Laser Lock Box

Moku:Lab 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 data logger feature enables delayed and lengthy data logging.

LIQUID INSTRUMENTS

V21-0204

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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 stabilization; 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 systems.

Principle of Operation

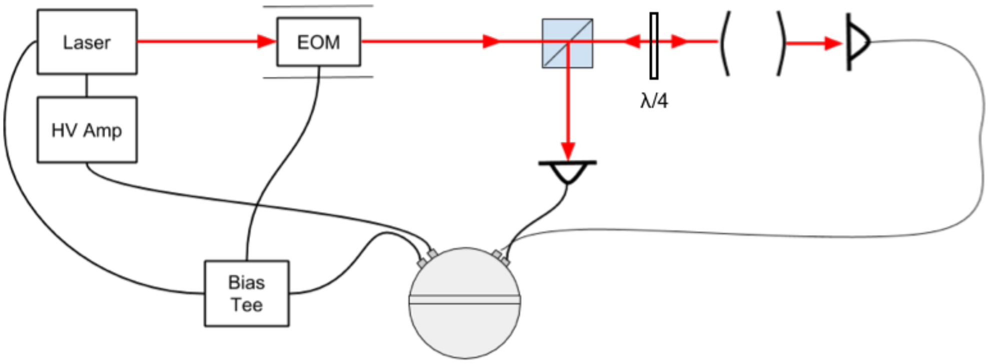
At the core of any laser locking technique is the measurement that provides the difference, or error, between the laser and a frequency reference. Often termed the "error signal", the quality of this signal ultimately determines the precision and accuracy of the entire locking system. A frequently-employed 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 measurements 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 measurement 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.

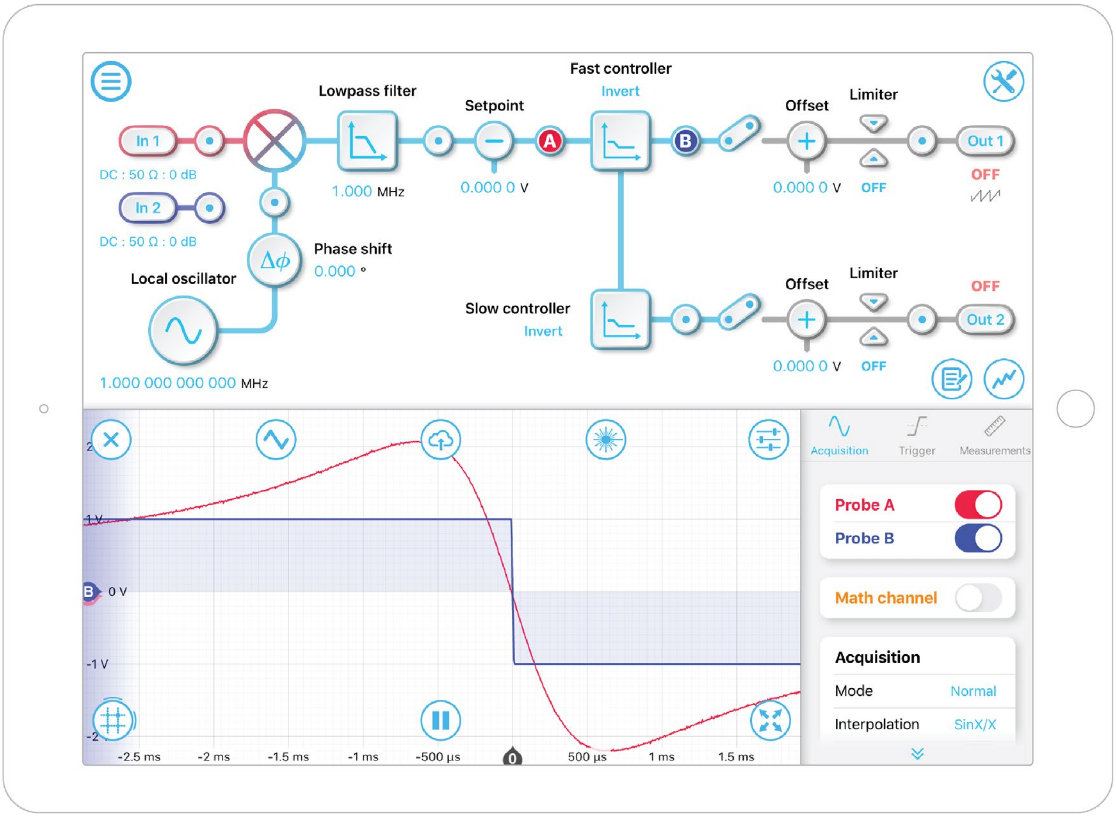
Laser Locking Using Moku:Lab’s Laser Lock Box

Moku:Lab’s 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. Moku:Lab’s Laser Lock Box was subsequently used to produce all signals required to lock the laser to the cavity resonance.

