the device under measurement. If the impedance is mismatched, some signal power will reflect off the Moku's input, 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 ($1\text{M}\Omega$) is used where the Moku 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 50Ω is most common for RF devices and signal generators.

Gain Ranges

The Moku contains a front-end attenuator that divides the signal by 10x, increasing the range of voltages that can be measured. In the Moku 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 $1/10^{\text{th}}$ of the input voltage to the Moku. To correct for this on the Moku oscilloscope's voltage scale, the probe factor can be entered on the "Channels" tab.

Overvoltage Protection

The Moku will disconnect its inputs automatically when the input voltage on the BNC connector exceeds approximately ± 7 volts. At this time, the Moku's oscilloscope will show a flat line at zero volts.

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

Coupling

Moku 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 the Moku:Lab activating its internal attenuator (see [Gain Ranges](#)).

Navigating your Signal

Trace Selection

The Moku oscilloscope can display up to two signal traces, plus a Maths Trace. Each signal trace may either be the Analogue Input (default) or a preview of the Analogue 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.

To toggle a trace between the Analogue Input and the preview of the Waveform Generator Output, tap the word "Input" or "Output" next to that slider.

Triggering

The triggering circuit of an oscilloscope allows you to indicate to the device 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. The Moku 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 practise, this limits the distance that you may scroll to the left and right.

In the Moku 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.

Trigger Modes

Trigger modes describe how the Moku 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. The Moku 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 Moku 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, Moku 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 Moku 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.


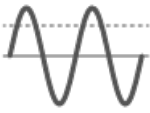

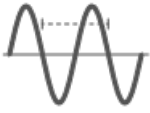





Making Measurements

Automatic Measurements

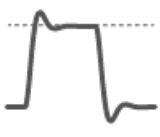
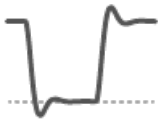


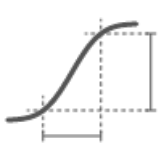
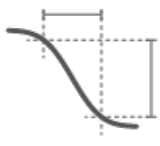
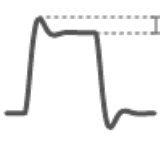
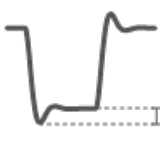
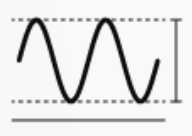
The Moku oscilloscope can automatically make a number of measurements on your data in real time. To open the Measurements pane, swipe up from the bottom or tap the Ruler icon. Add a new measurement by tapping the Plus button or configure an existing measurement by tapping the measurement itself. The 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. |
| 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 Moku 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 3 minutes.

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.

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 Moku oscilloscope processes data in two stages. First, data is acquired from the Analogue-to-Digital converters, 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 the Moku'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 500MSPS and the selected time span on the Moku oscilloscope requires 1MSPS, then 499 out of 500 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 500MSPS and the selected time span on the Moku oscilloscope requires 1MSPS, then 500 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.

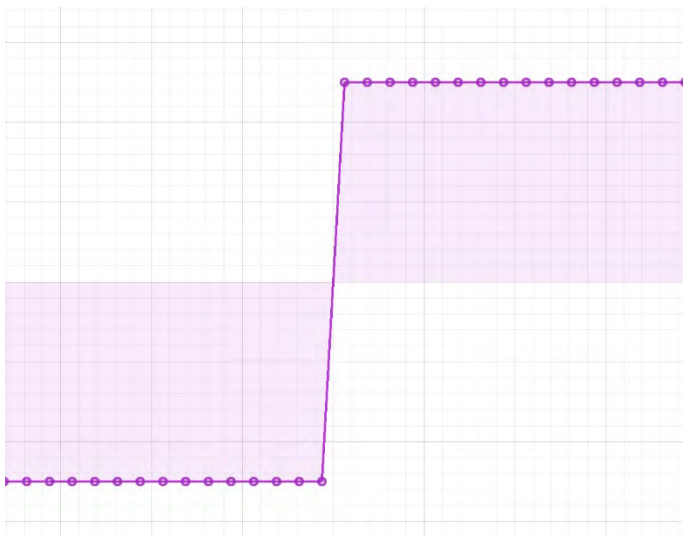
A common workflow would be to use Normal Mode to find the signal and align it as you want, then switch to Precision Mode to improve the signal quality for measurement.

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.

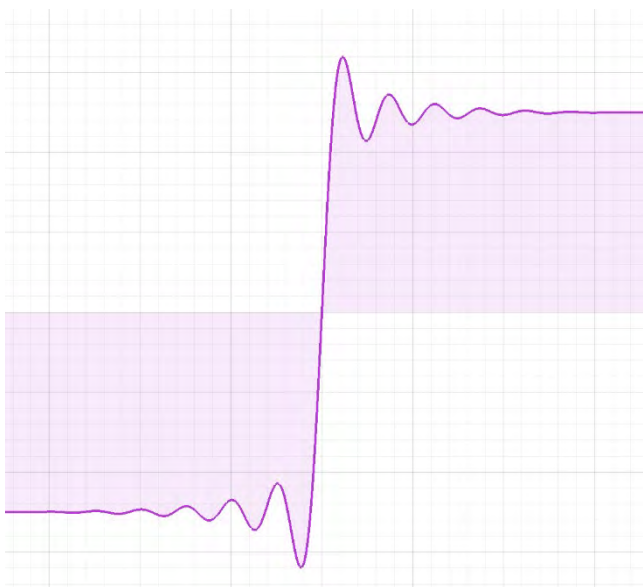


Linear



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

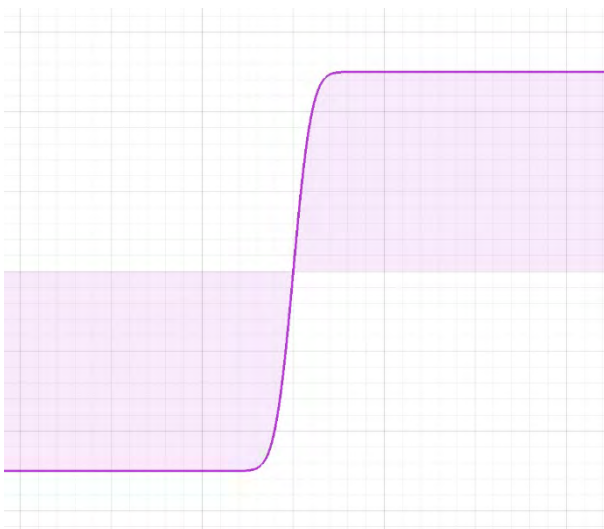


Also called “Sinc” interpolation, this mode preserves the frequency characteristics of the signal. In the time domain though, it can appear that there is over- or under-shoot that is not in fact present in the signal.

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 Moku 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.



Math Operations

The Moku 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 | | Product of two channels. The two channels can be the same, giving a squaring of the signal values. |
| Division | | Ratio of two channels. |
| 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 | | Discrete time-derivative (pointwise difference) of the trace |
| FFT | | Fast Fourier Transform of a trace, giving the frequency domain representation. This mode is complex and described in more detail below. |

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



Using the Built-in Waveform Generator

The Moku oscilloscope has a built-in Waveform Generator. This resembles Moku's Waveform Generator instrument, but without modulation and sweep properties.

| Waveform | Symbol | Description |
|----------|---|--|
| 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 wave, fixed 50% 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) |
| 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 Moku 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

Moku oscilloscope data can be saved through the Save Data icon in the centre-top. The following options are available, corresponding to the two different phases of data acquisition above.

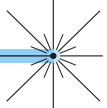
Channel Data: The data as viewed on the screen, including cubic down-sampling and interpolation.

High-res Data: The data directly from the Moku'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 Moku oscilloscope can save:

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

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.



Frequency Response Analyzer User Manual

Moku:Lab's Frequency Response Analyzer can be used to measure a system's frequency response from 10 mHz up to 120 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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Ensure Moku:Lab is fully updated. For the latest information:

www.liquidinstruments.com



Introduction

The Frequency Response Analyzer is an essential item of equipment in almost all engineering laboratories. Moku:Lab implements a frequency response analyzer as one of 12 high quality instruments.

Moku:Lab's Frequency Response Analyzer is a precision yet versatile instrument with a modern, touch based and intuitive interface. The tablet-based interface operates wirelessly, this enables the engineer or technician to operate the instrument fully, while free to move about the working environment.

Extensive measurements are readily available from the touch interface. Data, screenshots and logs can be readily captured to email or cloud-based services for rapid sharing and evaluation.

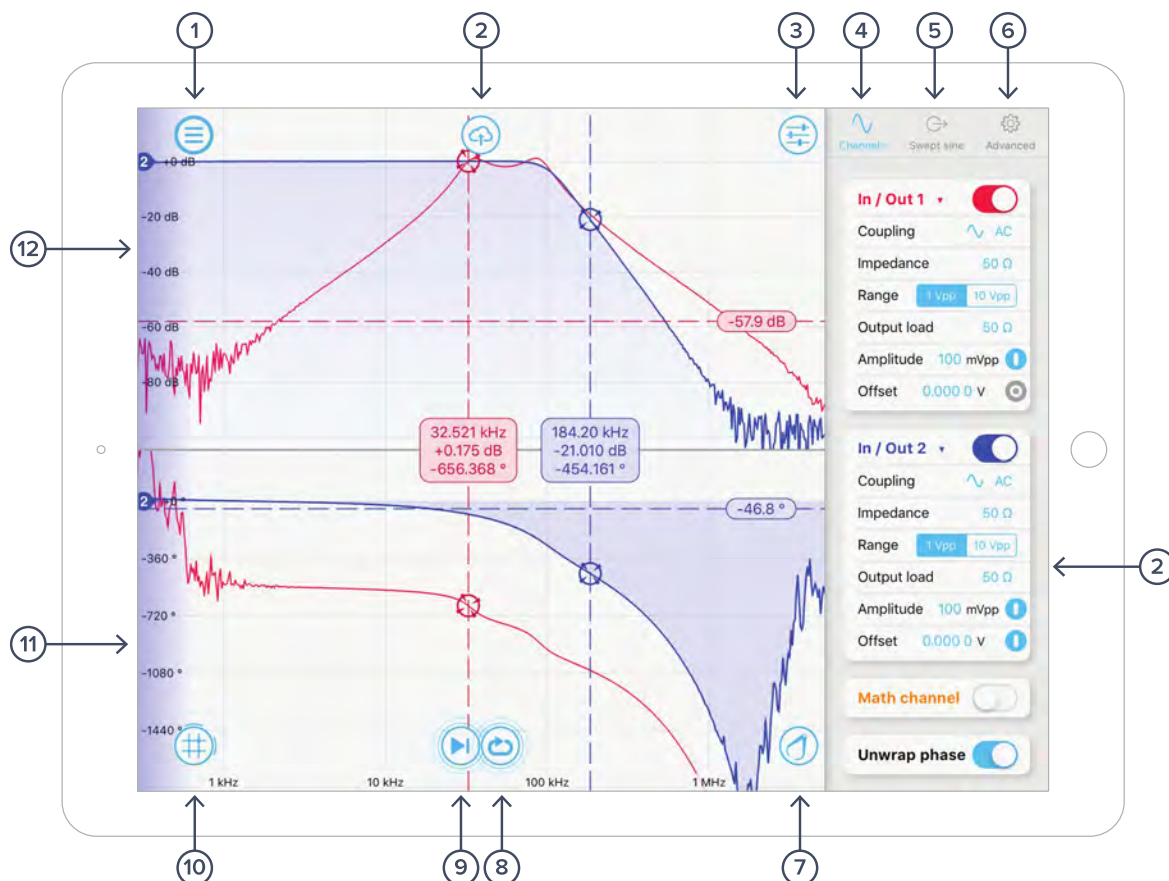
Moku:Lab's Frequency Response Analyzer also has Python, LabView and MATLAB interfacing capabilities.

Moku:Lab can be reconfigured nearly instantaneously to be one of:

- Oscilloscope
- Spectrum Analyzer
- Phasemeter
- Laser Lock Box
- Frequency Response Analyzer
- FIR Filter Builder
- Digital Filter Box
- Waveform Generator
- Arbitrary Waveform Generator
- PID Controller
- Data Logger
- Lock in Amplifier



User Interface

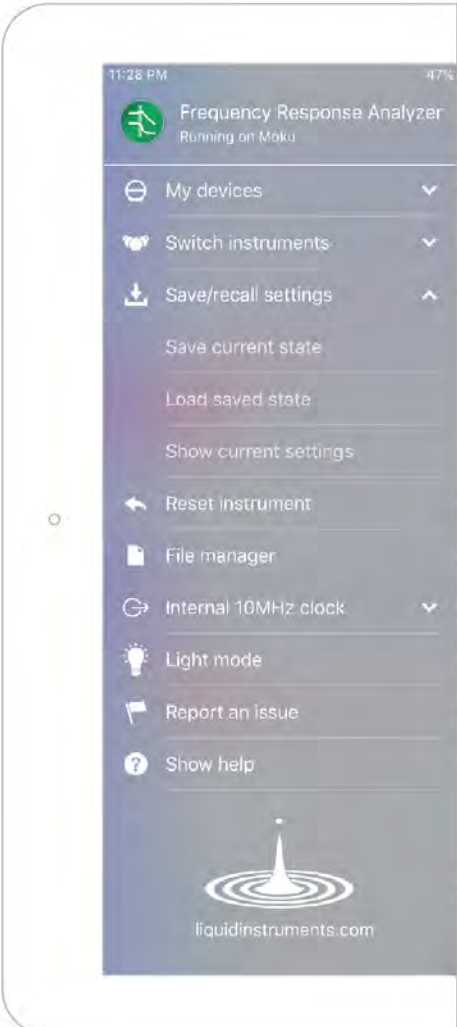


| ID | Description | ID | Description |
|----|--------------------------------|----|---------------------|
| 1 | Main menu | 7 | Calibration tool |
| 2 | Export data | 8 | Sweep mode |
| 3 | Instrument configuration menu | 9 | Start / pause sweep |
| 4 | Channel settings | 10 | Cursors |
| 5 | Swept 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:



The screenshot shows the main menu of the Frequency Response Analyzer. The menu items are listed on the left, and their functions are explained on the right with arrows pointing to the corresponding menu items.

-  My devices  ← Select device or return to selection screen
-  Switch instruments  ← Select instrument or return to selection screen
-  Save/recall settings  ← Save and load instrument settings
 - Save current state
 - Load saved state
 - Show current settings
-  Reset instrument ← Reset the instrument to its default state (cannot be undone)
-  File manager ← Access file manager
-  Internal 10MHz clock  ← Enable or disable external 10 MHz reference clock
-  Light mode ← Switch between light and dark user interface modes
-  Report an issue ← Notify the Liquid Instruments development team of an issue
-  Show help ← Get some help on how to use various instrument features
-  liquidinstruments.com ← Launch the liquidinstruments.com website

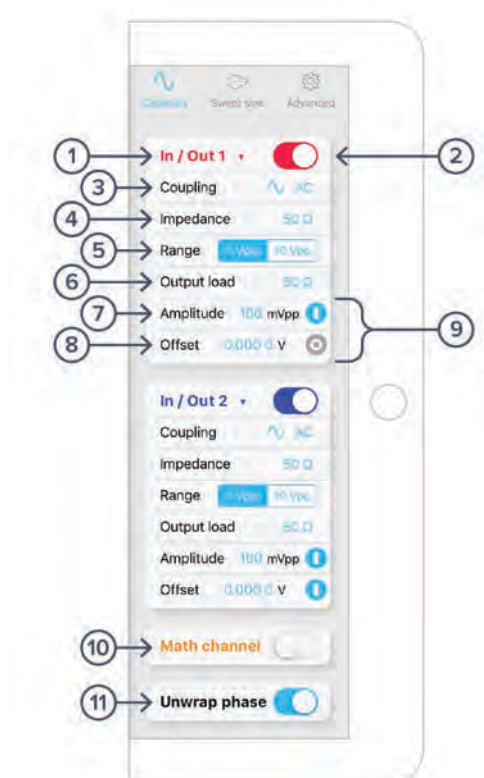


Instrument Configuration

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



| 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 1M Ω or 50 Ω input impedance | 10 | Enable/disable Math channel |
| 5 | Select input range 1V or 10V p-p | 11 | Unwrap/wrap phase |
| 6 | Select 11M Ω or 50 Ω output load | | |



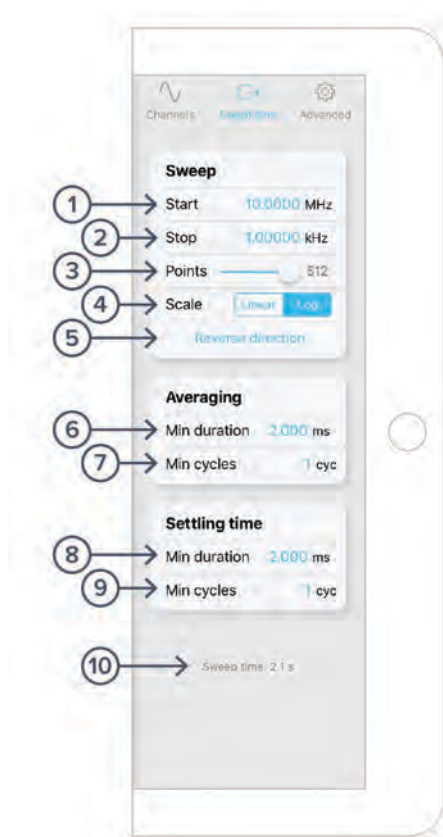
Math channel

- Select between addition, subtraction, multiplication and division of the two channels.
- Compare transfer functions of channel 1 and 2 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 point | 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 |



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:Lab'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

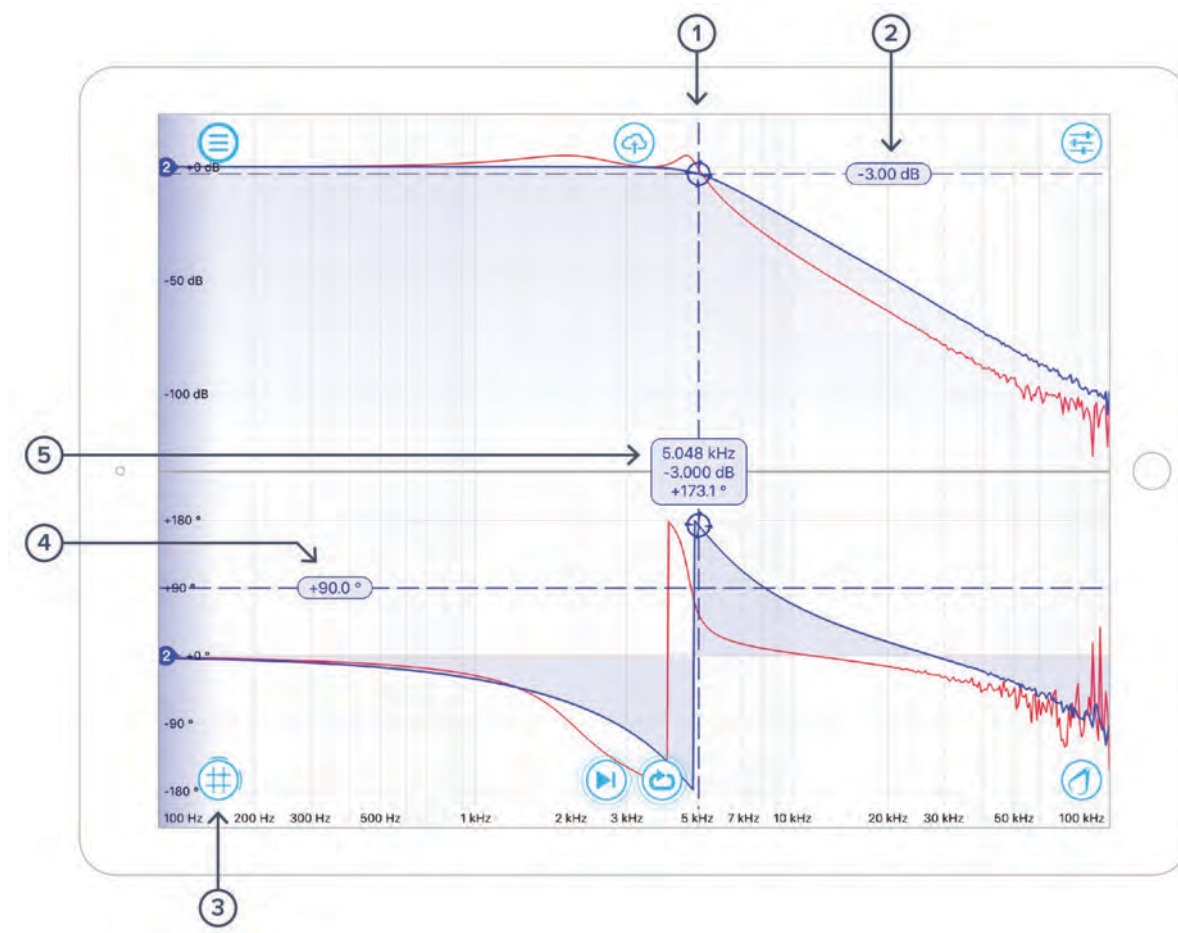
- The settling time determines how long the Frequency Reference Analyzer waits before performing measurements at each frequency in the sweep. Settling time is important when characterizing resonant systems with high Q-factors in order to allow excitations to 'settle' between measurements. It can also 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.



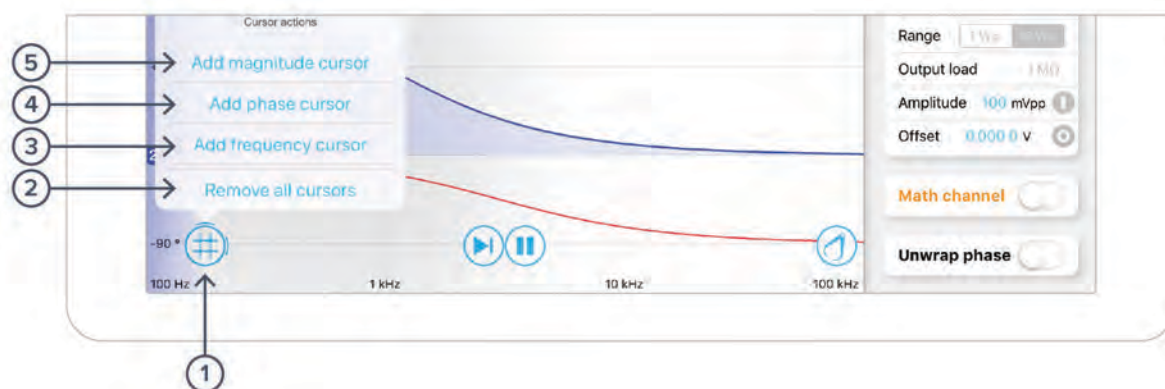
Cursors

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'.




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.

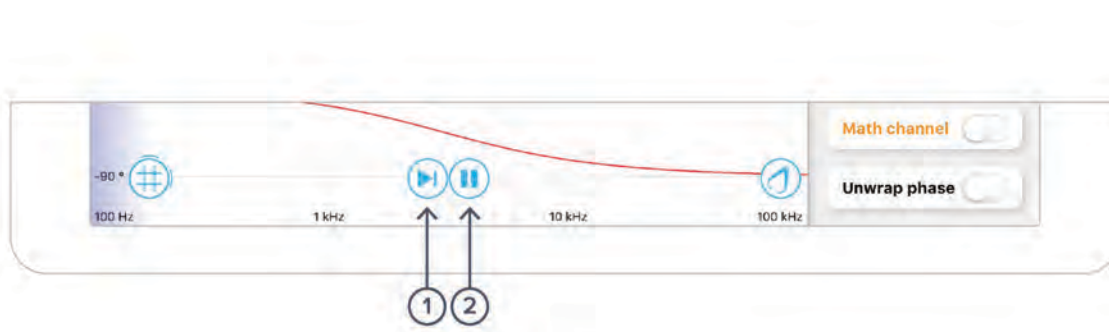
Continuous

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.

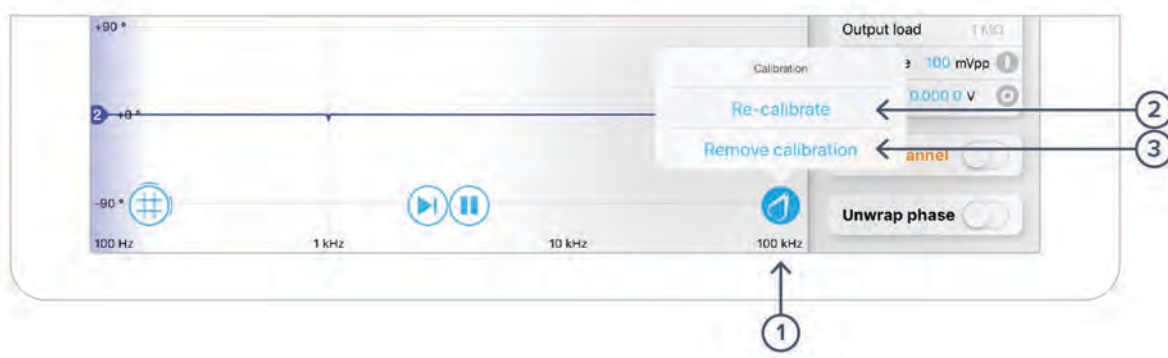


| ID | Description | ID | Description |
|----|--------------------|----|-------------|
| 1 | Start single sweep | 2 | Stop sweep |




Calibration

Moku:Lab'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.

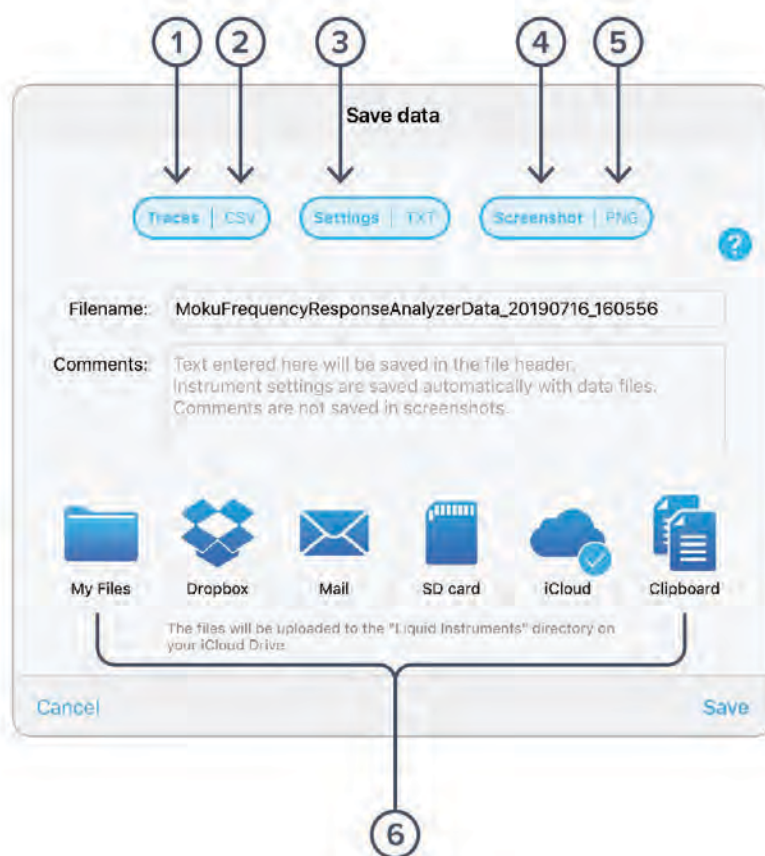


Exporting Data

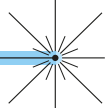
Measurement traces and screenshots can be uploaded to My Files (iOS 11 or later), Dropbox, E-mail, SD card, iCloud, Clipboard (screenshot is not copied to the clipboard).

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 |



Waveform Generator

User Manual

Moku:Lab's Waveform Generator is designed to generate common signals with high accuracy and configurability across two 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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Introduction

The waveform generator is an essential item of equipment in almost all engineering laboratories. The Moku:Lab implements a waveform generator as one of 12 high quality instruments.

The Moku waveform generator is a precision yet versatile instrument with a modern, touch based and intuitive interface. The tablet based interface operates wirelessly and this enables the engineer or technician to operate the Moku fully while free to move about the working environment.

Extensive configurations are readily available from the touch interface while the Moku can provide a precision timing reference or synchronize to an external time base.

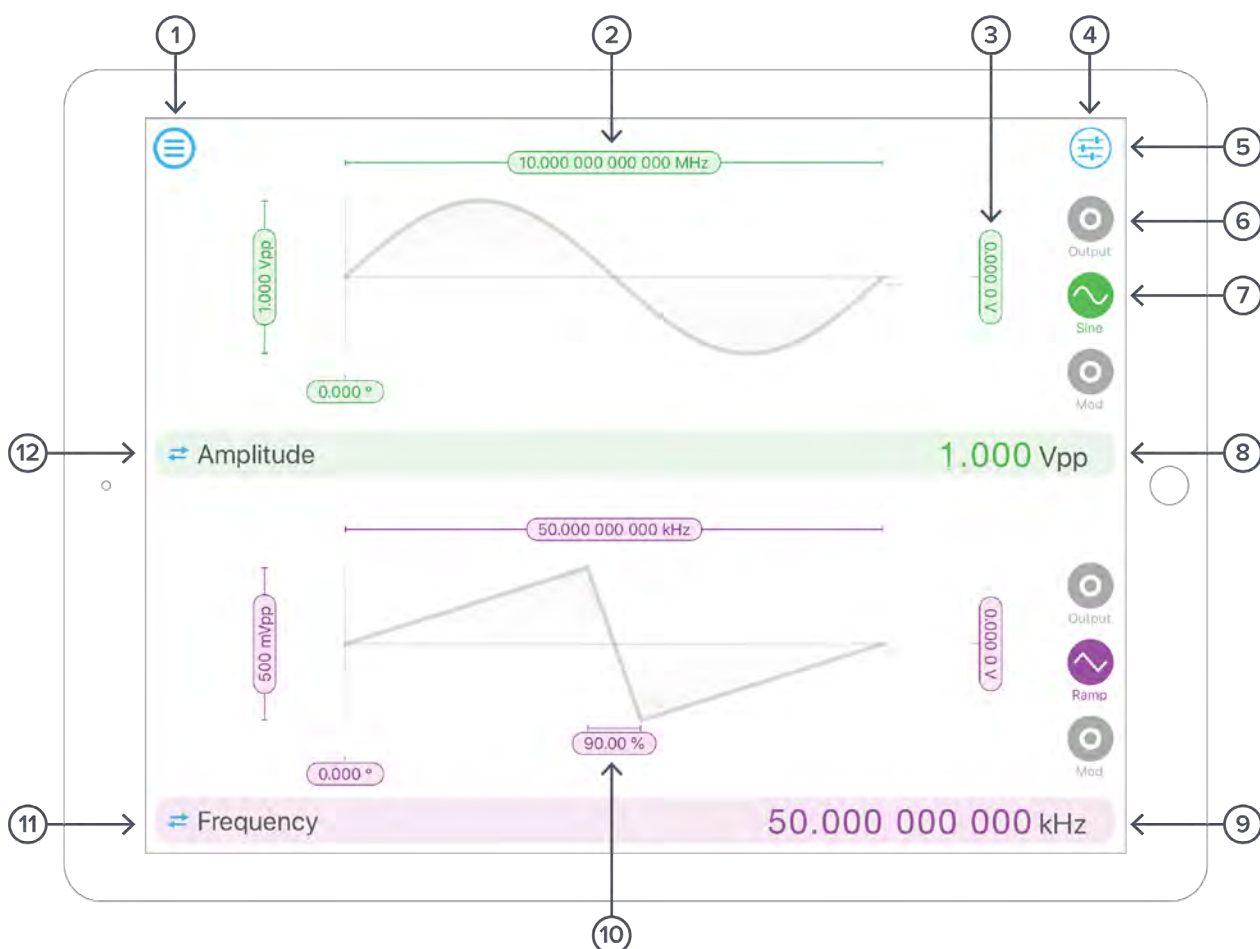
Moku also has Python, LabView and MATLAB interfacing capabilities.

The Moku waveform generator can be reconfigured nearly instantaneously to be one of:

- Oscilloscope
- Spectrum Analyzer
- Phasemeter
- Laser Lock Box
- Bode Analyzer
- FIR Filter Builder
- Digital Filter Box
- Waveform Generator
- Arbitrary Waveform Generator
- PID Controller
- Data Logger
- Lock in Amplifier



Quick start: User Interface

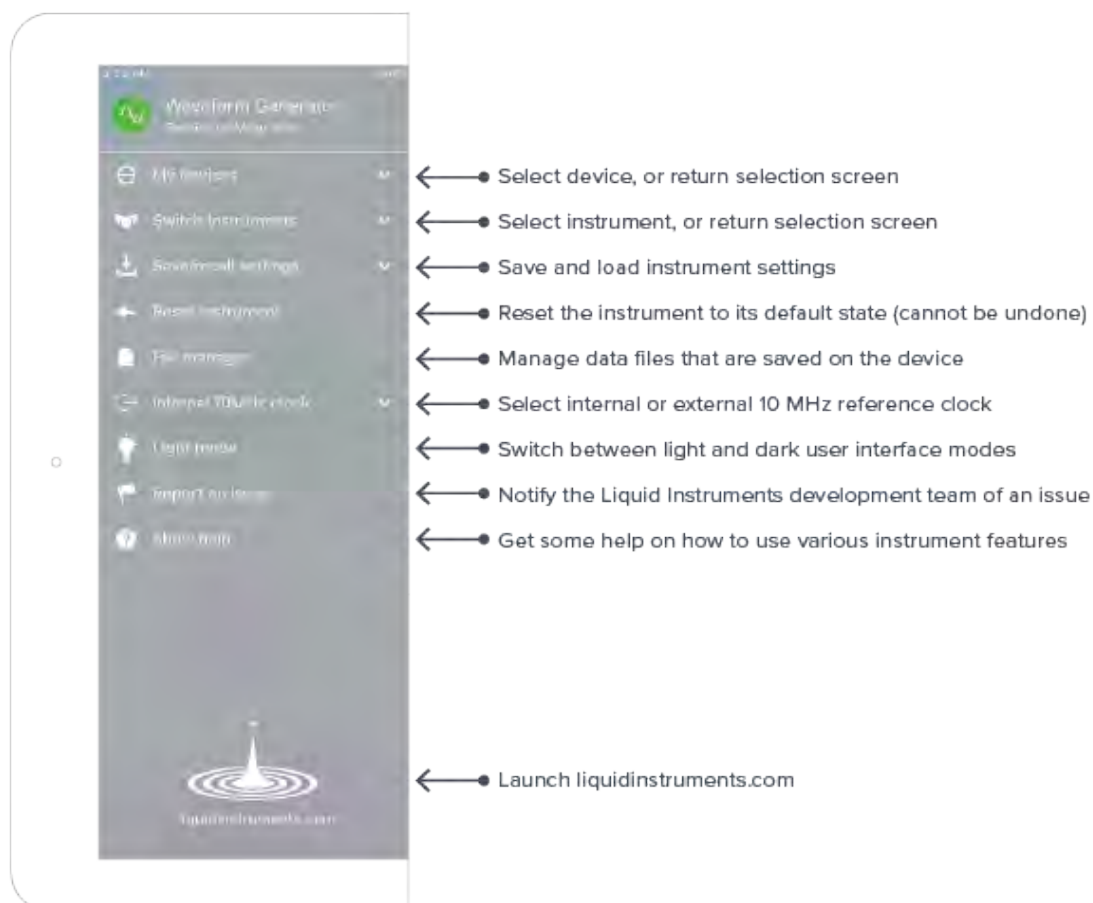


| ID | Description | ID | Description |
|----|------------------------------|----|--------------------------------------|
| 1 | Main menu | 7 | Configure modulation |
| 2 | Configure frequency / period | 8 | Configure displayed parameter (ch 1) |
| 3 | Configure waveform offset | 9 | Configure displayed parameter (ch 2) |
| 4 | Settings menu | 10 | Configure ramp symmetry |
| 5 | Enable / disable output | 11 | Switch between frequency and period |
| 6 | Waveform shape | 12 | Switch between frequency and period |




Main Menu

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

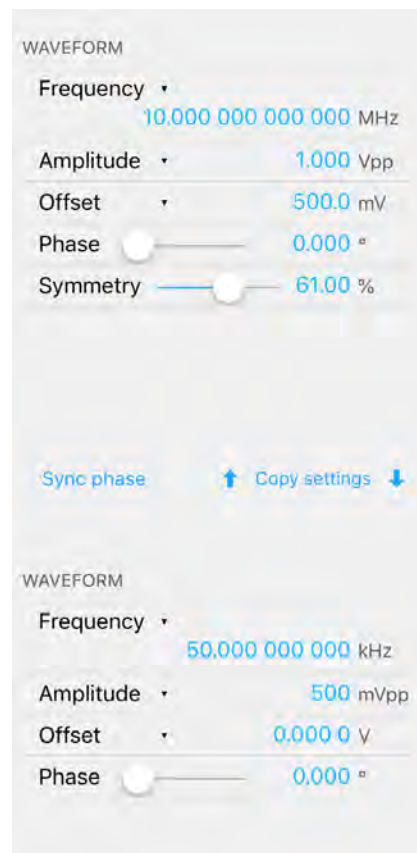




Settings

The settings menu can be accessed by tapping the  icon, allowing detailed waveform configurations on a per channel basis. Frequency, Amplitude, Phase and other waveform specific parameters can be entered manually

The settings on channel 1 can be instantly applied to channel two with [Copy Settings](#) and the two channels phase aligned with [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

Note on impedance

Moku'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. 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.

