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.

LIQUID INSTRUMENTS

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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 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

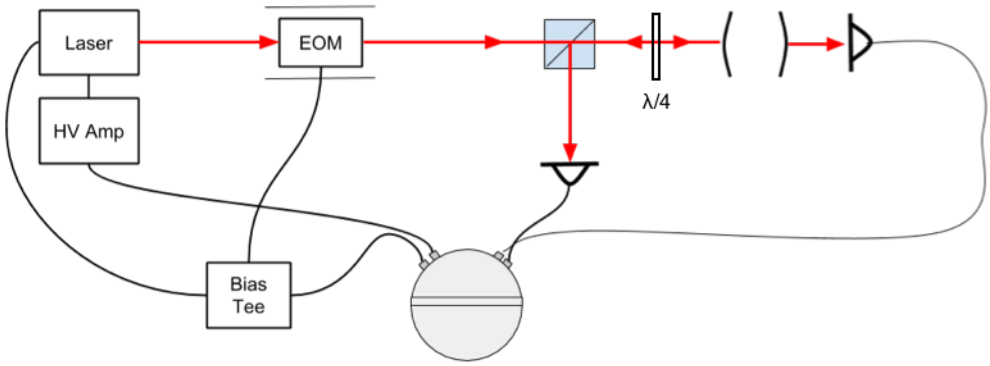
At the core of any Laser locking technique is the measurement that provides the difference, or error, between the laser and a frequency reference. Often termed the 'error signal', the quality of this signal ultimately determines the precision and accuracy of the entire locking system. A frequently employed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

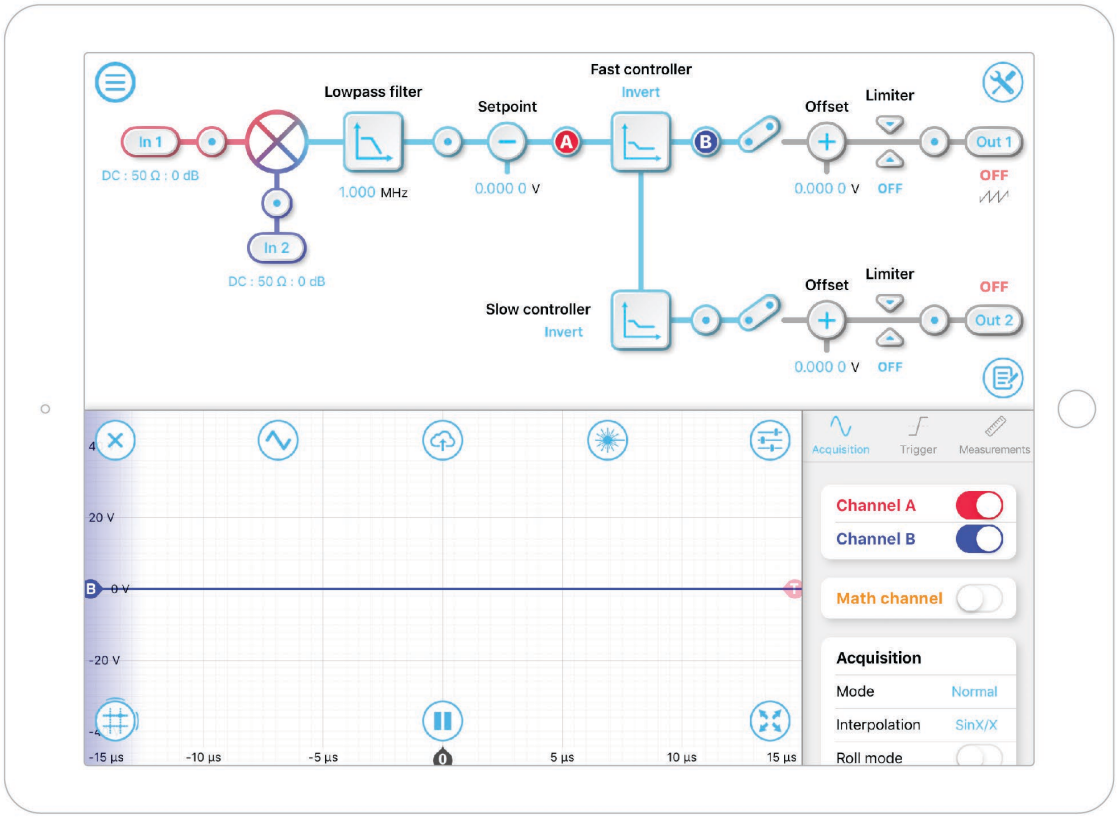
Laser Locking using the Moku:Laser Lock Box

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.