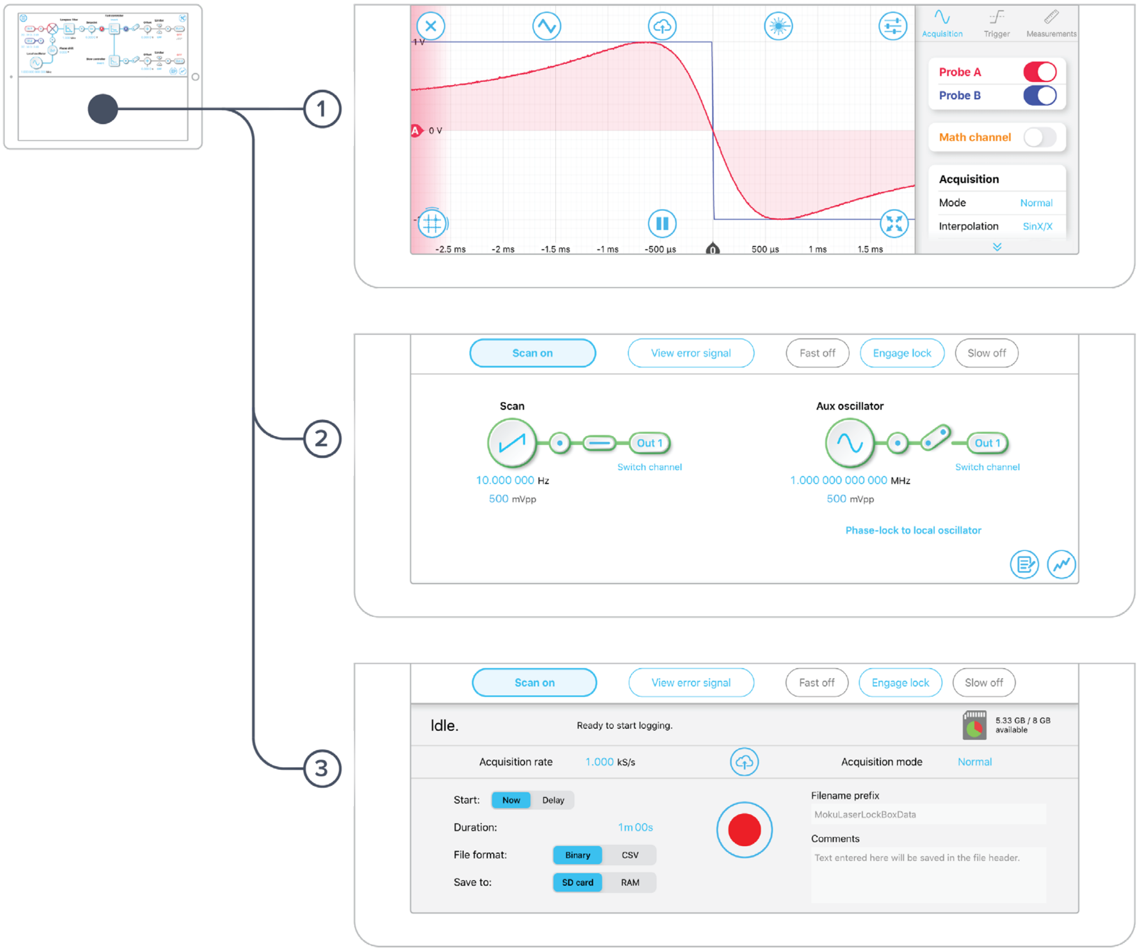


User Interface

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.