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.

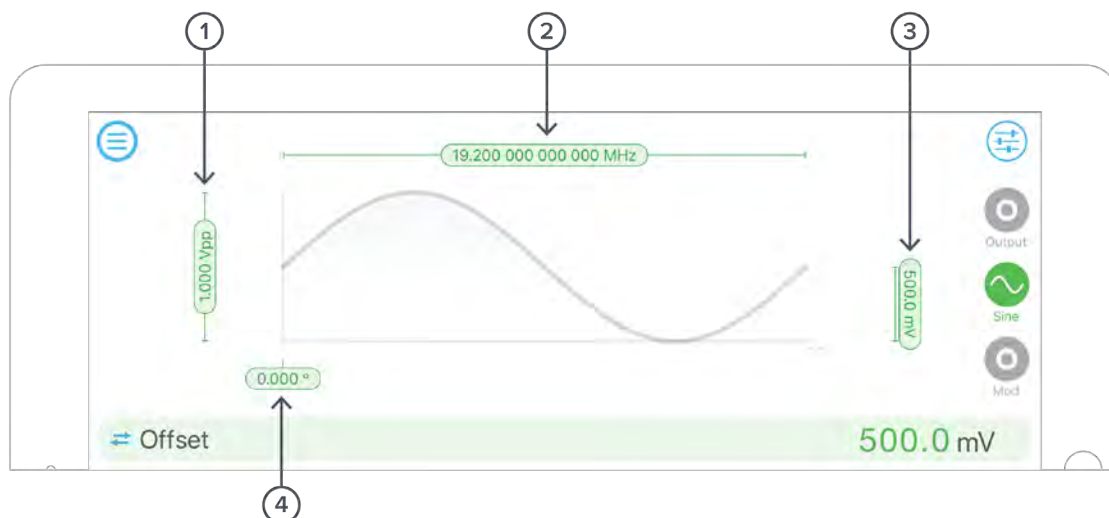
The Square wave is low jitter and symmetric (50% duty cycle)

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.



Sine Wave

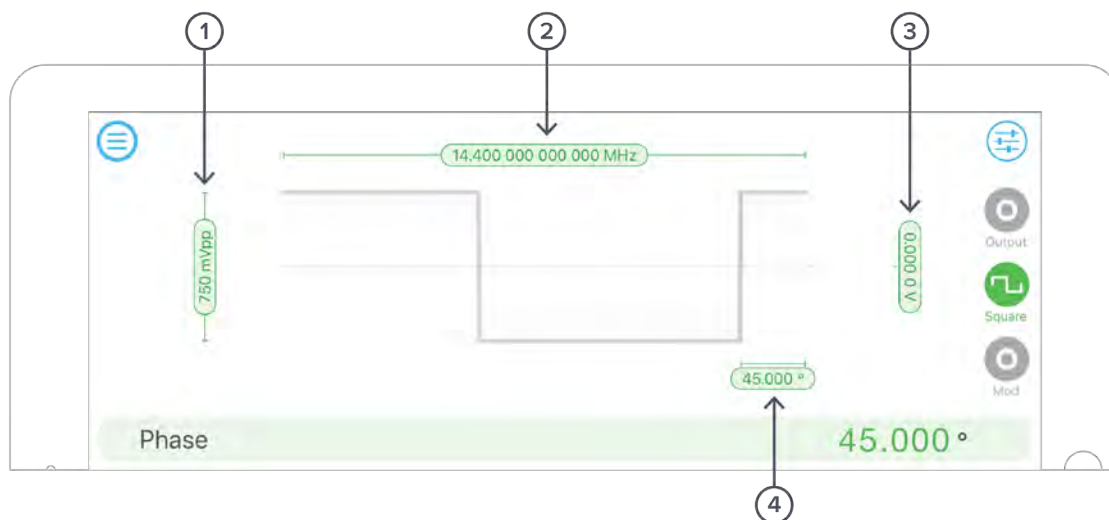


| ID | Description | ID | Description |
|----|---------------------------|----|--------------------|
| 1 | Amplitude (High Level) | 3 | Offset (Low Level) |
| 2 | Signal Frequency (Period) | 4 | Phase |

Tap Parameter Settings pill or bar to change. Parameter bar can show different representations of many parameters; these alternative representations are shown in brackets.



Square Wave

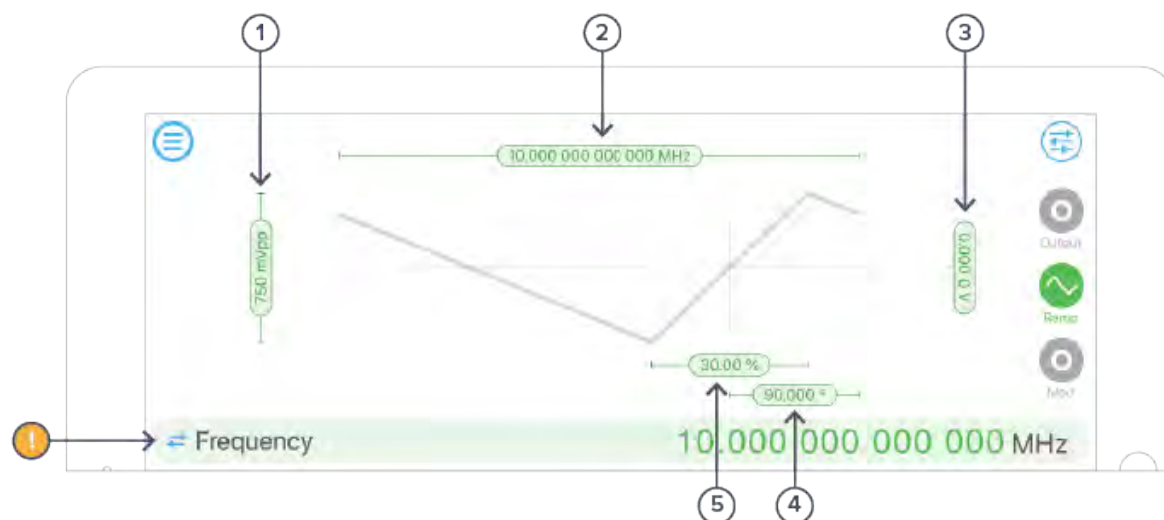


| ID | Description | ID | Description |
|----|---------------------------|----|--------------------|
| 1 | Amplitude (High Level) | 3 | Offset (Low Level) |
| 2 | Signal Frequency (Period) | 4 | Phase |

Tap Parameter Settings pill or bar to change. Parameter bar can show different representations of many parameters; these alternative representations are shown in brackets.



Ramp Wave



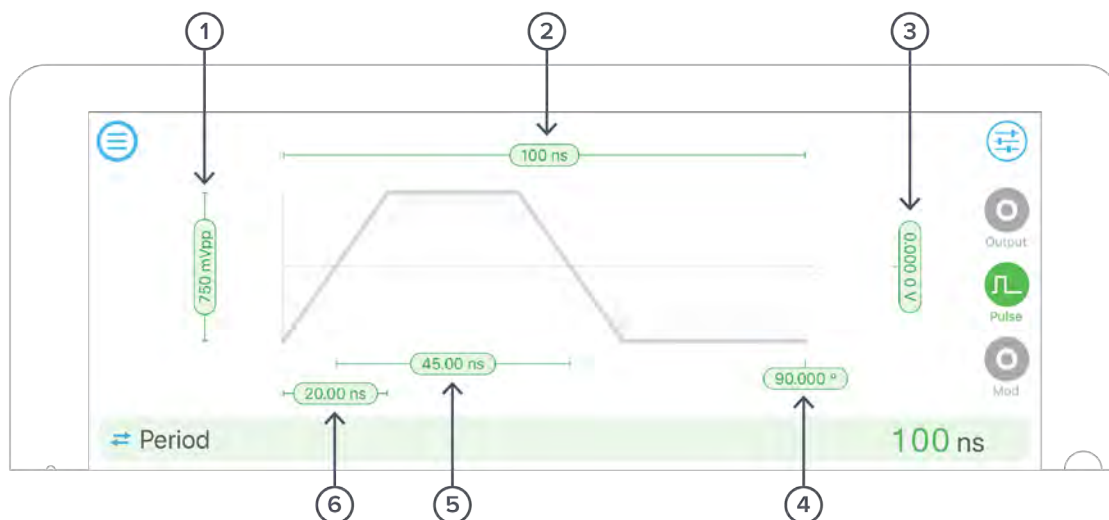
| ID | Description | ID | Description |
|----|---------------------------|----|-------------|
| 1 | Amplitude (High Level) | 4 | Phase |
| 2 | Signal Frequency (Period) | 5 | Symmetry |
| 3 | Offset (Low Level) | | |

 **HOT TIP:** Tap 'Frequency' to change to 'Period' and vice versa

Tap Parameter Settings pill or bar to change. Parameter bar can show different representations of many parameters; these alternative representations are shown in brackets.



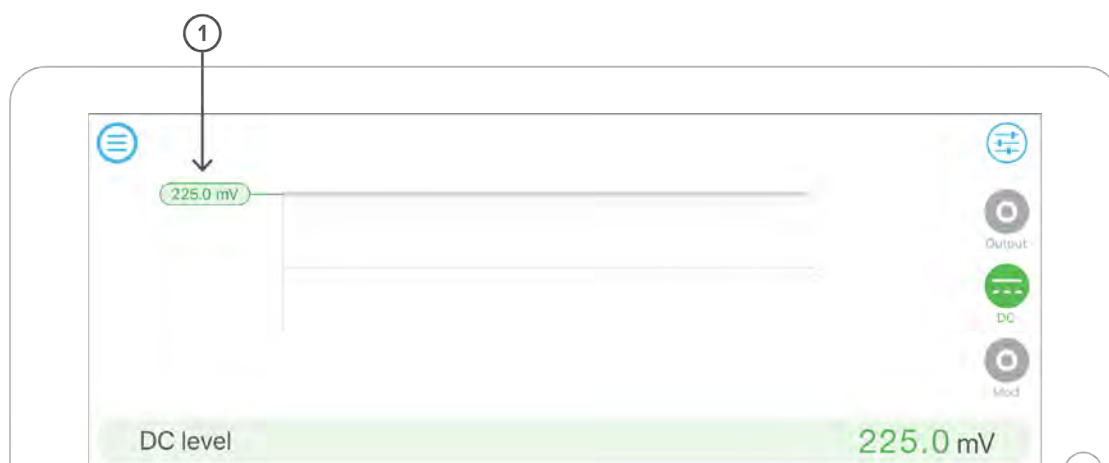
Pulse Wave



| 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.

DC wave



| ID | Description |
|----|-------------|
| 1 | DC level |

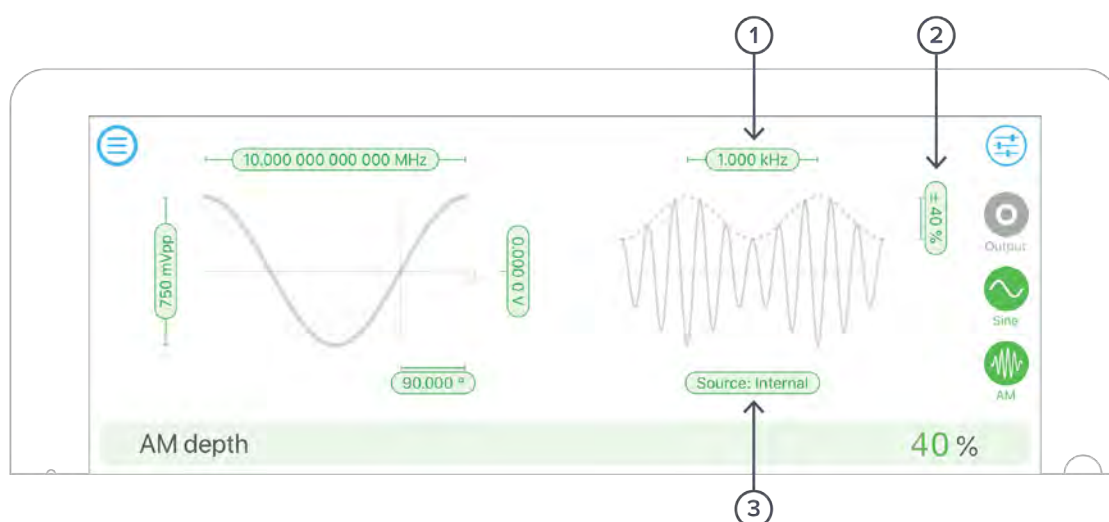
Tap Parameter Settings pill or bar to change. Parameter bar can show different representations of many parameters; these alternative representations are shown in brackets.



Modulation types

Moku'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.

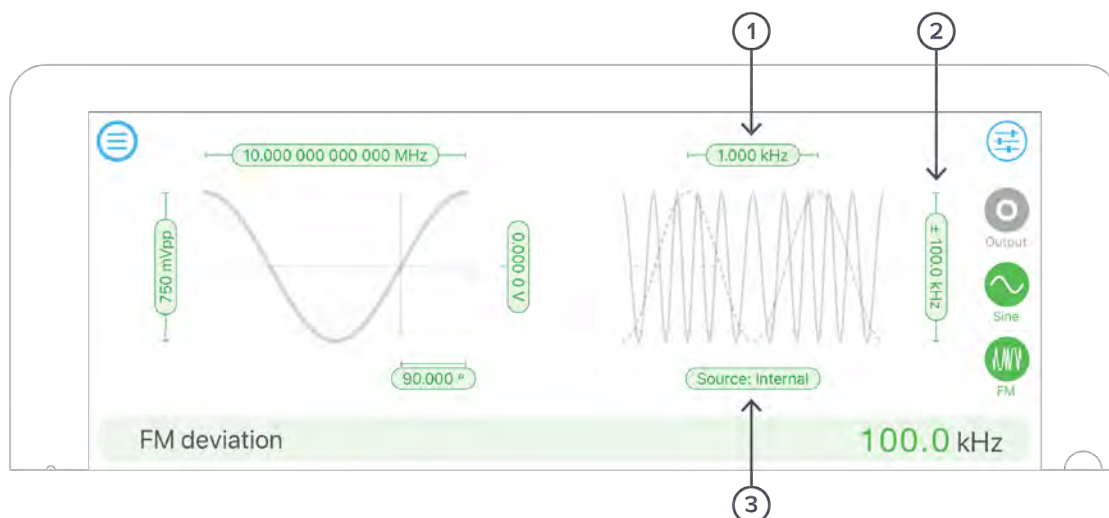
Amplitude modulation



| 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 input; the other Moku output or a “internal”, an internally-generated sinewave. |



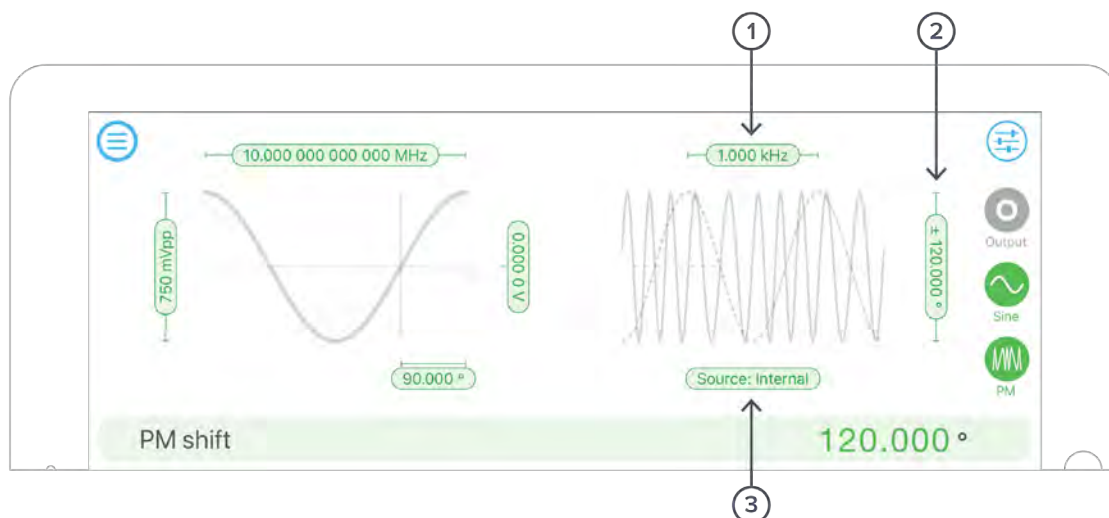
Frequency modulation



| 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 input; the other Moku output or a “internal”, an internally-generated sinewave. |



Phase modulation



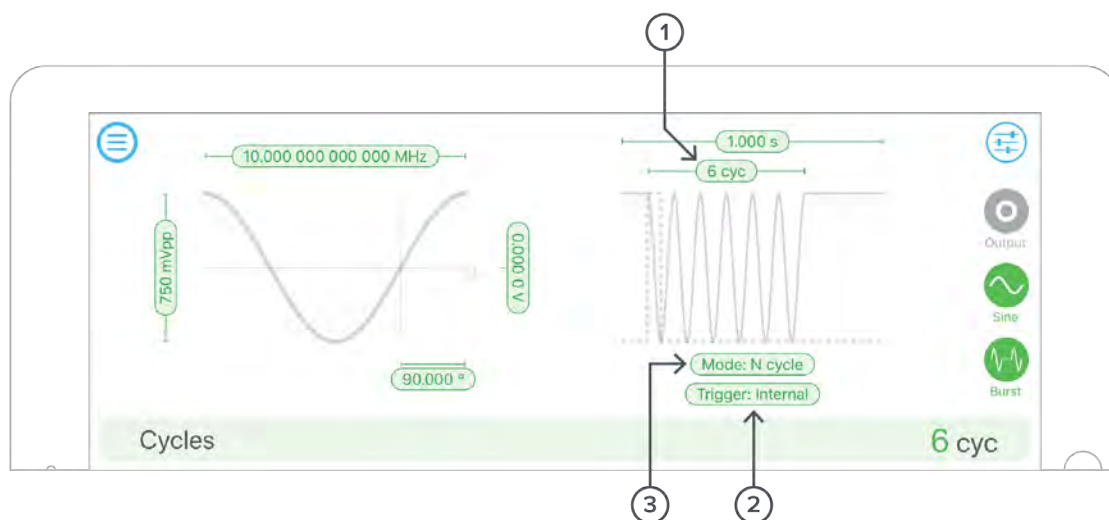
| ID | Parameter | Description |
|----|-------------------|---|
| 1 | Frequency | Only for “Internal” modulation; the frequency of the sine wave being used for modulation. |
| 2 | Depth | Full-range phase deviation. A full-range input signal will vary the output phase by this amount. |
| 3 | Modulation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

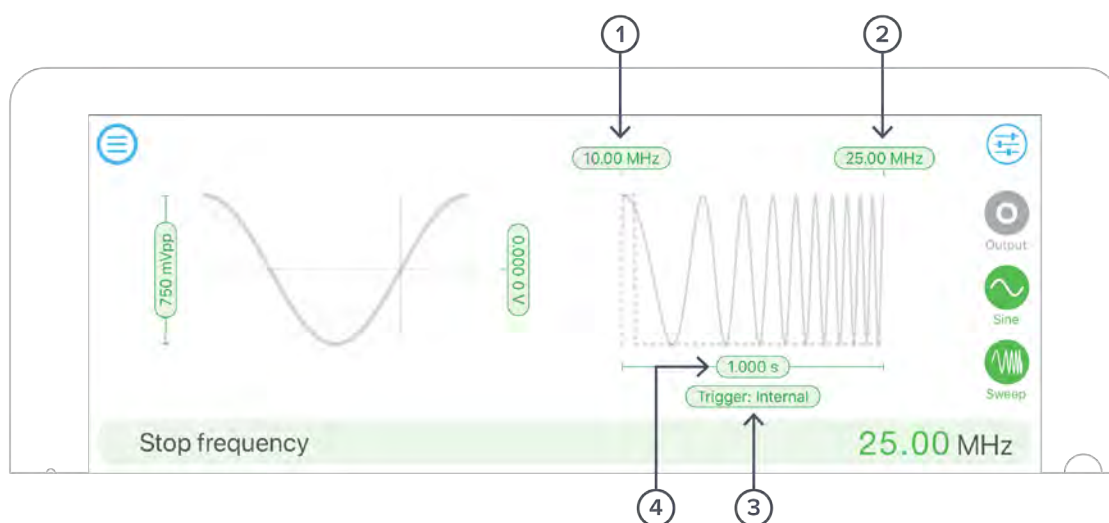
Burst



| ID | Parameter | Description |
|----|----------------|---|
| 1 | Cycle count | N - Cycle mode only. The number of cycles to generate before re-arming. |
| 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 opposite 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. |



Sweep



Sweep modulation acts like frequency modulation with a sawtooth, where the sawtooth starts on the trigger event.

| ID | Parameter | Description |
|----|-----------------|---|
| 1 | Start Frequency | Waveform frequency at the trigger event (sweep start) |
| 2 | End Frequency | Waveform frequency at the sweep end |
| 3 | 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 opposite output channel, at given voltage |
| 4 | Sweep Time | Time between sweep start and end |



Instrument Reference

Waveform Types

The Moku:Lab'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. 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 either channel of the Moku 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 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.



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's internal reference. By tapping the "Sync Phase" button in the Settings Drawer, this phase also becomes relative to the other 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:Lab 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). The depth is specified *per volt* on the input.

Output

Modulation for a given channel is driven by the opposite analogue output (i.e. Output 1 is modulated by the waveform on Output 2 and vice-versa). 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:Lab Technical Specifications available at www.liquidinstruments.com.

Input

The corresponding Analogue 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

The opposite Analogue output is 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.

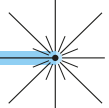
Sweep mode has three configurable parameters:



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.



PID Controller User Manual

Moku:Lab's PID (Proportional-Integrator-Differentiator) Controller features two fully real-time configurable PID controllers with an output sample rate of 10 MSa/s. This enables them to be used in applications requiring both low and high feedback bandwidths such as temperature and laser frequency stabilization. The PID Controller can also be used as a lead-lag compensator by saturating the integral and differential controllers with independent gain settings.





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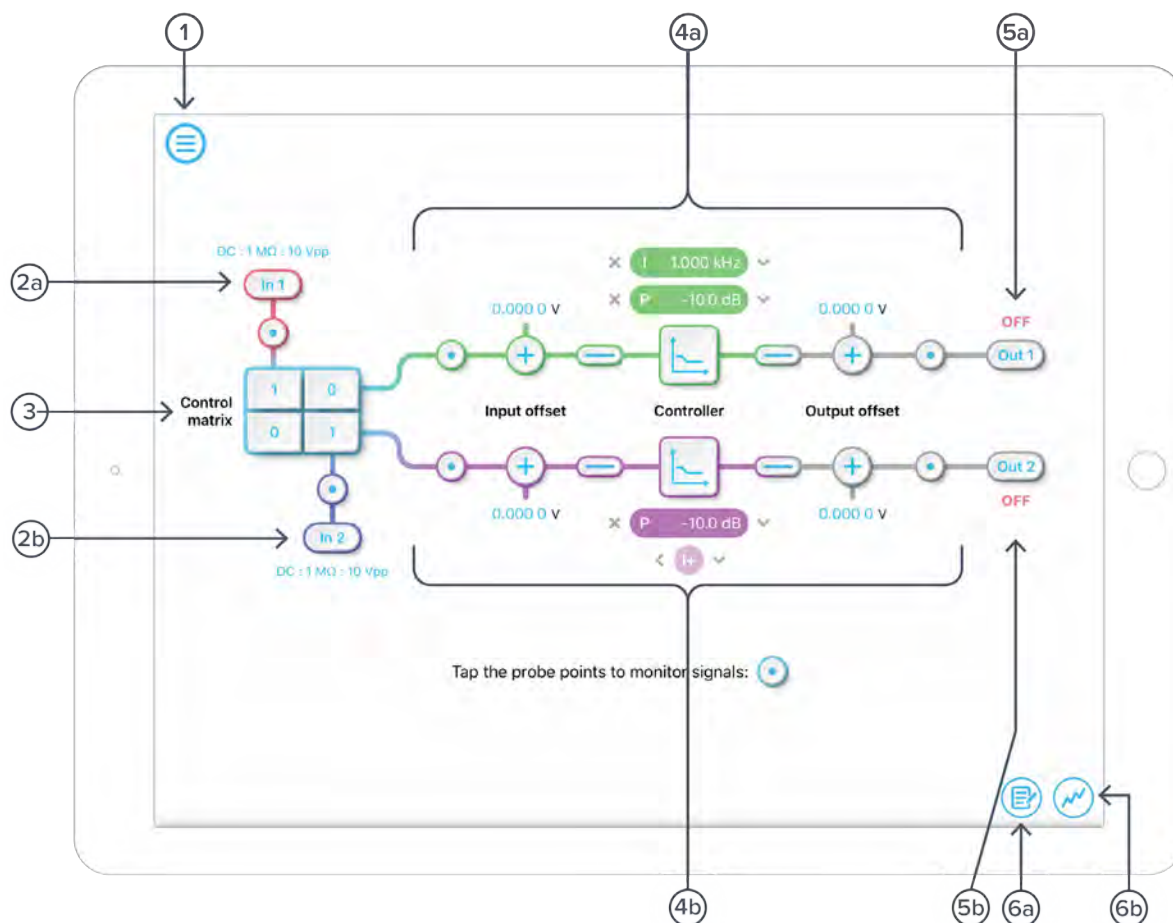


Ensure Moku:Lab is fully updated. For the latest information:

www.liquidinstruments.com



User Interface




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 |
| 6a | Enable the data logger |
| 6b | Enable the oscilloscope |



Main Menu

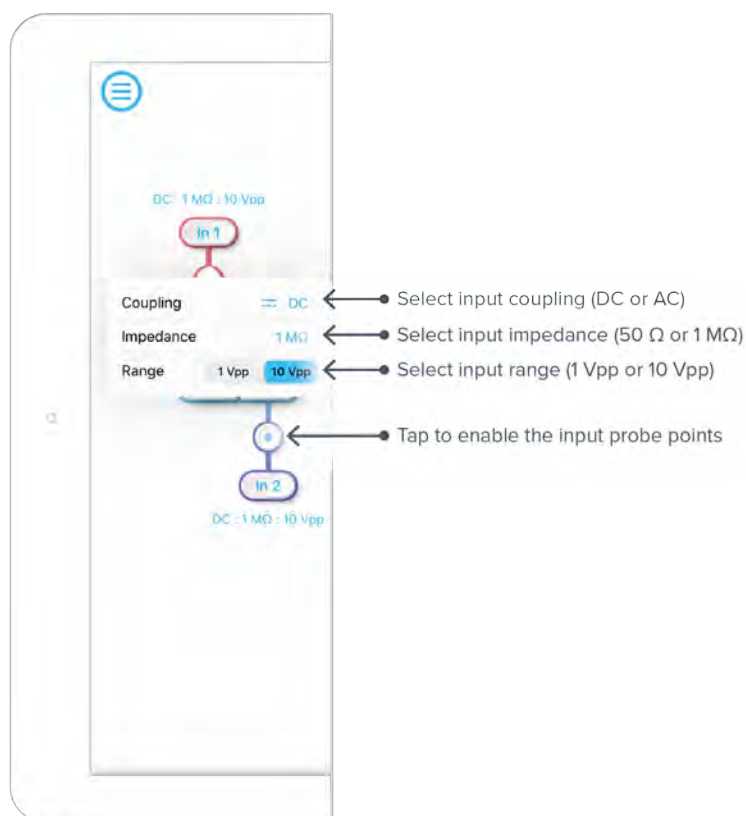
The **main menu** can be accessed by pressing the  icon, allowing you to:





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.

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

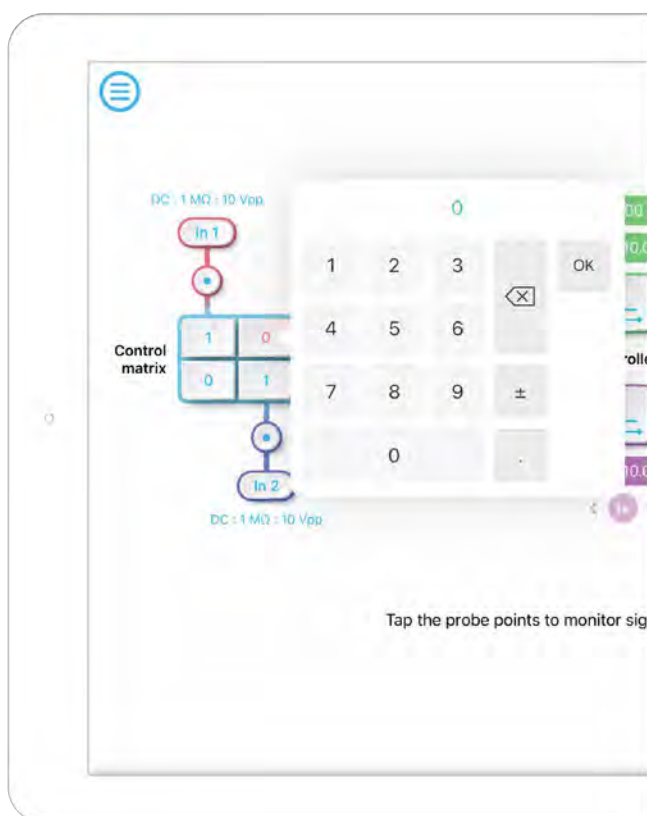
where

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

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

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.

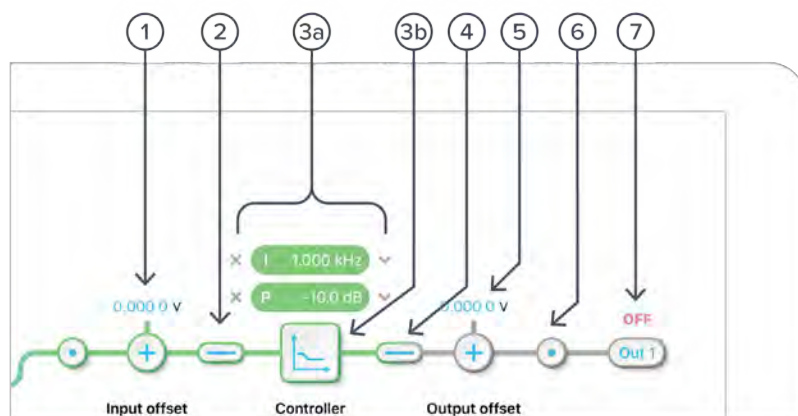




PID Controller

The two independent, fully real-time configurable PID controller paths follow the control matrix in the block diagram, represented in green and purple for controller 1 and 2, respectively. The PID generates a minimum latency of 733 ns. The latency is about 813 ns with all controllers enabled.

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:Lab output switch | Tap to enable/disable the Moku:Lab's DAC output. |

Input / Output Switches



Closed/Enable



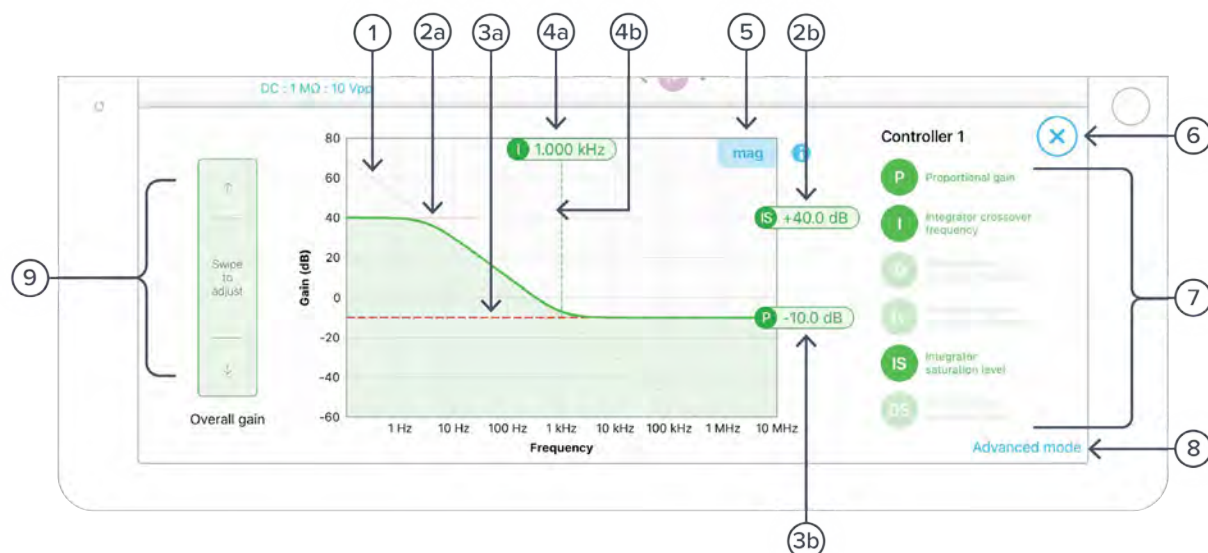
Open/disable



Controller (Basic Mode)

Controller Interface

Tap the  icon to open the full controller view.

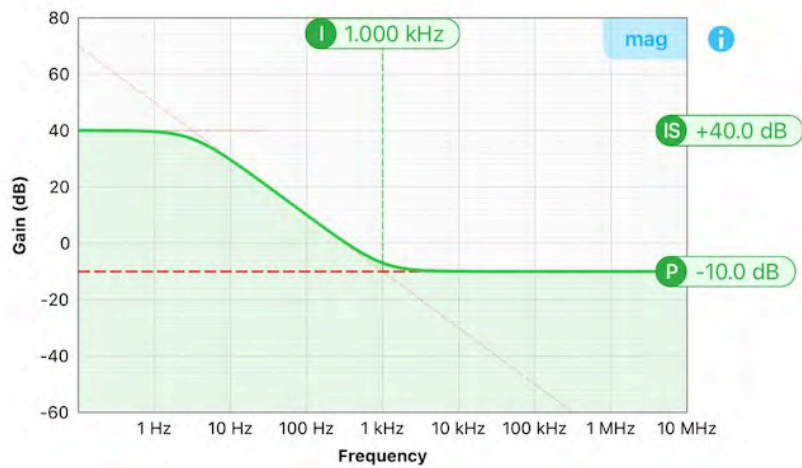


| ID | Parameter | Description |
|----|-----------------------|---|
| 1 | Design cursor 1 | Cursor for Integrator (I) setting. |
| 2a | Design cursor 2 | Cursor for Integrator Saturation (IS) level. |
| 2b | Cursor 2 reading | Reading for IS level. Drag to adjust the gain. |
| 3a | Design cursor 3 | 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 | 1 Hz to 100 kHz |
| Differentiator crossover frequency | 10 Hz to 1 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)

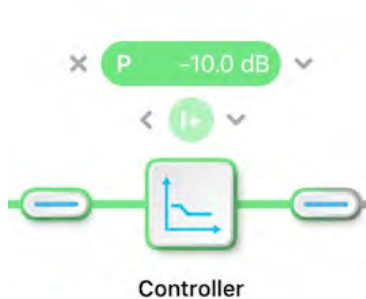
In **Advanced Mode**, users can build fully customized controllers with two independent sections (A and B), and six adjustable parameters in each section. Tap the **Advanced Mode** button in the full controller view to switch to the **Advanced Mode**.



| 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.

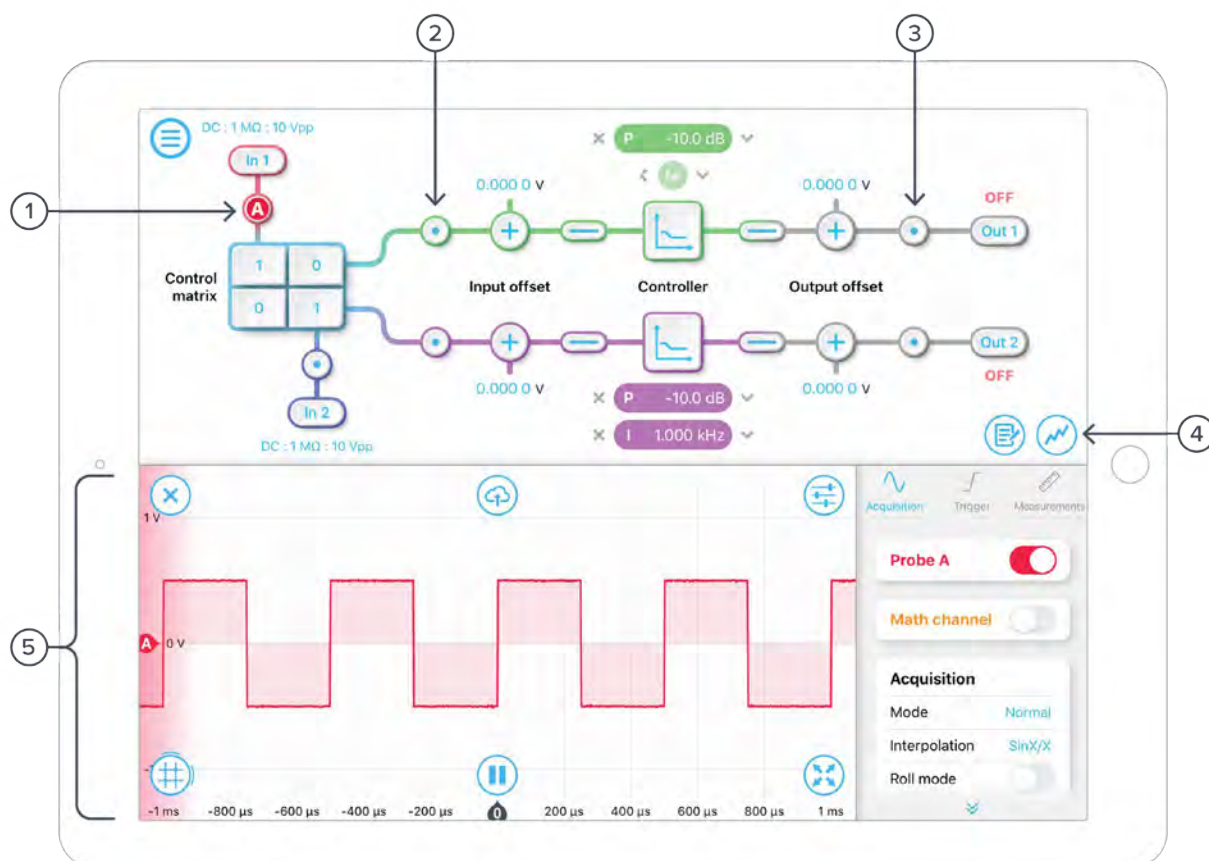
Tap the active controller path icon (i.e. ) to enter the value. Hold and slide to adjust the value.



