Phasemeter

Moku:Lab User Manual

Moku:Lab's Phasemeter measures phase with up to 6 µradian 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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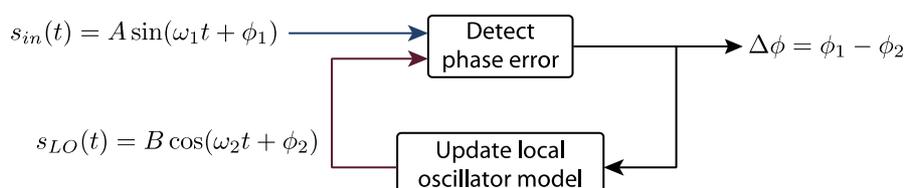Ensure Moku:Lab is fully updated. For the latest information:

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.

$$s_{in}(t) = A\sin(\omega_1 t + \phi_1)$$

Detect phase error

$$\Delta\phi = \phi_1 - \phi_2$$

$$s_{LO}(t) = B\cos(\omega_2 t + \phi_2)$$

Update local oscillator model

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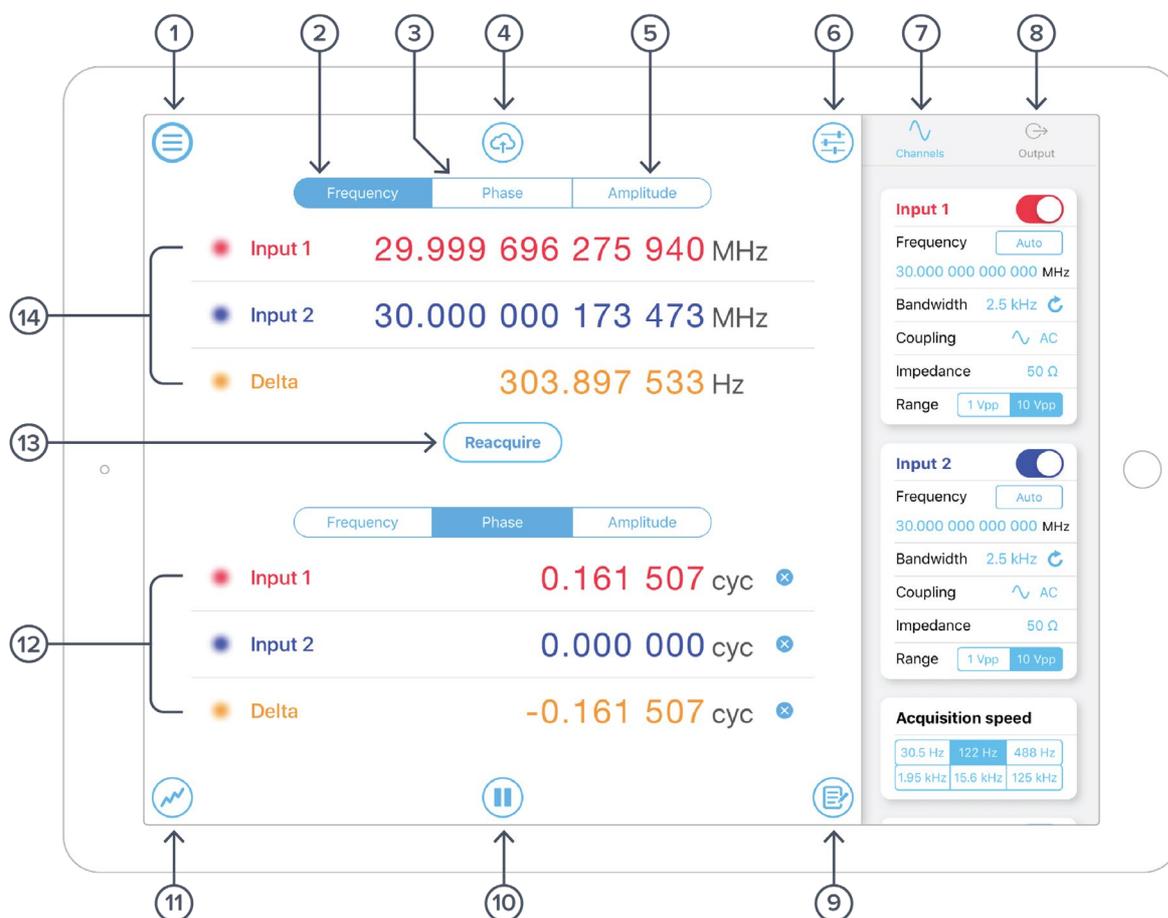
ID	Description	ID	Description
1	Main menu	**8**	Output settings
2	Display frequency data	**9**	Data logger
3	Display phase data	**10**	Start / pause measurement
4	Export data	**11**	Data visualization
5	Display amplitude data	**12**	Channel data display area 1
6	Instrument configuration menu	**13**	Reacquire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