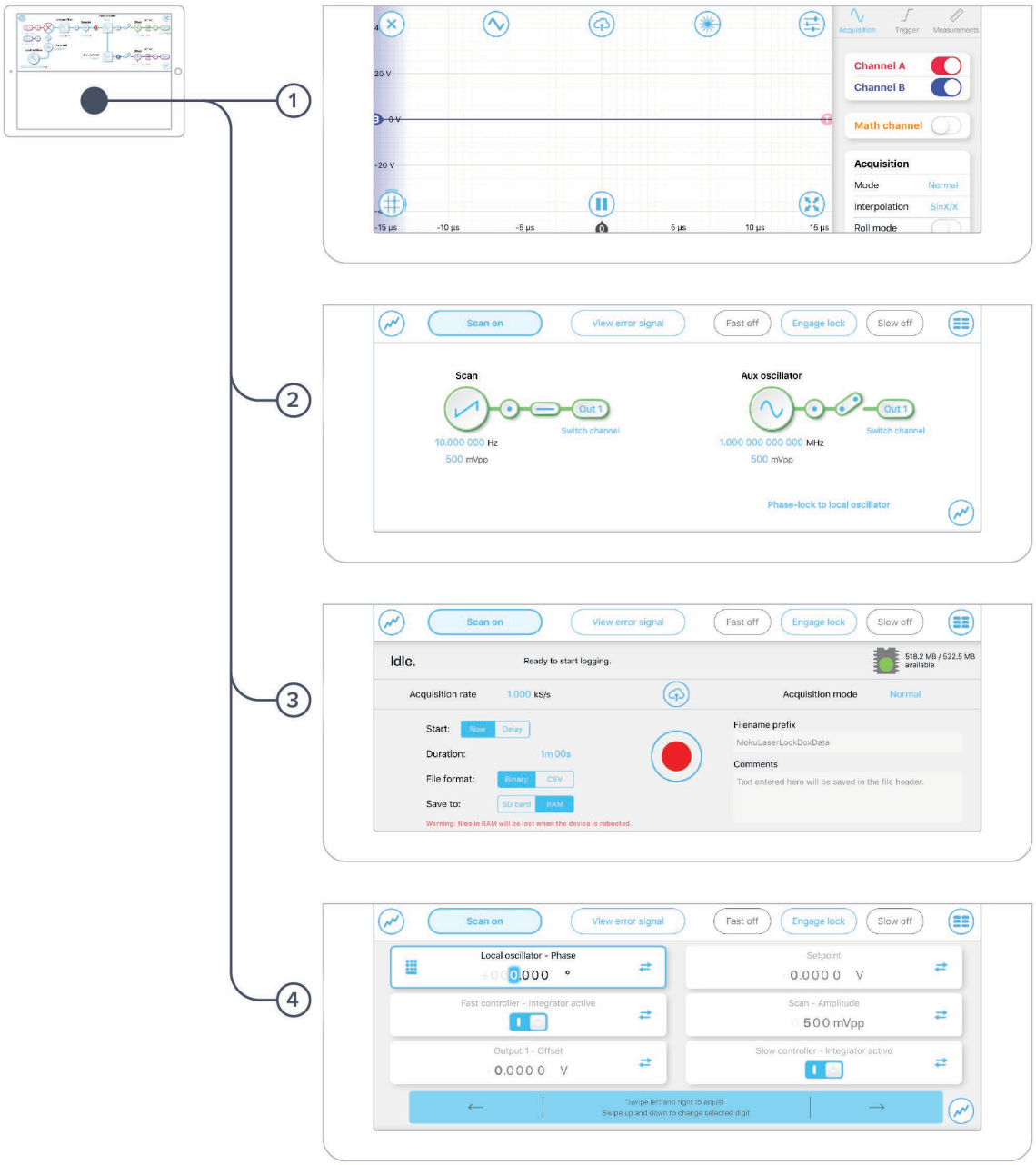


User Interface

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.