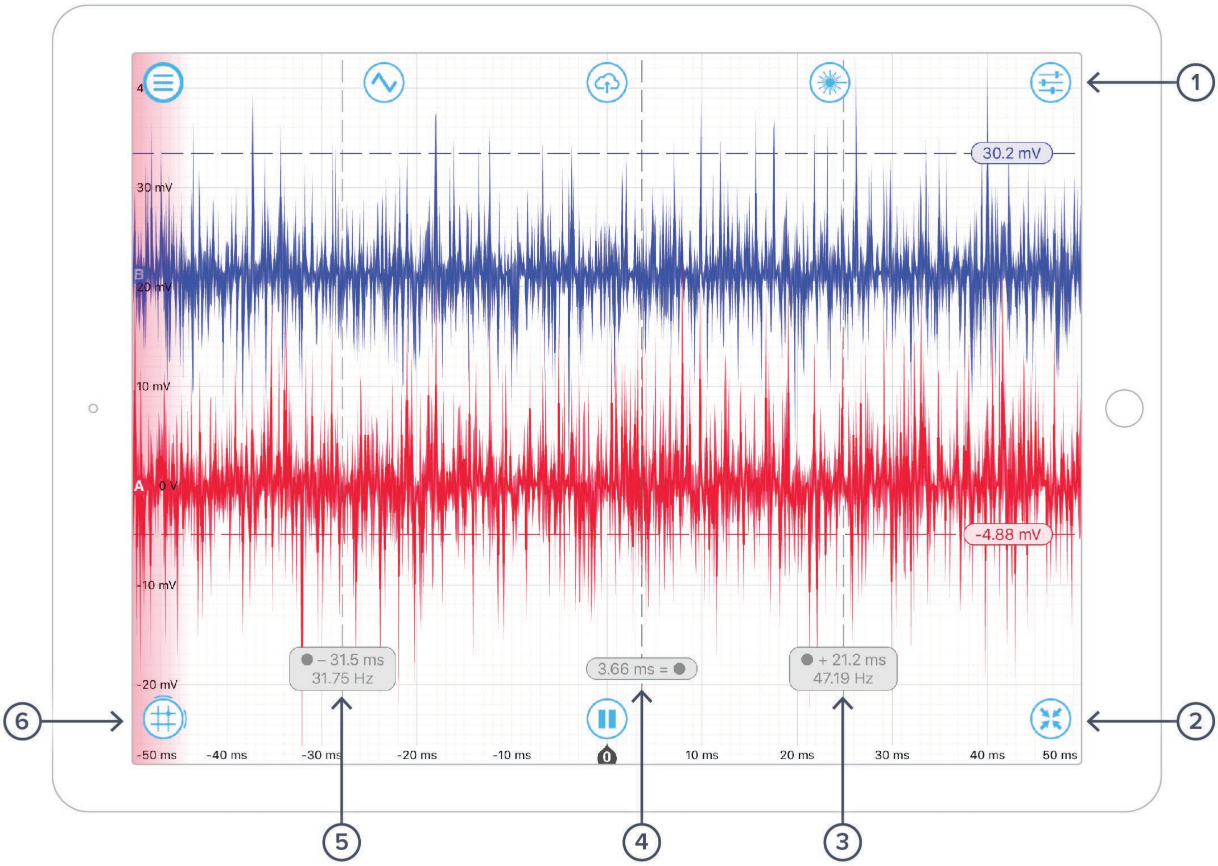


The lower half is readily set to display one of three parameter control panels: scan and aux oscillators, oscilloscope, and data logger.



ID	Description
1	Oscilloscope
2	Scan and aux oscillator control
3	Datalogger

The oscilloscope may also be set into full screen mode to take full advantage of the dynamic user interface.

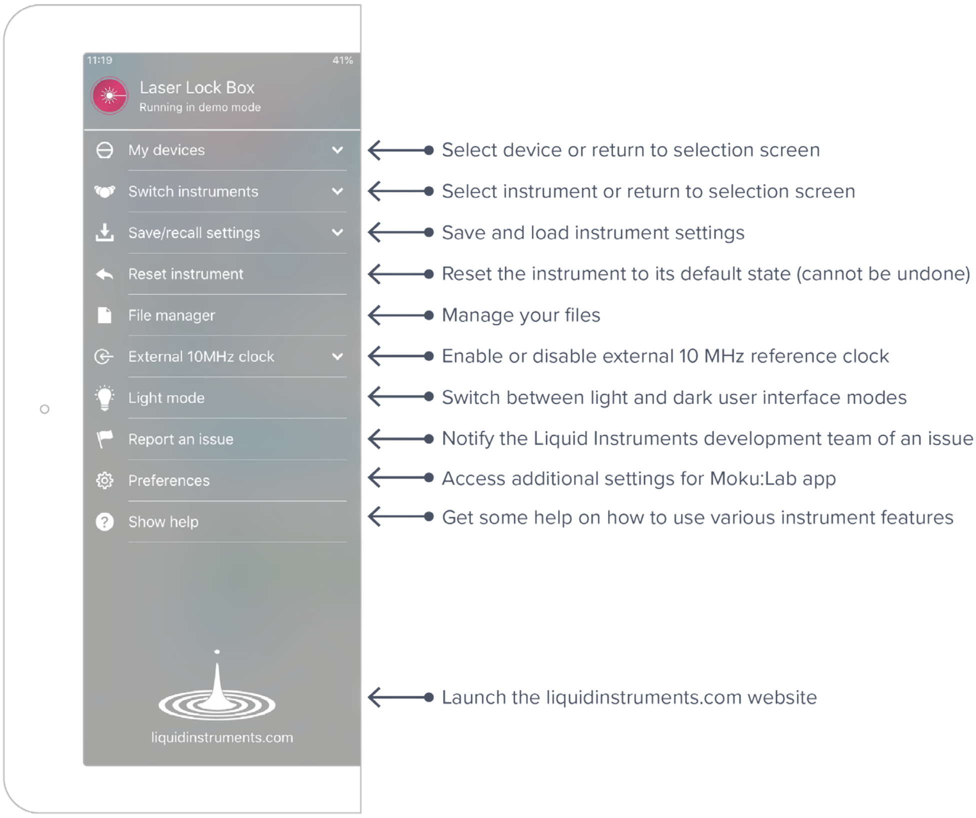


ID	Description	ID	Description
1	Settings side panel	4	Time access cursor set as reference
2	Half-screen Oscilloscope	5	Time axis cursor, with delta to reference
3	Time axis cursor, with delta to reference	6	Tap, drag left or drag up to create cursor