Probe Points

Moku:Lab'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.

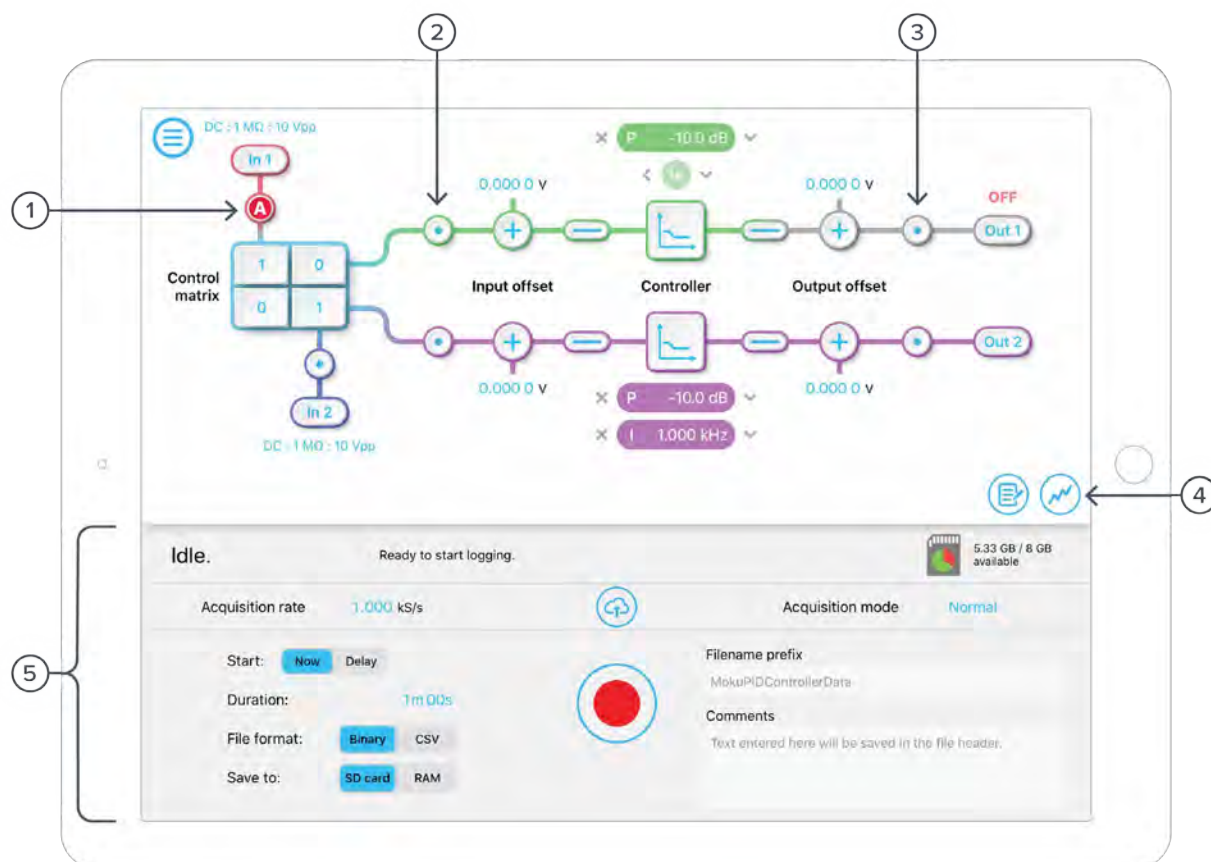
Oscilloscope



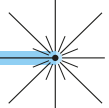
| ID | Parameter | Description |
|----|---------------------------------|---|
| 1 | Input probe point | Tap to place the probe point at input. |
| 2 | Pre-PID probe point | Tap to place the probe after the control matrix. |
| 3 | Output probe point | Tap to place the probe at output. |
| 4 | Oscilloscope/data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



Phasemeter User Manual

Moku:Lab's Phasemeter measures phase with up to 6 μ radian precision for input signals oscillating between 1 kHz and 200 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:Lab'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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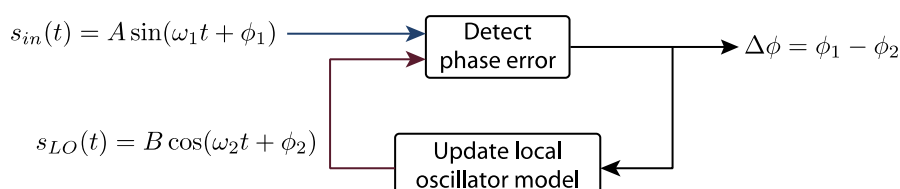
www.liquidinstruments.com



Introduction

How does it work?

Moku:Lab'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 phase that expected to drift over many wavelengths within the measurement time, but still require extremely high measurement precision.

Heterodyne interferometry

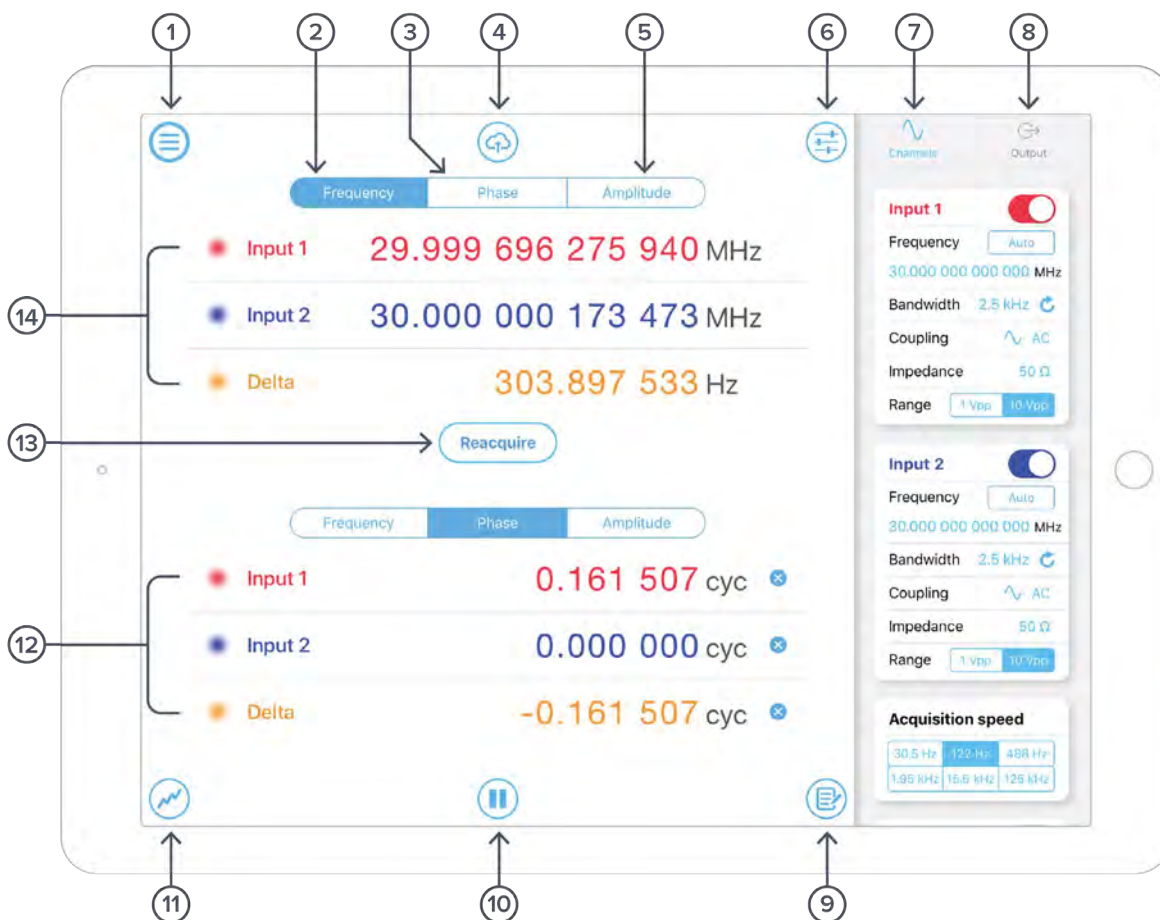
One key application of phasemeters is in heterodyne interferometry, where displacement information is stored within the phase of a beat-note produced by interfering two electric fields with slightly different frequencies at a photodetector. Laser heterodyne interferometers are typically used to measure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

At a laser wavelength of 1064 nano-meters, Moku:Lab'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.



User Interface



| ID | Description |
|----|-------------|
|----|-------------|

- | | |
|---|-------------------------------|
| 1 | Main menu |
| 2 | Display frequency data |
| 3 | Display phase data |
| 4 | Export data |
| 5 | Display amplitude data |
| 6 | Instrument configuration menu |
| 7 | Channel settings |

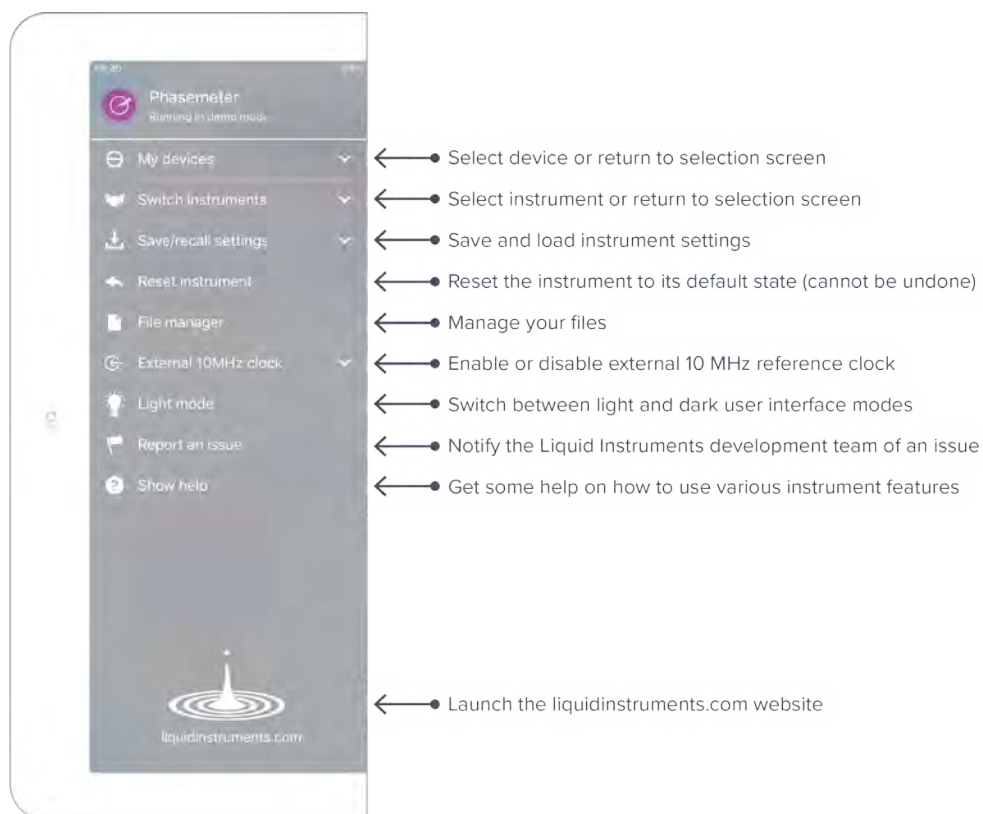
| ID | Description |
|----|-------------|
|----|-------------|

- | | |
|----|-----------------------------|
| 8 | Output settings |
| 9 | Data logger |
| 10 | Start / pause measurement |
| 11 | Data visualization |
| 12 | Channel data display area 1 |
| 13 | Reacquire button |
| 14 | Channel data display area 2 |



Main Menu

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





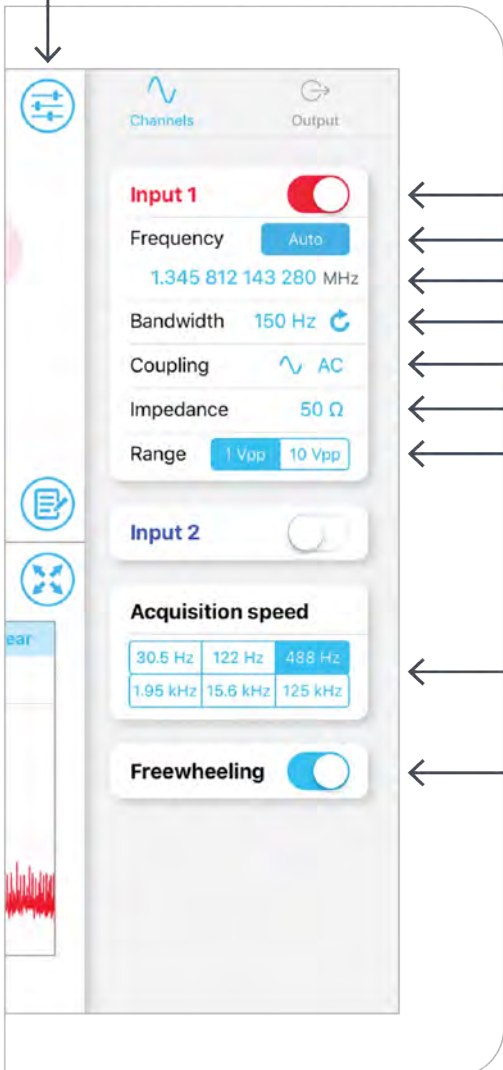
Channel Configuration

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

Access the measurement configuration menu by pressing the  icon.

Channels

● Show / hide the measurement configuration menu



- ← Activate / deactivate channel 1
- ← 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 MΩ** input impedance
- ← Select between **1 V_{pp}** and **10 V_{pp}** input range
- ← 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 specify 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 200 MHz

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

Bandwidth

- The Moku:Lab'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 10 V_{pp} input voltage range. If the amplitude of the input signal is lower than 1 V_{pp}, use the 1 V_{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.
- Data visualization (graphs) are not available for acquisition speeds above 500 Hz

Freewheeling

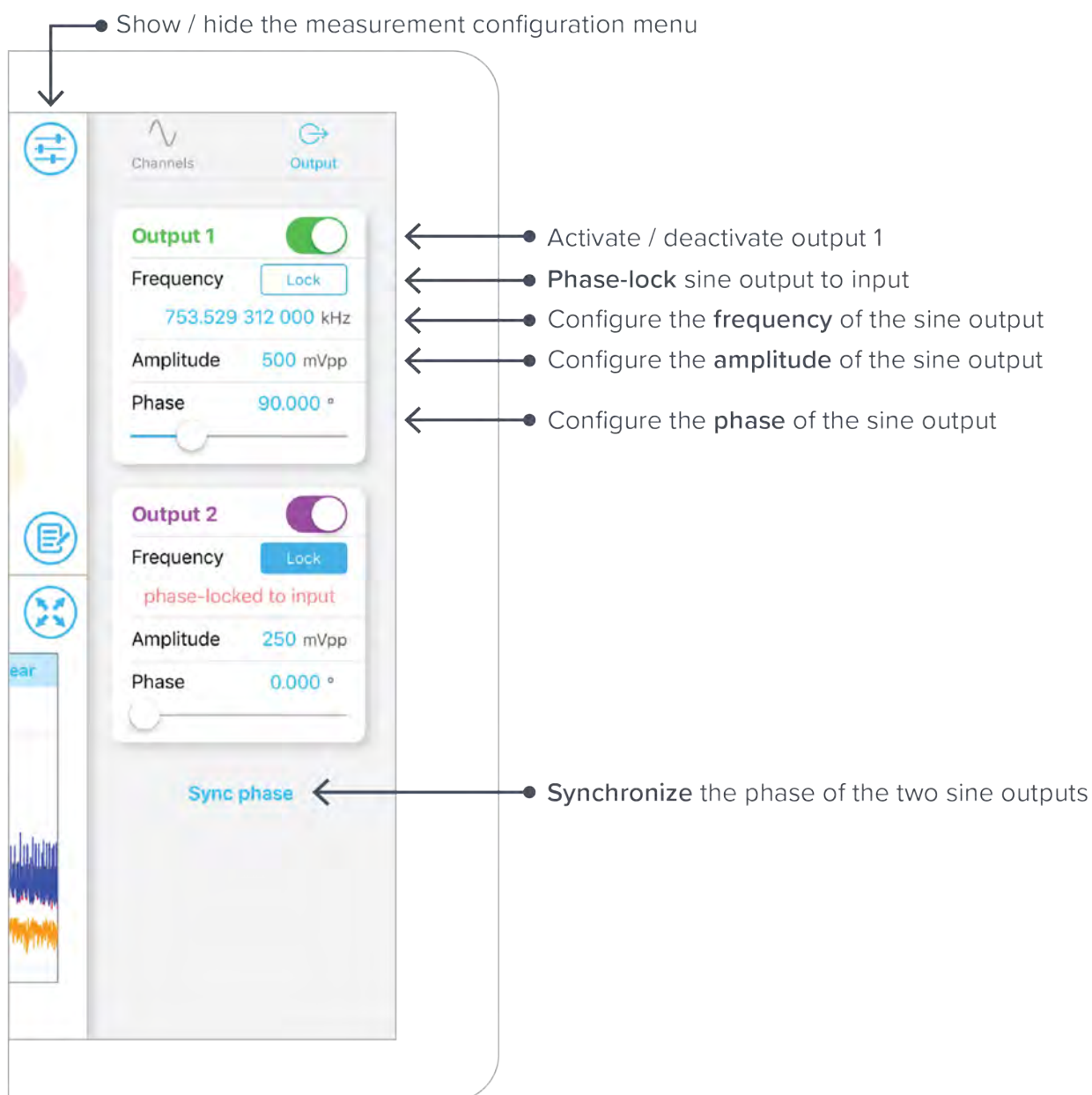
- When freewheeling mode is enabled, the phasemeter will continue to 'freewheel' at a constant frequency when the input signal is too weak to track reliably. The phasemeter will resume tracking the phase of the input signal when its amplitude returns to a reliable level
- The freewheeling frequency is 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



Outputs

The Phasemeter features two output 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 the two outputs can be synchronized by tapping the **Sync phase** button at the bottom of the tab.

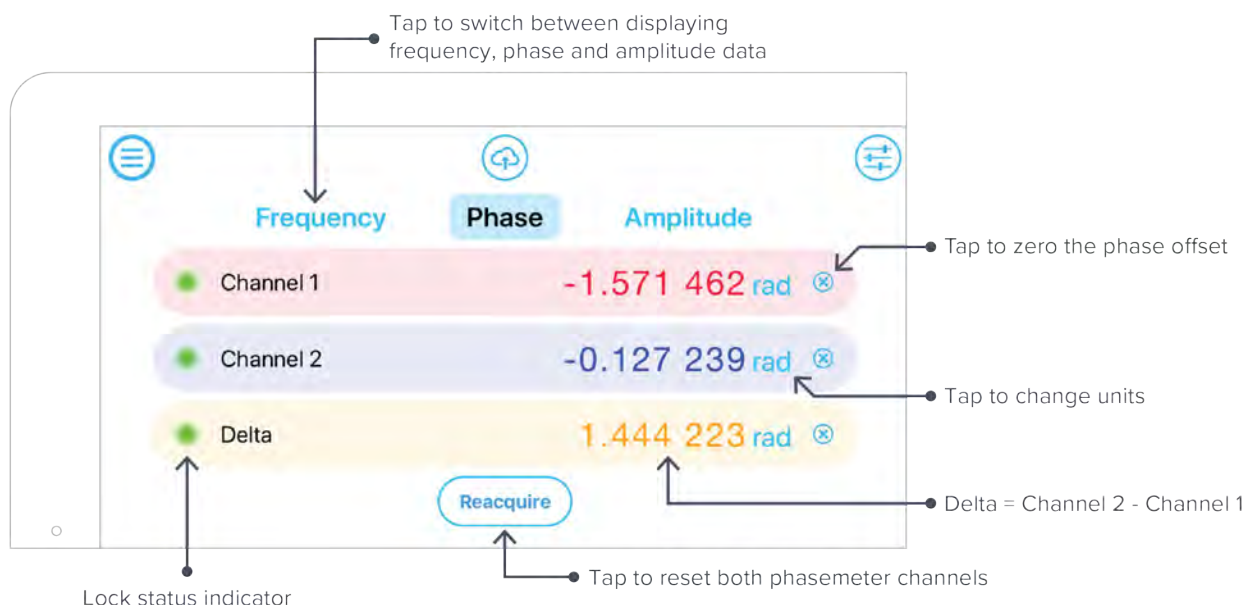


Phase-locked output

- 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



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 blue 'units' text to switch between units
- Zero the phase offset by tapping the icon on the right-hand side of the display. Zeroing the phase offset of the Delta channel will zero the phase offset of channels 1 and 2

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 blue 'units' text switch between units

Lock status indicator


- Indicates whether or not the phasemeter is tracking the input signal correctly. A red icon indicates that the phasemeter is not tracking the input signal

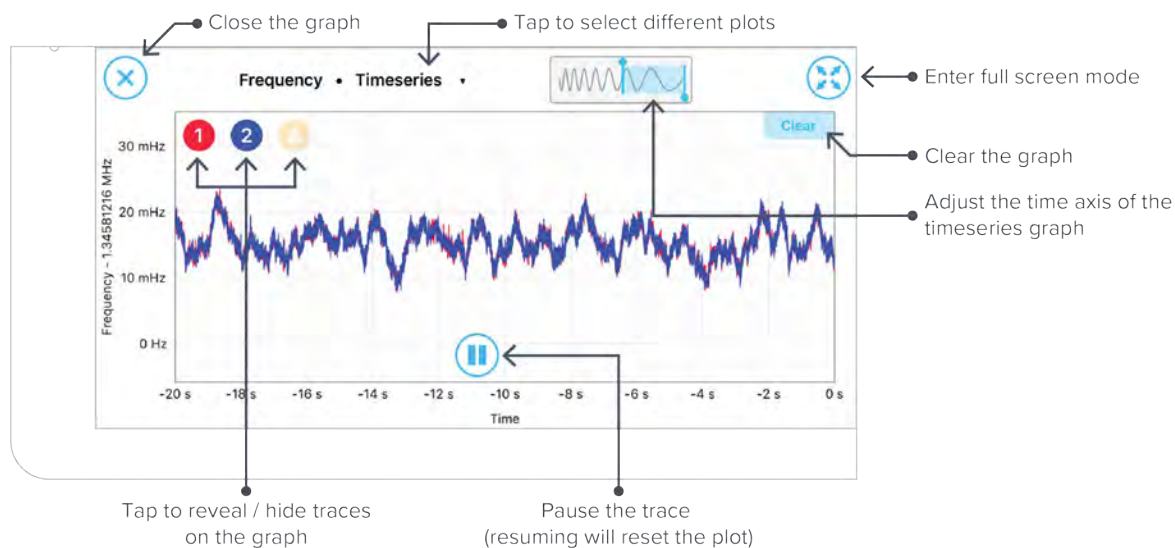
Reacquisition

- Tap the **Reacquire** button to reset both phasemeter channels simultaneously
- Both channels are reset at the same time to maintain synchronization



Data Visualization

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





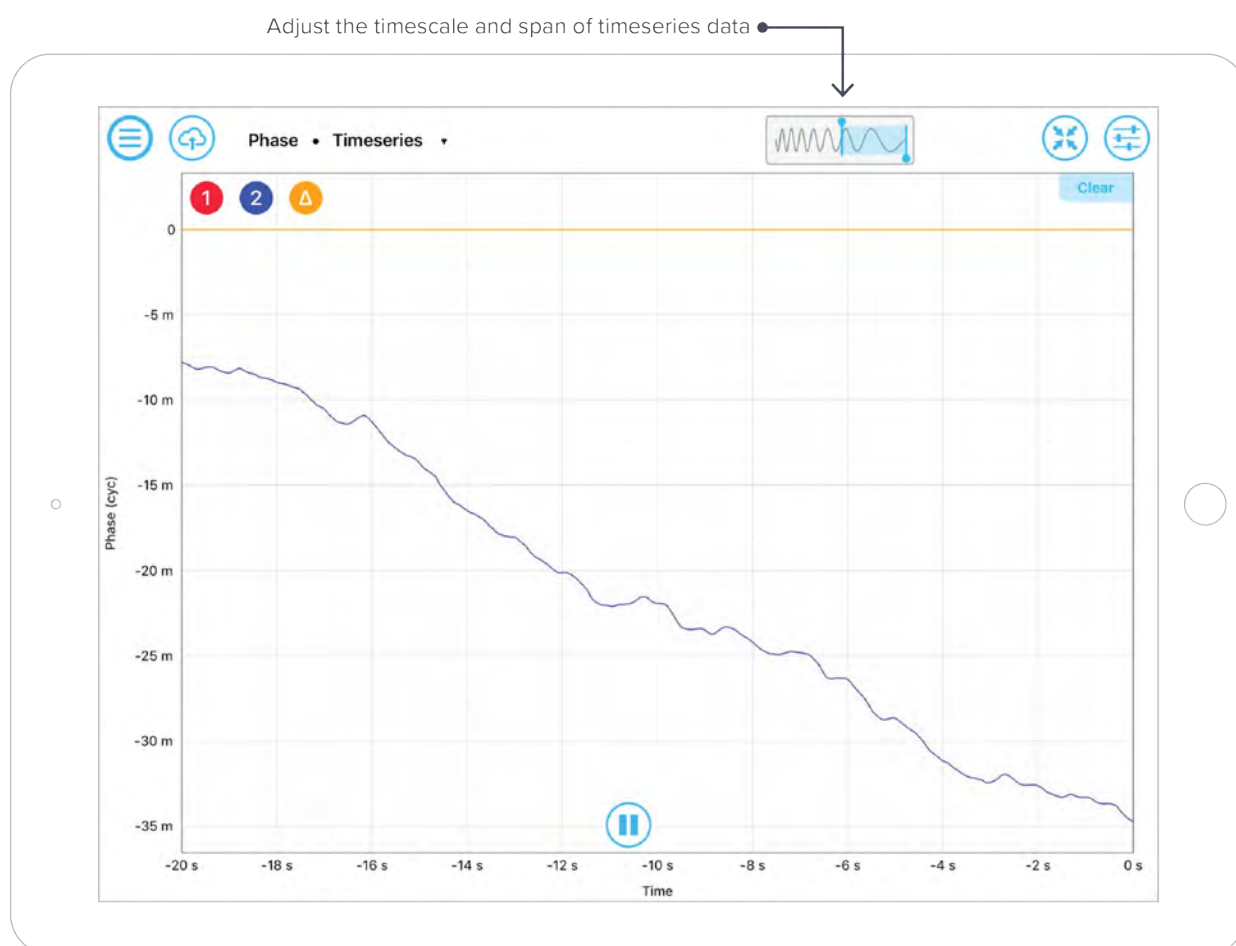
Plot Types

Frequency, Phase and Amplitude data can be displayed in different formats, including timeseries, power spectral density, amplitude spectral density, coherence, Raleigh spectrum and Allan deviation.

- All plot types can be auto-scaled by double tapping anywhere on the graph
- Individual traces can be hidden and revealed by tapping the **1**, **2** and **Δ** icons located at the top left of the graph

Timeseries

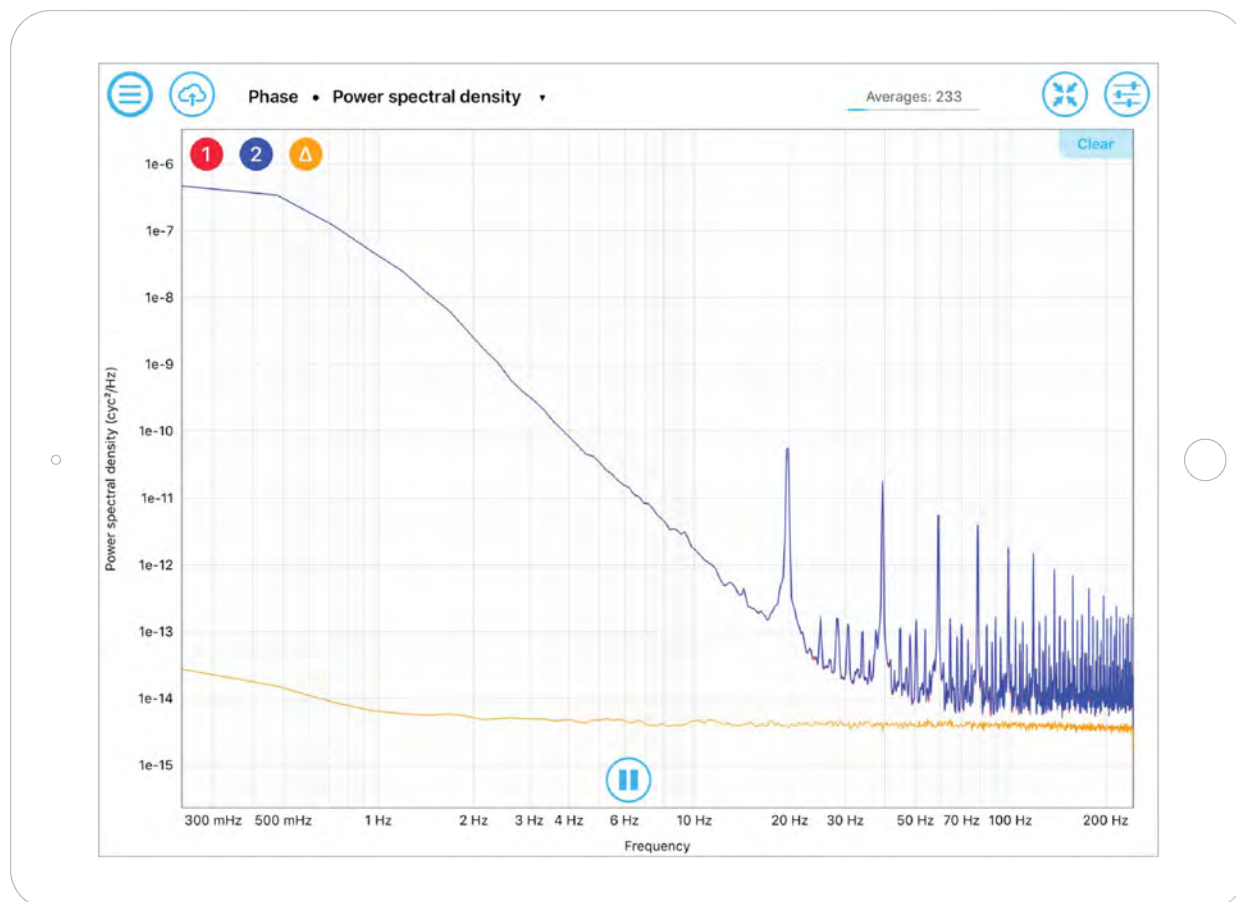
- Timeseries data can be viewed over time spans ranging from 0.5 seconds to 600 seconds
- Adjust timescale and span using pinch gestures anywhere on the graph
- Set the start and end times of the span manually using the slide rule located above the graph





Power spectral density

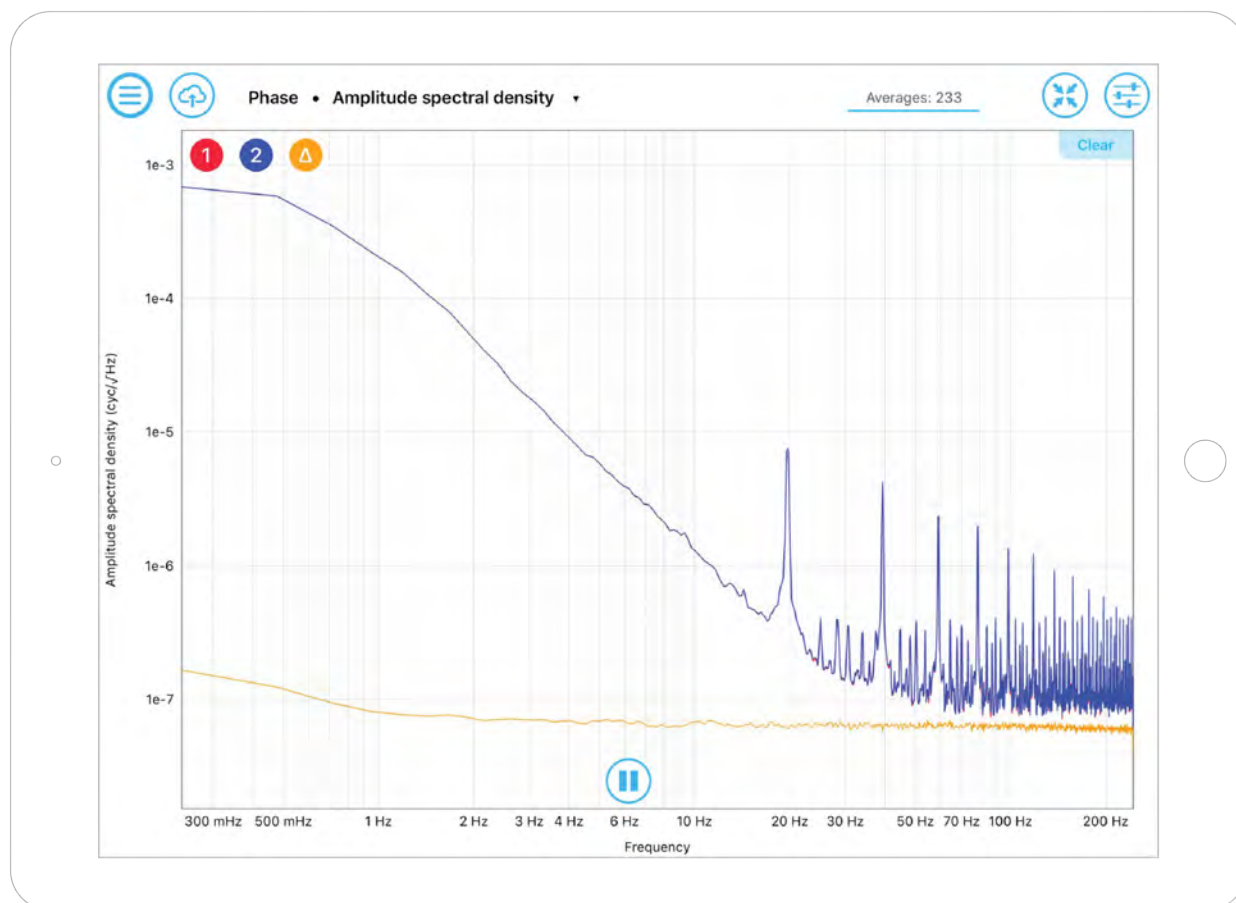
- Power spectral density describes a signal's distribution of power at different frequencies.
- The units of power spectral density are proportional to $\text{amplitude}^2/\text{Hz}$ (e.g., $\text{cycles}^2/\text{Hz}$)





Amplitude spectral density

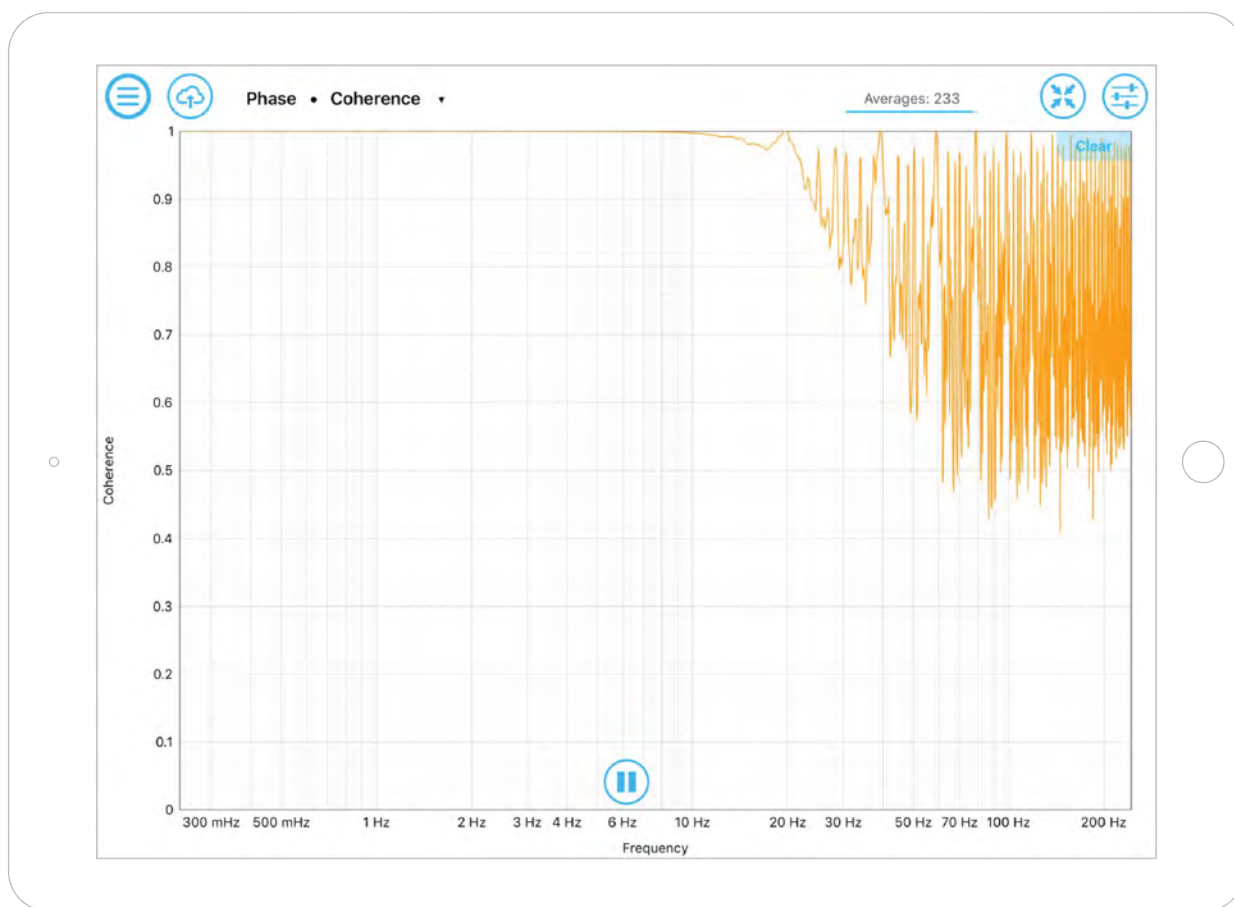
- Amplitude spectral density provides a measure of a signal's amplitude at different frequencies
- The units of amplitude spectral density are proportional to amplitude/ $\sqrt{\text{Hz}}$ (e.g. cycles/ $\sqrt{\text{Hz}}$)
- Amplitude spectral density is equal to the square root of the power spectral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

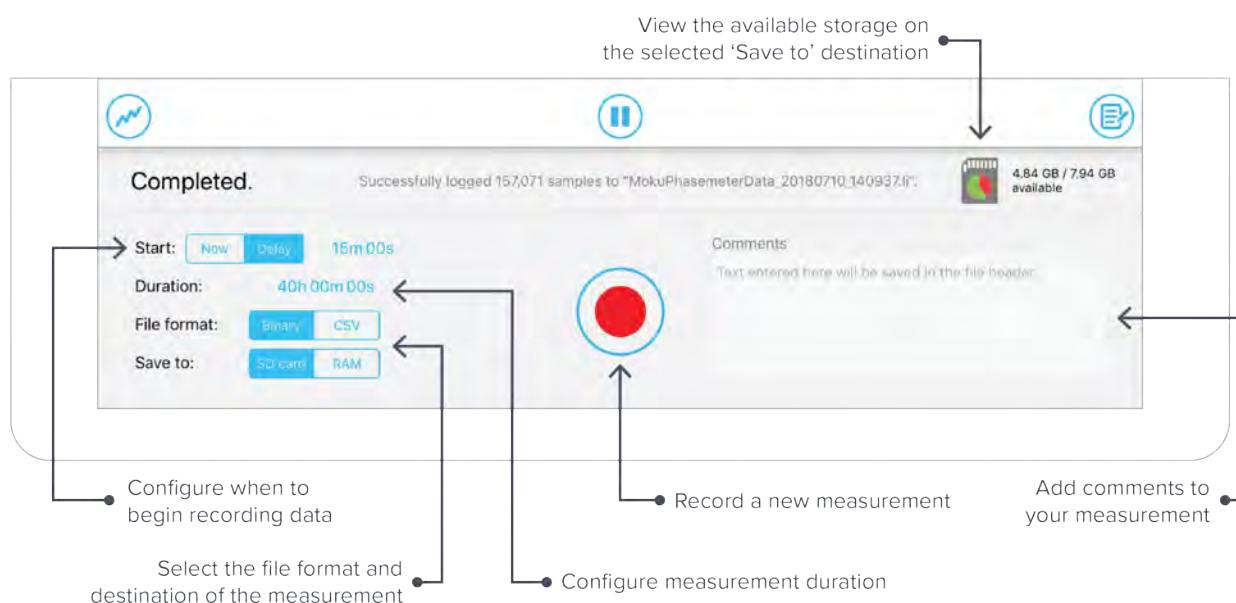




Data Acquisition

The Moku:Lab's Phasemeter can acquire data at a maximum **acquisition speed** of 62.5 kS/s for two channels and 125 kS/s for one channel. To access the data acquisition menu, press  icon.