Main Menu

The **main menu** can be accessed by pressing the ☰ icon, allowing you to:
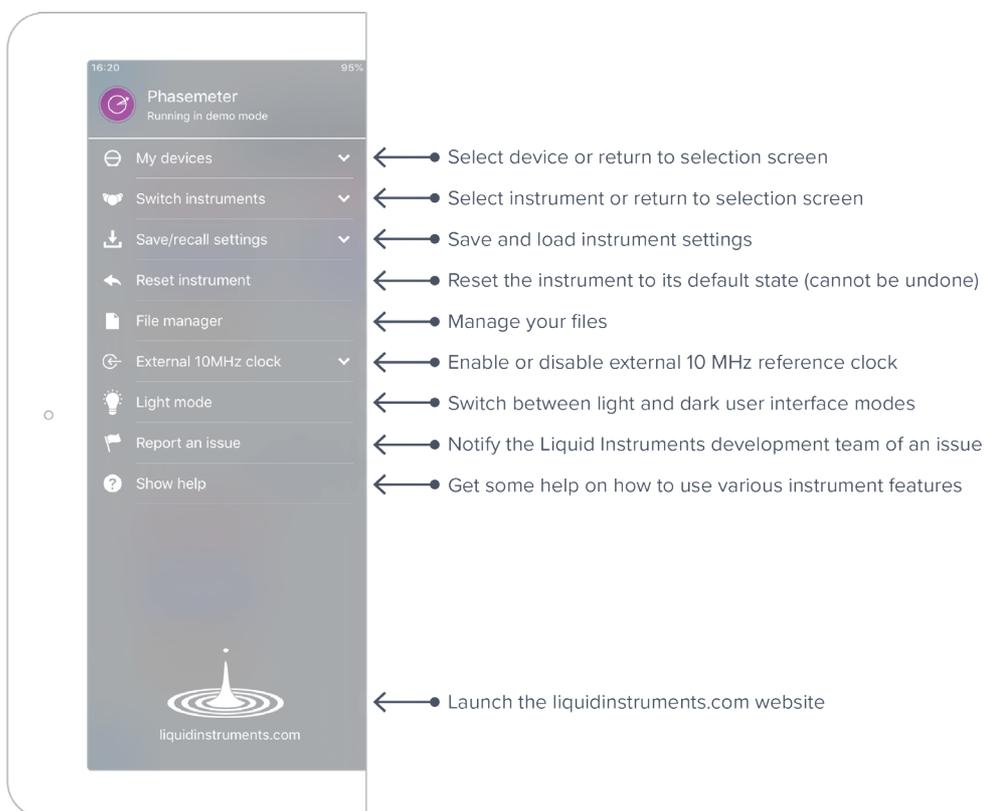
Menu item	Description
My devices	Select device or return to selection screen
Switch instruments	Select instrument or return to selection screen
Save/recall settings	Save and load instrument settings
Reset instrument	Reset the instrument to its default state (cannot be undone)
File manager	Manage your files
External 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

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
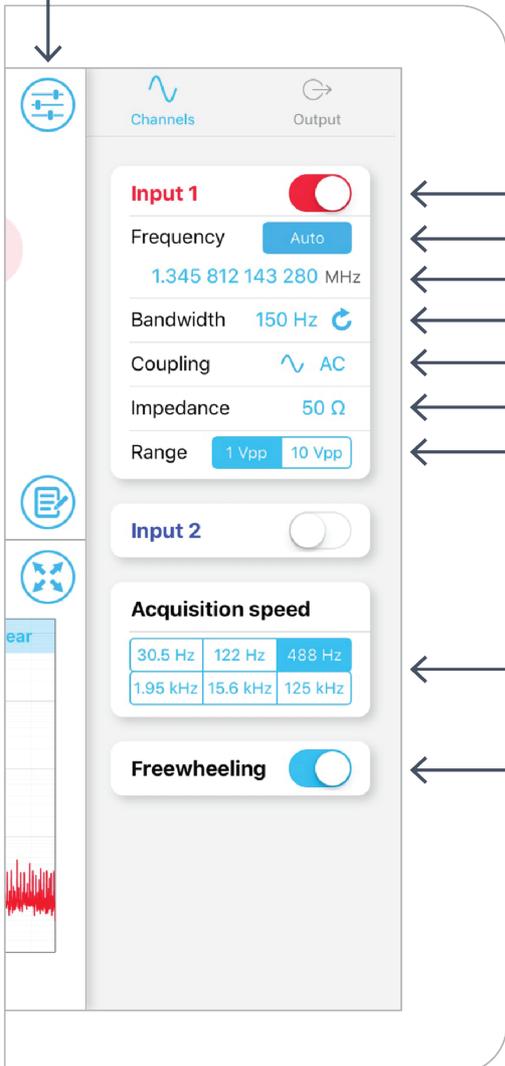
Activate / deactivate channel 1

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.

