# Phasemeter

# User Manual

The Moku:Lab's Phasemeter measures phase with better than 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 requiring the precise measurement of phase or frequency, including displacement measurements using heterodyne interferometry, channel characterisation in communication networks, clock recovery, and signal reconditioning.

LIQUID INSTRUMENTS

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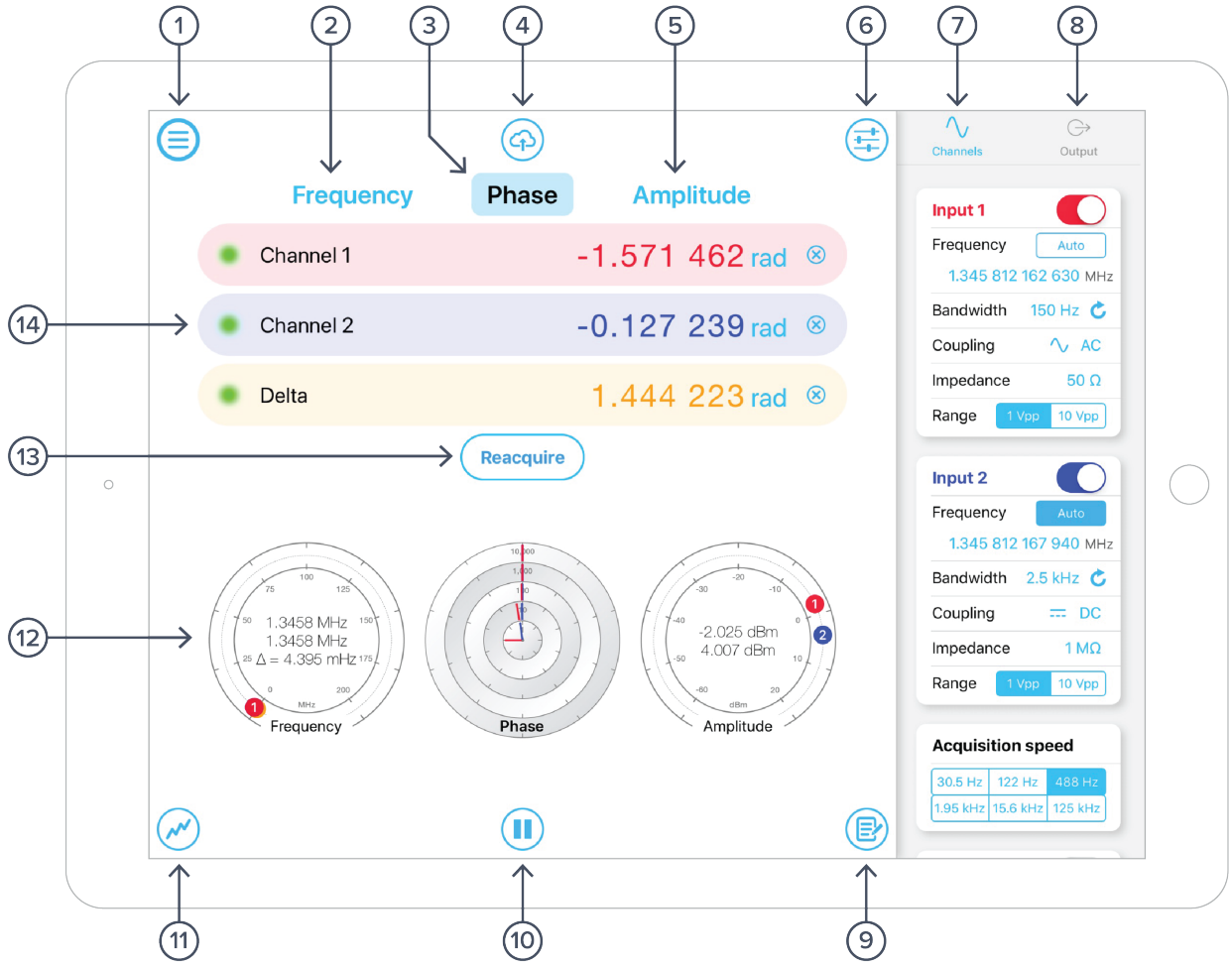