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

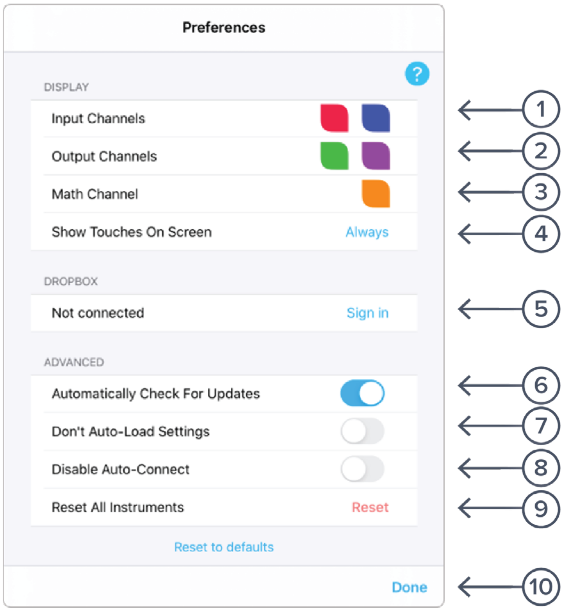
Main Menu

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



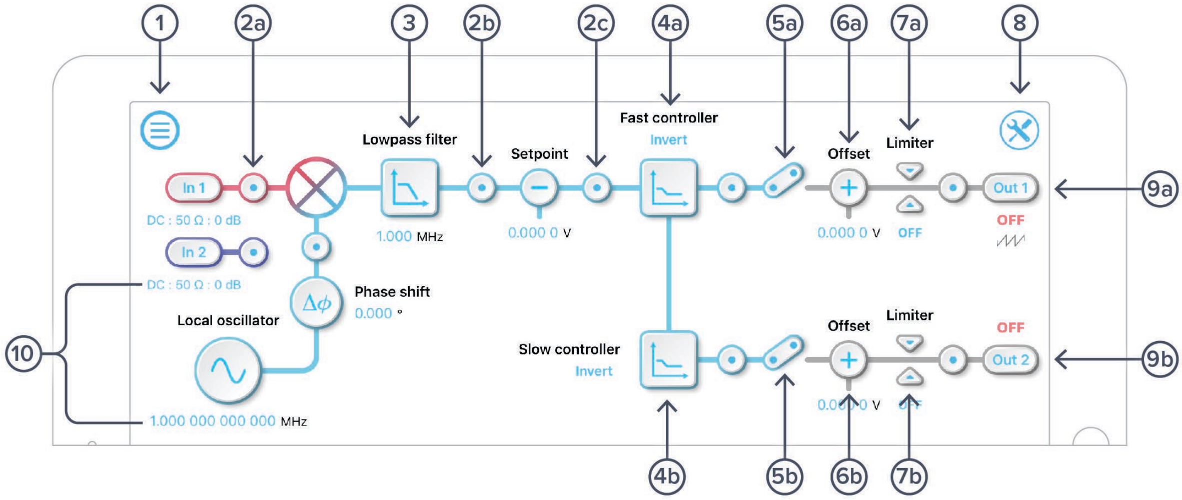
Preferences

The preferences pane can be accessed via the main menu. In here, you can reassign the color representations for each channel, connect to Dropbox, etc. Throughout the manual, the default colors (red for input 1, blue for input 2, green for output 1, purple for output 2) are used to present instrument features.