- Data can be saved to SD card or RAM with binary *.li or comma separated value *.csv file formats
- Files saved to RAM will be lost when the Moku:Lab is powered down or reset
- Files saved with binary *.li format can be converted to *.csv or *.mat using Liquid Instruments file conversion software (<https://github.com/liquidinstruments/lireader>)
- Record data for up to 240 hours, and delay the start of a measurement 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 measurement is taking place.



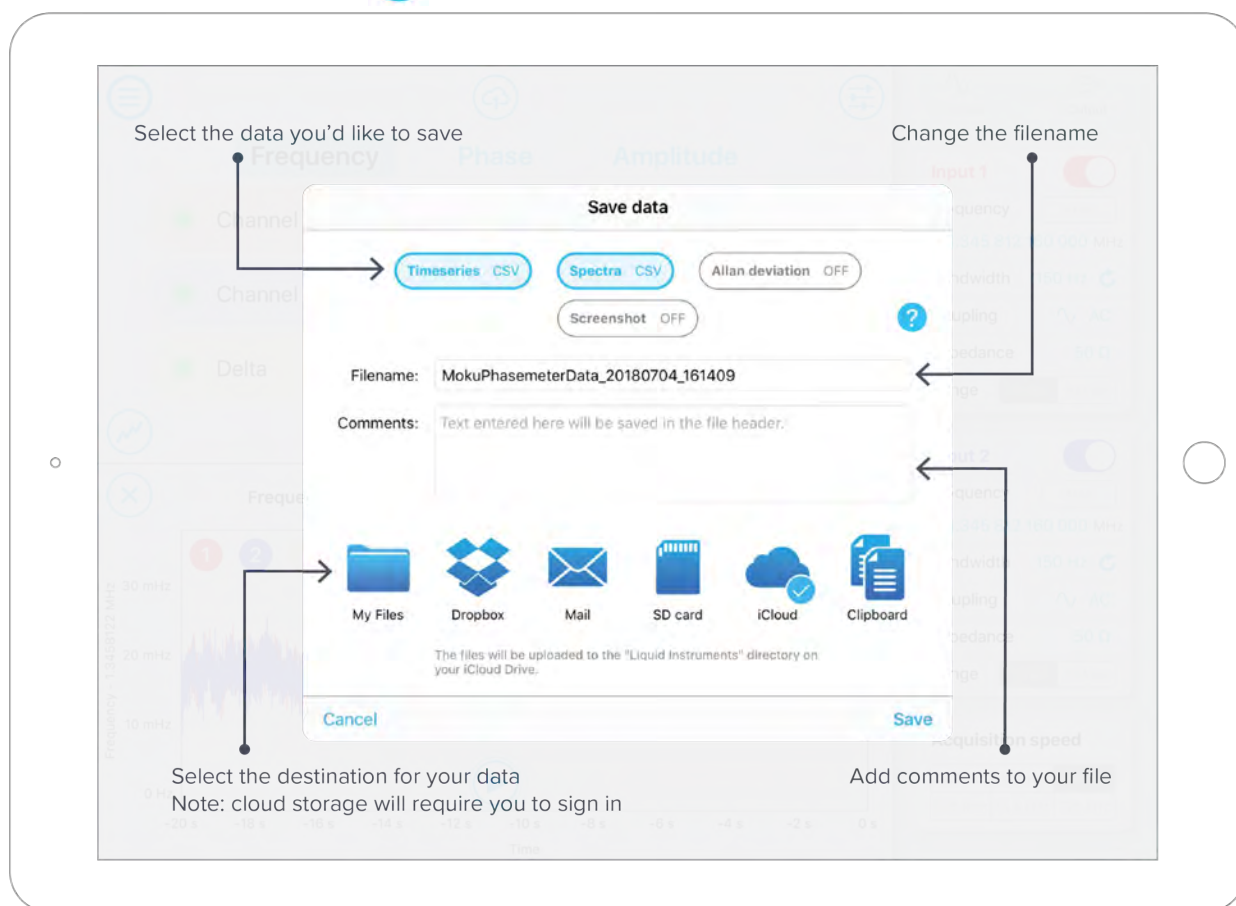
Exporting Data

Export data by pressing the  icon.

Live Data

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

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

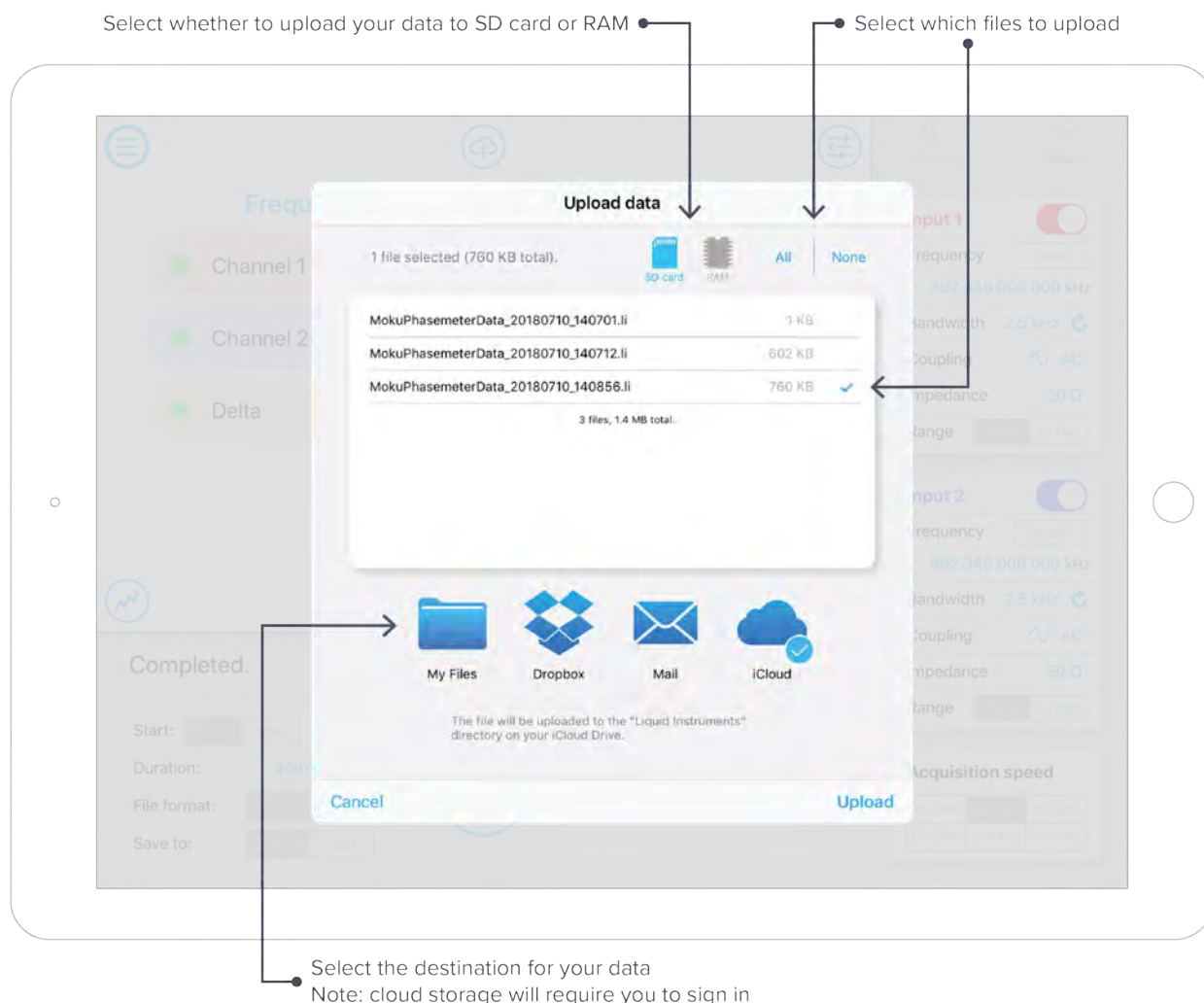




Logged data

Data that has been acquired to SD card or RAM 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.



SD card

- Upload files to SD card by inserting a compatible FAT32 formatted drive into the Moku:Lab's SD card slot, located on the rear of the device next to the power connector.




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:Lab's inputs.
2. 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.

3. When both channels have been configured, tap the **Reacquire** button to synchronously reset both phasemeter channels.
4. 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.

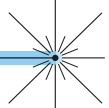
Tip: Tap the 'Clear' button at the top right of the graph every time you reacquire to discard transient data which can sometimes corrupt the quality of the graph

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

Note: If the Moku:Lab'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:Lab'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.



Data Logger User Manual

Moku:Lab's Data Logger instrument records time series voltages from 1 or 2 channels at rates from 1 sample per second up to 1 MS/s. The data can be logged to RAM or removeable SD card in a variety of formats.

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

Moku:Lab's Data Logger also includes an embedded waveform generator.





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www.liquidinstruments.com



User Interface Quick Reference

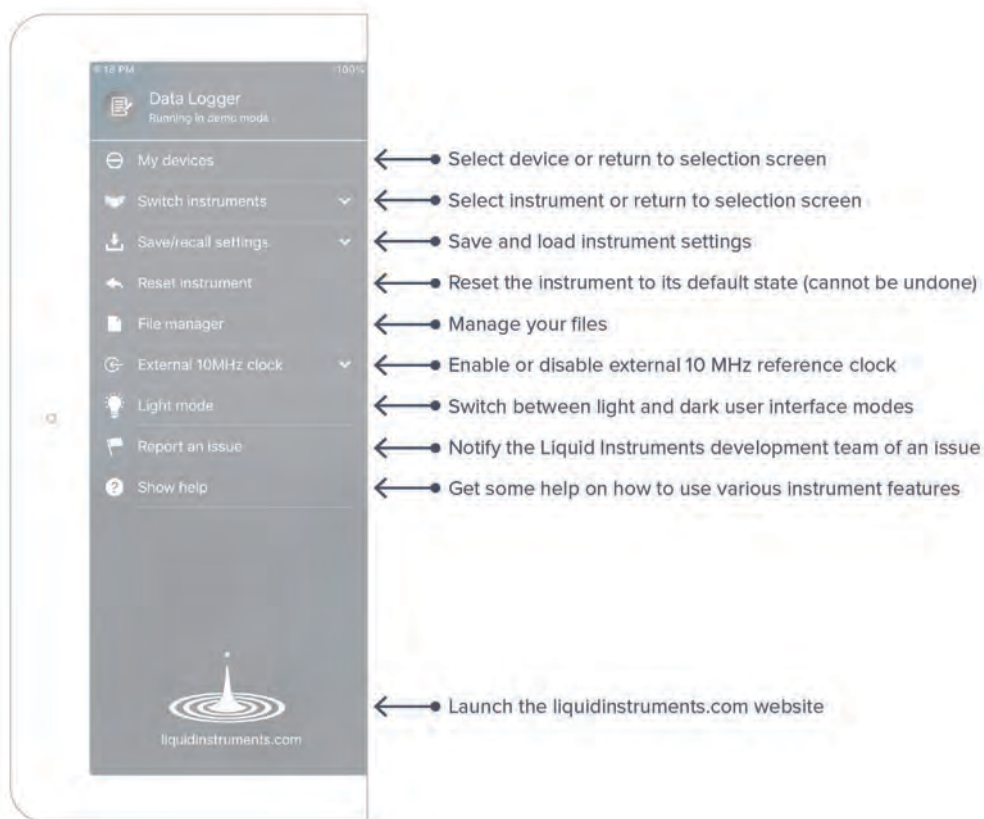


| ID | Button/icon | Description |
|----|-------------|---|
| 1 | Main menu | The main menu contains controls for switching instruments, switching devices, selecting device clock and user interface modes and more. See Main Menu |
| 2 | Share | The sharing button gives access to controls that allow you to save and share your data. See Saving and sharing data |
| 3 | Settings | Reveals or hides the settings drawer, giving access to acquisition and output settings. Also available by swiping in from/out to the right-hand side of the screen. See |
| 4 | Clear | Clears the datalog history |
| 5 | Red trace | Data channel 1 trace |
| 6 | Blue trace | Data channel 2 trace |
| 7 | Time axis | Tap to set time axis scaling |
| 8 | Y axis | Tap to set minimum and maximum Y axis display |



Main Menu

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





Datalogger control panel


Below the main datalogger trace display is the control panel



| ID | Button/icon | Description |
|----|------------------|---|
| 1 | Status | Logger status, either Idle, Aborted, Waiting, Logging |
| 2 | Memory | Displays the used and remaining memory available for logging. This may be either the internal Moku RAM or the removeable SD card. |
| 3 | Mode | Set acquisition mode as Normal or Precision |
| 4 | Filename | Configure the prefix to be used on the datalog filenames |
| 5 | Comment | Text entered here will be saved in the file header |
| 6 | Start/stop | Tap to start and top datalogging |
| 7 | Log memory | Tap to select log memory, either internal Moku RAM or SD card |
| 8 | Log format | Tap to select log format, CSV or LI binary format |
| 9 | Duration | Tap to set log duration, up to 240 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 datalogs. Dropbox, Mail and iCloud service settings are configured in the iPad preferences.



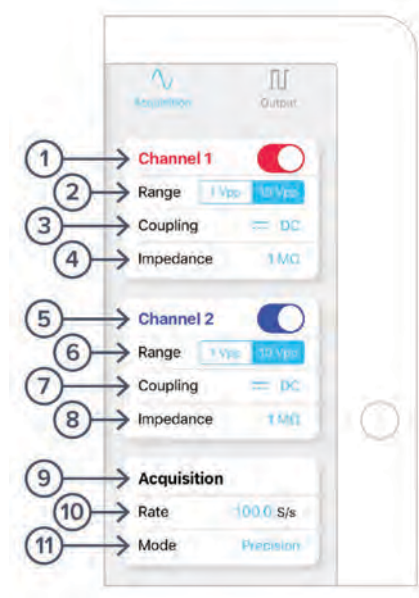
| ID | Button/icon | Description |
|----|--------------|--|
| 1 | SD Card | Tap to save files on Moku:Lab's removable SD card |
| 2 | RAM | Tap to save files on Moku:Lab's internal RAM |
| 3 | Save options | Tap to share datafiles to "My Files" or any of these online services |



Settings side bar

Acquisition

The acquisition sidebar configures the acquisition parameters of both input channels.

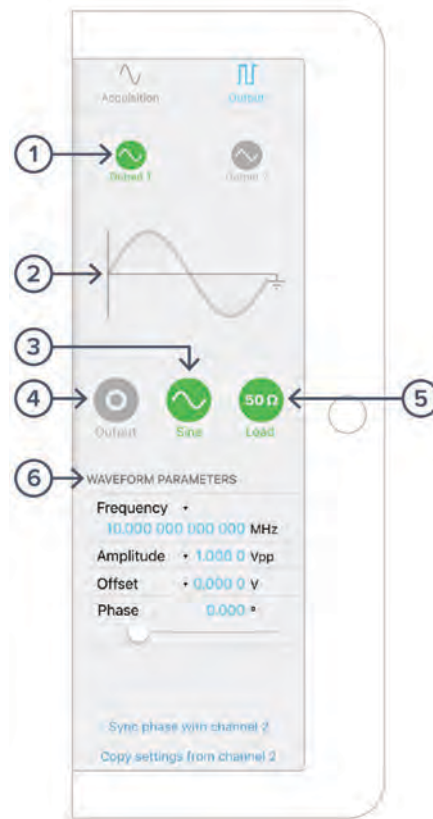


| ID | Button | Description |
|-----|----------------------|--|
| 1 | Channels 1 settings | Channel 1 (red) and Channel 2 (blue) settings are configurable independently |
| 2 | Range | Range selects the input range as either 1 V or 10 V peak-to-peak. |
| 3 | Coupling | Select AC or DC coupling |
| 4 | Impedance | Select high (1 M Ohm) or 50 Ohm input impedance |
| 5–8 | Channel 2 settings | Configure channel 2 as described above for channel 1 |
| 9 | Acquisition settings | Configure acquisition settings |
| 10 | Rate | For logging to Moku:Lab internal RAM, the maximum rate is 1 MS/s (1 channel) or 500 kS/s (2 channel) For logging to SDcard, maximum rate is 100 kS/s Note: logging to CSV is at a lower rate. See Liquid Instruments web site for binary -> CSV conversion utility |
| 11 | Mode | Precision, Normal |



Output

The Moku:Lab datalogger has a basic waveform generator capable of generating basic waveforms on the two output channel. For more complex waveforms, see Moku:Lab Waveform Generator and Arbitrary Waveform Generator.



| ID | Button | Description |
|----|---------------------|---|
| 1 | Configure channels | Tap to configure settings for channels 1 and 2. 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 ohm or high impedance (1M ohm) output load |
| 6 | Waveform parameters | Tap to configure the selected waveform parameters varying according the waveform type selected. |



Instrument Reference

Moku:Lab's datalogger is designed to be intuitive and straightforward to use.

One or two channels of time-series voltages are recorded by Moku:Lab, for a specified duration, and at a specified rate.

The maximum logging rate depends on a number of factors, such as the file format chosen, file storage location and the number of channels to be recorded.

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. Select your file type and destination, ensuring that the destination has enough free space for the log
4. Set the recording duration and any comments you want to be saved with the file
5. Optionally configure the Waveform Generator outputs
6. Tap Record.

Channel Configuration

Each channel can be enabled or disabled; 1Vpp or 10Vpp; AC or DC-coupled; and 50Ω or 1MΩ terminated.

Acquisition Parameters

The Acquisition Parameters refer to the logging rate and the downsampling mode used to reduce Moku:Lab's native sampling rate to the logging rate.

The logging rate must be between 10 S/s and 1 MS/s. The actual maximum is only achievable with a single channel, binary file format saved to RAM; other combinations will have lower maximum rates.

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 and Destinations

Moku:Lab's datalogger can save natively to standard text based CSV format files. CSV files contain a header that records the current instrument settings as well as any user-entered comments.

The Binary file format is proprietary to Moku:Lab and has been extensively optimized for speed and size. Using the Binary format, Moku:Lab 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 Application 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. The Binary format may also be used in Python through the Liquid Instruments pymoku software library.

Each file may be saved either to a removeable SD Card in Moku:Lab, or to the Moku:Lab's internal RAM.

RAM is extremely fast but volatile; if you restart your Moku:Lab before downloading your data, that data will be lost. The RAM has a capacity of 512MB.

SD Card provides non-volatile, high-capacity storage. You may store as many files on the card as the capacity allows, however each file is limited to 4GB in size due to the nature of the filesystem on the card¹.

The speed of each SD Card varies both with its quality and age, and this speed directly limits the maximum logging rate when saving to SD Card. A high quality, fast SD card may log up to 100x faster than an older slow device. A slow SD card may not be immediately apparent, it may cause the Moku:Lab datalogger to drop data several minutes into longer runs. If the user plans to log to SD Card at a rate above 1ksps, it's strongly advised that they test a new card with a few 10-minute logs before attempting anything longer.

When the file destination is changed, the Free Space icon in the top-right of the Control Panel will change to show the amount of space left on that destination. When a log is started, a warning will be shown if Moku:Lab datalogger estimates there is insufficient memory space.

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.

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

¹ Moku:Lab only supports SD Cards formatted with the FAT32 Filesystem. This is the default out of the box for most cards including the units shipped with Moku:Lab.



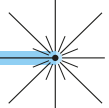
Accessing your Data

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

Additionally, datalogs saved to Moku:Lab's RAM may be moved to the SD card after logging.

Embedded Waveform Generator

Moku:Lab datalogger integrates a simple waveform generator capable of providing Sine, Square, Ramp, Pulse and DC waveforms on the output channels.



Spectrum Analyzer

User Manual

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





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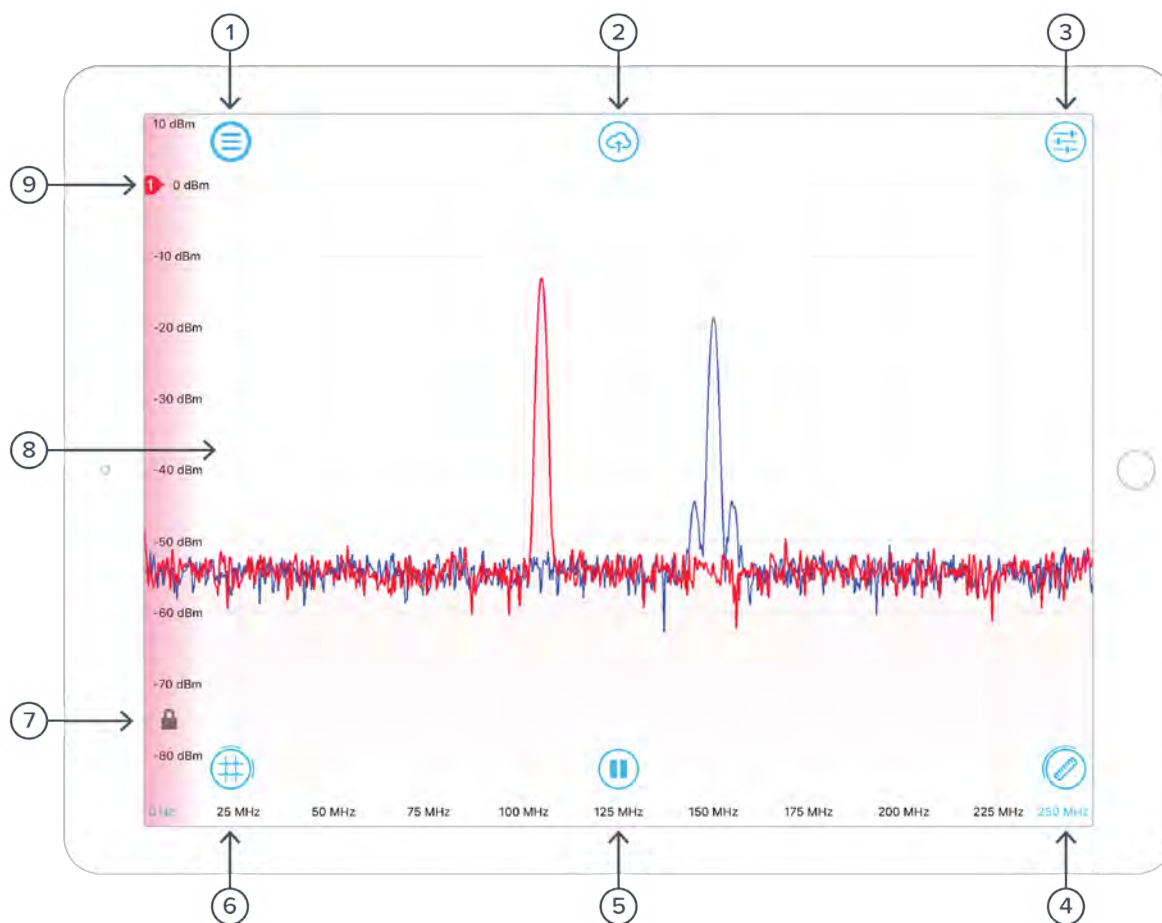


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User Interface

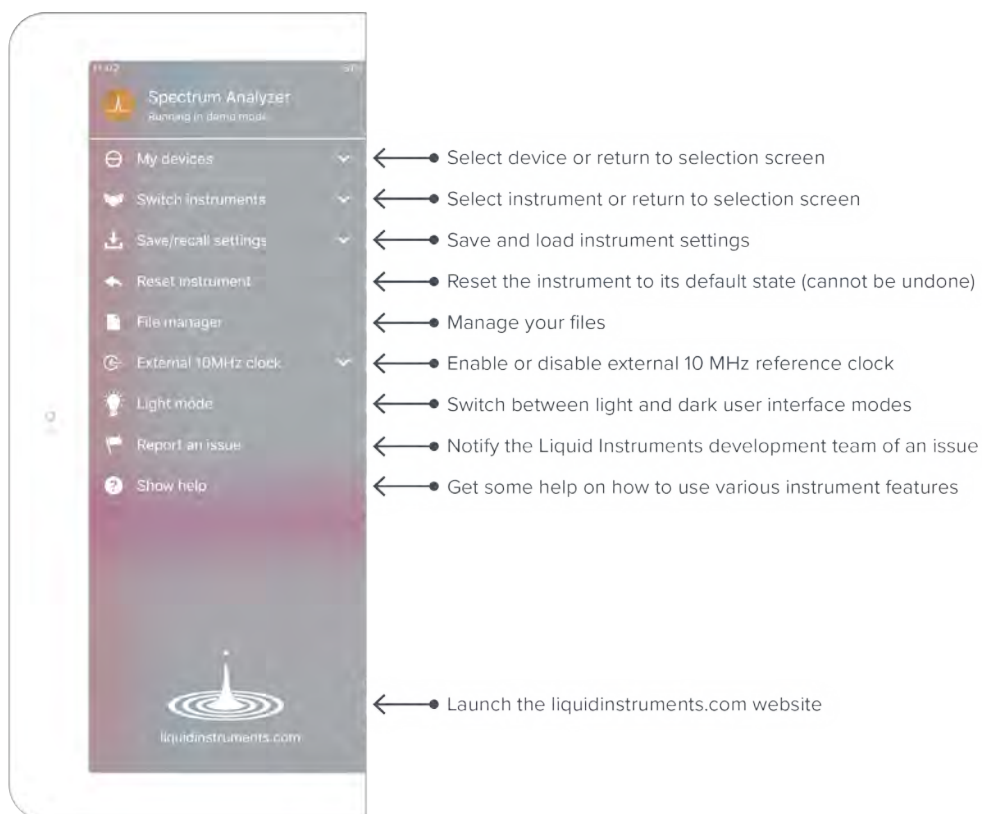


| ID | Description | ID | Description |
|----|--------------|----|------------------------------|
| 1 | Main menu | 6 | Cursors |
| 2 | Save data | 7 | Vertical scales lock |
| 3 | Controls | 8 | Signal display area |
| 4 | Measurements | 9 | Reference position indicator |
| 5 | Play/Pause | | |



Main Menu

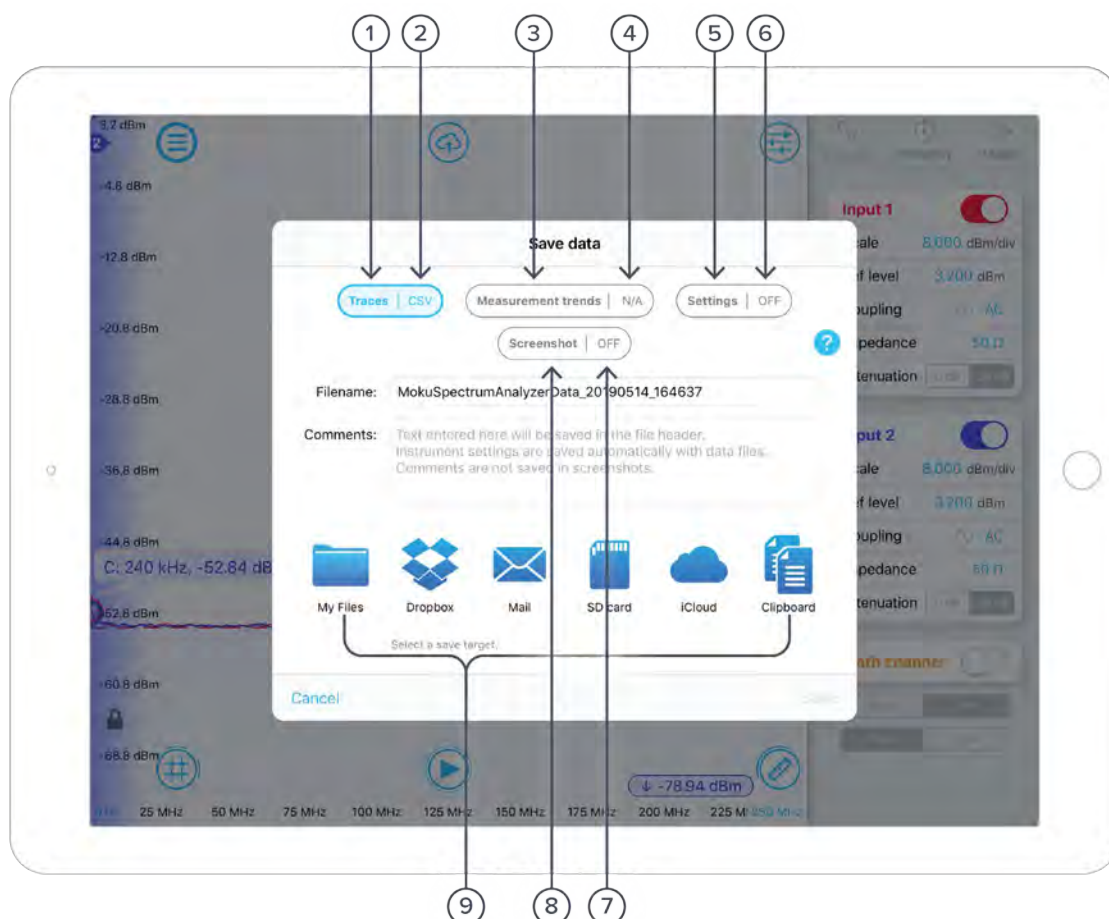
The **main menu** can be accessed by pressing the  icon, allowing you to:





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. |



Controls

The **controls** options can be accessed by pressing the  icon, allowing you to reveal or hide the control drawer, giving access to all instrument settings. Also available by swiping in from to the right-hand side of the screen. Controls drawer gives you access to Channels, Frequency, and Output settings.

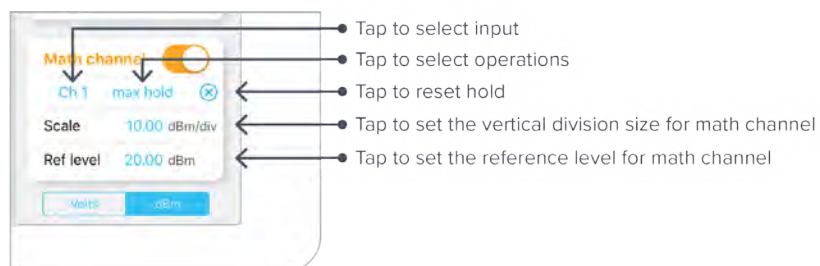
Channels

The **channels** pane allows you to change the input settings for each ADC channel and adjust the input scales, coupling, and enable/disable the math channel.





Additional settings when Math Channel is enabled:

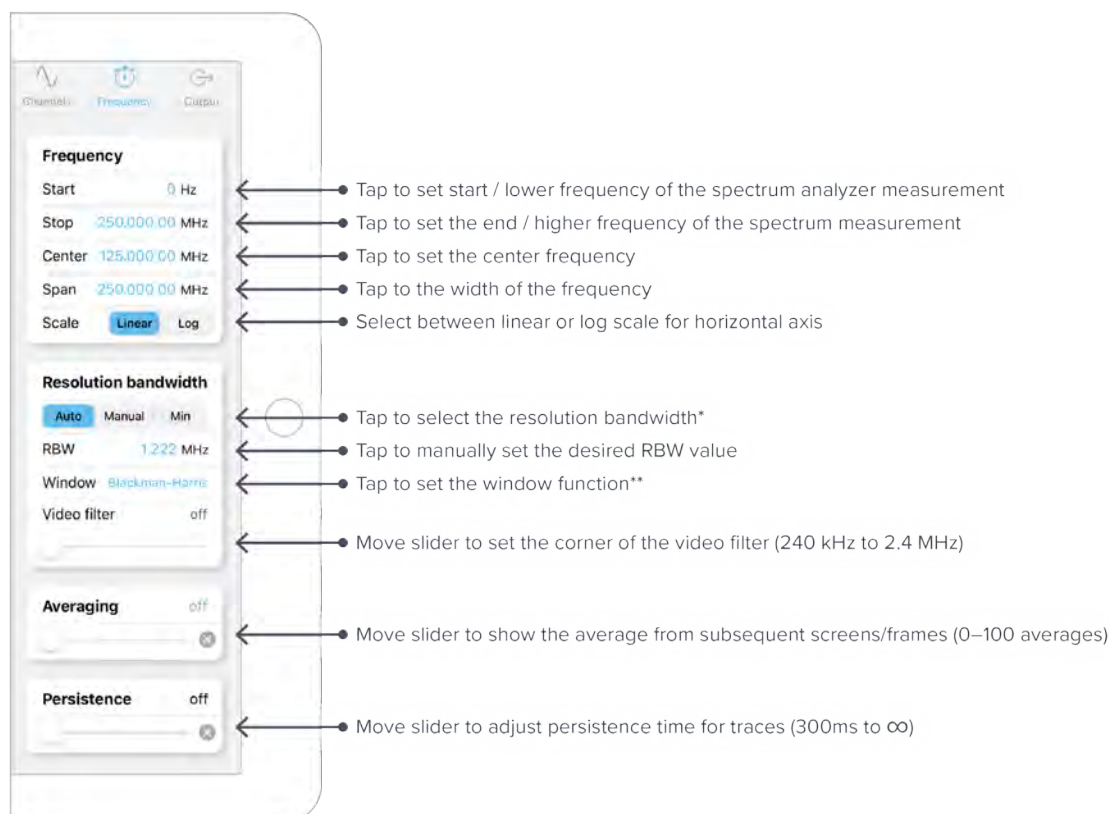


Four operations are currently supported by Moku:Lab's Spectrum Analyzer: +, ×, min hold and max hold.