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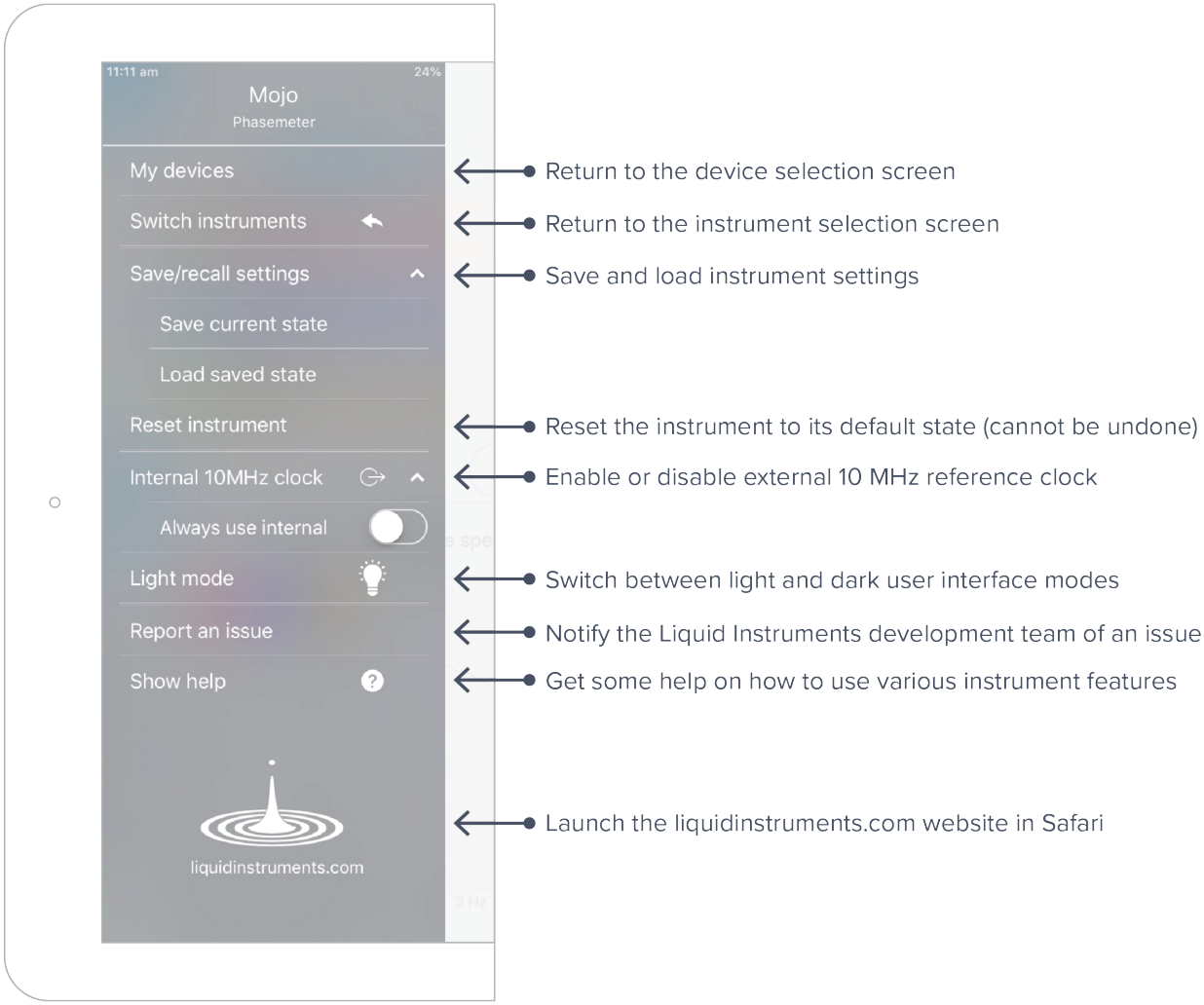
# Main Menu