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

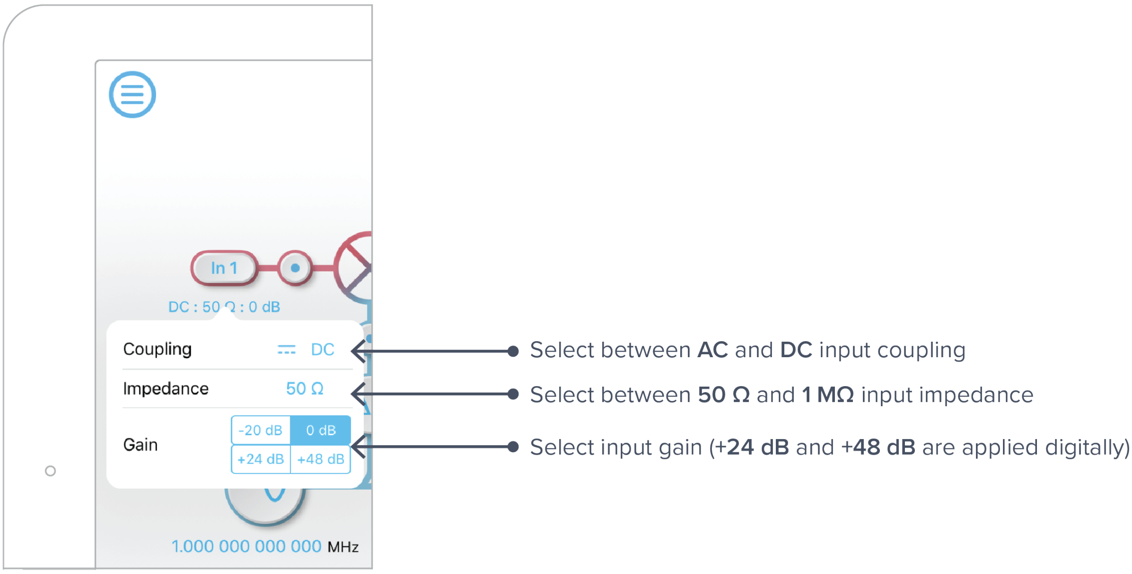
Upper user interface



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

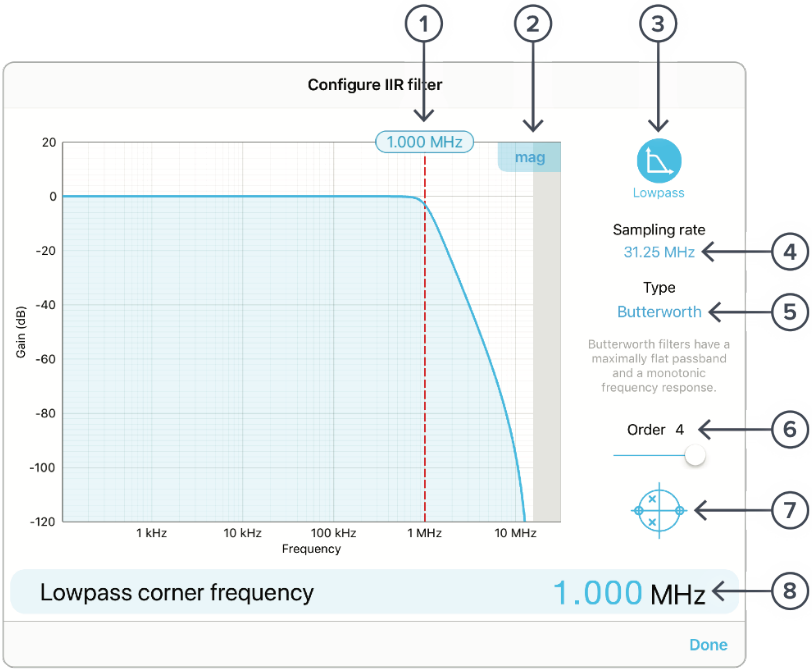
Signal Input

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



Digital filter configuration

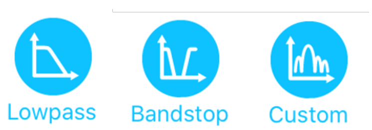
Immediately after the demodulator function, there is an digital filter designed to remove unwanted signal components. This is highly configurable; just tap the low pass filter icon.



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	Tap to select filter shape	7	Toggle view of poles/zeroes of filter
4	Fixed sample rate of 31.25 MHz	8	Tap to enter corner frequency

Filter Shapes

The shape of the filter can be selected by tapping the filter icon. There are two pre-defined filter shapes and a fully customizable filter option.

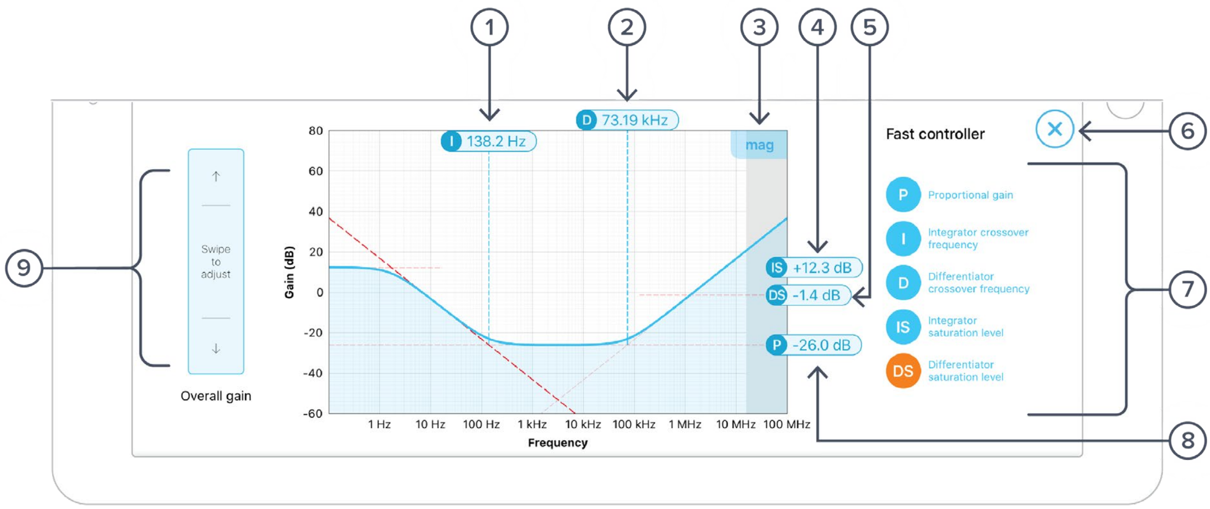


PID controllers

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

Both the fast and slow PID controllers can be configured graphically by 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.

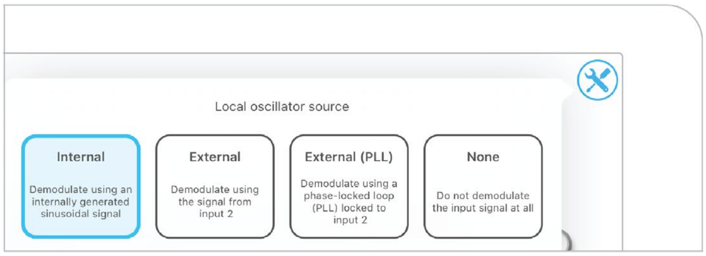


ID	Description	ID	Description
1	Drag or tap to enter integrator crossover frequency	6	Close the PID controller interface
2	Drag or tap to enter differentiator crossover frequency	7	Proportional, integrator, differentiator, integrator saturation and differentiator saturation settings
3	Toggle between magnitude or phase plots	8	Drag or tap to enter proportional gain
4	Drag or tap to enter integrator saturation	9	Swipe to adjust selected PID parameter
5	Tap to set differentiator saturation		

Local oscillator

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

Select between **Internal**, **External**, **External (PLL)**, and **None** demodulation modes



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 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 user configurable bandwidth. To configure the bandwidth of the PLL, tap the PLL icon to select the bandwidth between 300 mHz to 10 kHz. The PLL will automatically lock to the strongest harmonic of the external reference in the range of 1 MHz to 200 MHz with a manually configurable local phase shift. For lower frequencies, the PLL can be manually set as low at 10 kHz. The reacquire button can be used to re-lock to the external reference.