Show / hide the measurement configuration menu

Activate / deactivate output 1

Phase-lock sine output to input

Configure the **frequency** of the sine output

Configure the **amplitude** of the sine output

Configure the **phase** of the sine output

Synchronize the phase of the two sine outputs
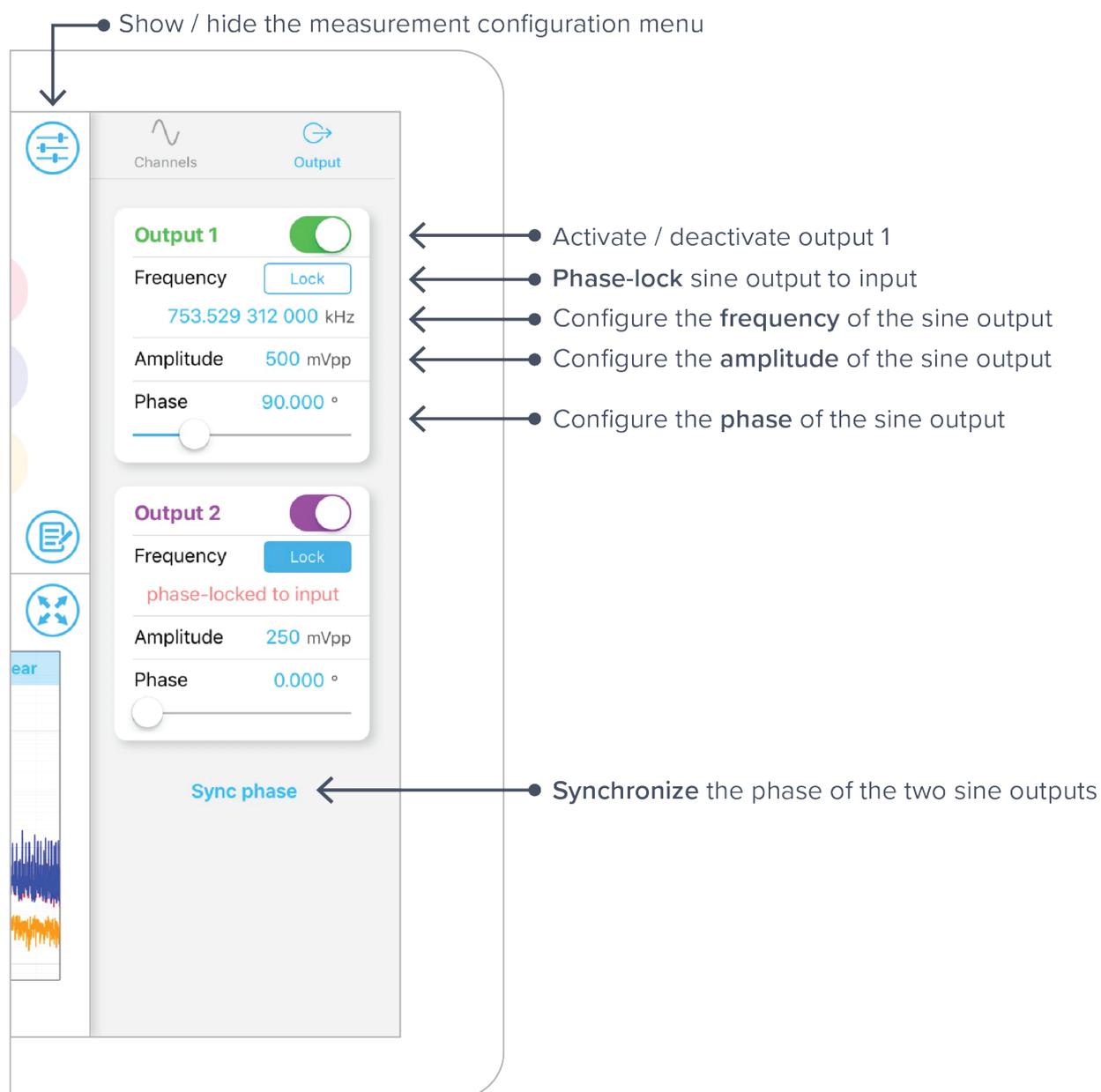
Phase-locked output