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

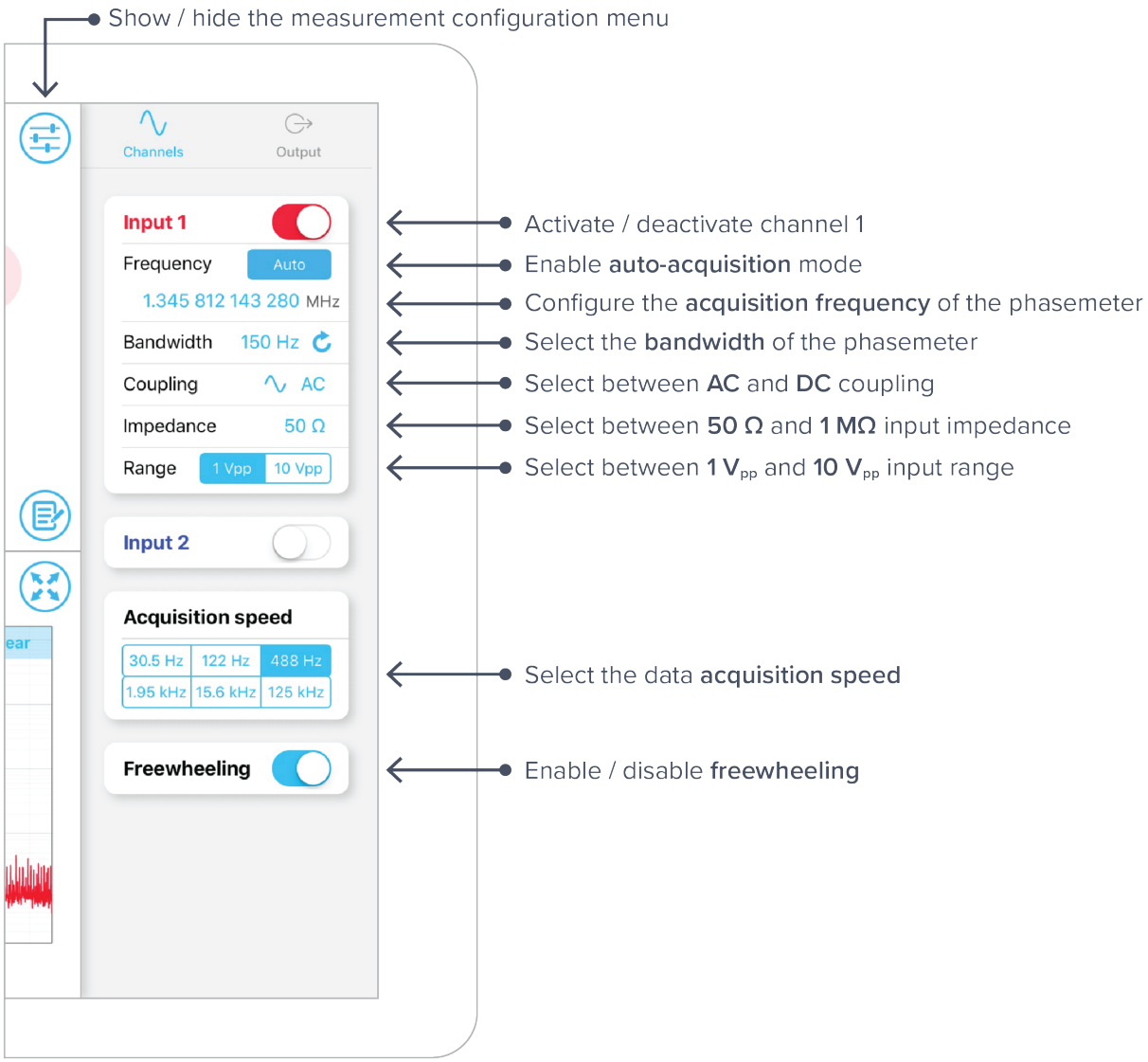


# Channel Configuration

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



### 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

### 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

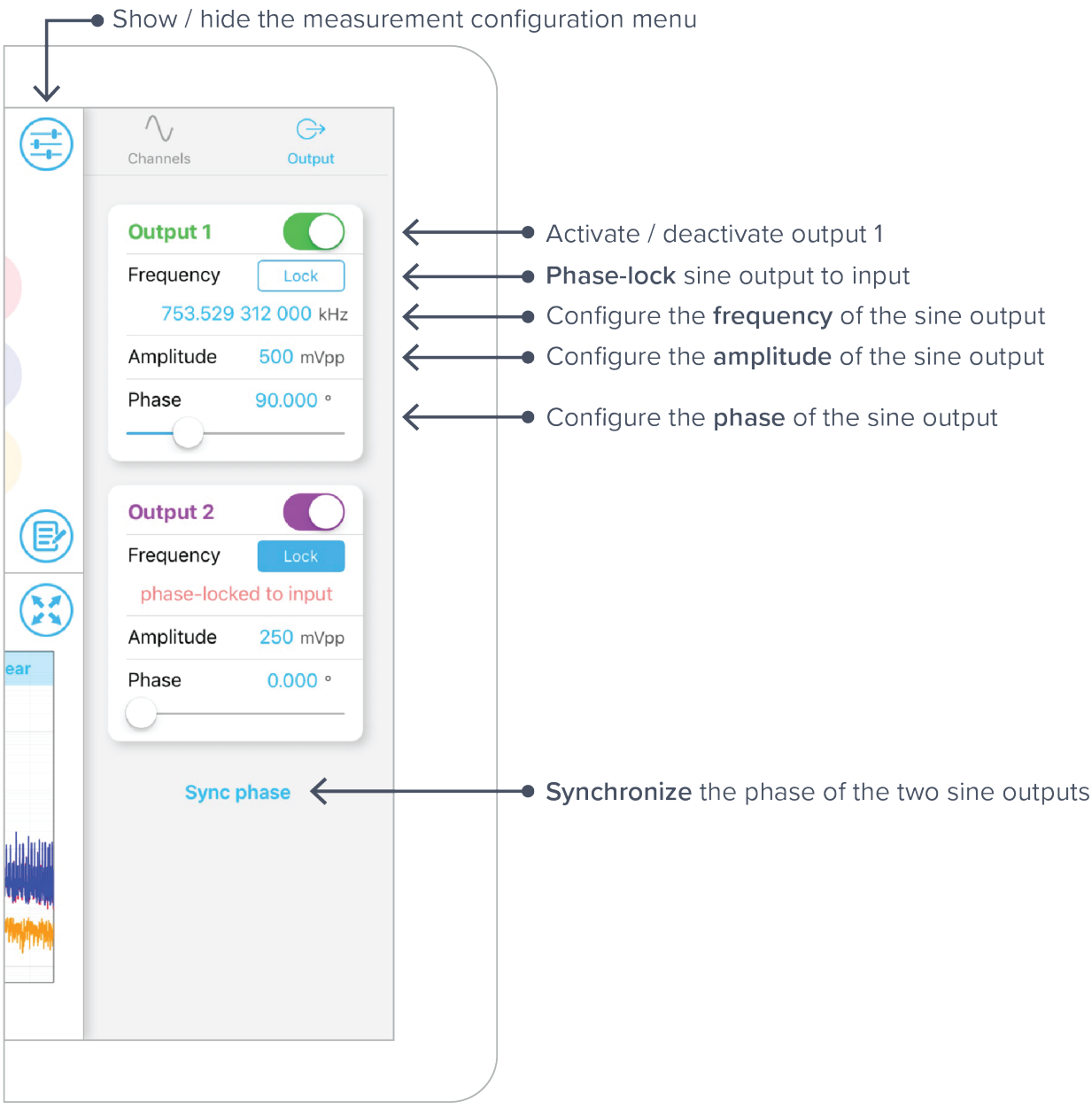
### Freewheeling

- 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.