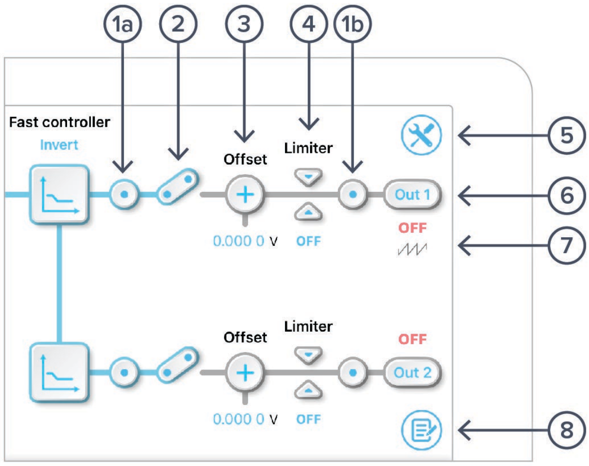
None

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

Outputs

Enable the PID, configure the voltage offset and limiter of the two output channels, and enable / disable either output channel by tapping the Out 1 and Out 2 ons.

View the signal at the output of each channel using the probe points

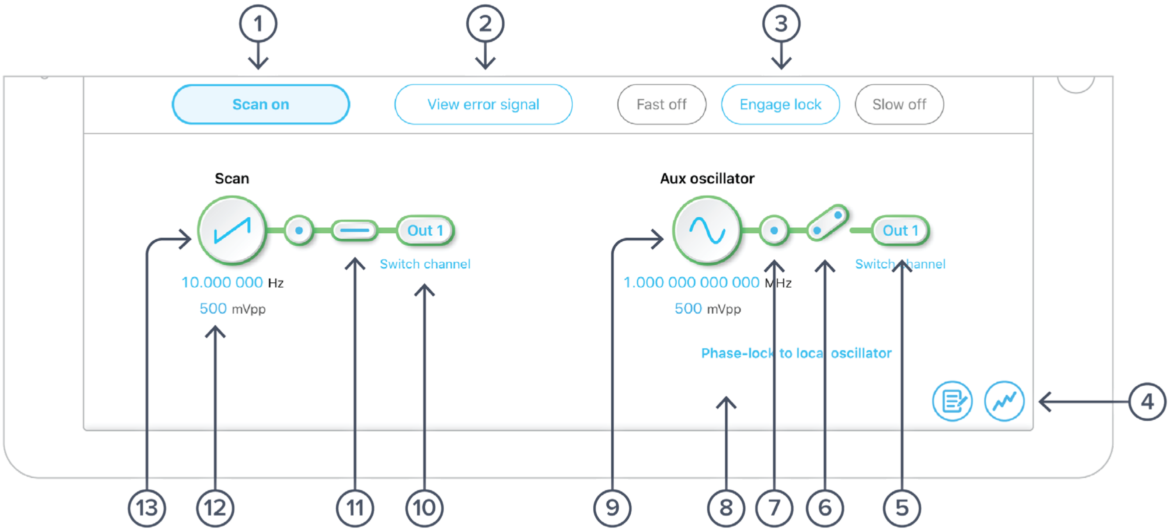


ID	Description	ID	Description
1a,b	Drop point for oscilloscope	5	Tools to configure local oscillator
2	Tap to enable PID controller output	6	Turn output 1 on/off
3	Enable & set a fixed offset	7	Indicates scan active on output 1
4	Enable & set output limiter	8	Access the built-in data logger instrument

Lower User Interface

The lower user interface is used to either control the scan and aux oscillator, or to display the half screen oscilloscope or data logger.

Scan and aux oscillator



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

Oscilloscope

Moku:Lab's Laser Lock Box includes a built-in oscilloscope, enabling you to observe and record data of up to two signals at a time in the Laser Lock Box's processing chain. More details about Moku:Lab's Oscilloscope can be found in the 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	Tap to access more Acquisition settings
4	Select zero crossing to lock to	11	Set oscilloscope to full screen
5	Reveal/hide settings sidebar	12	Pause/run oscilloscope
6	Acquisition tab selected	13	Tap to add time/voltage cursors, or drag right or drag up to create a cursor
7	Tap to select trigger tab	14	Oscilloscope sub-panel

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

You can hide the oscilloscope by pressing the con and reveal it by pressing the n.

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.