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:Lab will automatically update the other pair if one is changed.

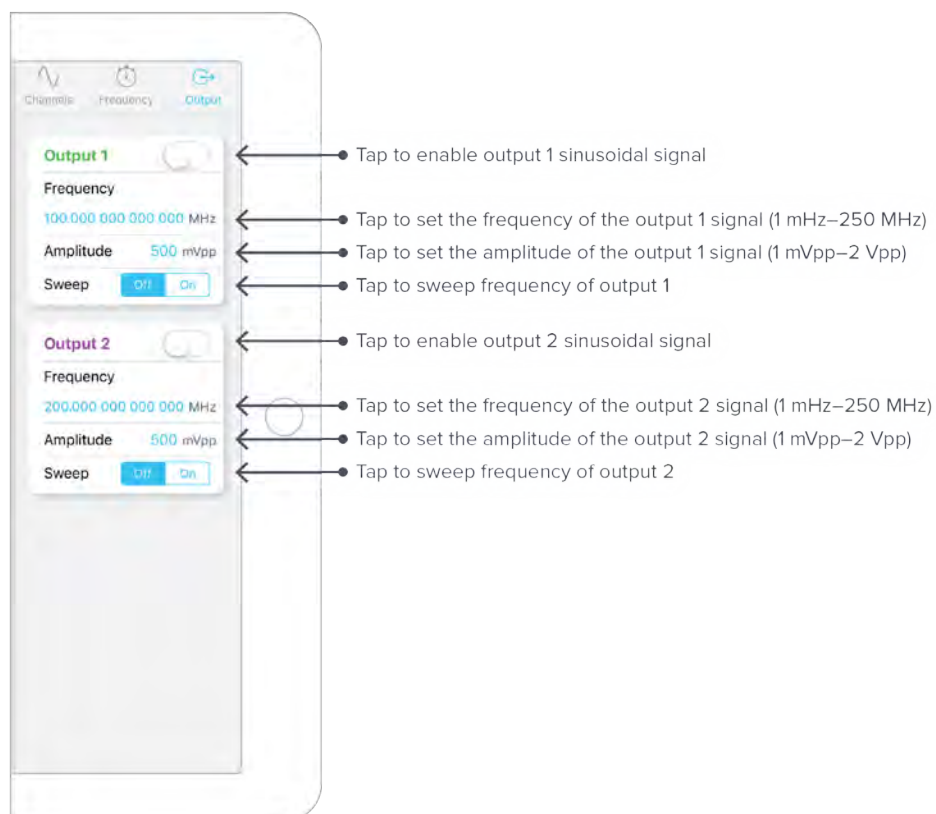
* Auto: determines the best resolution to sync; Manual: manually set the resolution bandwidth of the spectrum analyzer; Min: uses the smallest RBW available.

** 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.

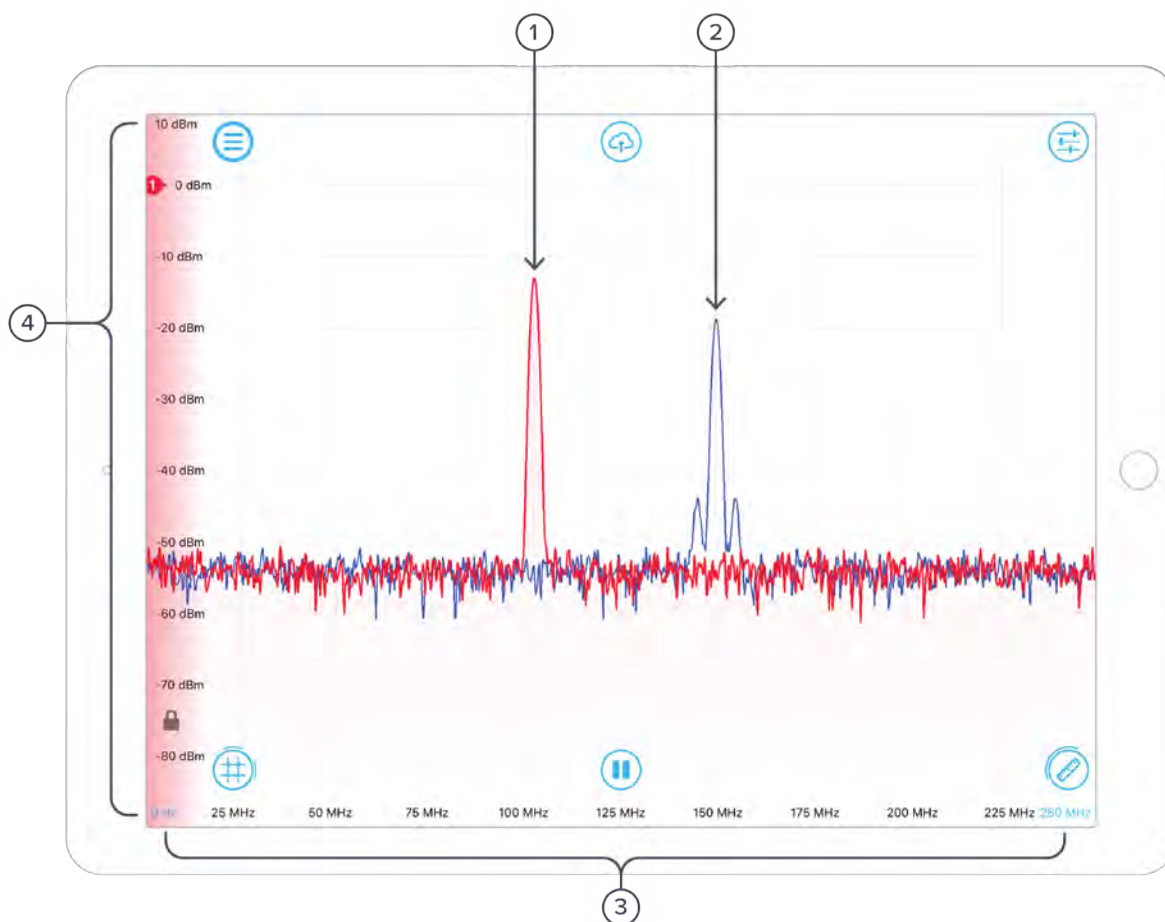




Display

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 PSD in linear or log scales.



ID Description

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

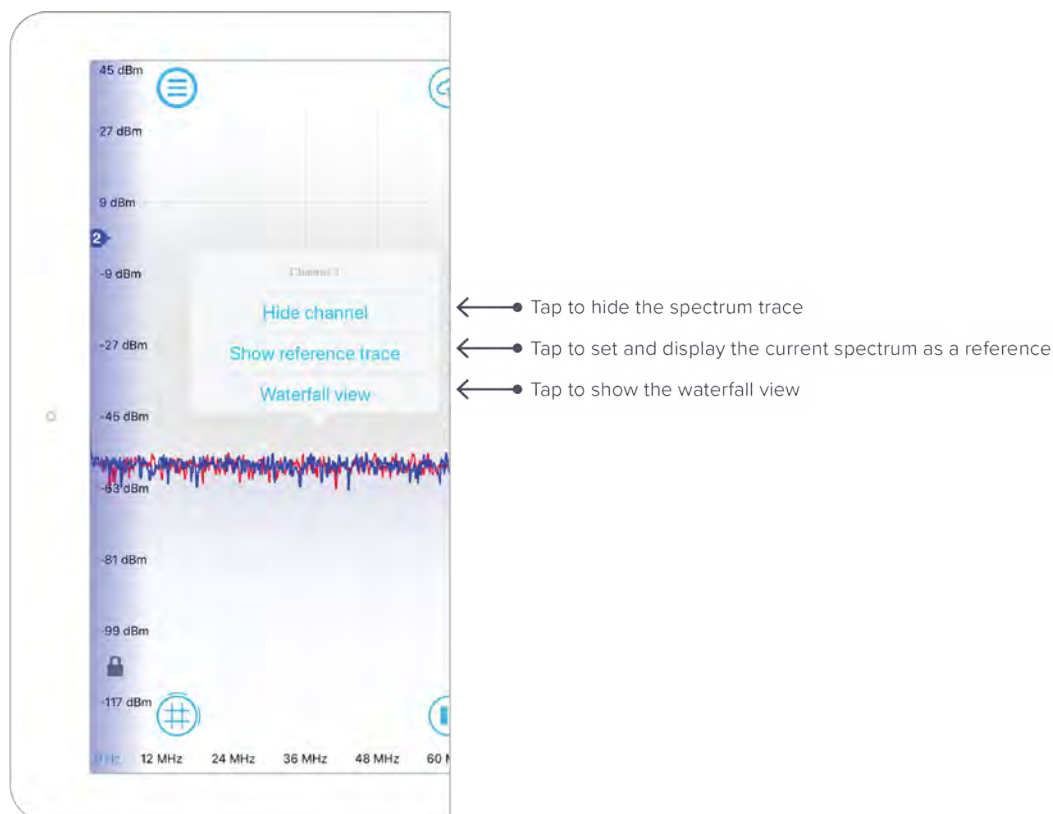
The scales of both axes can be adjusted by pinching the touch screen.

* The shaded color near the vertical axis indicates the active channel. Red represents channel 1, blue represents channel 2, and yellow represents the math channel. The vertical scales of the two channels can be locked with the  button.



Spectrum Trace

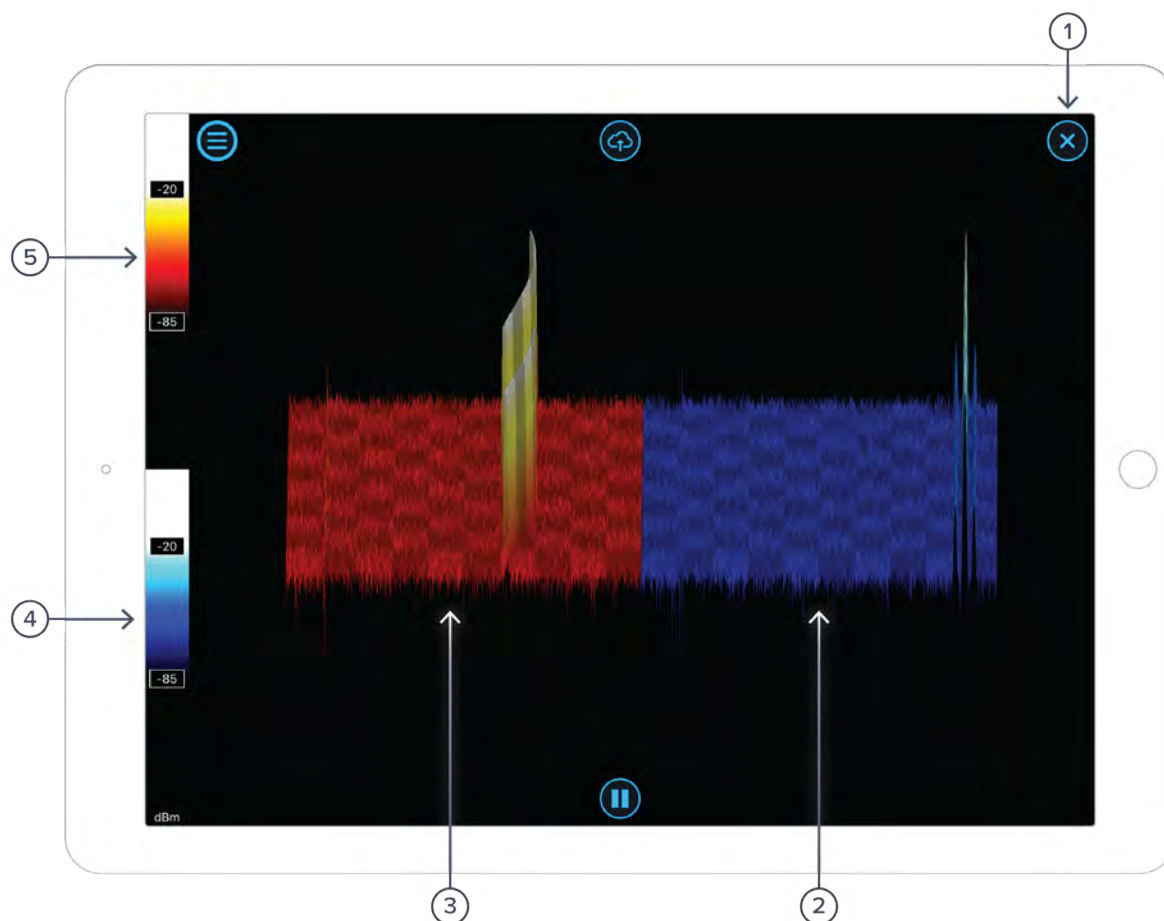
Press and hold the spectrum trace to reveal additional viewing options:





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

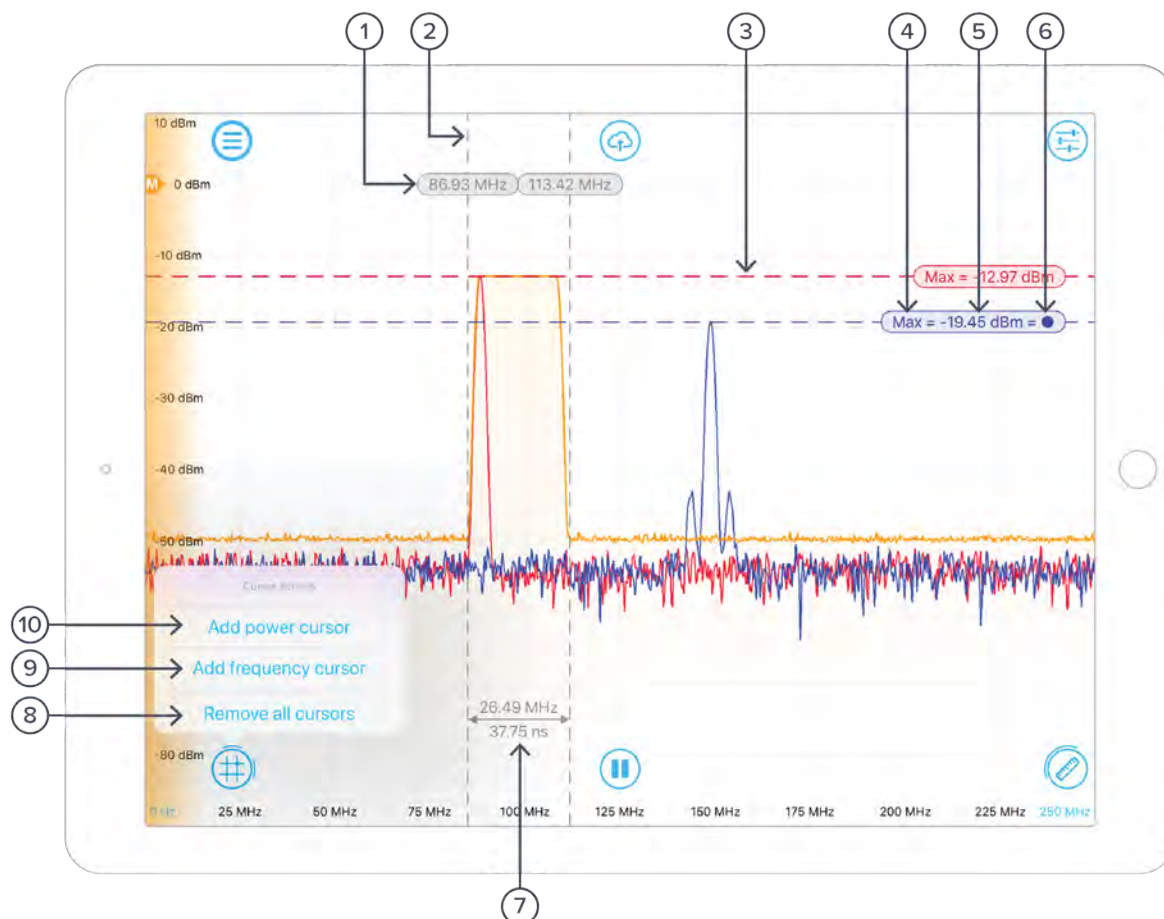
- | ID | Description |
|----|----------------------------------|
| 1 | Tap to close the waterfall view. |
| 2 | Waterfall view for input 2. |
| 3 | Waterfall view for input 1. |
| 4 | Color scale for Channel 2. |
| 5 | Color scale for Channel 1. |



Cursors

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

User Interface



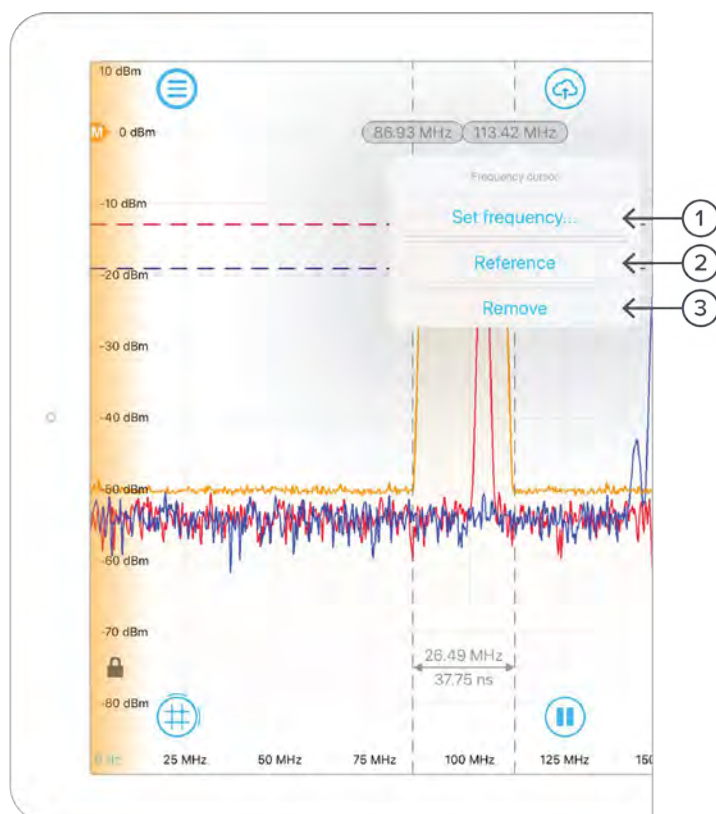
| ID | Parameter | Description |
|----|----------------------|---|
| 1 | Frequency reading | Tap to reveal frequency cursor options. |
| 2 | Frequency cursor | Drag left or right to set positions. |
| 3 | Power cursor | Drag up or down to set positions. Color represents the channel of the measurement (Red – Channel 1, Blue – Channel 2, Yellow - Math). |
| 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

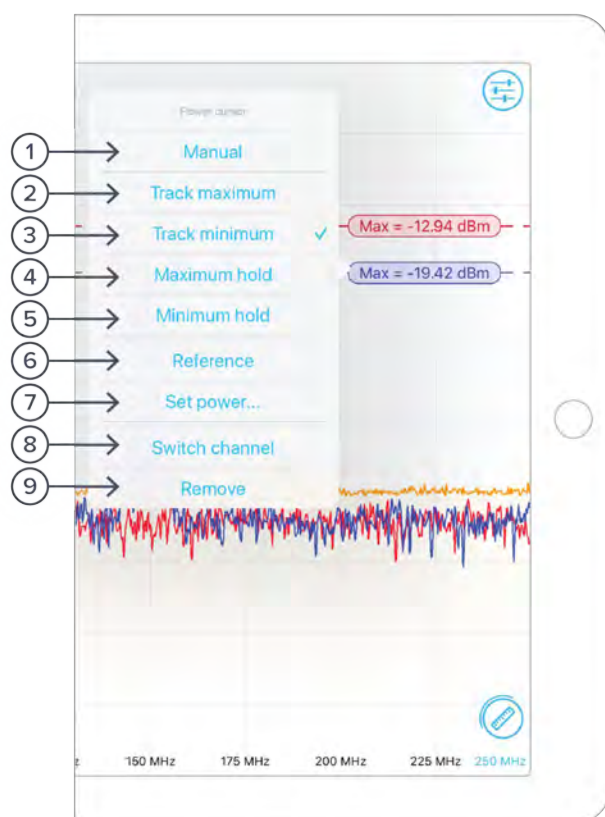
Tap the cursor reading to reveal additional frequency cursor options:



| 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



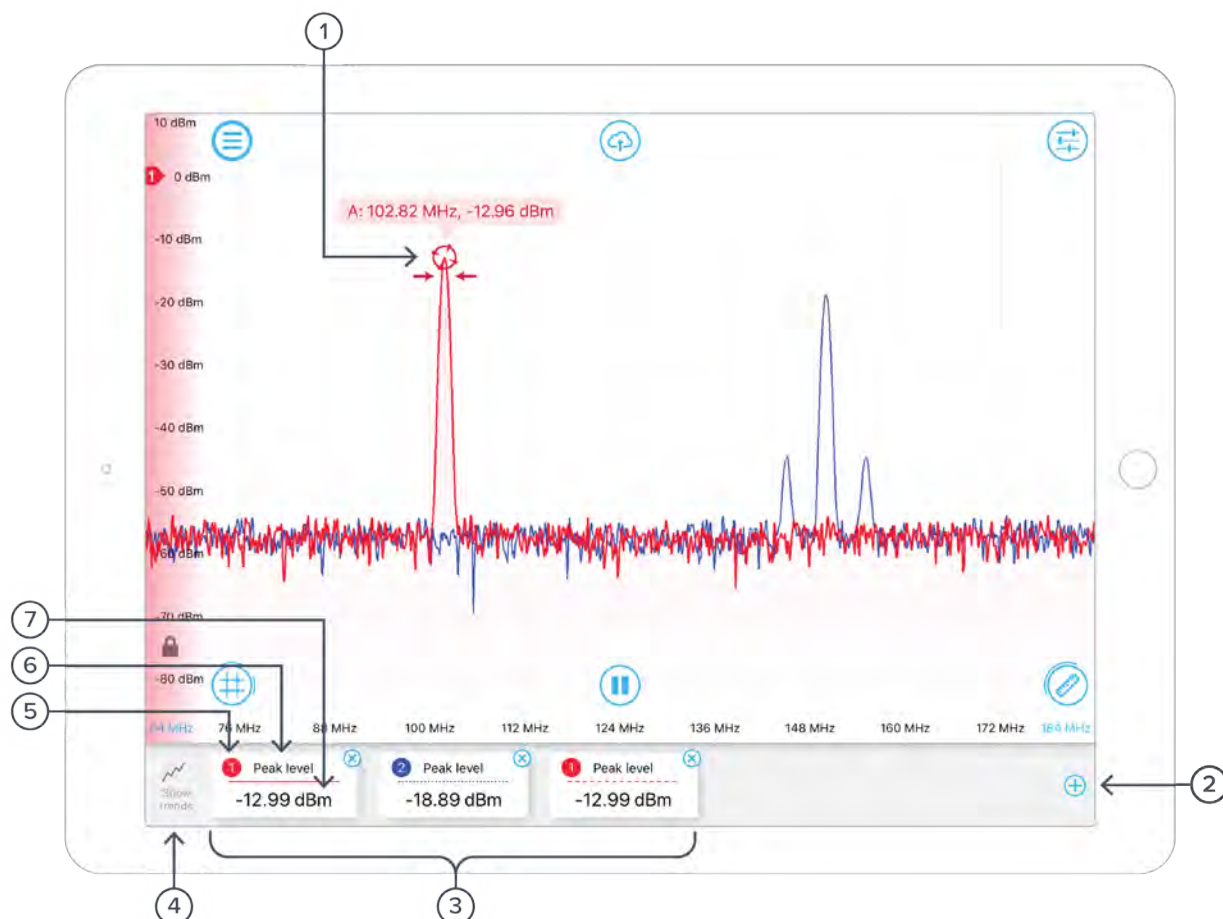
| ID | Parameter | Description |
|----|----------------|--|
| 1 | Manual | Tap to manually set the vertical position of the cursor. |
| 2 | Track maximum | Tap to set the cursor to track the maximum power/amplitude. |
| 3 | Track minimum | Tap to set the cursor to track the minimum power/amplitude. |
| 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

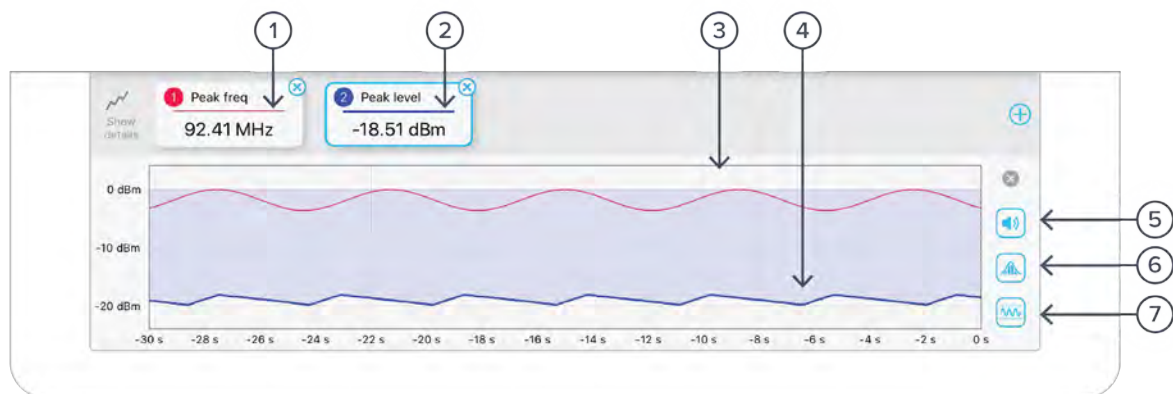


ID Description

- | 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. |



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

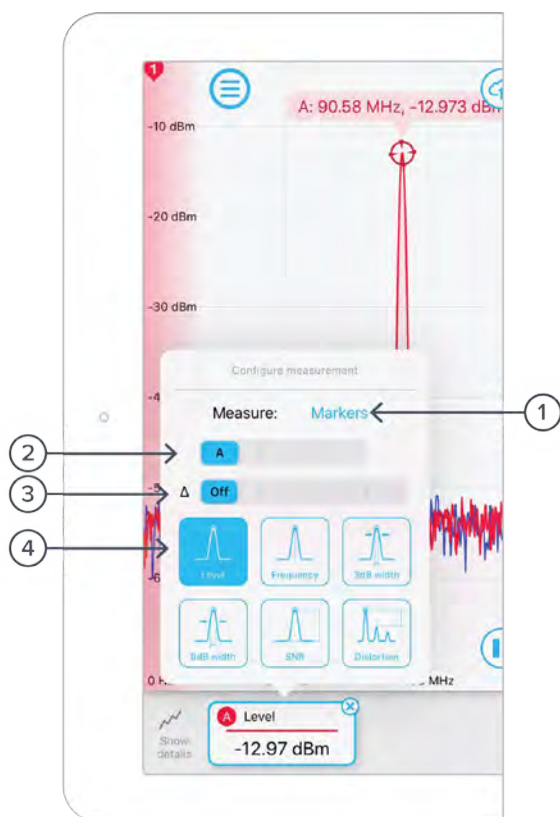


ID Description

- | | |
|---|---|
| 1 | Tap to switch to measurements from markers. |
| 2 | Tap to select measurement source. |
| 3 | Tap to select measurement type. |



Options for measurements from markers



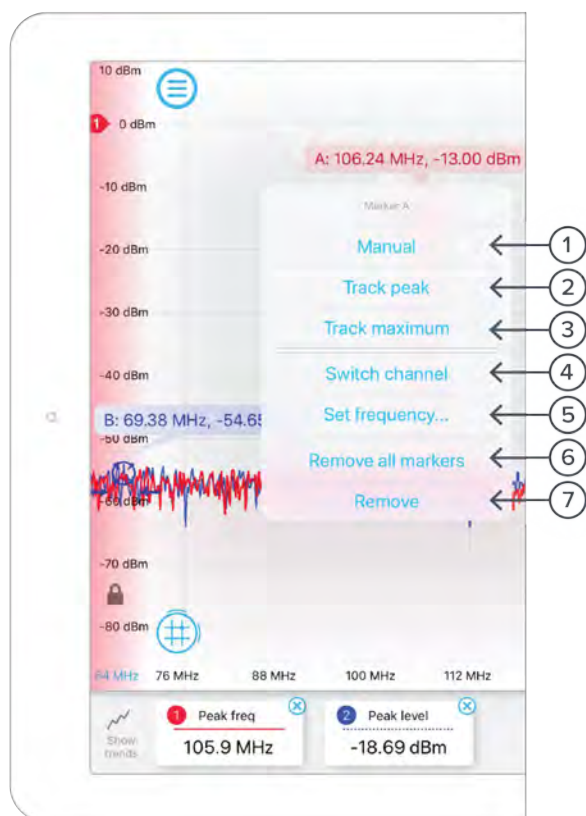
ID Description

- | | |
|---|--|
| 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. |

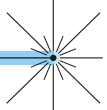


Measurement Marker Options

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. |



Laser Lock Box User Manual

Moku:Lab's Laser Lock Box enables you to stabilize a laser's frequency to a reference cavity or atomic transition using high-performance modulation locking techniques. The Laser Lock Box includes a 'Tap-to-Lock' feature, enabling you to quickly lock to any zero-crossing on the demodulated error signal. It also features an integrated 2-channel oscilloscope, allowing you to observe signals at any point in the signal processing chain at up to 500 MSa/s. Additionally, the built-in datalogger feature enables delayed and lengthy data logging.





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

www.liquidinstruments.com



Introduction

Laser locking systems are widely used to control and match a laser's frequency to an optical frequency reference, such as an optical reference cavity or atomic transition. Such systems are vital for high resolution interferometric measurement, spectroscopy, and time and frequency standards.

Locking a laser by forcing the laser and reference frequency to be equal allows for two scenarios:

- the locking system steers the laser frequency to be equal to the reference frequency, which is referred to as frequency stabilisation; and
- the locking system forces the reference frequency to follow the laser frequency, which is referred to as frequency tracking.

Whether used for frequency stabilization or frequency tracking, Moku:Lab's Laser Lock Box is designed to assist in high-performance, high-gain laser locking systems. It offers advanced setup, acquisition and diagnostic features that makes it easier and quicker to set up and characterize laser locking system

Principle of Operation

At the core of any Laser locking technique is the measurement that provides the difference, or error, between the laser and a frequency reference. Often termed the 'error signal', the quality of this signal ultimately determines the precision and accuracy of the entire locking system. A frequently employed and precise method for obtaining an error signal is the Pound-Drever-Hall (PDH) technique. Using the PDH error signal in feedback systems has proven to give an extremely accurate and precise measure of changes in the laser or cavity, resulting in its use in a myriad of applications such as absorption spectroscopy and gravitational wave detection. The PDH error signal technique has several key advantages such as:

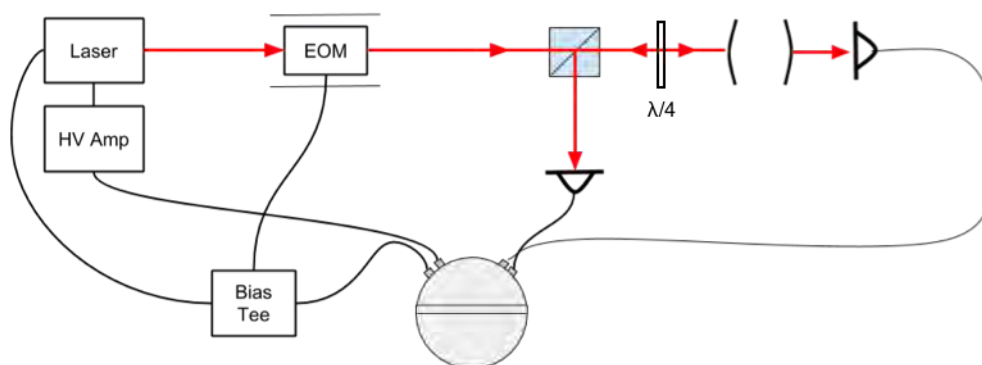
- The technique provides highly accurate and precise measures of phase and frequency differences between the laser and the cavity resonance.
- The sensing technique provides a zero-crossing error signal with zero frequency difference corresponding to a null error signal.
- Assuming all signal processing is done digitally, it avoids low frequency noise generated in analog electronics and demodulation circuits

These advantages do come with some challenges. To obtain such a precise measure of the frequency/phase, the PDH technique utilizes radio frequency (RF) modulation and demodulation techniques. This adds considerable complexity to the signal processing system as well as some complexity to the optical system. But once understood, these complexities are minor compared to the advantages of the PDH systems.



Laser Locking using the Moku:Laser Lock Box

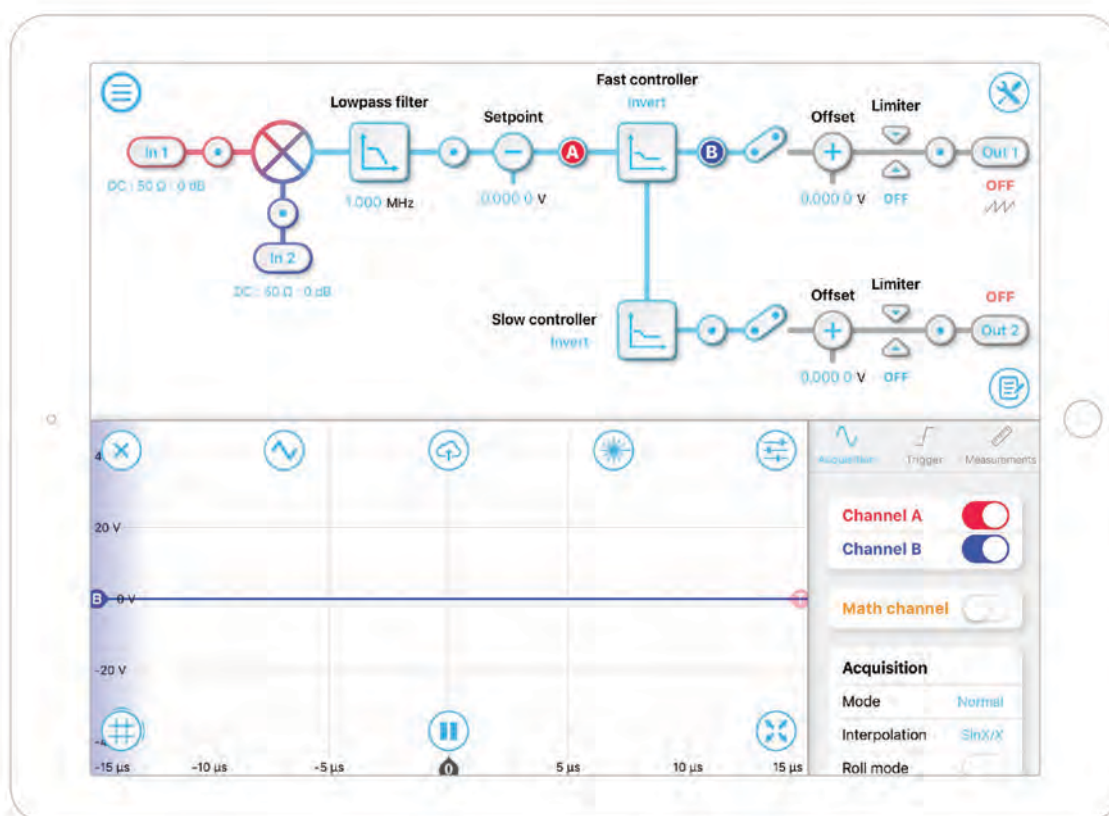
The Moku:Lab Laser Lock Box deals with much of the complexity usually associated with operating and using a PDH locking system. The figure below illustrates an example of a PDH laser locking system. The setup uses a solid state laser, which is aligned and mode-matched to a moderate finesse cavity. The Moku:Lab Laser Lock Box was subsequently used to produce all signals required to lock the laser to the cavity resonance.