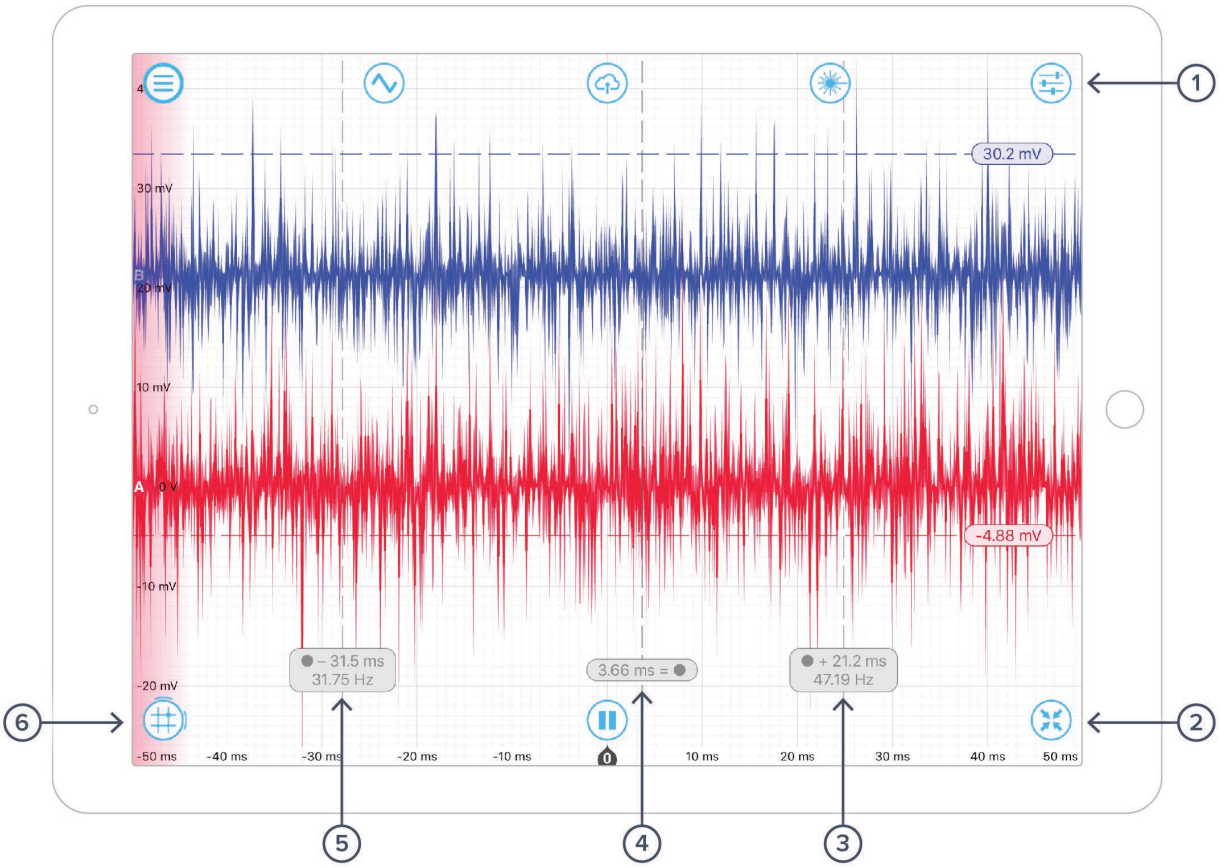


The lower half is readily set to display one of scan and aux oscillators, oscilloscope, data logger, parameter control panel