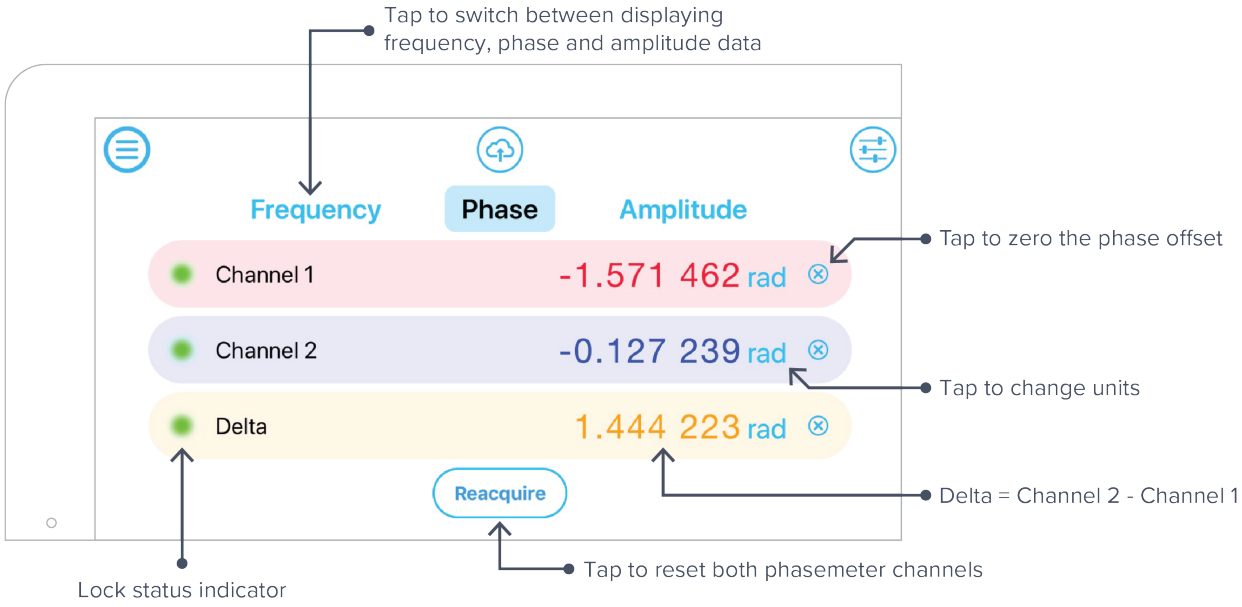
The phase of the two outputs can be synchronized by tapping the **Sync phase** button at the bottom of the tab.




### 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

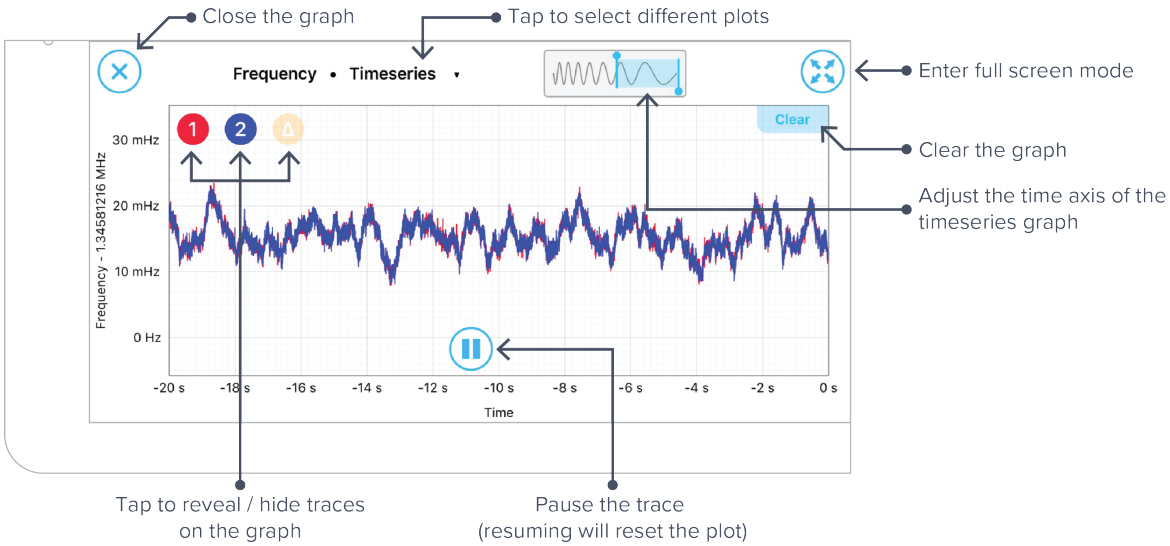
- Indicates whether or not the phasemeter is tracking the input signal correctly. A red icon indicates that the phasemeter is not tracking the input signal