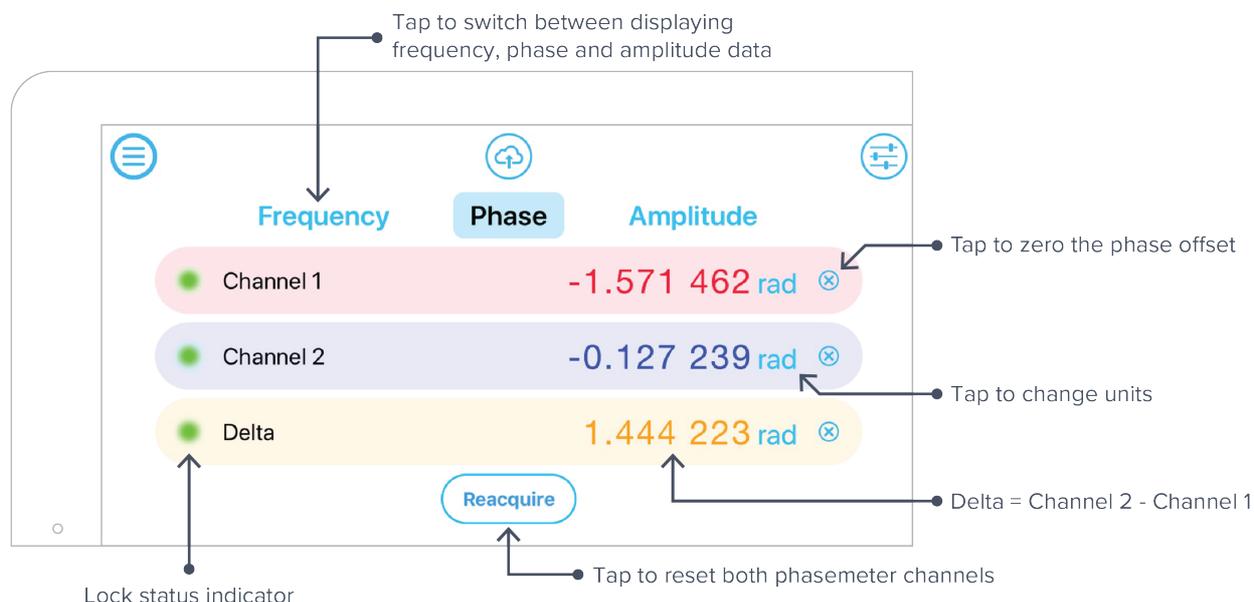- Generate an output tone with the same frequency and phase of the input signal
- The amplitude and phase of the generated tone remains configurable

Measurement Data

Tap to switch between displaying
frequency, phase and amplitude data

Frequency	**Phase** **Amplitude**

Channel 1   -1.571 462 rad ⊗ — Tap to zero the phase offset

Channel 2   -0.127 239 rad ⊗ — Tap to change units

Delta   1.444 223 rad ⊗ — Delta = Channel 2 - Channel 1

Reacquire

Lock status indicator

Tap to reset both phasemeter channels

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.

Close the graph

Tap to select different plots

Enter full screen mode

Clear the graph

Adjust the time axis of the timeseries graph

Tap to reveal / hide traces on the graph

Pause the trace (resuming will reset the plot)
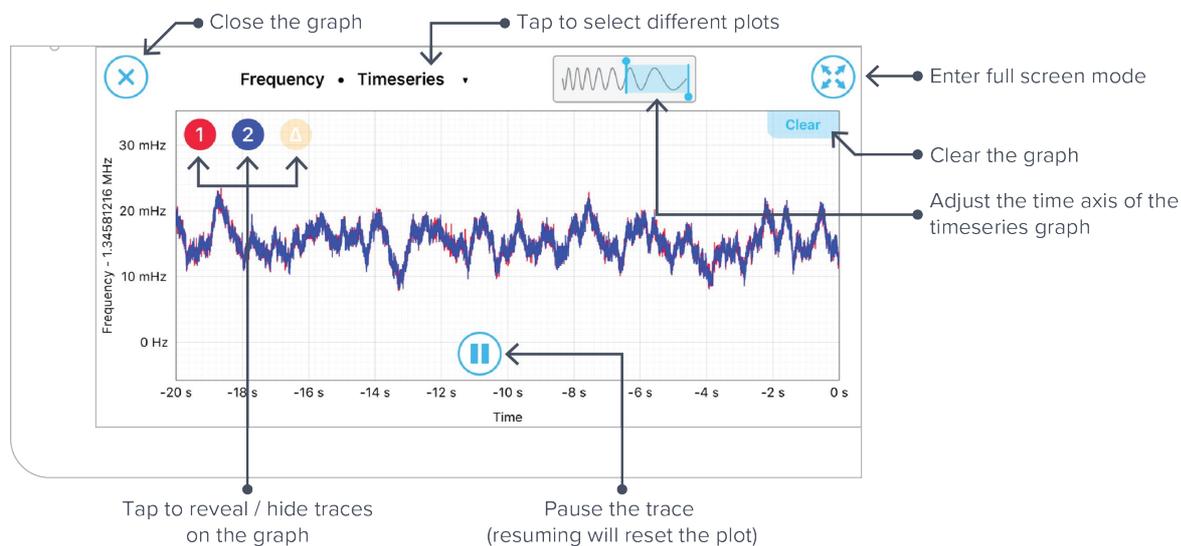
Plot Types

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 △ 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