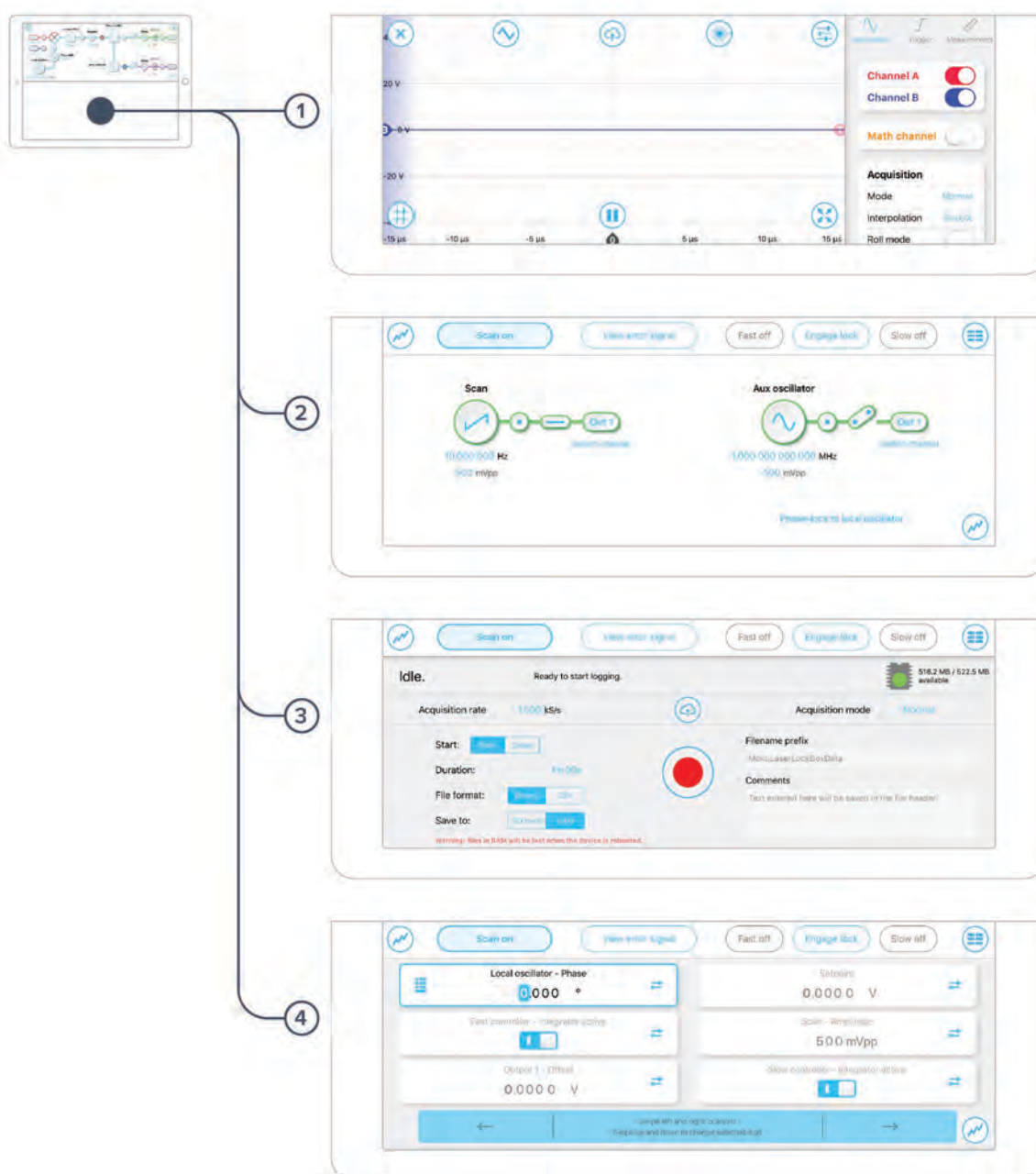
User Interface

The main user interface is divided into upper and lower screen sections and described individually below. The upper user interface displays the processing chain and principal controls of the laser lock box.





The lower half is readily set to display one of scan and aux oscillators, oscilloscope, data logger, parameter control panel

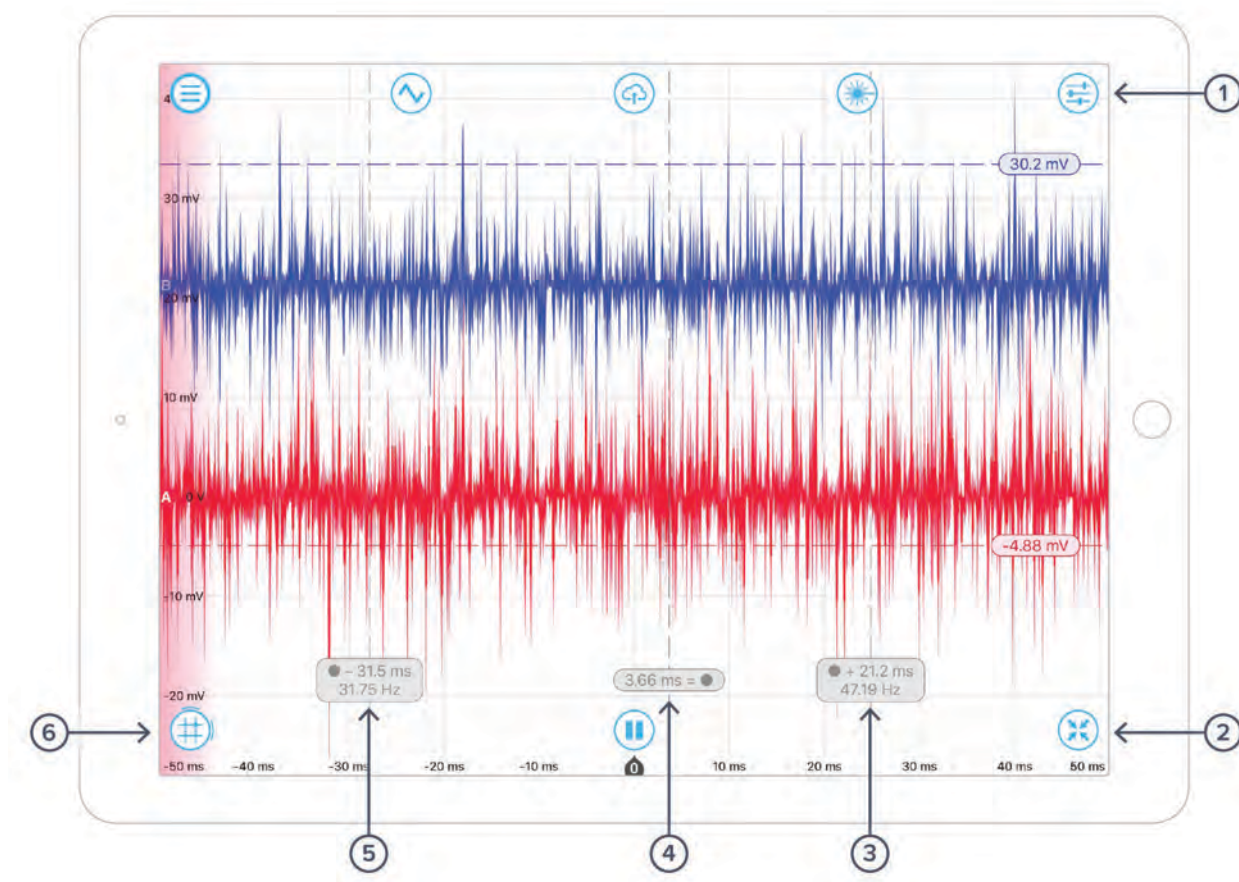


ID Description

- | | |
|---|---------------------------------|
| 1 | Oscilloscope |
| 2 | Scan and aux oscillator control |
| 3 | Datalogger |
| 4 | Parameter adjustment panel |



The oscilloscope may also be set into full screen mode to take full advantage of the iPad screen



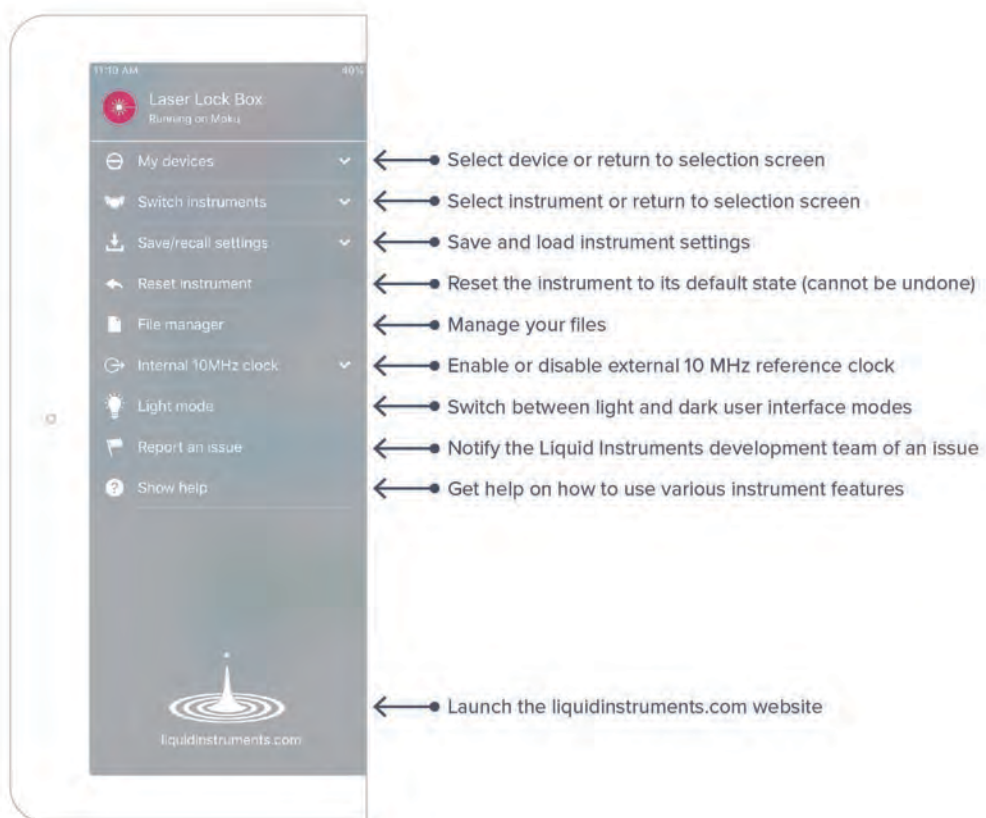
| ID | Description | ID | Description |
|----|---|----|--|
| 1 | Settings side panel | 4 | Time access cursor set as reference |
| 2 | Half screen oscilloscope | 5 | Time axis cursor, with delta to reference |
| 3 | Time axis cursor, with delta to reference | 6 | Tap, drag left or drag up to create cursor |

See Oscilloscope for full details of the oscilloscope user interface and controls.



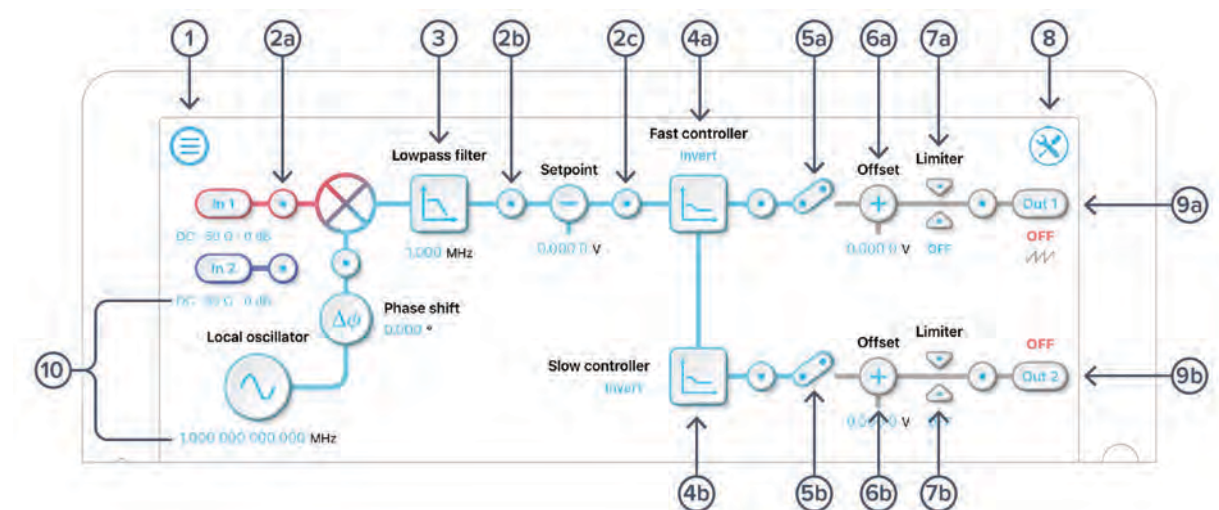
Main Menu

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





Upper user interface

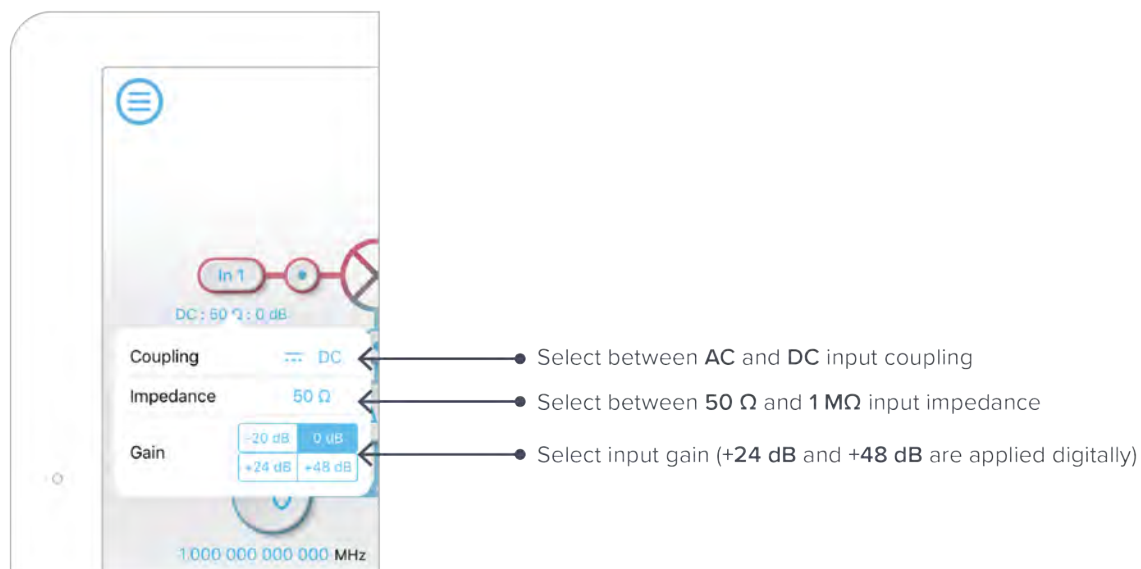


| ID | Description | ID | Description |
|------|---|----|--|
| 1 | Main menu | 6a | Apply DC offset to fast PID chain |
| 2a-c | Tap to drop one of two oscilloscope probe points to examine signals within the processing chain | 6b | Apply DC offset to slow PID chain |
| 3 | Tap to configure low pass filter | 7a | Configure output limiter on fast PID chain |
| 4a | Tap to configure fast PID controller | 7b | Configure output limiter on slow PID chain |
| 4b | Tap to configure slow PID controller | 8 | Configure local oscillator |
| 5a | Turn on/off fast PID chain output | 9a | Turn fast PID output on/off |
| 5b | Turn on/off slow PID chain output | 9b | Turn slow PID output on/off |
| 6a | Apply DC offset to fast PID chain | 10 | Control local oscillator frequency and phase shift |



Signal Input

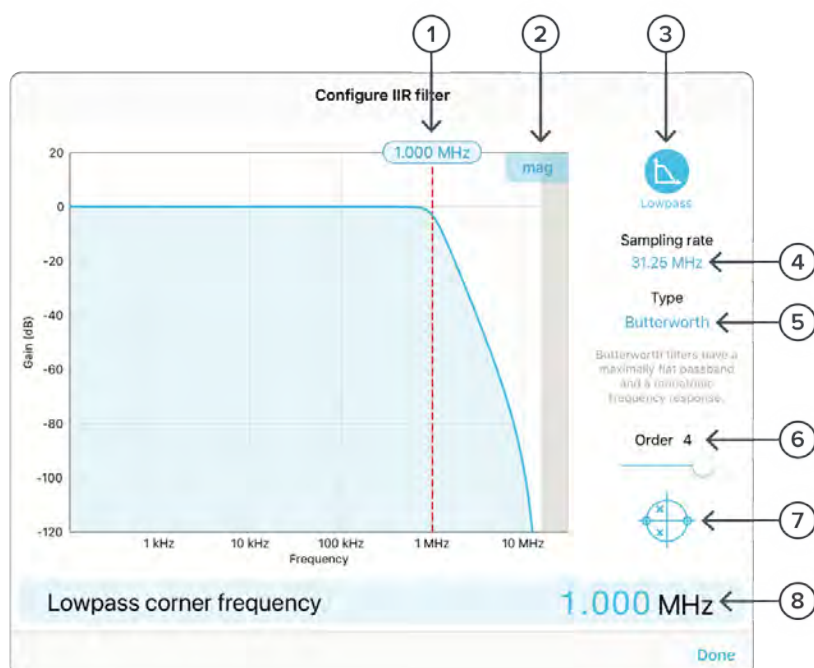
Tap the **In 1** icon to configure the input settings for the signal input. Similar configurations can be made on input 2





Lowpass filter

Immediately after the demodulator function, there is a low pass filter designed to filter higher harmonics. This is highly configurable, tap the low pass filter icon.



| ID | Description | ID | Description |
|----|---|----|--------------------------------------|
| 1 | Configure lowpass filter corner frequency, tap to enter frequency or touch and drag | 5 | Tap to select filter type |
| 2 | Toggle between magnitude or phase plots | 6 | Tap to select filter order |
| 3 | Fixed function of low pass filter | 7 | Toggle view of poles/zeros of filter |
| 4 | Fixed sample rate of 31.25 MHz | 8 | Tap to enter corner frequency |

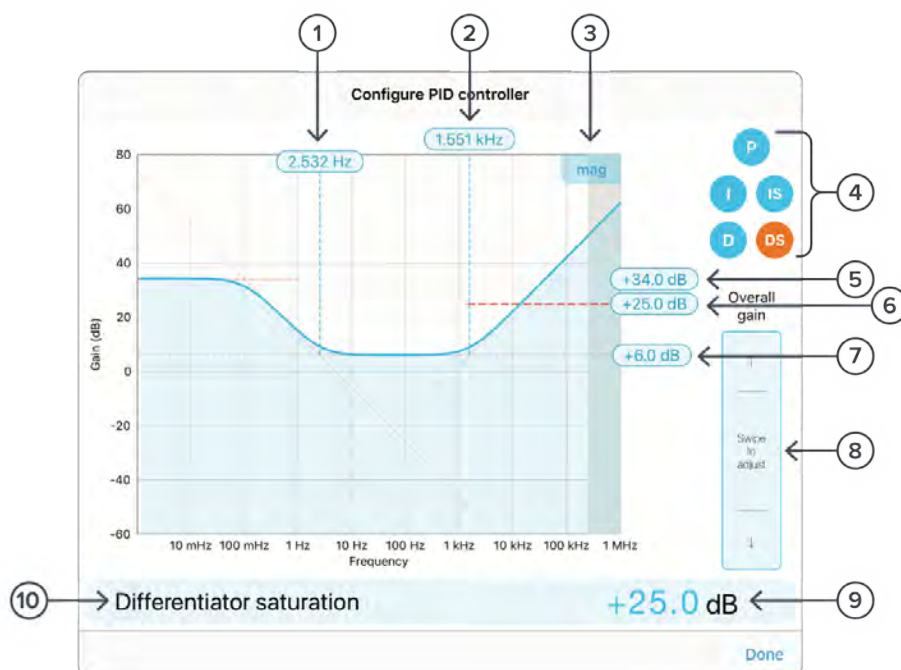


PID controllers

The Moku:Lab Laser Lock Box implements two PID controllers, a fast (100MHz) controller and a slow (1 MHz) controller

Both the fast and slow PID controllers can be configured graphically with dragging interactively on the magnitude chart. Or by tapping on cross-over tabs and entering frequency or gain on the soft keypad.

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

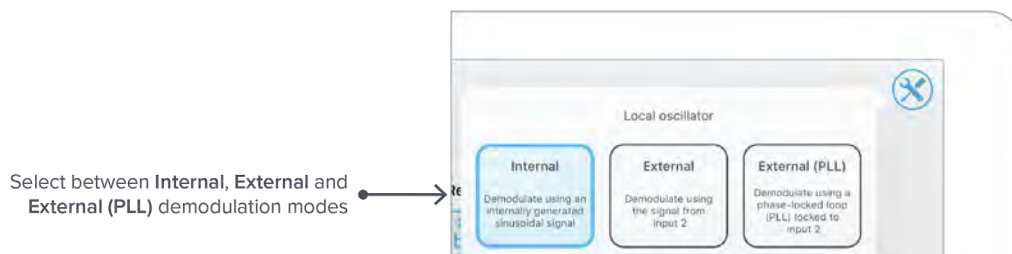


| ID | Description | ID | Description |
|----|--|----|---|
| 1 | Tap to enter integrator crossover frequency | 6 | Tap to set differentiator saturation |
| 2 | Tap to enter differentiator crossover frequency | 7 | Tap to set proportional gain |
| 3 | Toggle between magnitude or phase plots | 8 | Swipe to adjust selected PID parameter |
| 4 | Proportional, integrator, differentiator, integrator saturation and differentiator saturation settings | 9 | Tap to use keypad to enter selected PID parameter |
| 5 | Tap to set integrator saturation | 10 | Selected PID parameter |



Local oscillator

The demodulation signal source can be configured in the settings dialog.



Demodulation

The demodulation mode determines which reference oscillator 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 the Moku:Lab's internal clock and thus shares the same time-base. The frequency range of the internal reference is 1 MHz to 200 MHz.

External (direct)

The input signal can be demodulated by a direct external reference, permitting the use of non-sinusoidal demodulation of the input signal applied on input 2.

External (PLL)

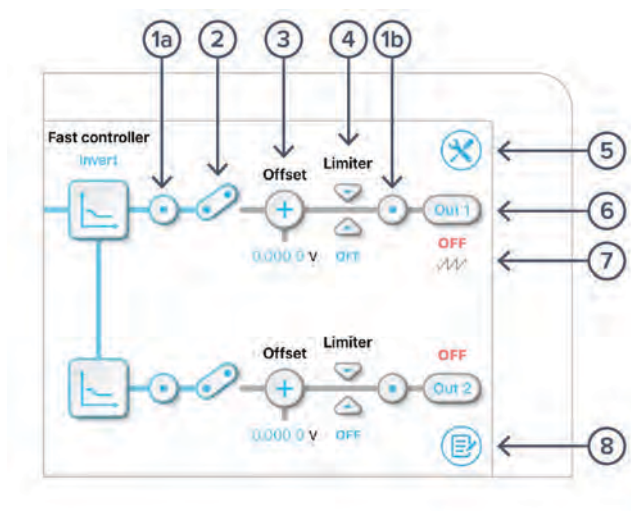
External (PLL) mode enables the Laser Lock Box to lock to an externally sourced demodulation reference, applied to input 2. This mode uses a digitally implemented phase-locked loop (PLL) to track the phase of the external reference with a tracking bandwidth of 10kHz. The PLL will automatically lock to the strongest harmonic of the external reference in the range of 2MHz to 200MHz with a manually configurable local phase shift. The reacquire button can be used to re-lock to the external reference.



Outputs

Enable the PID, configure the voltage offset and limiter, 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 .



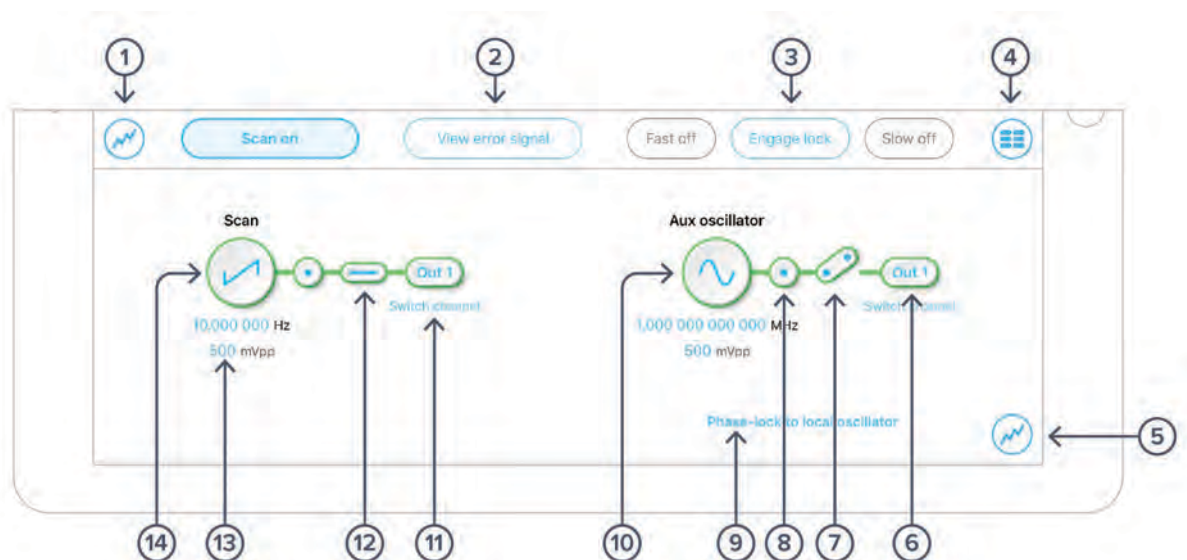
| ID | Description | ID | Description |
|------|-------------------------------------|----|-------------------------------------|
| 1a,b | Drop point for oscilloscope | 5 | Tools to configure local oscillator |
| 2 | Tap to enable PID controller output | 6 | Turn output 1 on/off |
| 3 | Enable & set a fixed offset | 7 | Indicates scan active on output 1 |
| 4 | Enable & set output limiter | 8 | Select datalogger instrument |



Lower User Interface

The lower user interface is used to either control the scan and aux oscillator; display the half screen oscilloscope, datalogger instrument or the parameter control panel.

Scan and aux oscillator

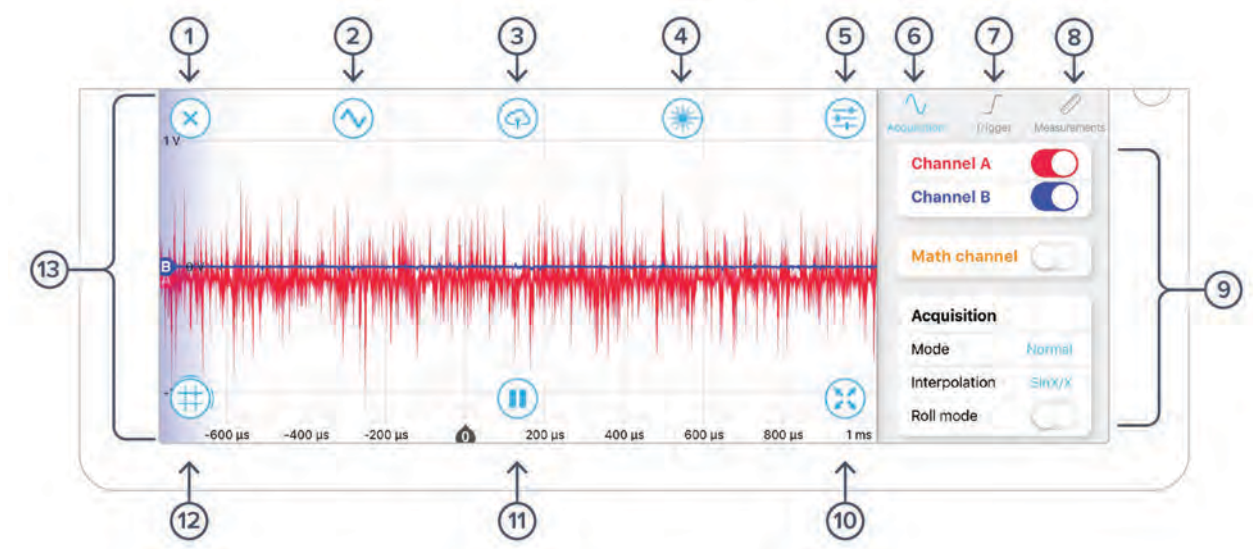


| ID | Description | ID | Description |
|----|--|----|---|
| 1 | Toggle oscilloscope view | 8 | Drop point for in-built oscilloscope |
| 2 | View error signal in oscilloscope | 9 | Phase lock aux to local oscillator |
| 3 | Engage lock enables the fast and slow PID controller outputs | 10 | Configure aux oscillator frequency and amplitude |
| 4 | Toggle parameter configuration panel | 11 | Switch channel for scan waveform |
| 5 | Toggle oscilloscope view | 12 | Turn on/off scan waveform |
| 6 | Switch channel for aux oscillator | 13 | Configure scan amplitude and frequency |
| 7 | Turn on/off aux oscillator | 14 | Tap to configure scan as positive ramp, negative ramp or triangle |



Oscilloscope

Moku:Lab's Laser Lock Box includes a built-in oscilloscope, enabling you to observe and record data of up to two signals in the laser lock box's processing chain at a time. More details about the oscilloscope can be found in the Moku:Lab Oscilloscope manual.




| ID | Description | ID | Description |
|----|---------------------------------|----|--|
| 1 | Close oscilloscope panel | 8 | Tap to select measurements tab |
| 2 | Toggle scan sync mode | 9 | Settings sidebar |
| 3 | Share oscilloscope data | 10 | Set oscilloscope to full screen |
| 4 | Select zero crossing to lock to | 11 | Pause/run oscilloscope |
| 5 | Reveal/hide settings sidebar | 12 | Tap to add time/voltage cursors; or drag right or drag up to create a cursor |
| 6 | Acquisition tab selected | 13 | Oscilloscope sub-panel |
| 7 | Tap to select trigger tab | | |

The oscilloscope will appear automatically when a probe point  is activated.

You can hide the oscilloscope by pressing the  icon and reveal it by pressing the  icon.



Probe Points

Add or move probe points  to view signals at different locations in the digital signal processing chain.

Tip: Quickly add voltage cursors by dragging your finger up from the cursor icon. Add time cursors by dragging your finger to the right, away from the icon.





Play / Pause

The measurement trace can be paused at any time by pressing the  button. This allows you to closely inspect features in the most recently captured trace. No new measurement data will be displayed until the measurement is resumed by pressing the  icon.

Pressing the “Share” button will also pause capture and must be resumed from this button.

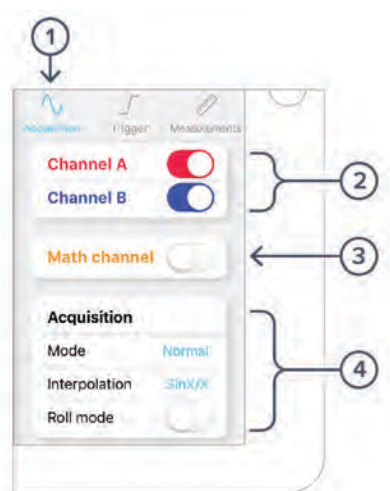
Full Screen Mode

Press the  icon to enter full screen mode. Exit full screen mode by pressing .

Oscilloscope side panel

The oscilloscope measurement side panel is revealed by tapping the settings button. 

It allows configuration of the oscilloscope acquisition, trigger and measurements.



Acquisition

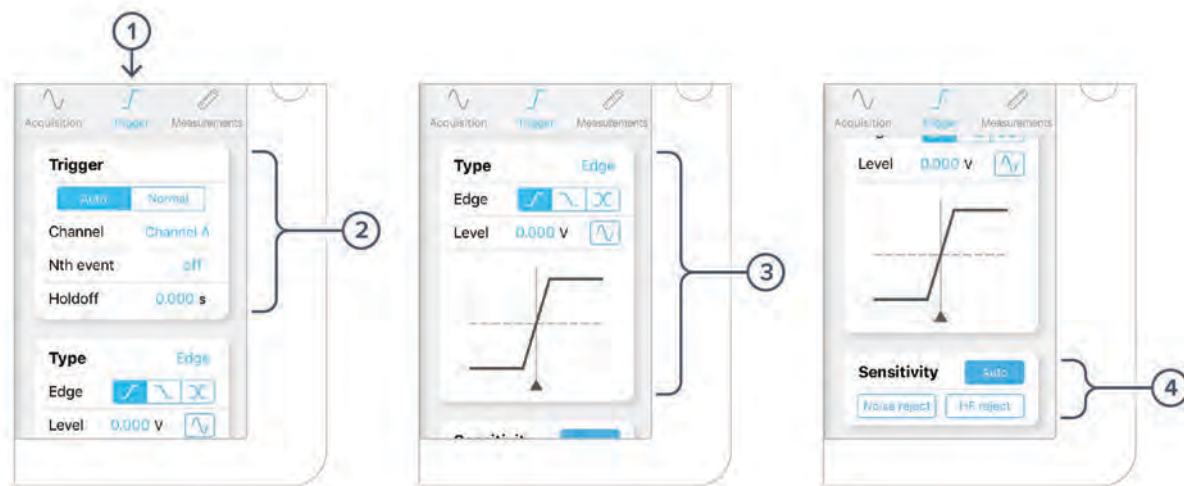
| ID | Description |
|----|--|
| 1 | Acquisition sub-tab |
| 2 | Display/hide toggles for channel A and B |
| 3 | Display/hide toggles for Math channel |
| 4 | Acquisition settings, normal/precision*, SinX/X, Gaussian and Linear interpolation |

***Normal** mode down-samples by discarding points between those needed. **Precision** mode down-samples by averaging, increasing precision and reducing noise.



Trigger

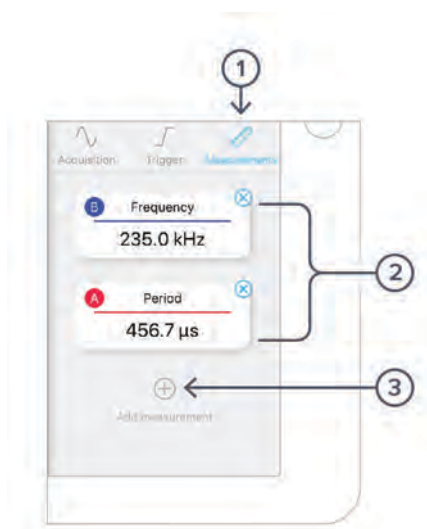
Tip: Quickly adjust trigger settings by tapping the trigger marker 



| ID | Description |
|----|--|
| 1 | Trigger sub-tab |
| 2 | Trigger channel, mode, holdoff |
| 3 | Configure level or edge trigger |
| 4 | Set trigger sensitivity and filter options |



Measurements

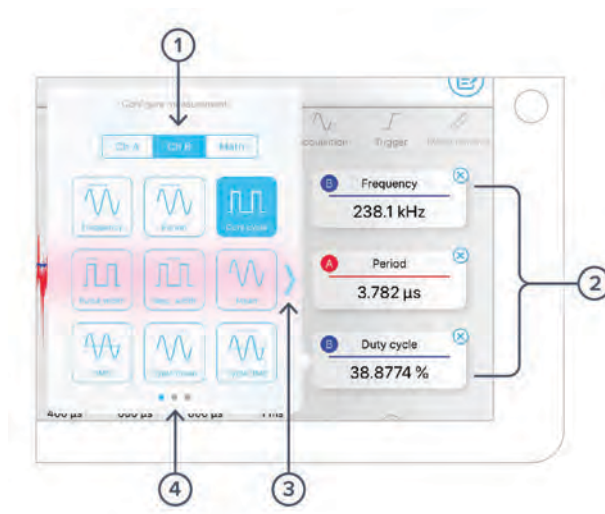


The measurements menu  allows you to measure up to seven attributes at a time across both input channels and the math channel.

| ID | Description |
|----|---|
| 1 | Measurements sub-tab, select individual attributes for each channel |
| 2 | Various measurement tablets, tap to configure channel and parameter |
| 3 | Tap to add new measurement |



Measurement setup

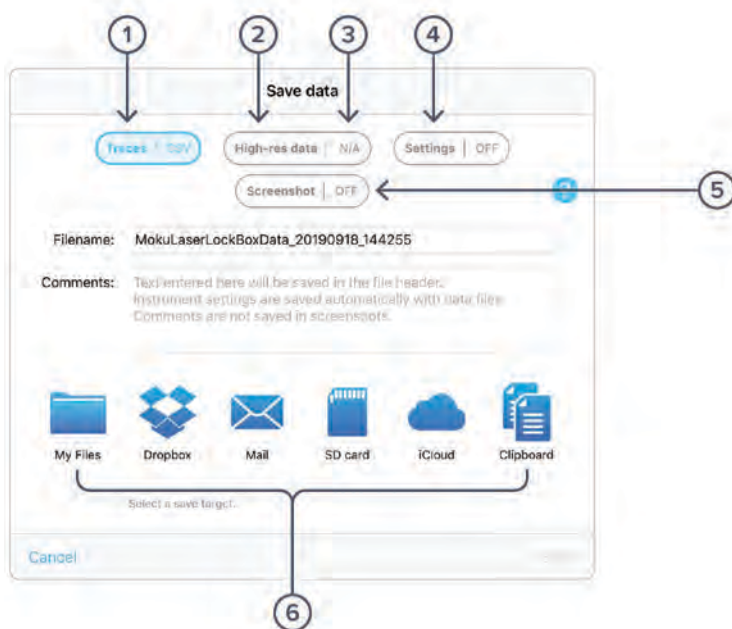


| ID | Description |
|----|----------------------------------|
| 1 | Source channel |
| 2 | Multiple measurement tabs |
| 3 | Tap for more measurement options |
| 4 | 3 panes of measurement options |



Save oscilloscope data to files or cloud services


To export a measurement trace, press the  icon on the oscilloscope



| ID | Description | ID | Description |
|----|------------------------------------|----|--|
| 1 | Save traces, CSV or MATLAB formats | 4 | Save Laser Lock box instruments settings to TXT file |
| 2 | Save High res data | 5 | Save screenshot, JPG or PNG formats |
| 3 | High res data format | 6 | Select save data destination |

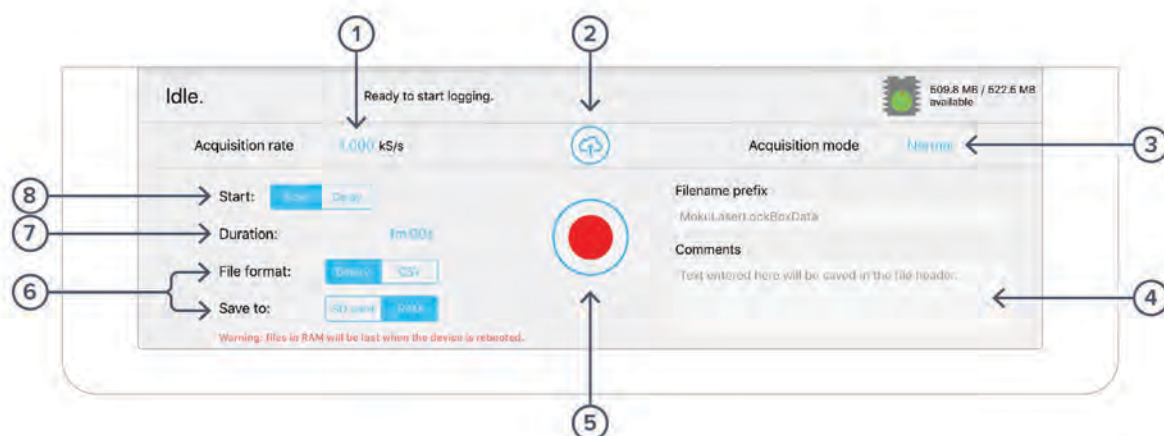


Datalogger

The inbuilt data logger allows you to acquire data from up to two probe points at a time at a maximum sampling rate of 500 kS/s for two channels and 1 MS/s for one channel. To access the data acquisition menu, press the  icon.