## 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.



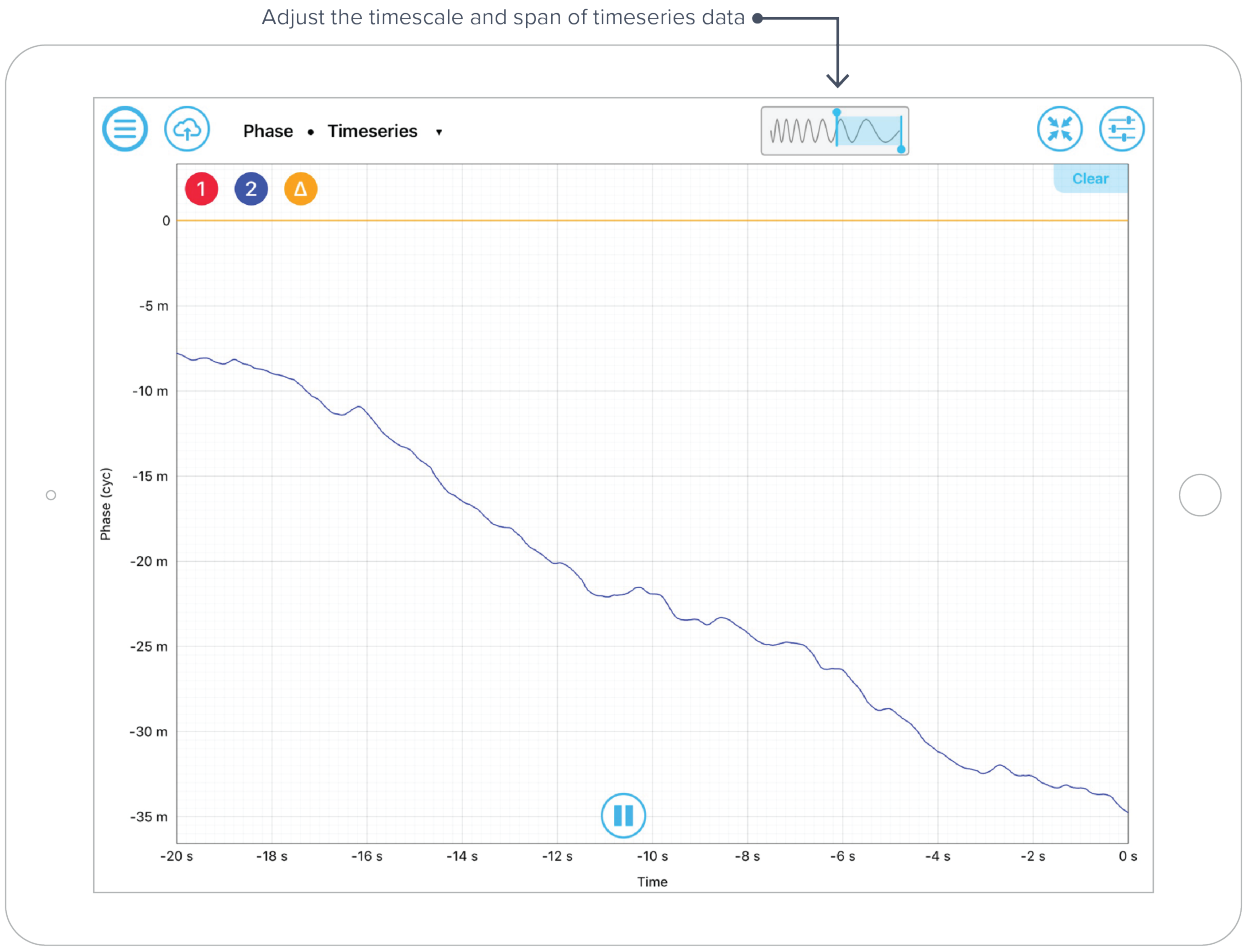
# Plot Types

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

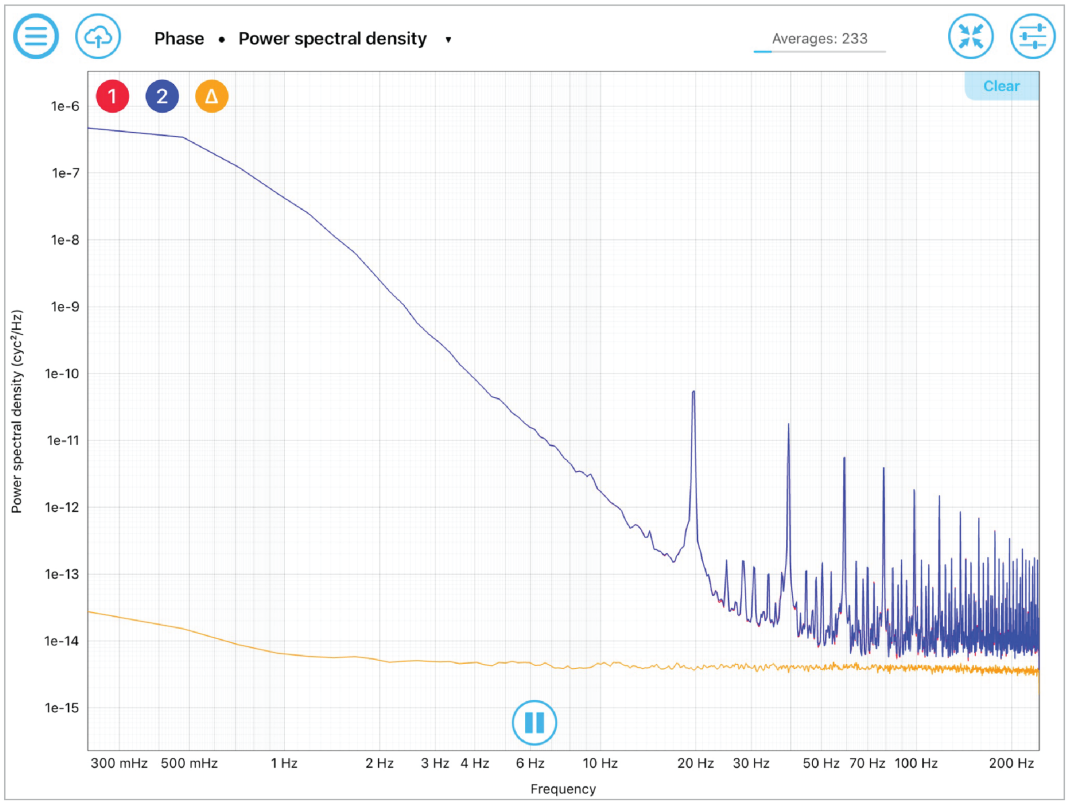