Adjust the timescale and span of timeseries data
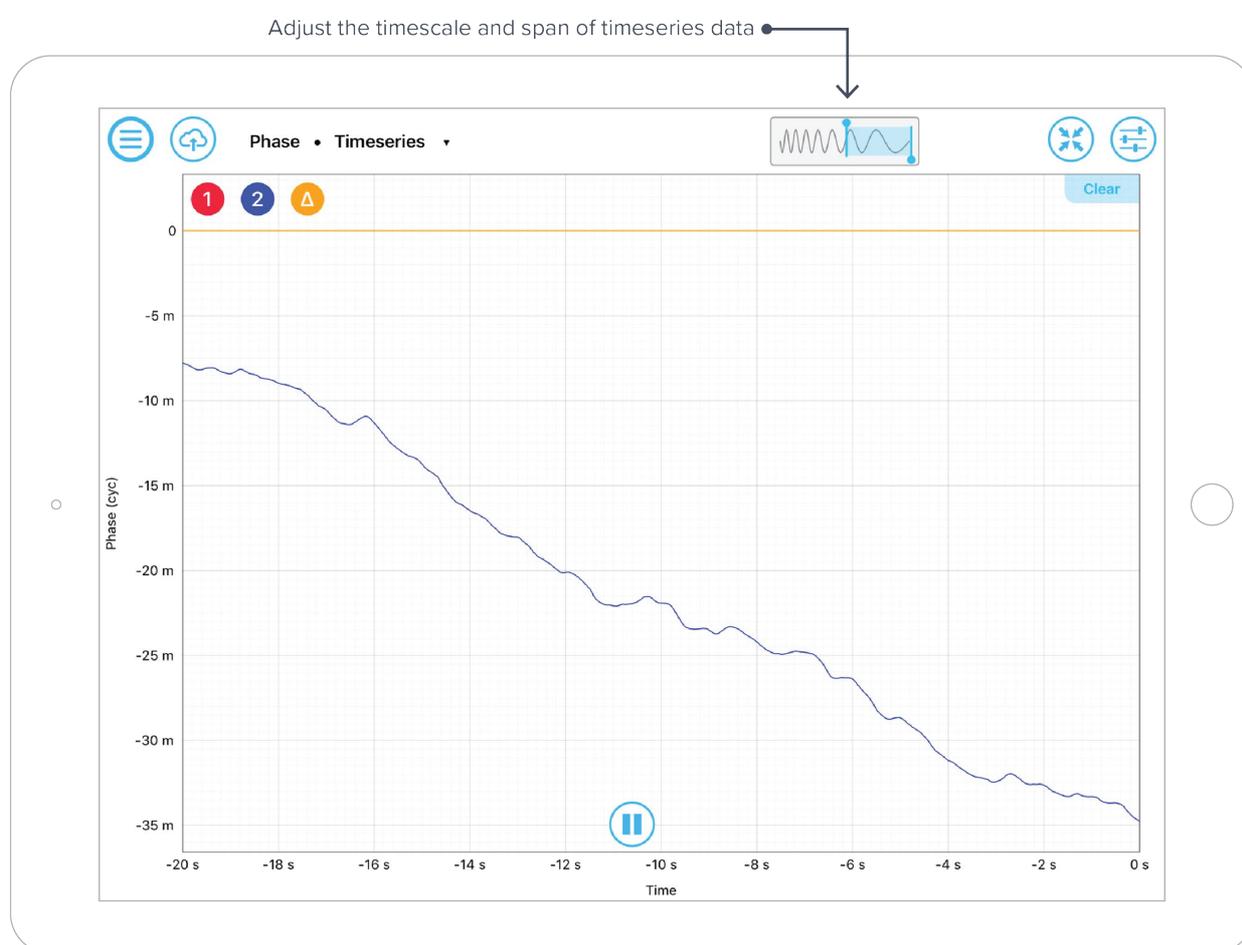
Power spectral density