Data can be acquired in one of two acquisition modes, Normal and Precision. Precision mode filters channel data according to the selected acquisition rate, increasing vertical resolution and attenuating aliased harmonics.

- Data can be saved to SD card or RAM with binary *.li or comma separated value *.csv file formats
- Files saved to RAM will be lost when the Moku:Lab is powered down or reset
- Files saved with binary *.li format can be converted to *.csv or *.mat using Liquid Instruments file conversion software (<https://github.com/liquidinstruments/lireader>)
- Record data for up to 240 hours, and delay the start of a measurement for up to 240 hours
- Start a measurement by pressing the red record circle



| ID | Description |
|----|---|
| 1 | Select the sampling rate at which your measurement is recorded |
| 2 | Upload saved data |
| 3 | Select between Normal and Precision acquisition modes |
| 4 | Add comments to your measurement |
| 5 | Record a new measurement |
| 6 | Select the file format and destination of the recorded measurement data |
| 7 | Configure measurement duration |
| 8 | Configure when to begin recording data |

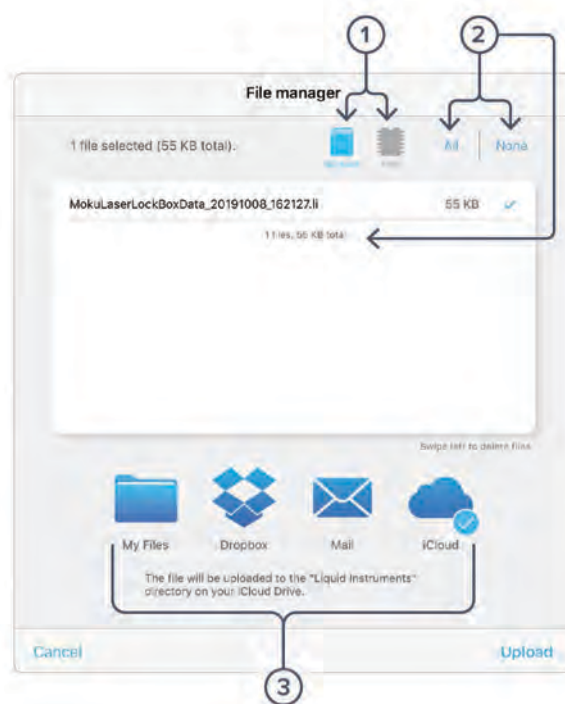
Note: As a precaution, you will be warned about switching instruments while a measurement is taking place.



Exporting Data

Data that has been acquired to SD card or RAM can be exported to My Files (iOS 11 or later), Dropbox, E-mail, and iCloud.

To export acquired data, press the  icon in the data logger.



| ID | Description |
|----|---|
| 1 | Select whether to upload your data from SD card or RAM |
| 2 | Select which files to upload |
| 3 | Select the destination for your data. Note: cloud storage will require you to sign in |

SD card

- Upload files to SD card by inserting a compatible FAT32 formatted drive into the Moku:Lab's SD card slot, located on the rear of the device next to the power connector.

Dropbox

- Upload files to Dropbox by logging in to your account with the Moku:Lab iPad app.





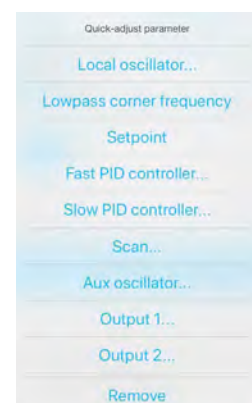
Parameter controls panel

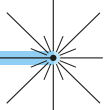
The parameters panel allows quick and convenient adjustment of many of the laser lock box parameters. Selected parameters can be adjusted by swiping left or right on the lower adjustment bar; or direct numerical values entered by tapping the keypad icon 



| ID | Description | ID | Description |
|----|--------------------------------------|----|--|
| 1 | Switch lower display to oscilloscope | 6 | Turn on/off slow PID controller |
| 2 | Turn off/on scan function | 7 | Toggle display between parameters panel and oscillator control |
| 3 | View plot of error signal | 8 | Configurable parameters panel |
| 4 | Turn on/off fast PID controller | 9 | Switch lower panel to oscilloscope |
| 5 | Engage lock | 10 | Swipe left/right to adjust selected parameter |

The specific quick adjust parameters that are available can be set up by tapping  (add quick adjust parameters), or existing parameters in the panel changed by tapping .





Digital Filter Box

User Manual

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





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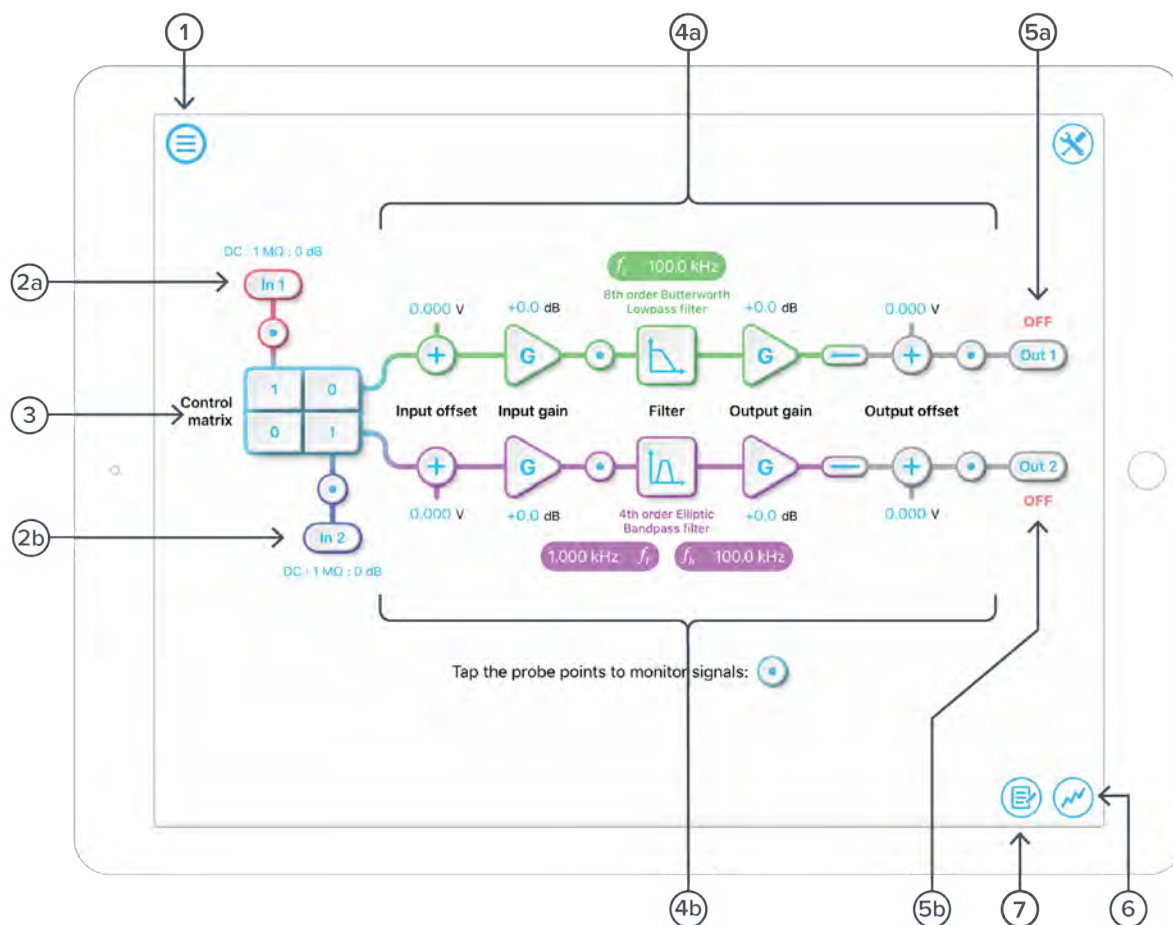


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User Interface

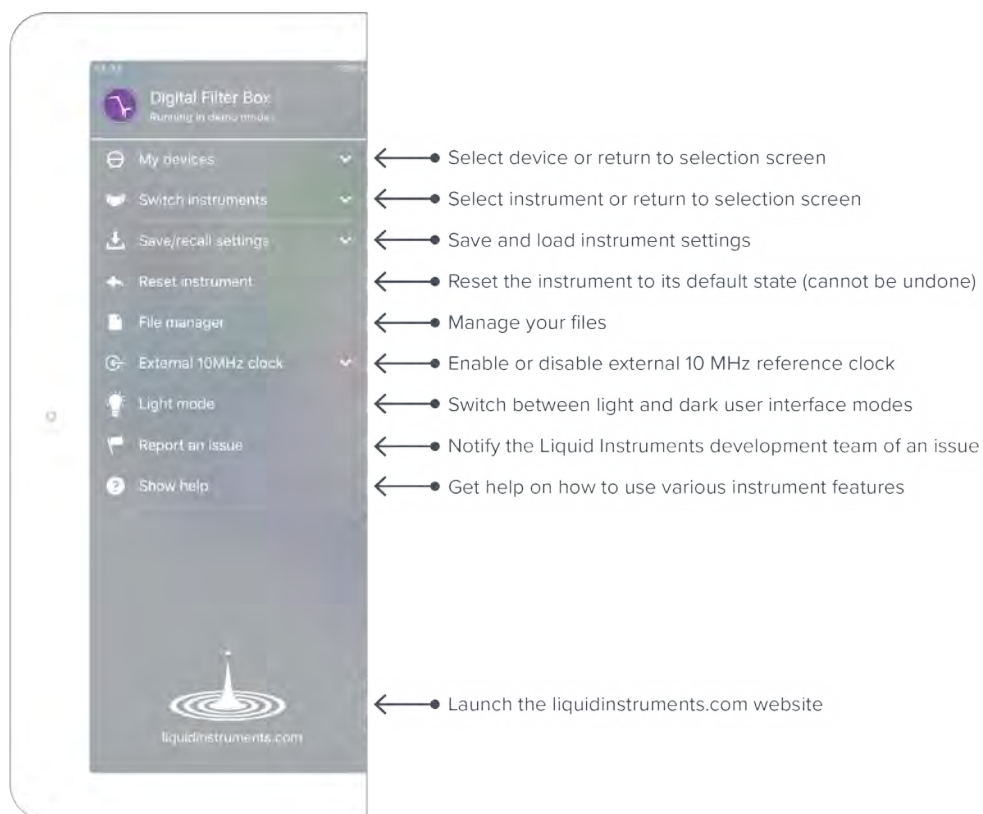


| ID | Description |
|----|-----------------------------------|
| 1 | Main menu |
| 2a | Input configuration for Channel 1 |
| 2b | Input configuration for Channel 2 |
| 3 | Control matrix |
| 4a | Configuration for Filter 1 |
| 4b | Configuration for Filter 2 |
| 5a | Output switch for Filter 1 |
| 5b | Output switch for Filter 2 |
| 6 | Enable the oscilloscope |
| 7 | Enable the datalogger |



Main Menu

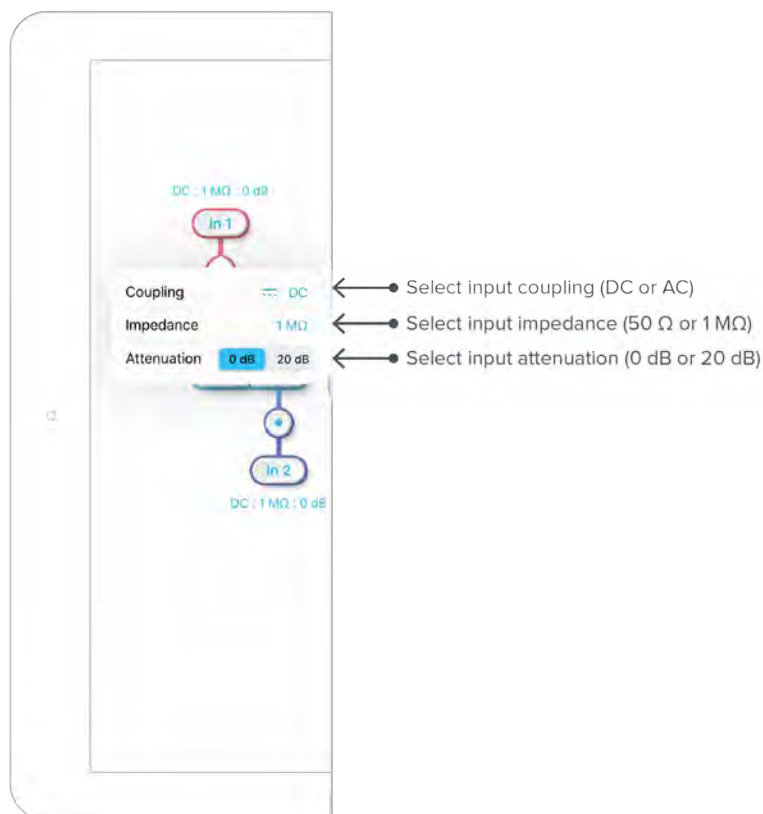
The **main menu** can be accessed by pressing the  icon, allowing you to:





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 signals to the two independent digital filters. The output vector is the product of the control matrix multiplied by the input vector.

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

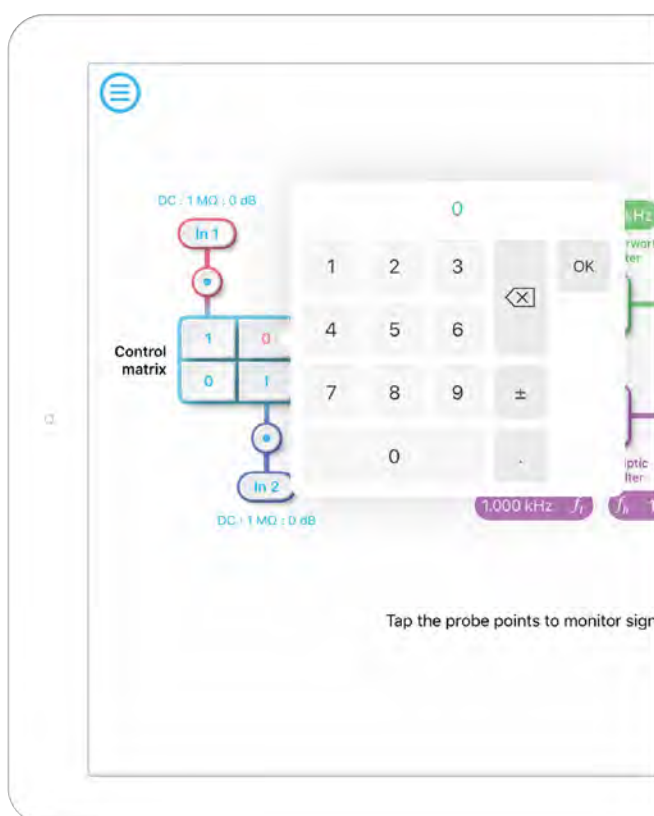
where

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

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

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

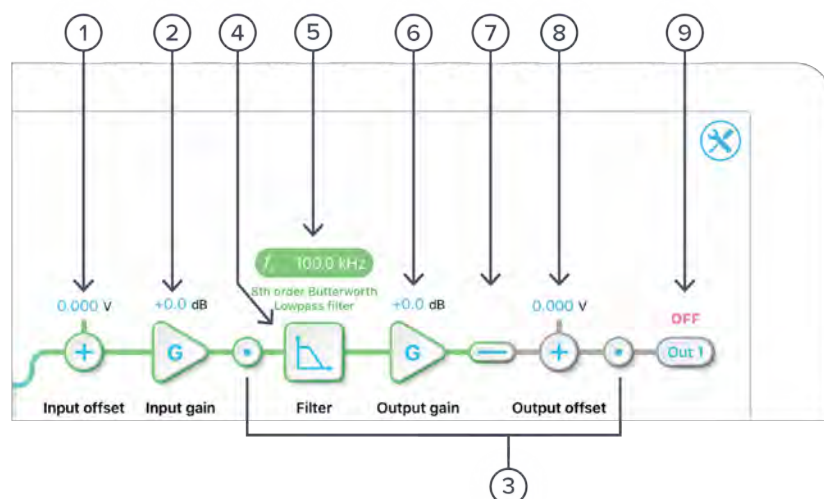




Digital Filter

The two independent, fully real-time configurable digital filter paths follow the control matrix in the block diagram, represented in green and purple for filter 1 and 2, respectively.

User Interface




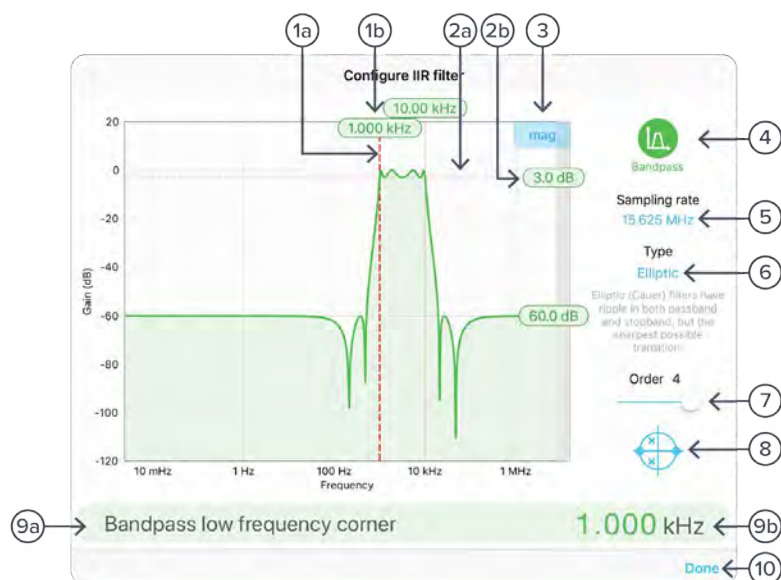
| ID | Parameter | Description |
|----|----------------------|---|
| 1 | Input offset | Tap to adjust the input offset (-1 to +1 V). |
| 2 | Input gain | Tap to adjust the input gain (-40 to 40 dB). |
| 3 | Probe points | Tap to enable/disable the probe points. See Probe Points section for details. |
| 4 | Digital filter | Tap to view and configure the digital filter builder. |
| 5 | Quick filter control | Tap or slide to quickly adjust the filter settings |
| 6 | Output gain | Tap to adjust the input gain (-40 to 40 dB). |
| 7 | Output switch | Tap to zero the filter output. |
| 8 | Output offset | Tap to adjust the output offset (-2 to +2 V). |
| 9 | DAC switch | Tap to enable/disable Moku:Lab's DAC output. |



Digital Filter Builder

Filter Builder Interface

Tap the  icon to open the filter builder view.



| ID | Parameter | Description |
|----|-------------------------------|--|
| 1a | Frequency (horizontal) cursor | Cursor for corner frequency. |
| 1b | Cursor reading | Reading for frequency cursor. Drag to adjust the corner frequency. Tap to manually enter corner frequency. |
| 2a | Gain (vertical) cursor | Cursor for ripple/gain/attenuation level. |
| 2b | Cursor reading | Reading for gain cursor. Drag to adjust the gain/ripple level. Tap to manually enter passband ripple. |
| 3 | Display toggle | Toggle between magnitude and phase response curve. |
| 4 | Filter shape selection | Tap to select between lowpass, highpass, bandpass, bandstop, and custom filters. |
| 5 | Sampling rate | Tap to select between 15.625 MHz or 122.07 kHz. |
| 6 | Filter type selection | Tap to select between Butterworth, Chevyshev I/II, Elliptic, Bessel, Gaussian, Cascaded or Legandre filters. |
| 7 | Filter order | Slide to adjust filter orders. |
| 8 | s-plane plot | Tap to view the filter poles and zeros in s-plane. |
| 9a | Active configurable parameter | Name of the active configurable parameter. |
| 9b | Parameter value | Tap to manually enter the active configurable parameter value. |
| 10 | Save and close | Tap to save and close the filter builder. |



Filter Response Plot

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



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

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

The red dashed lines represent other user editable cursors.

Filter Shapes

The shape of the filter can be selected by pressing the ④ button (on Page 9). There are four pre-defined filter shapes and a fully customizable filter option.





Sampling Rates

Users can select a high (15.625 MHz) or a low (122.07 kHz) output sampling rate mode based on the desired corner frequencies. The following table summarizes the lower and upper bounds for each shape of pre-defined filters with different sampling rates:

| Shape | Sampling Rate | Minimum corner frequency | Maximum corner frequency |
|----------|---------------|--------------------------|--------------------------|
| Lowpass | Low | 23.45 mHz | 54.93 kHz |
| | High | 3.002 Hz | 7.031 MHz |
| Highpass | Low | 289.5 mHz | 54.93 kHz |
| | High | 37.05 Hz | 7.031 MHz |
| Bandpass | Low | 1.221 Hz | 54.93 kHz |
| | High | 156.3 Hz | 7.031 MHz |
| Bandstop | Low | 23.45 mHz | 54.93 kHz |
| | High | 3.002 Hz | 7.031 MHz |

Filter Types

The type of filter can be selected by pressing the ⑥ button (on Page 9). There are seven pre-defined filter types with user-selectable filter orders from 2 up to 8, depending on the filter shapes.

| Filter Types | Description |
|---------------------|---|
| Butterworth | Butterworth filters have a maximally flat passband and a monotonic frequency response. |
| Chebyshev I | Chebyshev I filters have ripple in the passband but a sharper transition than Butterworth filters. |
| Chebyshev II | Chebyshev II filters have ripple in the stopband but a sharper transition than Butterworth filters. |
| Elliptic | Elliptic (Cauer) filters have ripple in both passband and stopband, but the sharpest possible transition. |
| Cascaded | Cascaded first-order filters have zero overshoot in the time domain. |
| Bessel | Bessel filters have a maximally flat group and phase delay in the passband, thus preserving the wave shape of passed signals. |
| Gaussian | Gaussian filters have the minimum possible group delay, and a step response with no overshoot and minimum rise and fall time. |
| Legendre | Legendre (Optimum L) filters have the sharpest possible transition while maintaining a monotonic frequency response. |

Filter Orders

For single sided filters, the order of the filter can be selected between 2, 4, 6, and 8. For double sided filters, the order of the filter can be selected between 2 and 4.



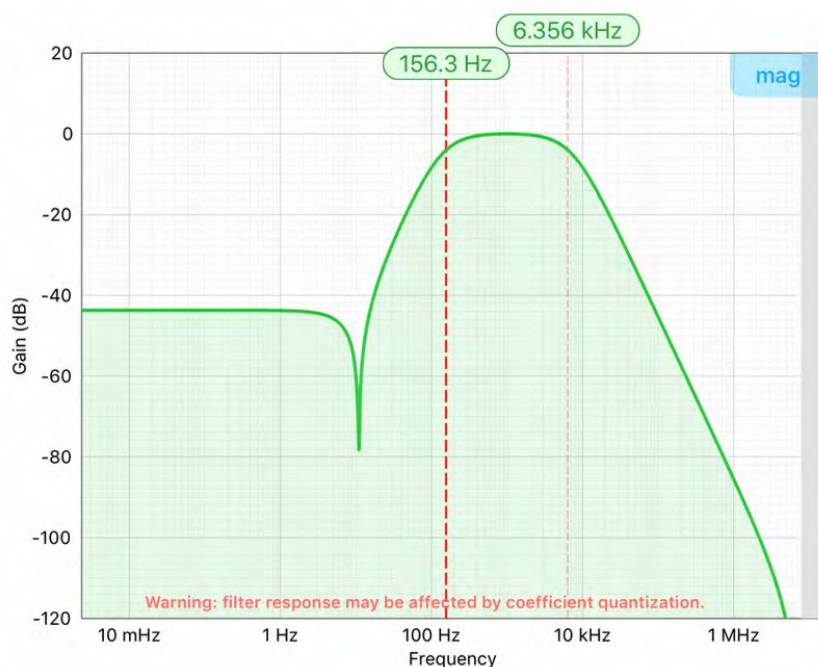
Ripples

Chebyshev I, II, and Elliptic filters have ripples on either passband, stopband or both. The following table summarizes the adjustable range for the passband and stopband ripples for these filter types.

| Filter Types | Passband Ripple | Stopband Ripple |
|---------------------|---|---|
| Chebyshev I | 0.1 dB to 10.0 dB with 0.1 dB increment | N/A |
| Chebyshev II | N/A | 10.0 dB to 100.0 dB with 1 dB increment |
| Elliptic | 0.1 dB to 10.0 dB with 0.1 dB increment | 10.0 dB to 100.0 dB with 1 dB increment |

Coefficient Quantization

Due to the limit of digitization depth, the quantization error is pronounced at certain FIR filter settings. A red coefficient quantization warning may appear on the bottom of the response plot.





Custom Filter

The custom filter implements infinite impulse response (IIR) filters using 4 cascaded Direct Form I second-order stages with a final output gain stage. The total transfer function can be written:

$$H(z) = g \prod_{k=1}^4 s_k \frac{b_{0k} + b_{1k}z^{-1} + b_{2k}z^{-2}}{1 + a_{1k}z^{-1} + a_{2k}z^{-2}}$$

To specify a filter, you must supply a text file containing the filter coefficients on Moku:Lab's SD card or iPad storage. The file should have six coefficients per line, with each line representing a single stage. If output scaling is required, this should be given on the first line:

| | | | | | | |
|---------------------|---------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| <i>g</i> (optional) | 7.8357416974, | | | | | |
| Stage 1 | 1.0000000000, | 0.0044157497, | 0.0088314994, | 0.0044157497, | -1.6692917152, | 0.9692269375 |
| Stage 2 | 1.0000000000, | 0.0472217267, | 0.0944434535, | 0.0472217267, | -1.8988580275, | 0.9341904809 |
| Stage 3 | 1.0000000000, | 0.0375275838, | 0.0750551677, | 0.0375275838, | -1.9259771042, | 0.9311308010 |
| ⋮ | <i>s</i> | <i>b</i> ₀ | <i>b</i> ₁ | <i>b</i> ₂ | <i>a</i> ₁ | <i>a</i> ₂ |

Each coefficient must be in the range [-4.0,+4.0). Internally, these are represented as signed 48-bit fixed-point numbers, with 45 fractional bits. The output scaling can be up to 8,000,000. Filter coefficients can be computed using signal processing toolboxes in e.g. MATLAB or SciPy.

Some coefficients may result in overflow or underflow, which degrade filter performance. Filter responses should be checked prior to use.



Quick Filter Control

This panel (⑤) allows users quickly to view and adjust the filter parameters without opening the full filter builder.




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

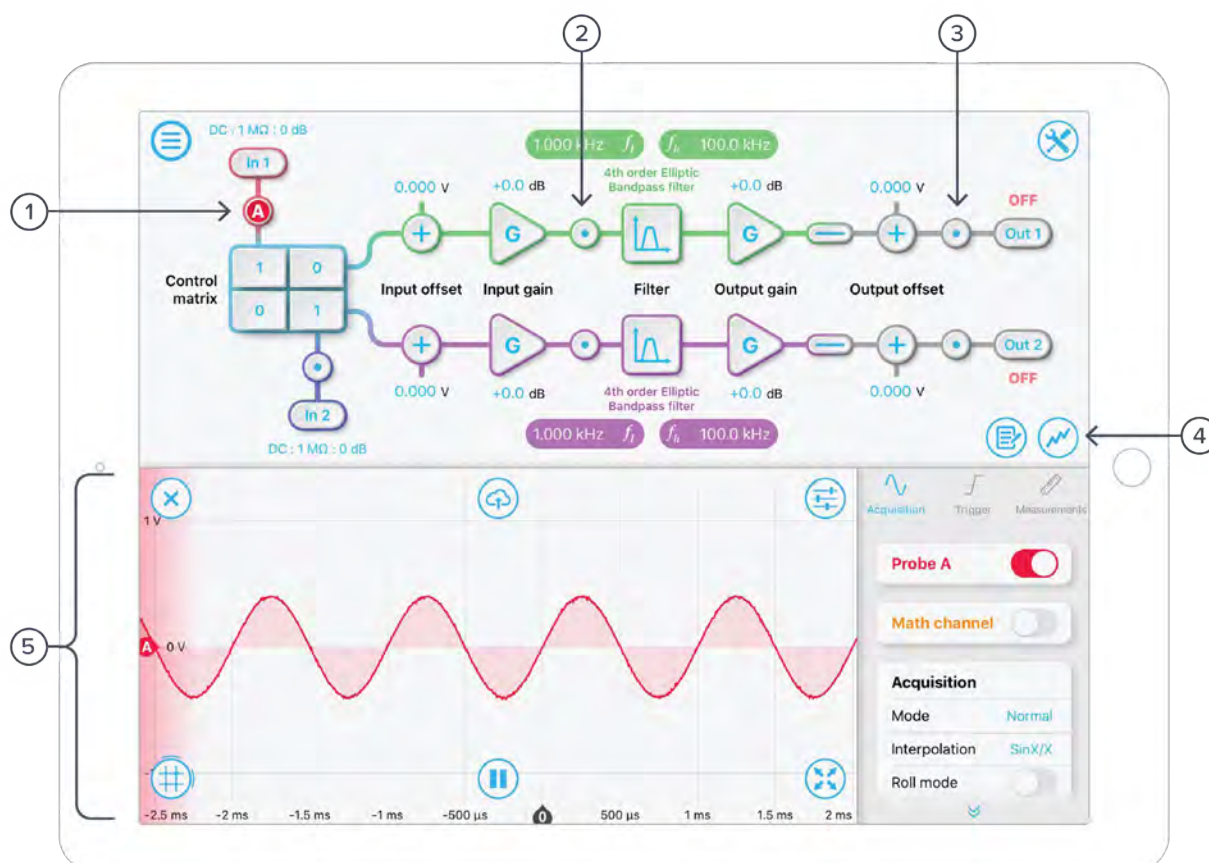
| ID | Description |
|-------|-----------------------|
| f_l | Low frequency corner |
| f_h | High frequency corner |



Probe Points

Moku:Lab's Digital Filter Box has an integrated oscilloscope and data logger that can be used to probe or record the signal at the input, pre-filter, and output stages. The probe points can be added by tapping the  icon.

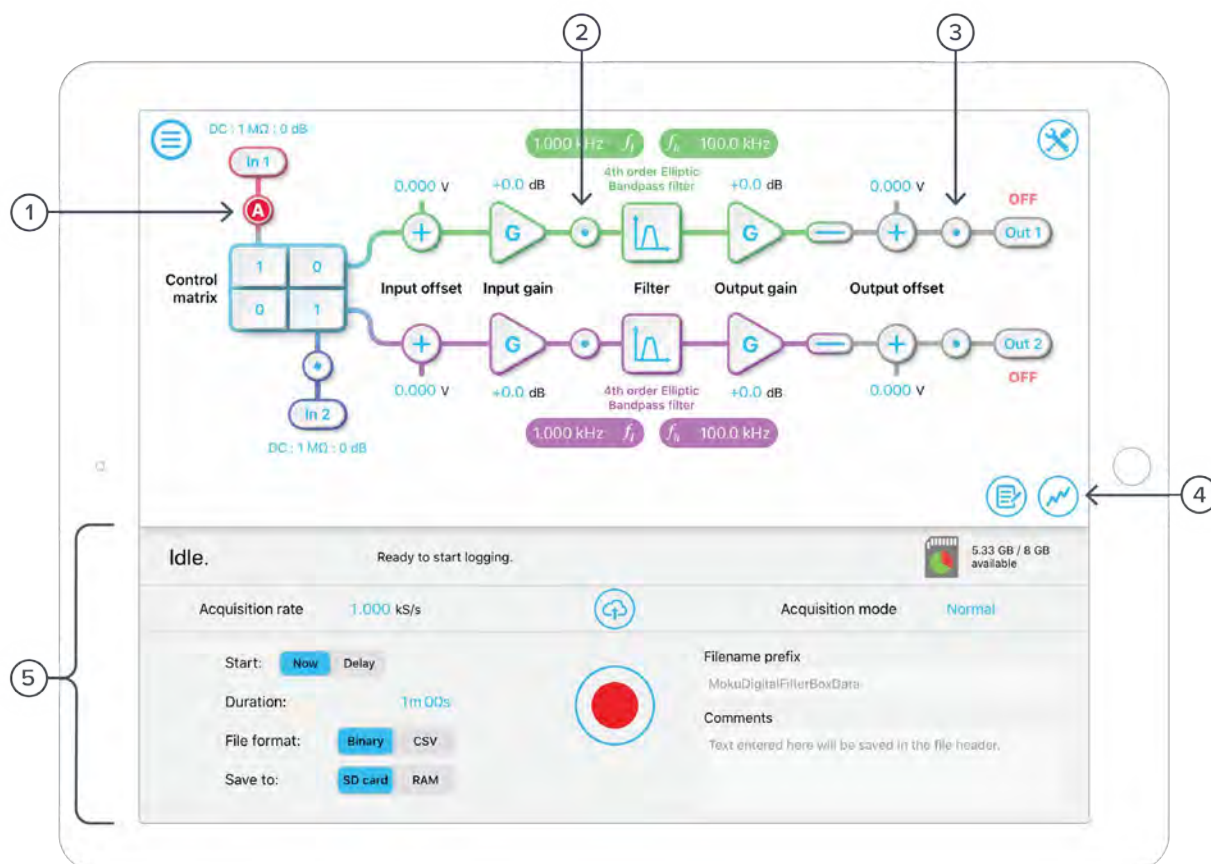
Oscilloscope



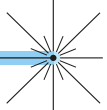
| ID | Parameter | Description |
|----|---------------------------------|---|
| 1 | Input probe point | Tap to place the probe point at inputs. |
| 2 | Pre-Filter probe point | Tap to place the probe before the filter. |
| 3 | Output probe point | Tap to place the probe at outputs. |
| 4 | Oscilloscope/data logger toggle | Toggle between built-in oscilloscope or data logger. |
| 5 | Oscilloscope | Refer to Moku:Lab's Oscilloscope manual for the details. |



Data Logger



| ID | Parameter | Description |
|----|---------------------------------|--|
| 1 | Input probe point | Tap to place the probe point at inputs. |
| 2 | Pre-Filter probe point | Tap to place the probe before the filter. |
| 3 | Output probe point | Tap to place the probe at outputs. |
| 4 | Oscilloscope/data logger toggle | Toggle between built-in oscilloscope or data logger. |
| 5 | Data Logger | Refer to Moku:Lab's Data Logger manual for the details. |



FIR Filter Builder User Manual

With Moku:Lab's FIR Filter Builder, you can design and implement lowpass, highpass, bandpass, and bandstop finite impulse response (FIR) filters with up to 14,819 coefficients at a sampling rate of 244.1 kHz, or 232 coefficients at a sampling rate up to 15.63 MHz. Moku:Lab's iPad interface allows you to fine tune your filter's response in the frequency and time domains to suit your specific application. Select between four frequency response shapes, five common impulse responses, and up to eight window functions.