## Timeseries

- 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



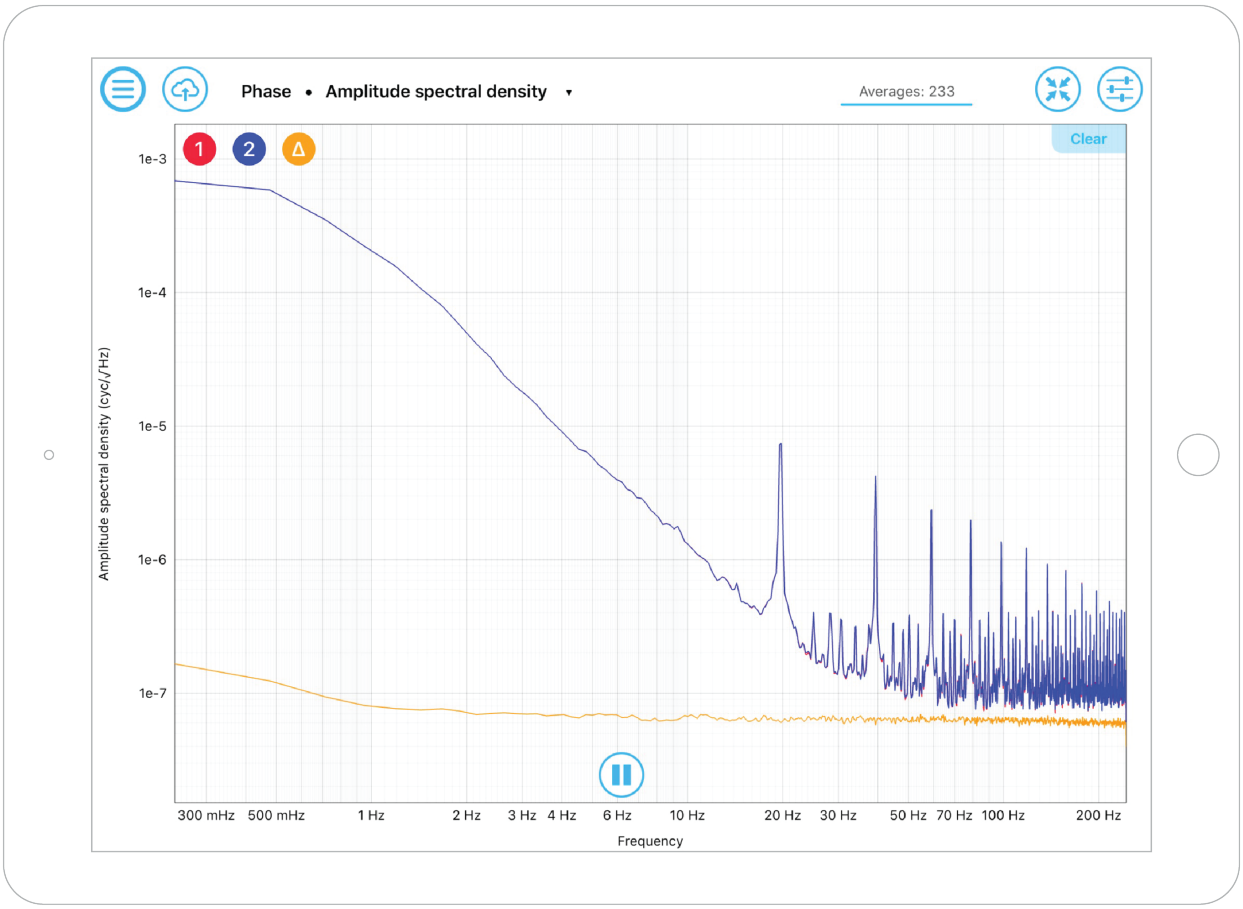
## Power spectral density

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



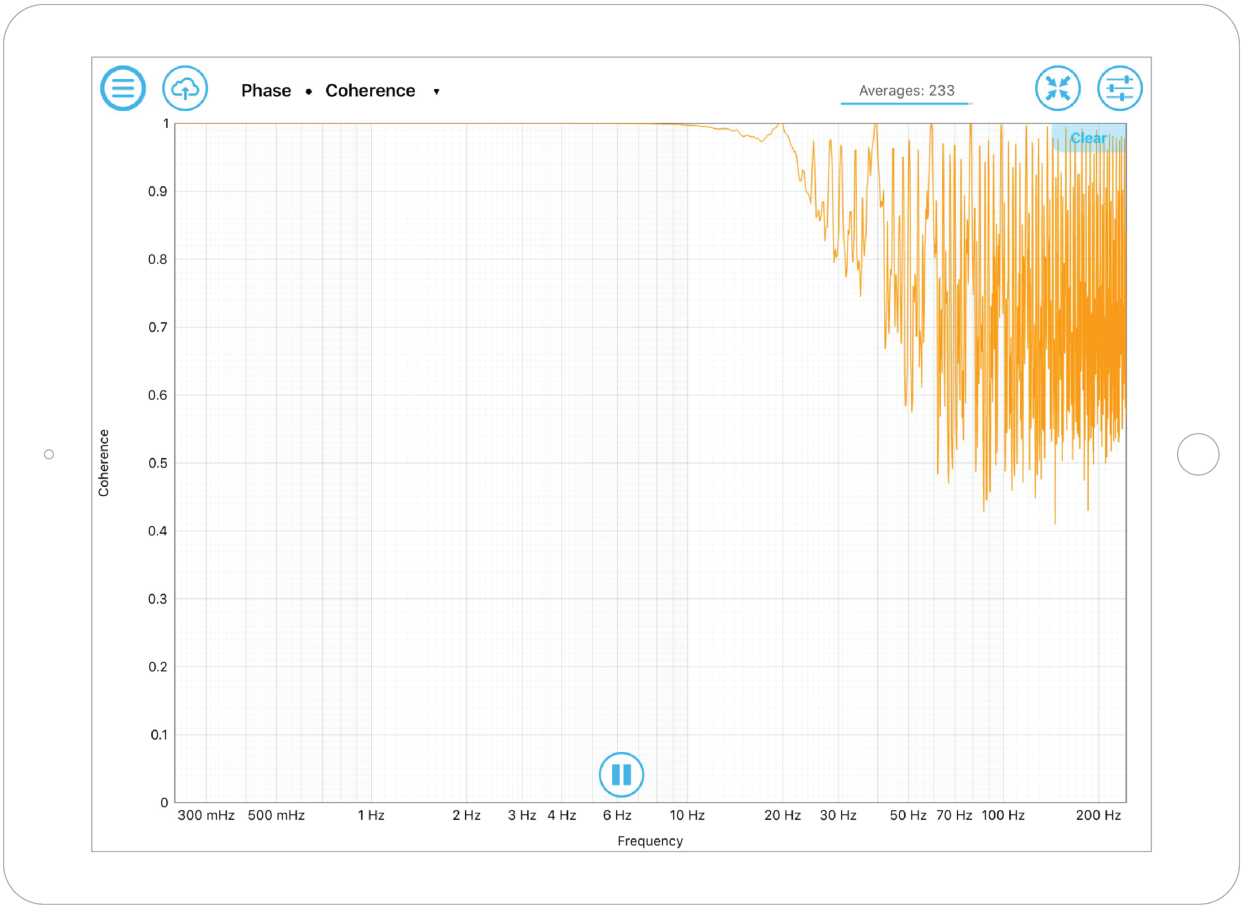
## Amplitude spectral density

- 