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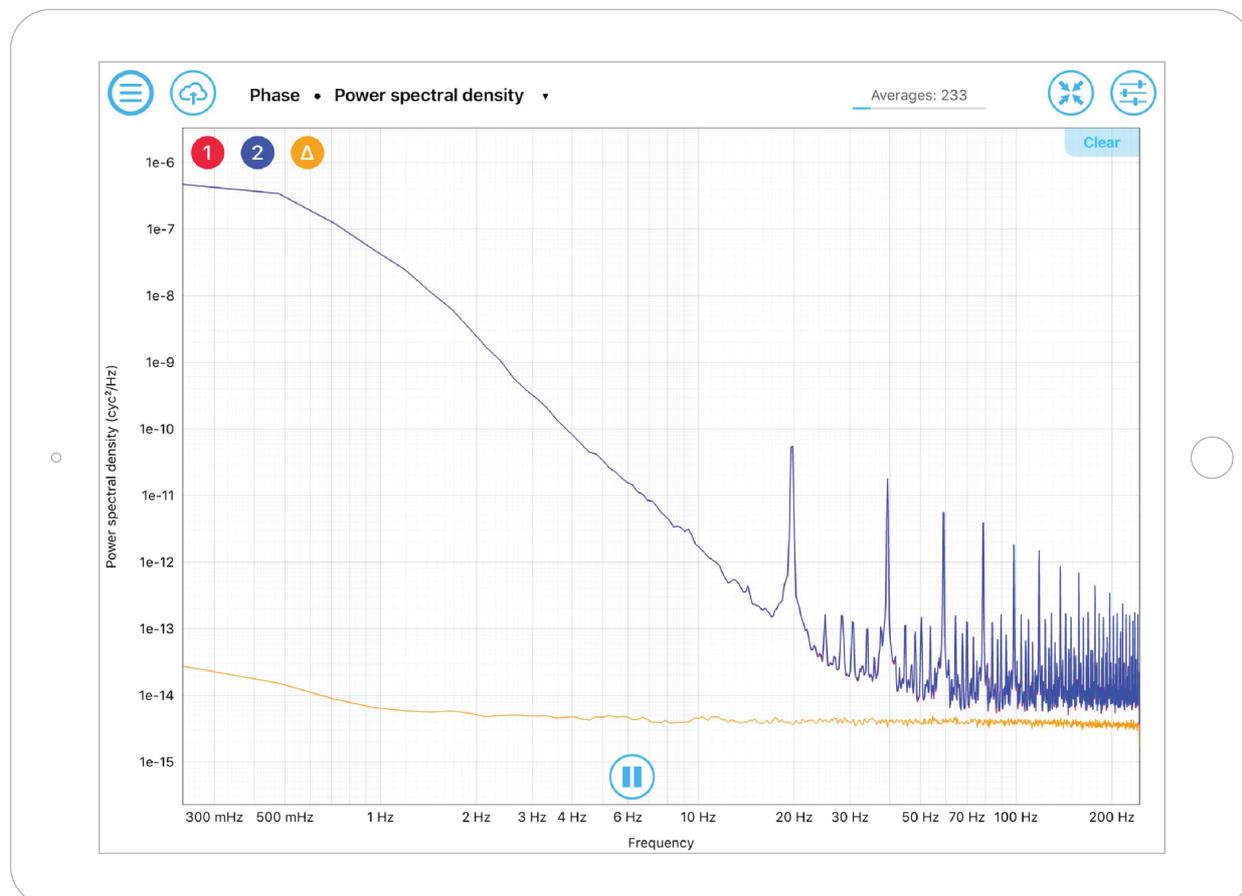
Amplitude spectral density

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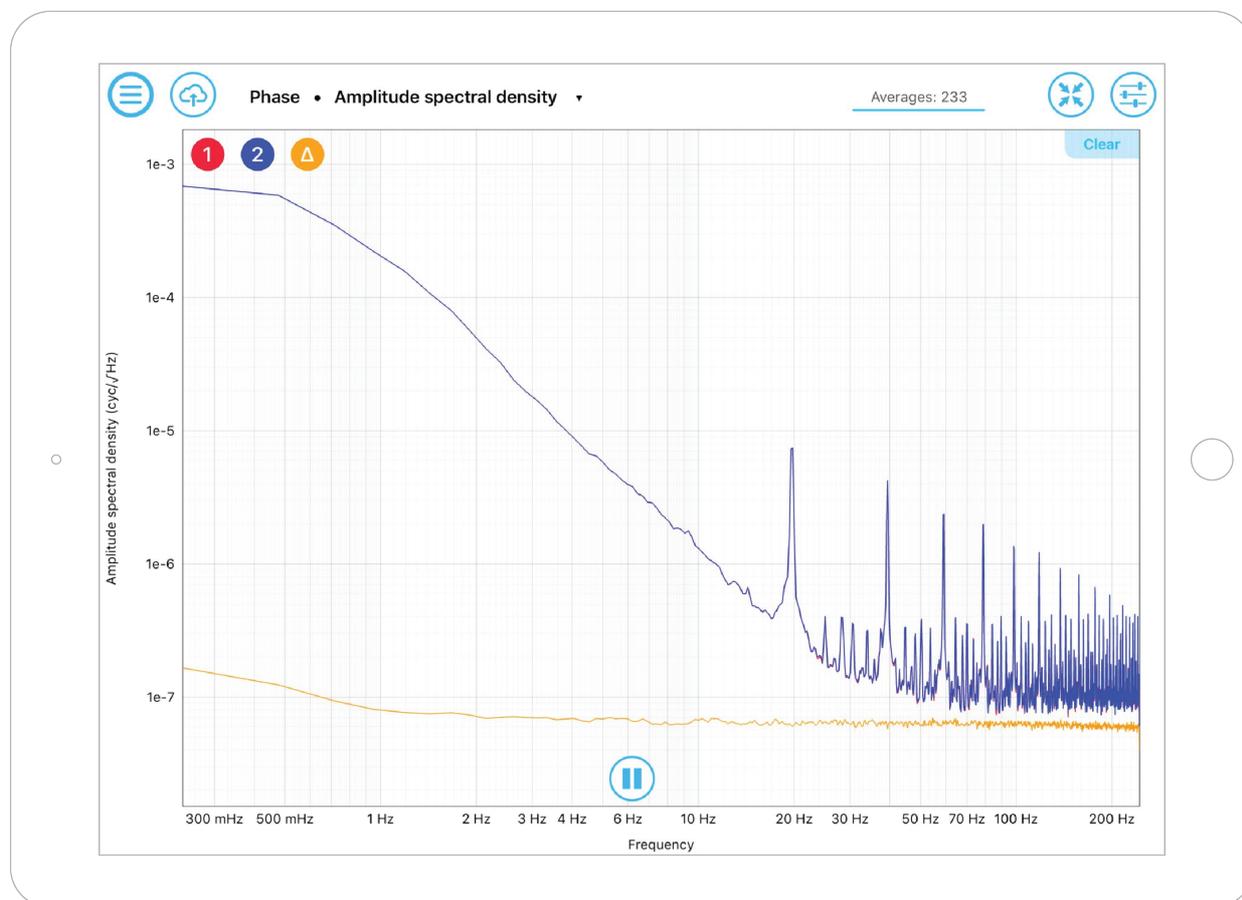
Coherence