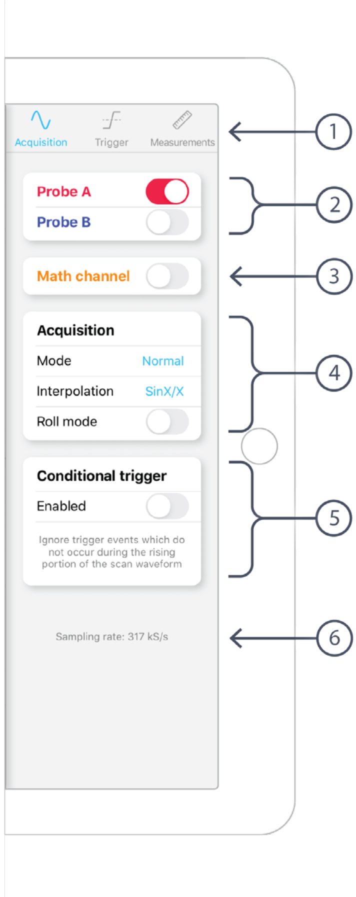
Full Screen Mode

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.



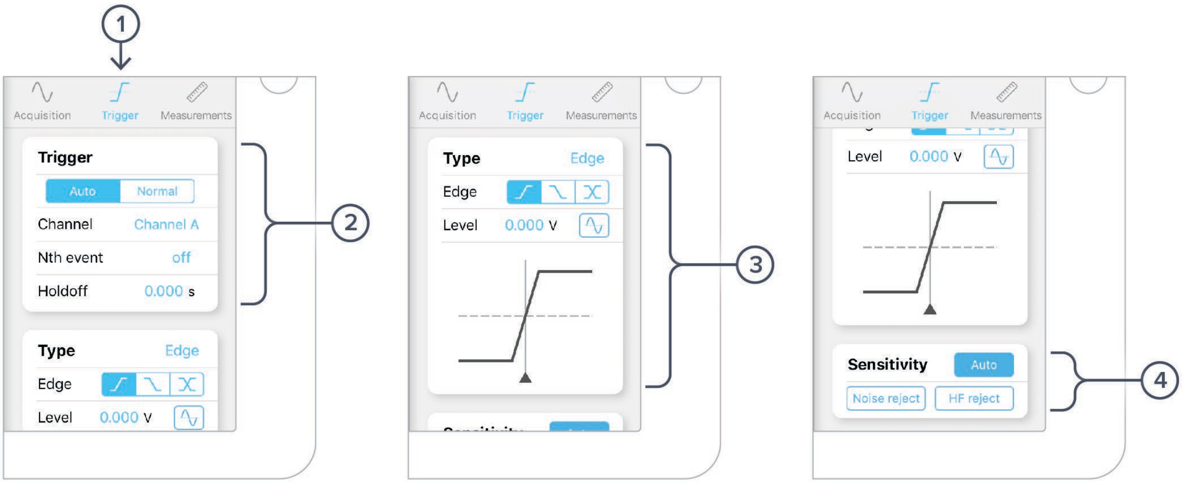
Acquisition

ID	Description
1	Tap to switch tabs
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
5	Enable / Disable conditional trigger
6	Current sampling rate