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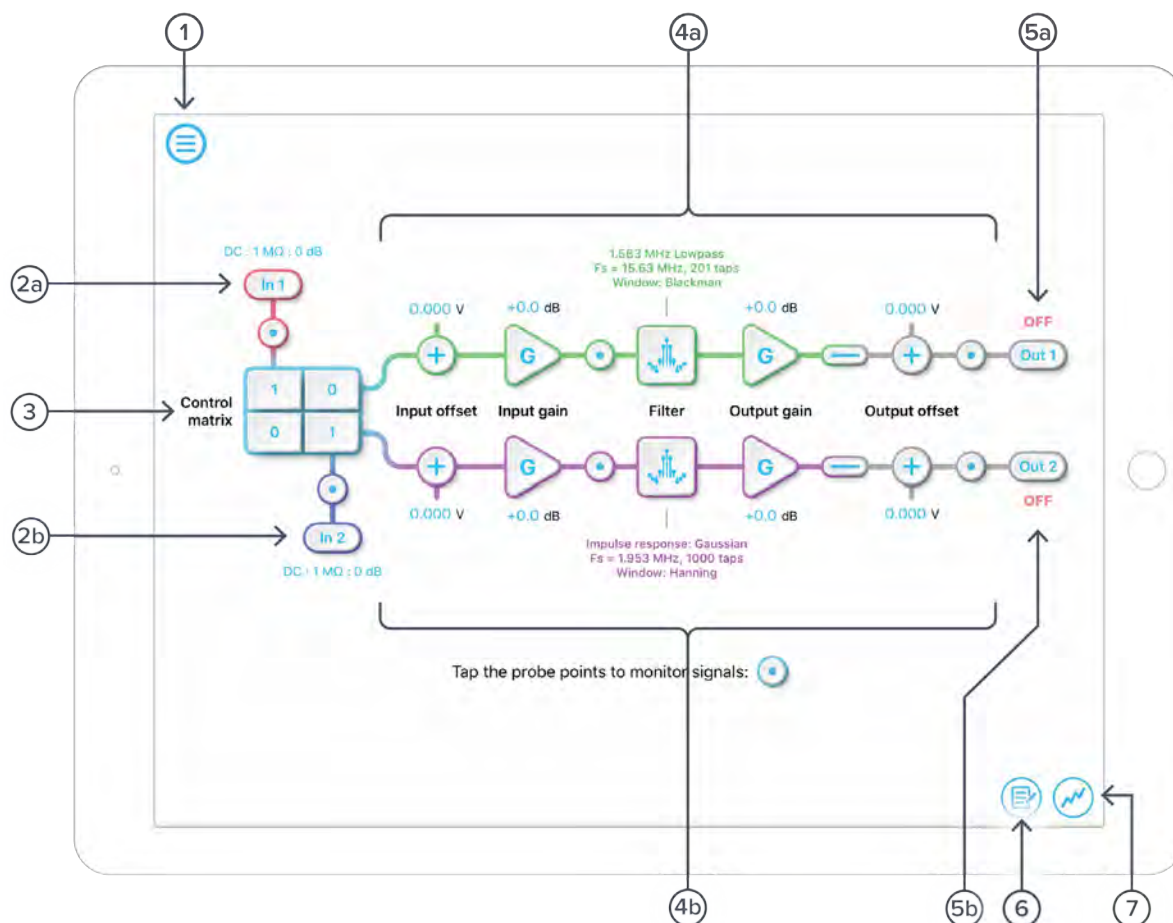


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User Interface

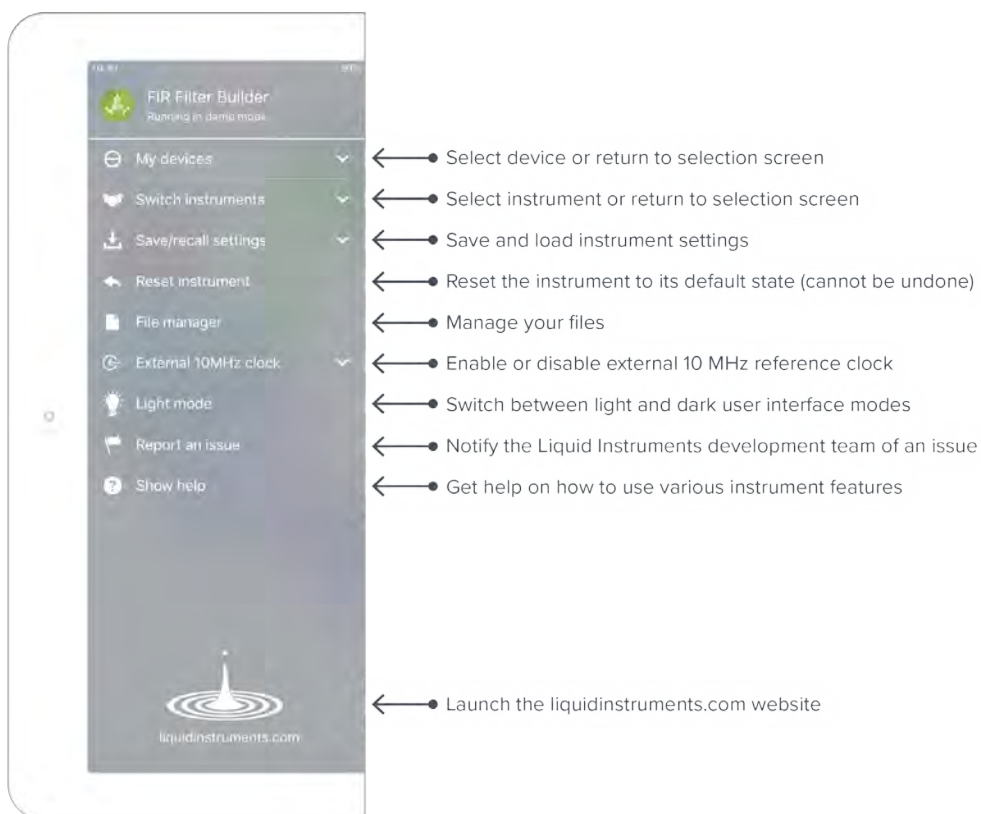


| ID | Description |
|----|-----------------------------------|
| 1 | Main menu |
| 2a | Input configuration for Channel 1 |
| 2b | Input configuration for Channel 2 |
| 3 | Control matrix |
| 4a | Configuration for FIR filter 1 |
| 4b | Configuration for FIR filter 2 |
| 5a | Output switch for FIR filter 1 |
| 5b | Output switch for FIR filter 2 |
| 6 | Enable the data logger |
| 7 | Enable the oscilloscope |



Main Menu

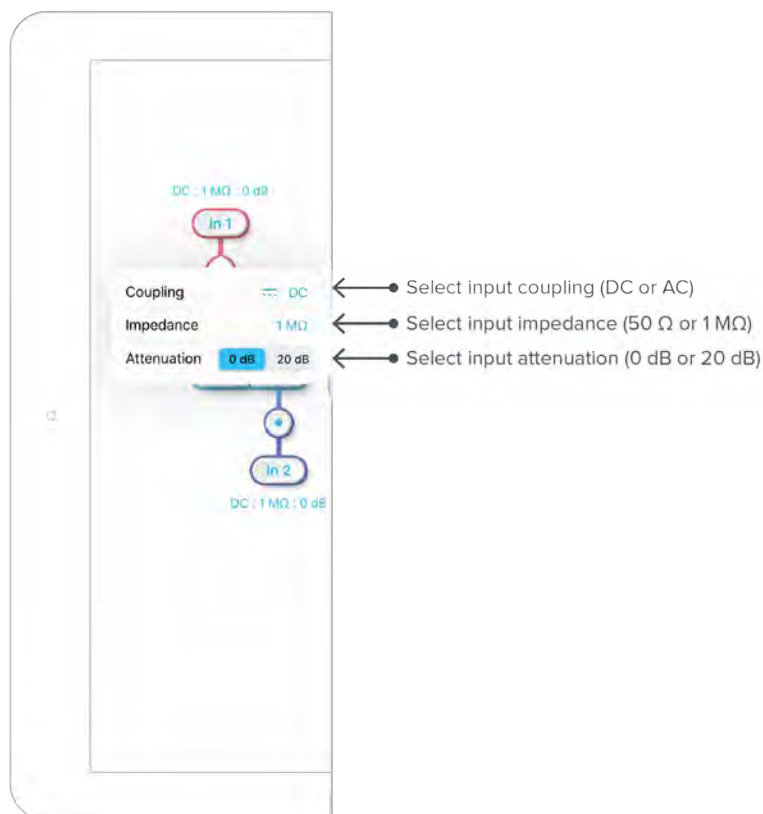
The **main menu** can be accessed by pressing the  icon, allowing you to:





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 signals to the two independent FIR filters. The output vector is the product of the control matrix multiplied by the input vector.

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

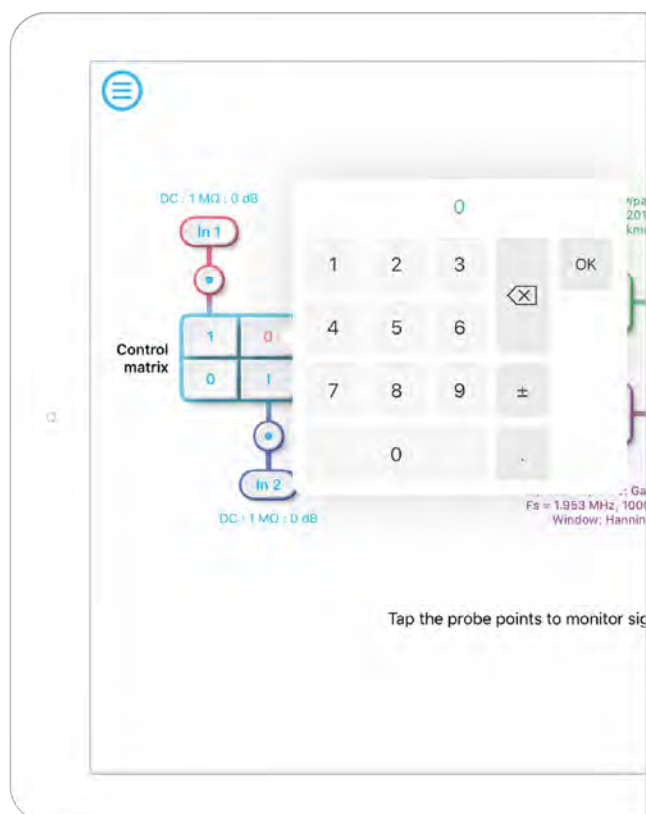
where

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

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

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

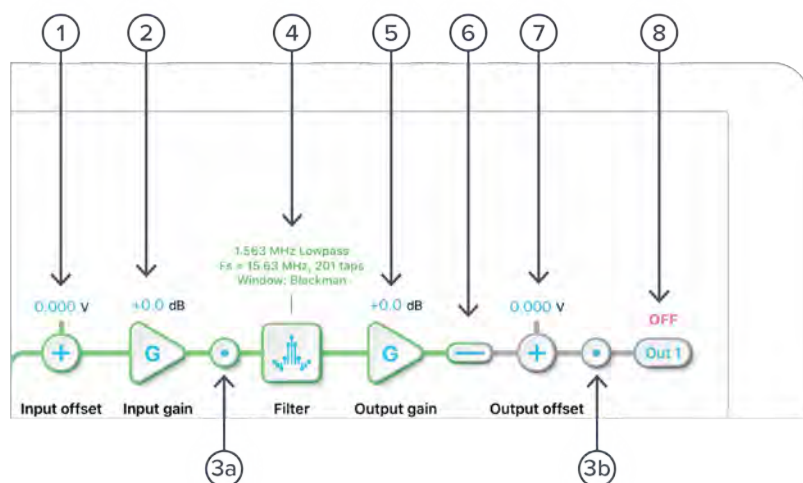




FIR Filter

The two independent, fully real-time configurable FIR filter paths follow the control matrix in the block diagram, represented in green and purple for filter 1 and 2, respectively.

User Interface




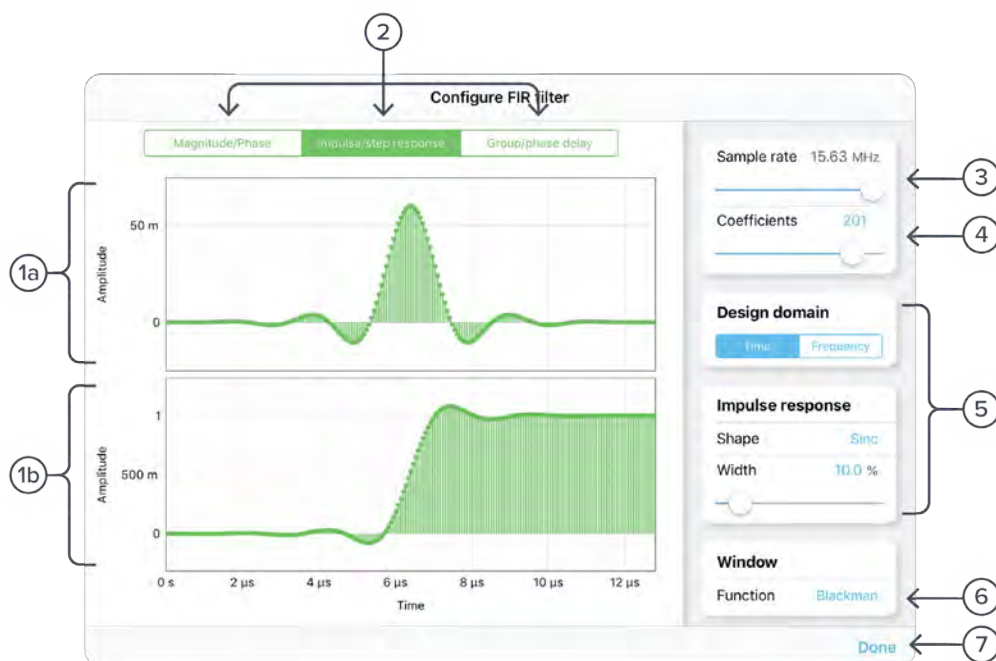
| ID | Parameter | Description |
|----|------------------|---|
| 1 | Input offset | Tap to adjust the input offset (-1 to +1 V). |
| 2 | Input gain | Tap to adjust the input gain (-40 to 40 dB). |
| 3a | Pre-filter probe | Tap to enable/disable the pre-filter probe point. See Probe Points section for details. |
| 3b | Output probe | Tap to enable/disable the output probe point. See Probe Points section for details. |
| 4 | FIR filter | Tap to open view and configure the FIR filter builder. |
| 5 | Output gain | Tap to adjust the input gain (-40 to 40 dB). |
| 7 | Output switch | Tap to zero the filter output. |
| 7 | Output offset | Tap to adjust the input offset (-2 to +2 V). |
| 8 | DAC switch | Tap to enable/disable Moku:Lab's DAC output. |



FIR Filter Builder

Builder Interface

Tap the  icon to open the full **FIR Filter Builder** view.



| ID | Parameter | Description |
|----|------------------------|--|
| 1a | Plot 1 | Impulse response plot. |
| 1b | Plot 2 | Step response plot. |
| 2 | Plot set selection | Tap to select the set of plots to display in the plot area. |
| 3 | Sampling rate | Adjust the sampling rate for the input. Slide between 122.1 kHz and 15.63 MHz. |
| 4 | Number of coefficients | Tap the number to enter or slide the slider to adjust the number of coefficients. |
| 5 | Filter design | Configure the parameters for the FIR filter. Detailed information can be found in a later section. |
| 6 | Window function | Tap to select the window function. |
| 7 | Save & close | Tap to save and close the filter builder view. |

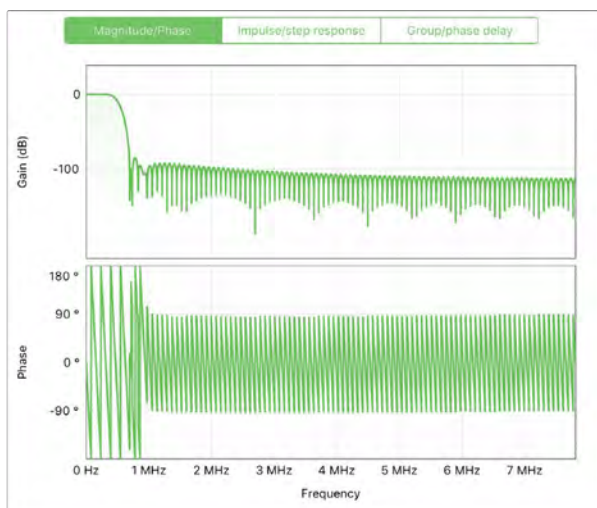


Filter Characteristic Graphs

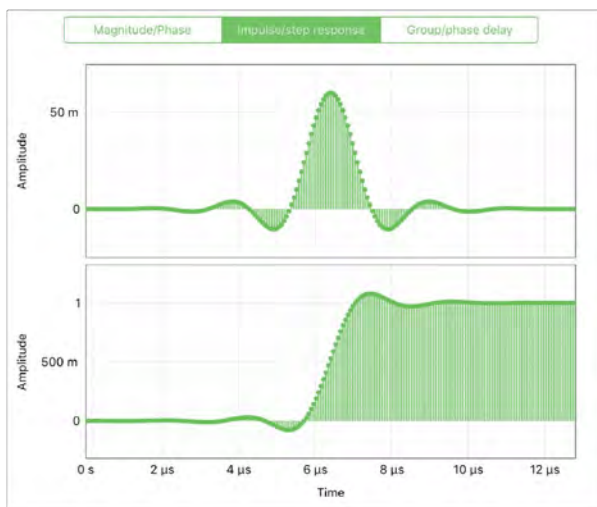
A set of two real-time filter characteristic plots can be shown at a time in the FIR filter builder. Tap the **plot set selection** buttons ② to select between **Magnitude/Phase**, **Impulse/step response**, and **Group/phase delay** plot sets.

| | Magnitude/Phase | | Impulse/step response | | Group/phase delay | |
|----------|-----------------|----------------------|-----------------------|--------|------------------------------|--------|
| | Plot 1 | Plot 2 | Plot 1 | Plot 2 | Plot 1 | Plot 2 |
| X - axis | Frequency (MHz) | | Time (μ s) | | Frequency (MHz) | |
| Y - axis | Gain (dB) | Phase ($^{\circ}$) | Amplitude (V) | | Group/phase Delay (μ s) | |

Magnitude/Phase plot set:

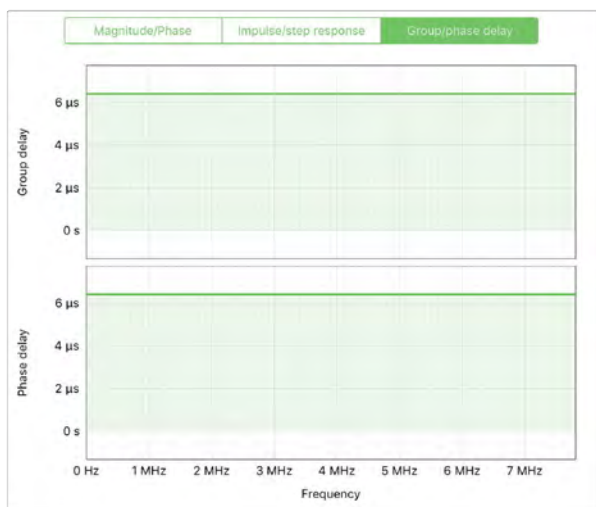


Impulse/step response plot set:





Group/phase delay plot sets:



Sampling Rate/Coefficients

The maximum number of coefficients depends on the chosen sampling rate. Available sampling rates with their corresponding maximum numbers of coefficients are listed in the table below.

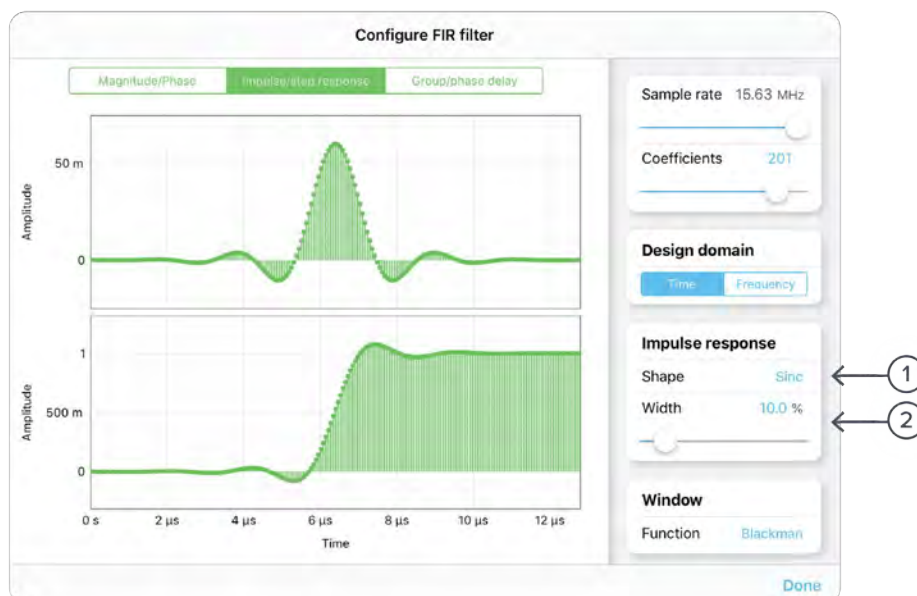
| Sampling rate | Maximum number of coefficients |
|---------------|--------------------------------|
| 122.1 kHz | 14,819 |
| 244.1 kHz | 14,819 |
| 488.3 kHz | 7,424 |
| 976.6 kHz | 3,712 |
| 1.953 MHz | 1,856 |
| 3.906 MHz | 928 |
| 7.813 MHz | 464 |
| 15.63 MHz | 232 |



Design Domain

The FIR filter can be designed in either time or frequency domain. In **time domain designer**, an impulse response function builder is accessible. Several predefined functions are available. Users can also enter an equation with the **equation editor** or load their own set of coefficients with the **custom impulse response** option. In **frequency domain designer**, a frequency response builder is accessible. Lowpass, highpass, bandpass, and bandstop filters are available with adjustable cut-off frequencies.

Time Domain Designer



| ID | Parameter | Description |
|----|---------------|--|
| 1 | Impulse shape | Tap to select the shape of the impulse response. |
| 2 | Impulse width | Tap the number to enter or slide the slider to adjust the impulse width. |

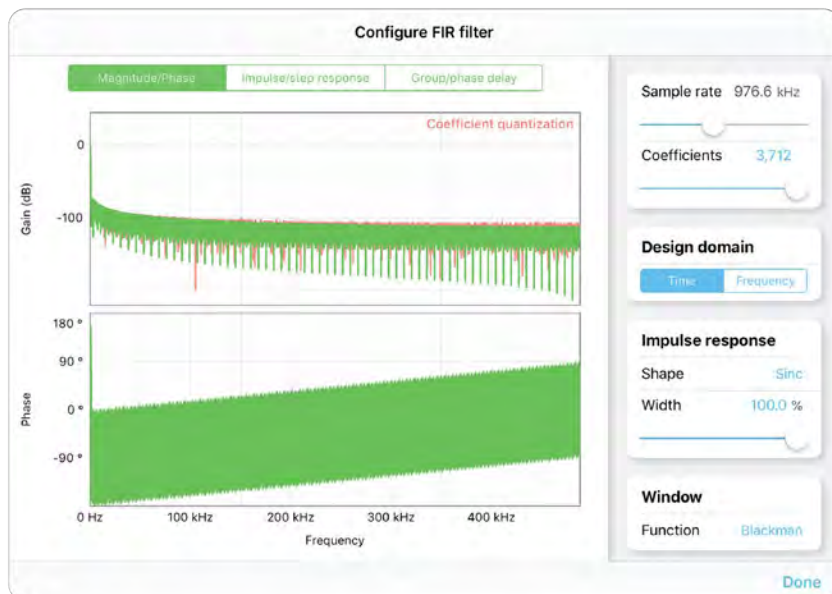
List of available shapes

| Shape | Note |
|-------------|--|
| Rectangular | |
| Sinc | Width adjustable from 0.1 % to 100 %. |
| Triangular | |
| Gaussian | Width adjustable from 0.1 % to 100 %. |
| Equation | Tap the equation to open the equation editor. Details about the equation editor can be found in the in the Equation Editor section. |
| Custom | Details about the custom impulse response can be found in Custom Impulse Response section |






Coefficient Quantization

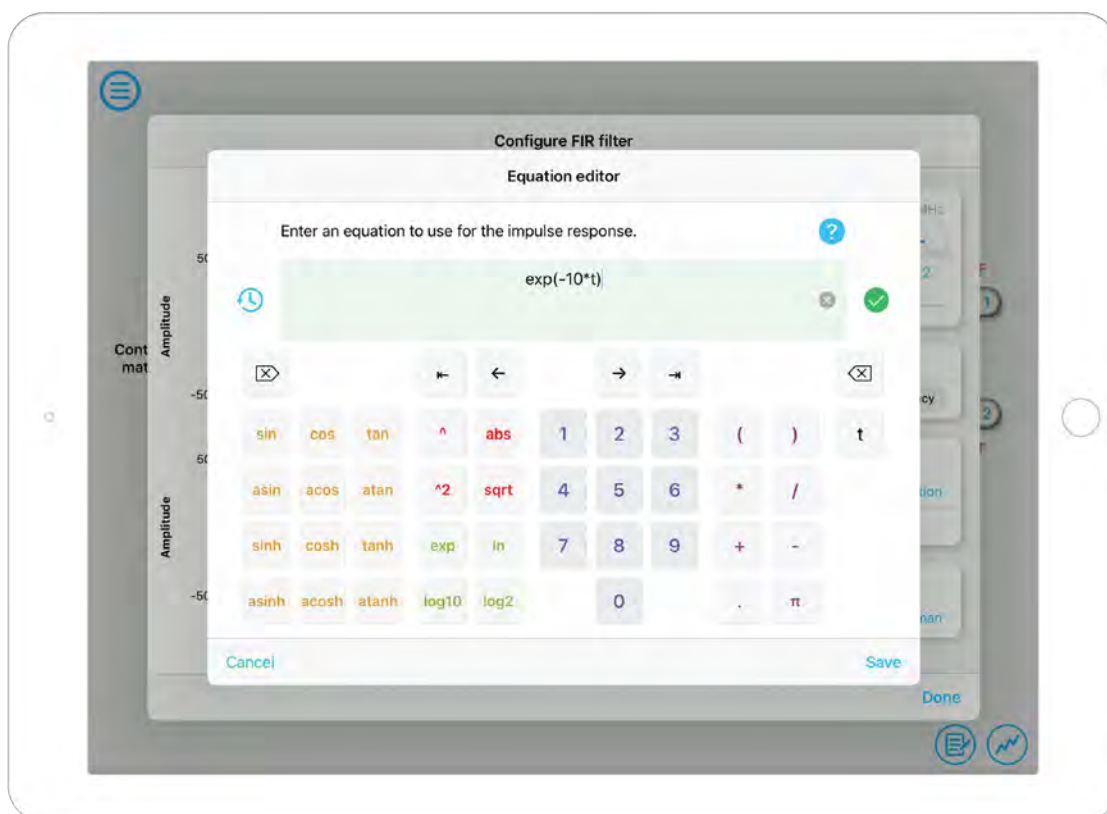
Due to the limit of digitization depth, the quantization error is pronounced at certain FIR filter settings. A red Coefficient quantization warning may appear on the top-right corner of the plot, and the actual response curve will be plotted in red.





Equation Editor

- The equation editor allows you to define arbitrary mathematical functions for the impulse response.
- 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.





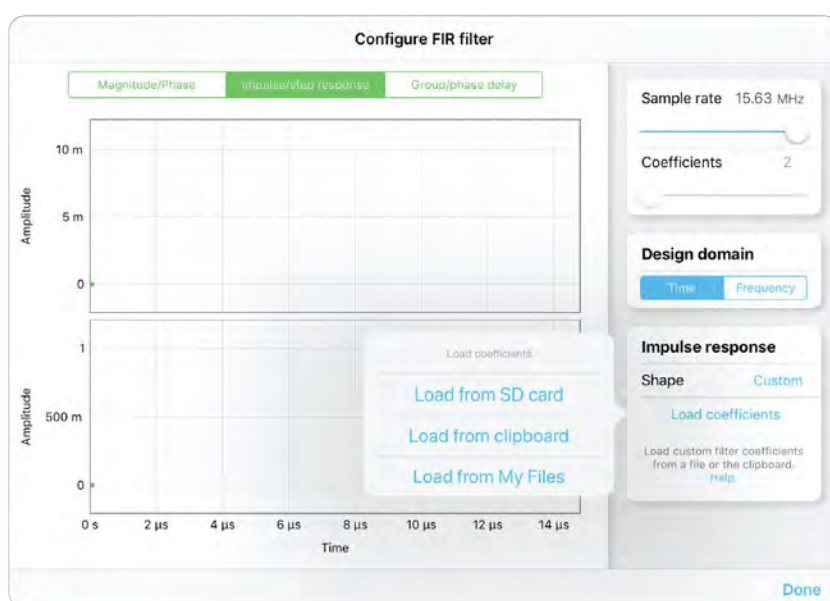
Custom Impulse Response

The output of the FIR filter is a weighted sum of the most recent input values:

$$y[n] = \sum_{i=0}^{N-1} c_i x[n - i]$$

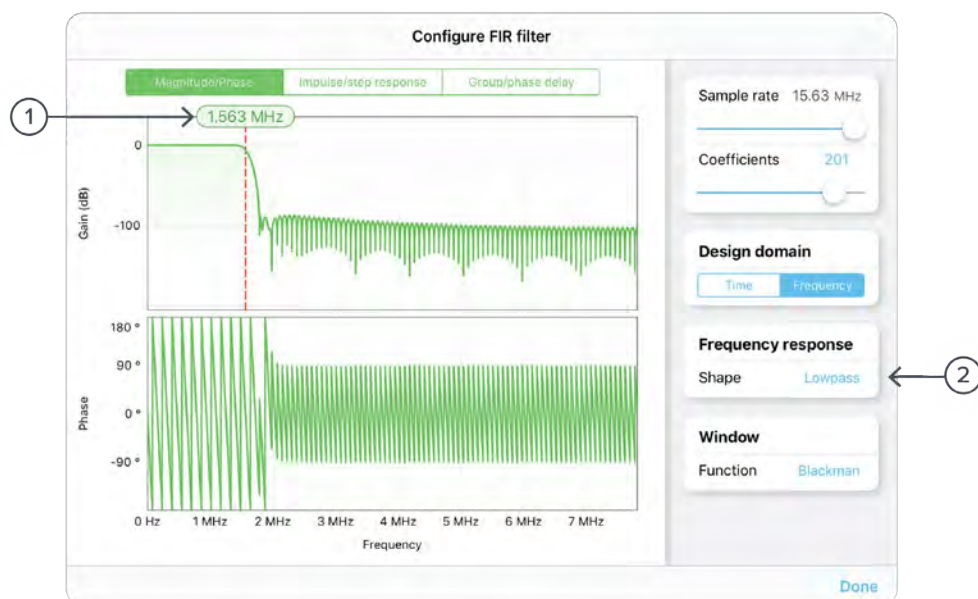
To specify a custom filter, you must supply a text file containing the filter coefficients on Moku:Lab's SD card or iPad storage. The file can contain up to 14,819 coefficients separated by commas or new lines. The coefficients also can be loaded from the iPad clipboard. Each coefficient must be in the range of [-1.0, +1.0]. Internally, these are represented as signed 25-bit fixed-point numbers, with 24 fractional bits. Filter coefficients can be computed using signal processing toolboxes in MATLAB, SciPy, etc.

Some coefficients may result in overflow or underflow, which degrade filter performance. Filter responses should be checked prior to use.





Frequency Domain Designer




| ID | Parameter | Description |
|----|----------------|--|
| 1 | Cut-off cursor | Tap to enter a specific number or hold to slide in the frequency axis. |
| 2 | Impulse width | Tap to select the filter shape. |

List of available shapes:

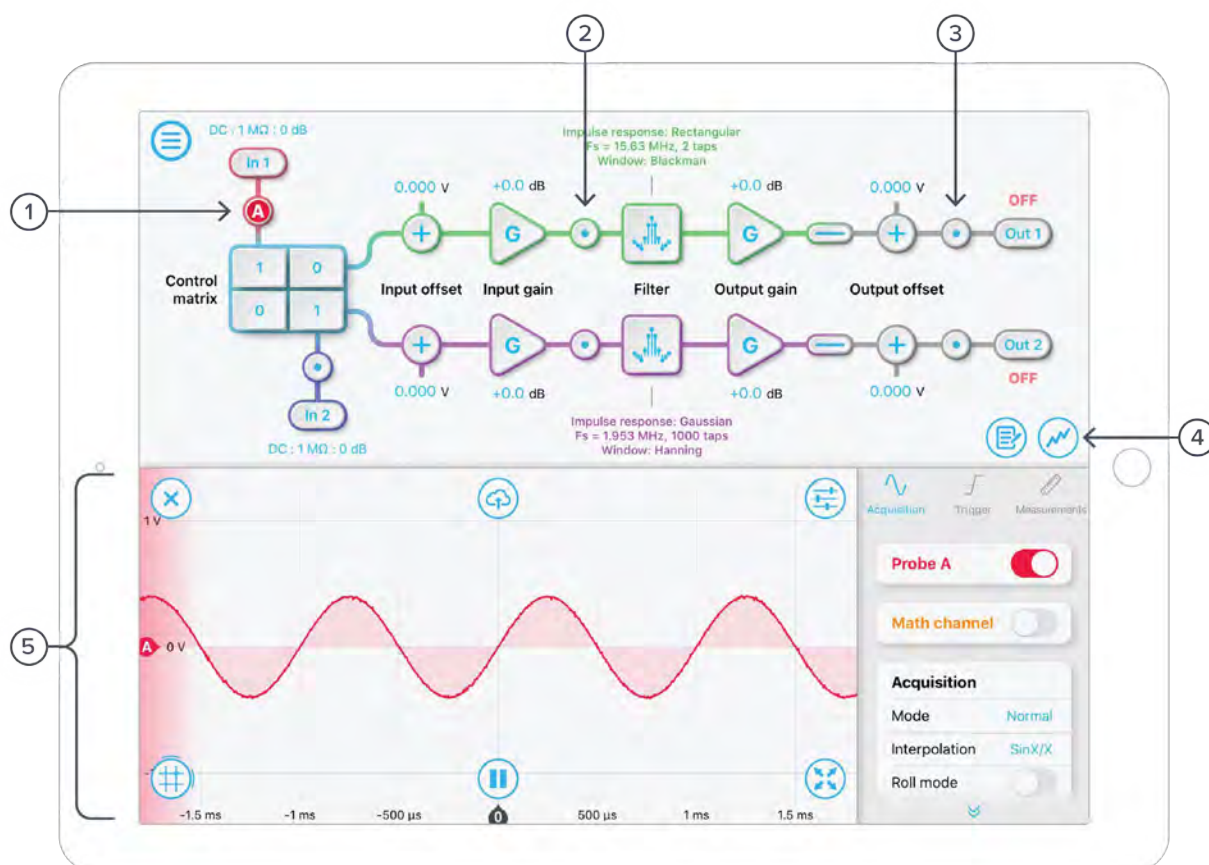
| Shape | Note |
|----------|---------------------------|
| Lowpass | Single adjustable cursor. |
| Highpass | Single adjustable cursor. |
| Bandpass | Two adjustable cursors. |
| Bandstop | Two adjustable cursors. |



Probe Points

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

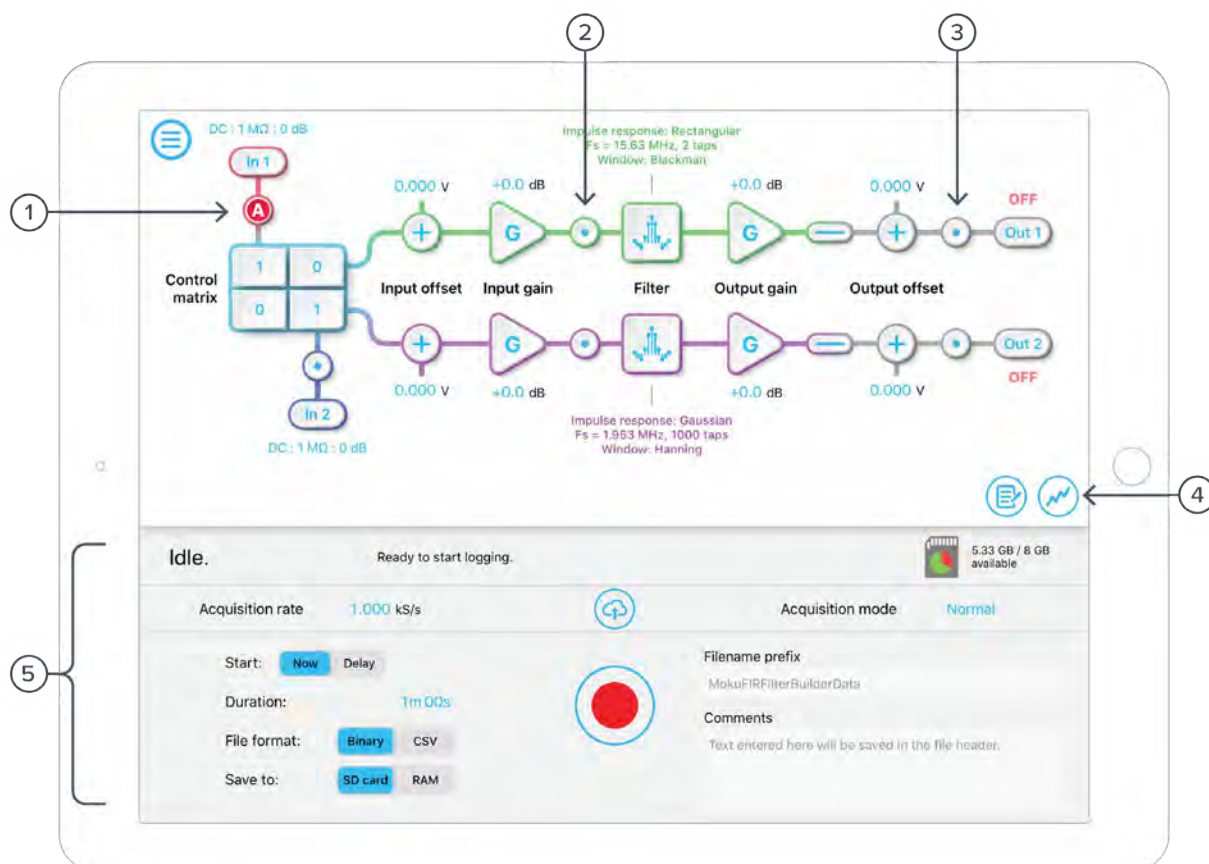
Oscilloscope



| ID | Parameter | Description |
|----|---------------------------------|---|
| 1 | Input probe point | Tap to place the probe point at input. |
| 2 | Pre-FIR probe point | Tap to place the probe before the FIR filter. |
| 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 Moku:Lab'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-FIR probe point | Tap to place the probe before the FIR filter. |
| 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:Lab's Data Logger manual for the details. |