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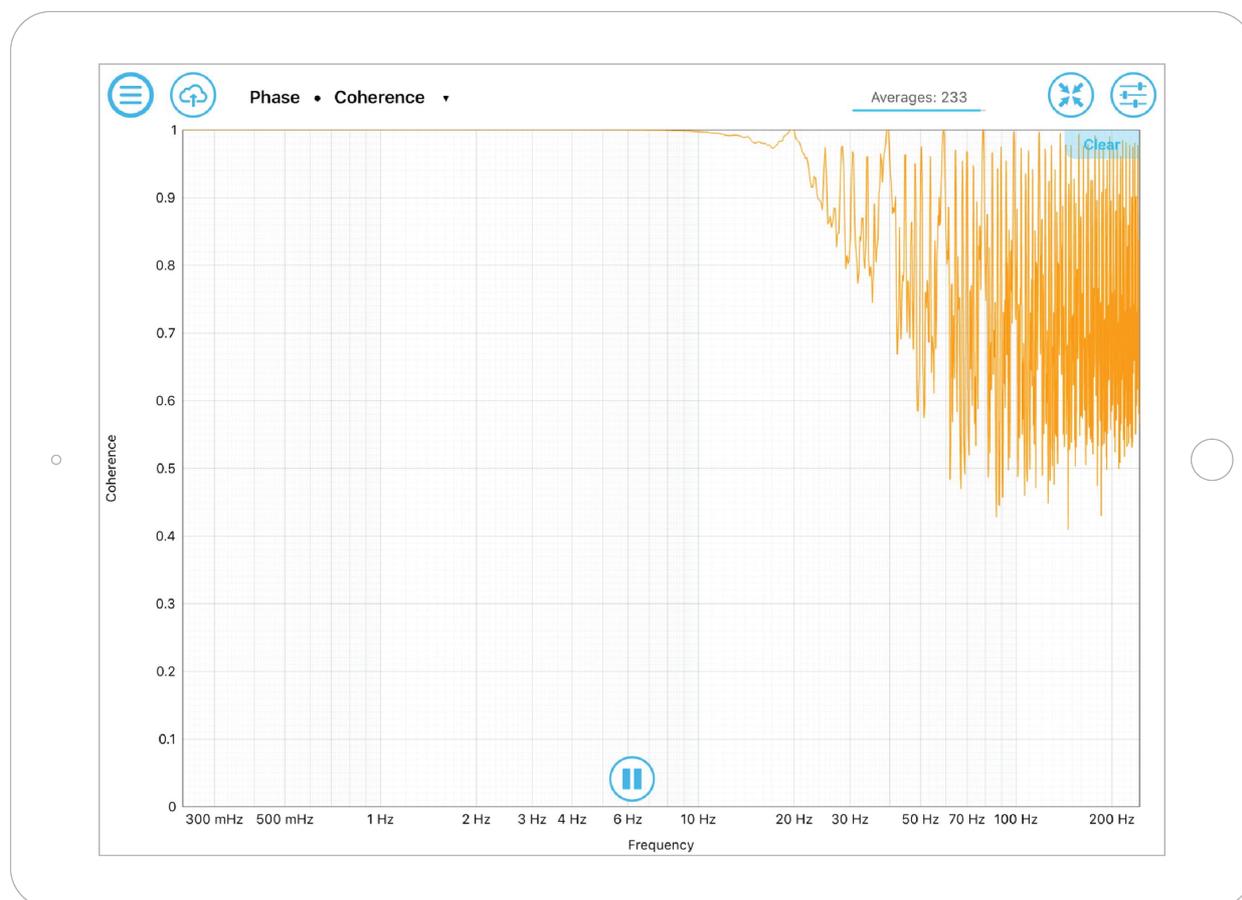
Allan deviation

- 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 the ⊞ 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

View the available storage on the selected 'Save to' destination

Completed.   Successfully logged 157,071 samples to "MokuPhasemeterData_20180710_140937.li".   4.84 GB / 7.94 GB available

Start: Now | Delay   15m 00s

Duration: 40h 00m 00s

File format: Binary | CSV

Save to: SD card | RAM

Comments
Text entered here will be saved in the file header.

Configure when to begin recording data

Record a new measurement

Add comments to your measurement

Select the file format and destination of the measurement

Configure measurement duration

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.