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

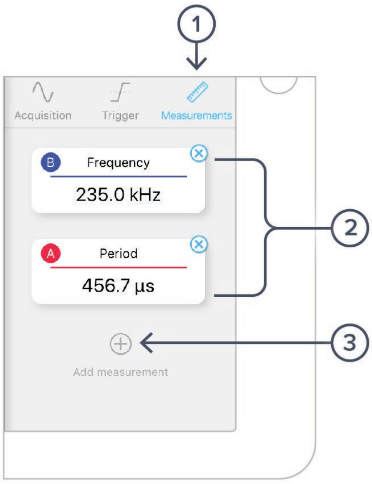
Trigger

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

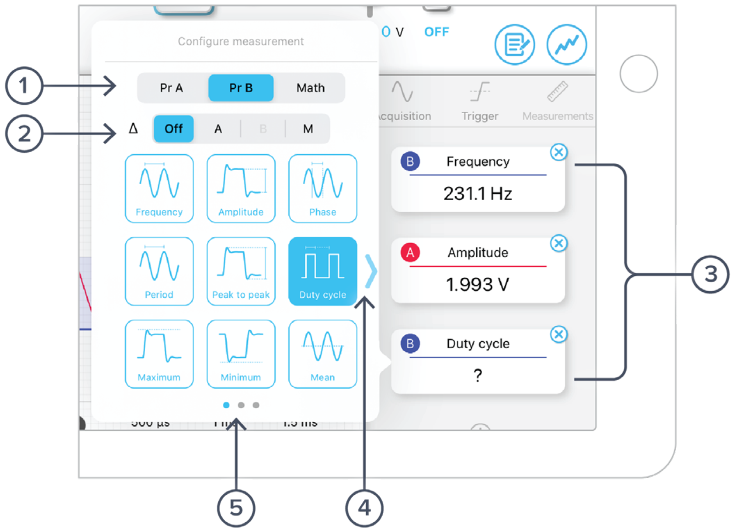
Measurements



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

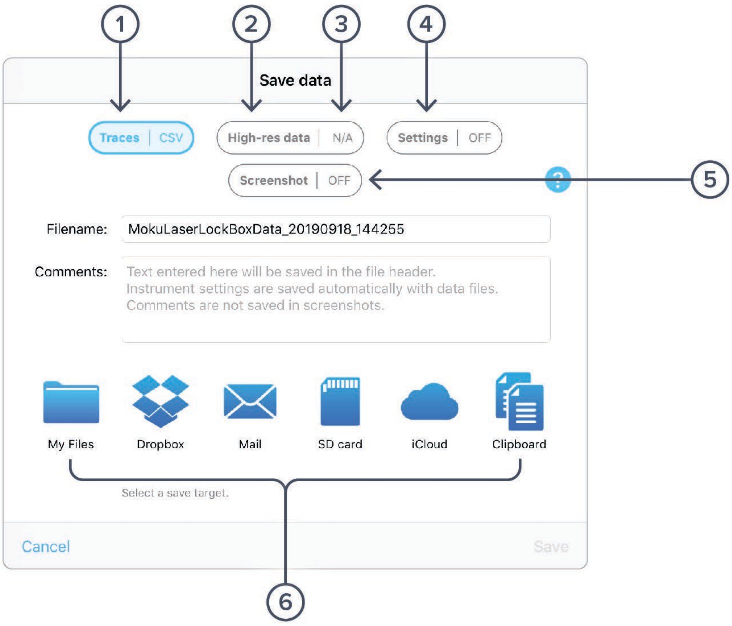
Measurement setup



ID	Description
1	Source channel
2	Displays the difference with respect to another channel
3	Multiple measurement tabs
4	Tap for more measurement options
5	3 panes of measurement options

Save oscilloscope data to files or cloud services

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



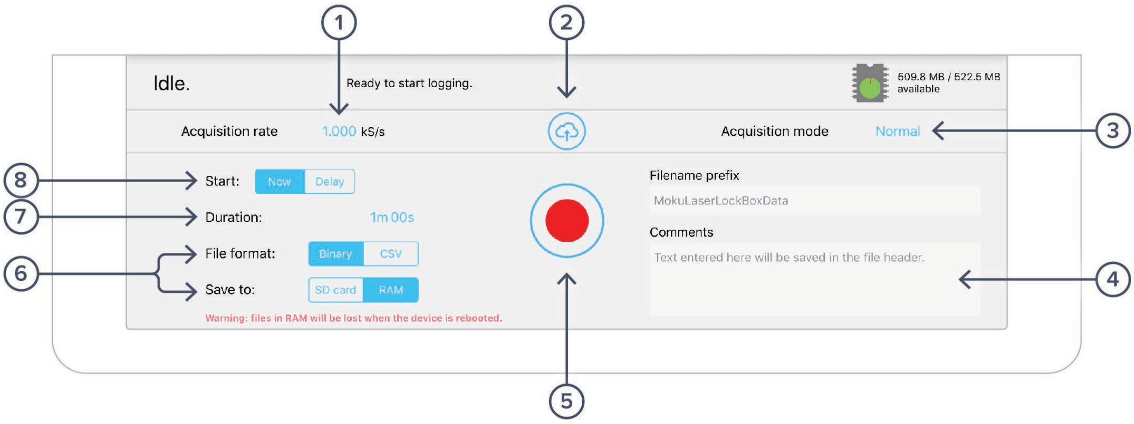
ID	Description	ID	Description
1	Save traces in CSV or MATLAB formats	4	Save Laser Lock Box instrument settings to TXT file
2	Save high res data	5	Save screenshot in JPG or PNG formats
3	High res data format	6	Select save data destination

Data logger

The built-in 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 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 240 hours
- Start a measurement by pressing the red record circle



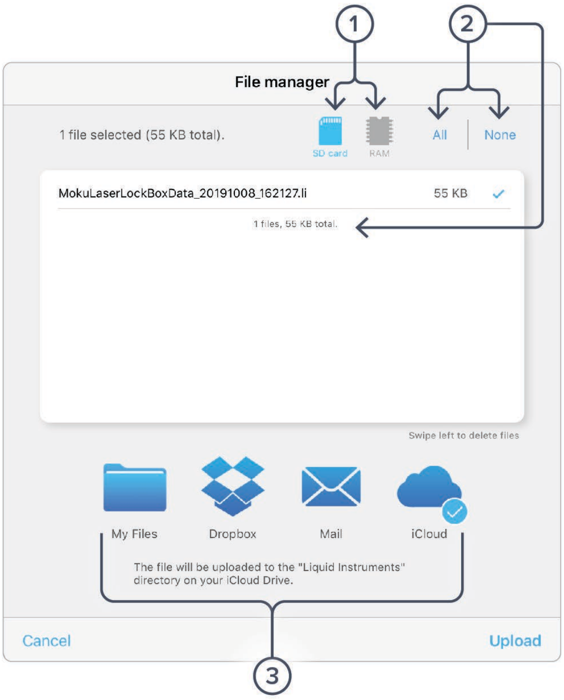
ID	Description
1	Select the sampling rate at which your measurement is recorded
2	Upload saved data
3	Select between **Normal** and **Precision** acquisition modes
4	Add comments to your measurement
5	Record a new measurement
6	Select the file format and destination of the recorded measurement data
7	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 and mail 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.

My Files: Upload files to the "Moku:Lab" directory in the "On My iPad" location in the Files app.

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

Mail: Files will be attached to an email, which you can send using the iPad's default email client.

iCloud: Upload files to the "Liquid Instruments" directory on your iCloud Drive.

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