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



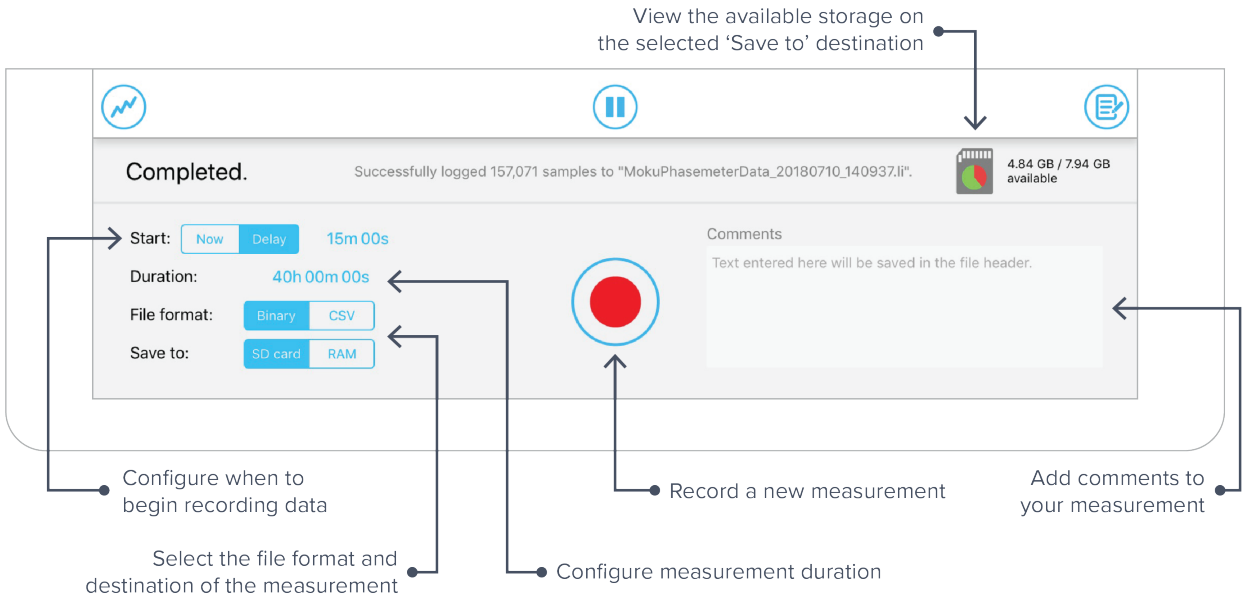
## Allan deviation

- 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 x $10^{-6}$ 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 x $10^{-6}$ cycles