Select the data you'd like to save   Change the filename

Save data

| Timeseries CSV | Spectra CSV | Allan deviation OFF |

Screenshot OFF   ?

Filename: MokuPhasemeterData_20180704_161409

Comments: Text entered here will be saved in the file header.

My Files   Dropbox   Mail   SD card   iCloud   Clipboard

The files will be uploaded to the "Liquid Instruments" directory on your iCloud Drive.

Cancel   Save

Select the destination for your data   Add comments to your file
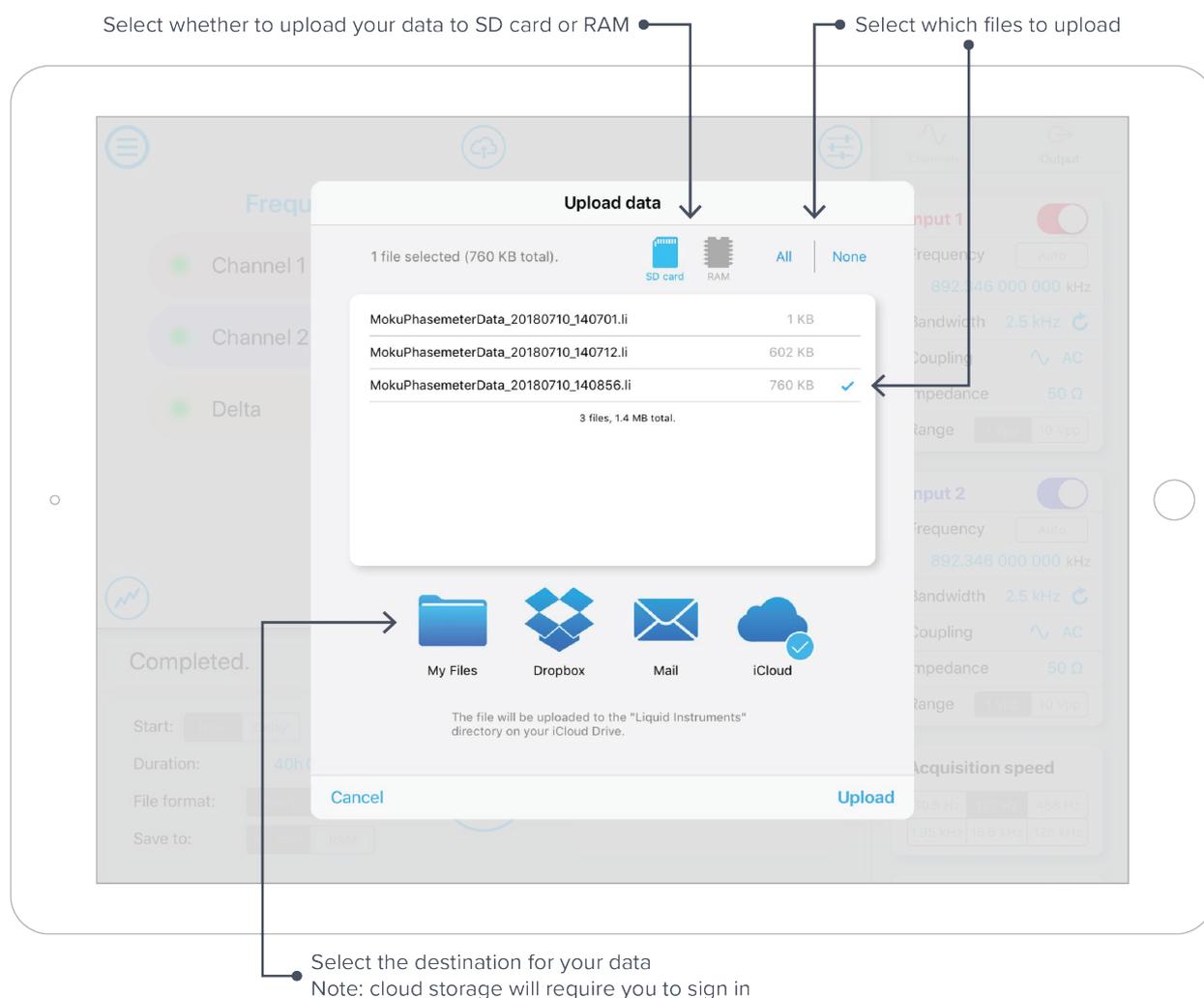Note: cloud storage will require you to sign in

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.

Select whether to upload your data to SD card or RAM

Select which files to upload

Upload data

1 file selected (760 KB total).

SD card   RAM   All   None

MokuPhasemeterData_20180710_140701.li   1 KB
MokuPhasemeterData_20180710_140712.li   602 KB
MokuPhasemeterData_20180710_140856.li   760 KB ✓

3 files, 1.4 MB total.

My Files   Dropbox   Mail   iCloud

The file will be uploaded to the "Liquid Instruments" directory on your iCloud Drive.

Cancel   Upload

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.

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.

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

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