# Data Acquisition

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




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

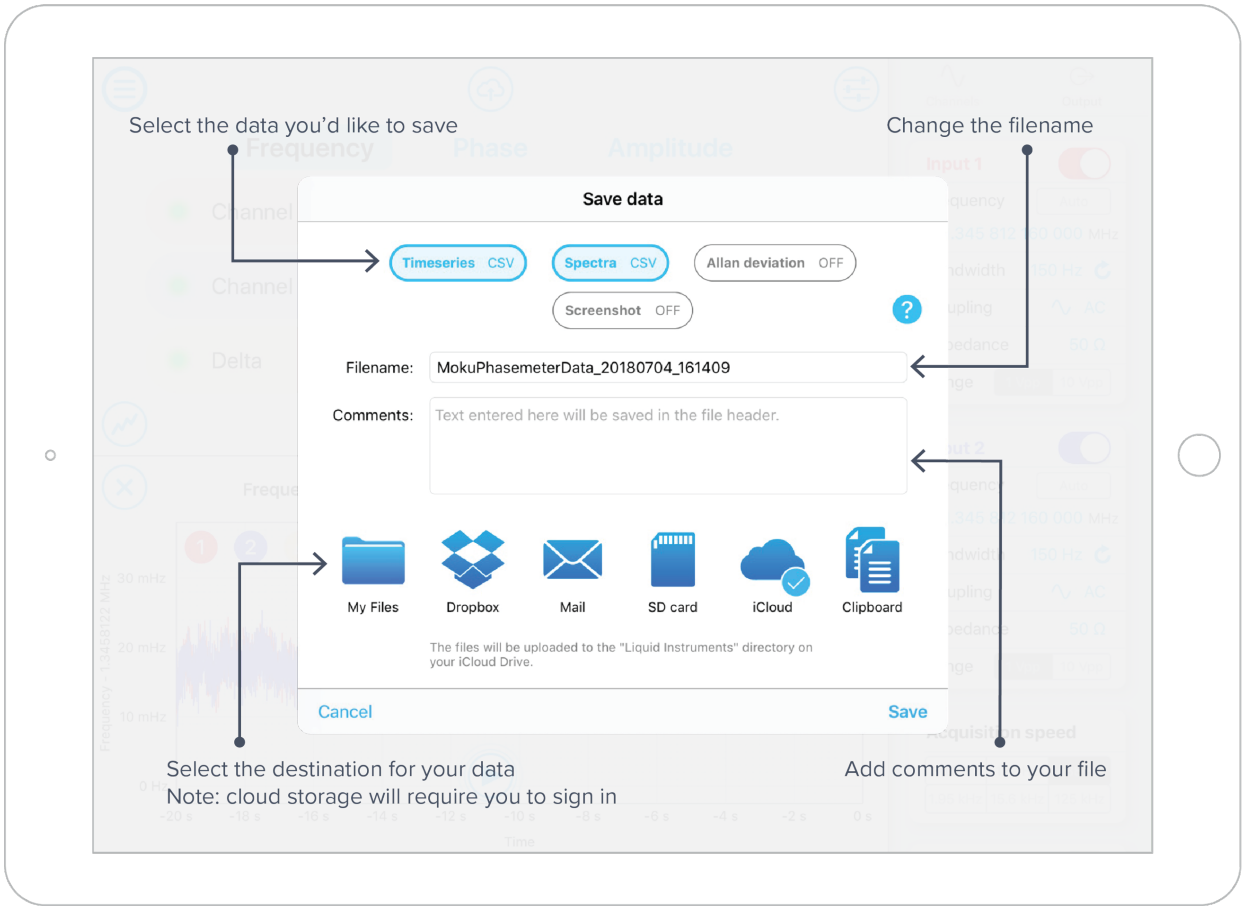
# Exporting Data

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).

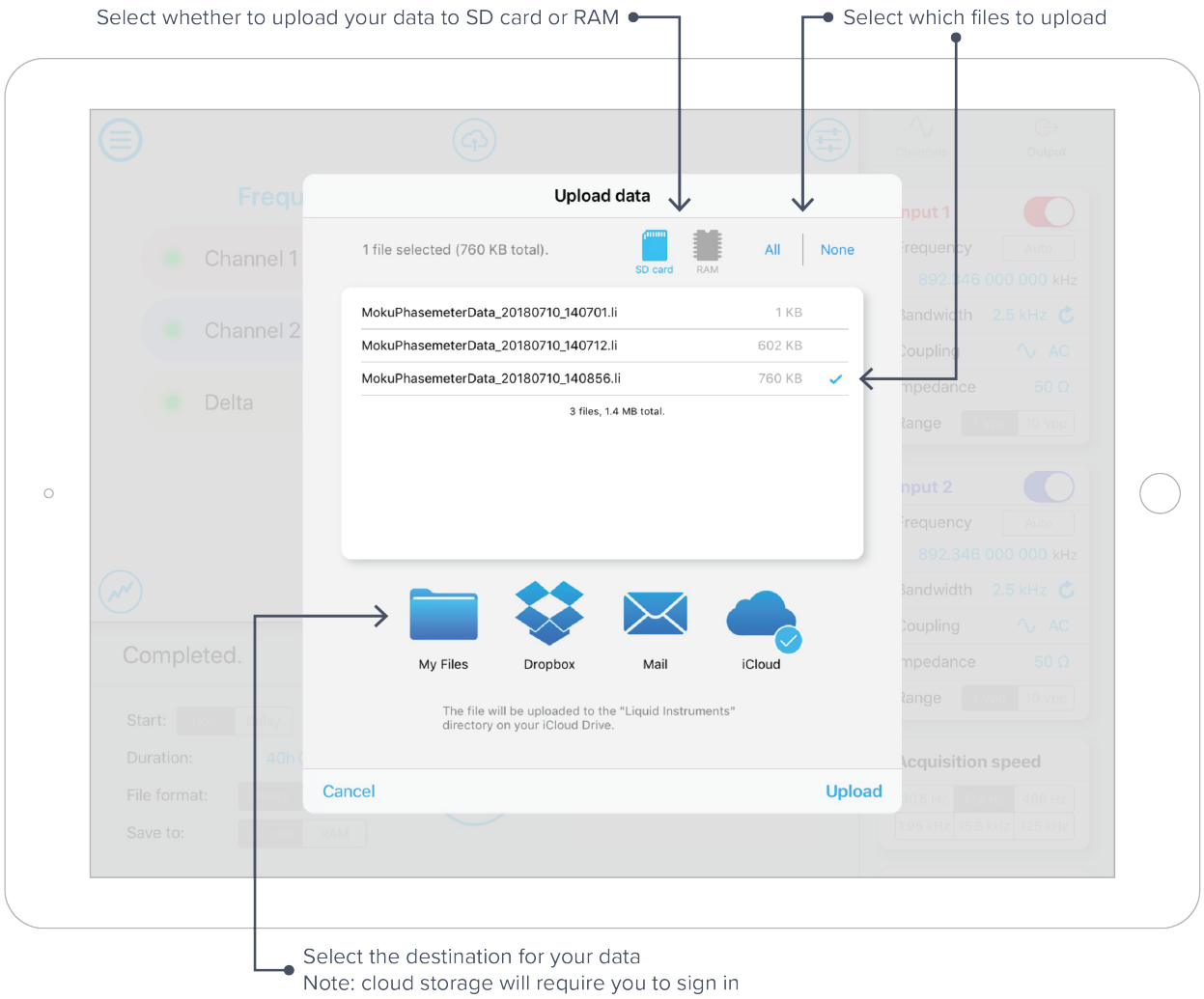
To export a live data, tap the icon and select the ‘Live Data’ option.



## 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.