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

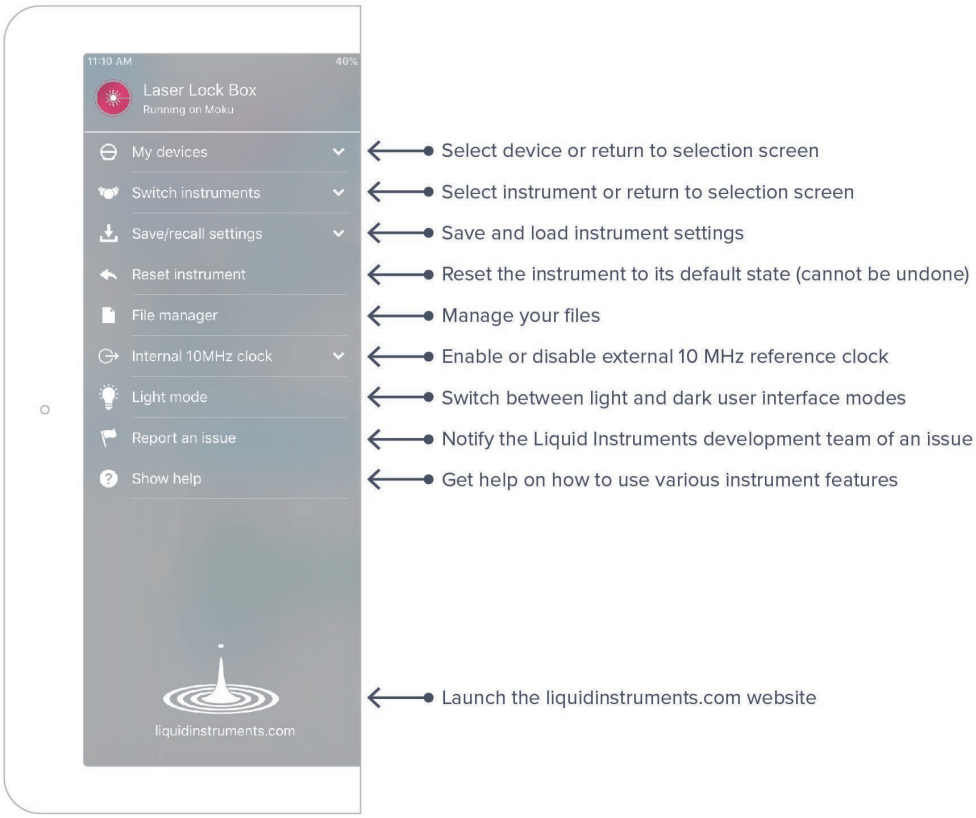


ID	Description	ID	Description
1	Settings side panel	4	Time access cursor set as reference
2	Half screen oscilloscope	5	Time axis cursor, with delta to reference
3	Time axis cursor, with delta to reference	6	Tap, drag left or drag up to create cursor

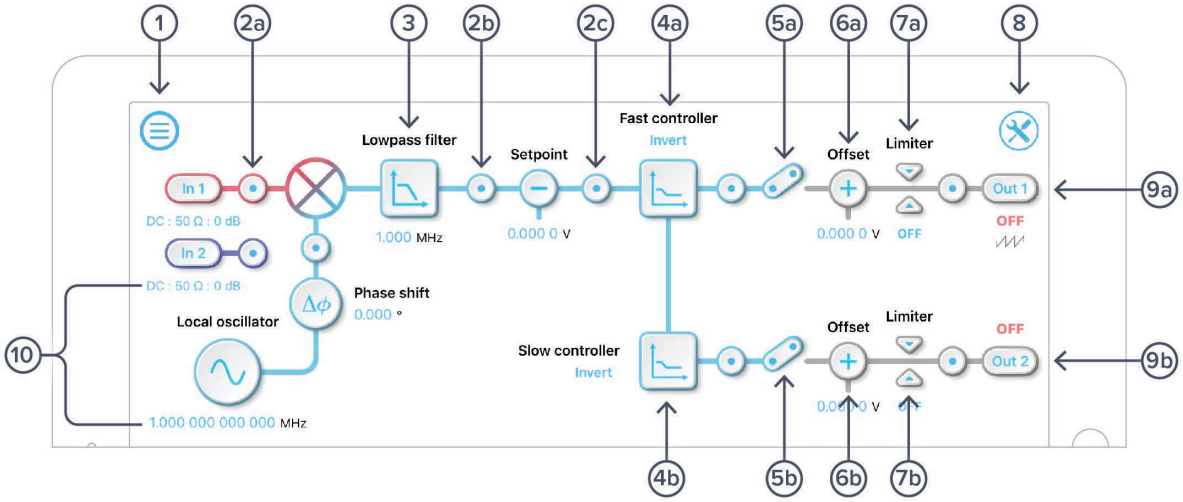
See Oscilloscope for full details of the oscilloscope user interface and controls.

Main Menu

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



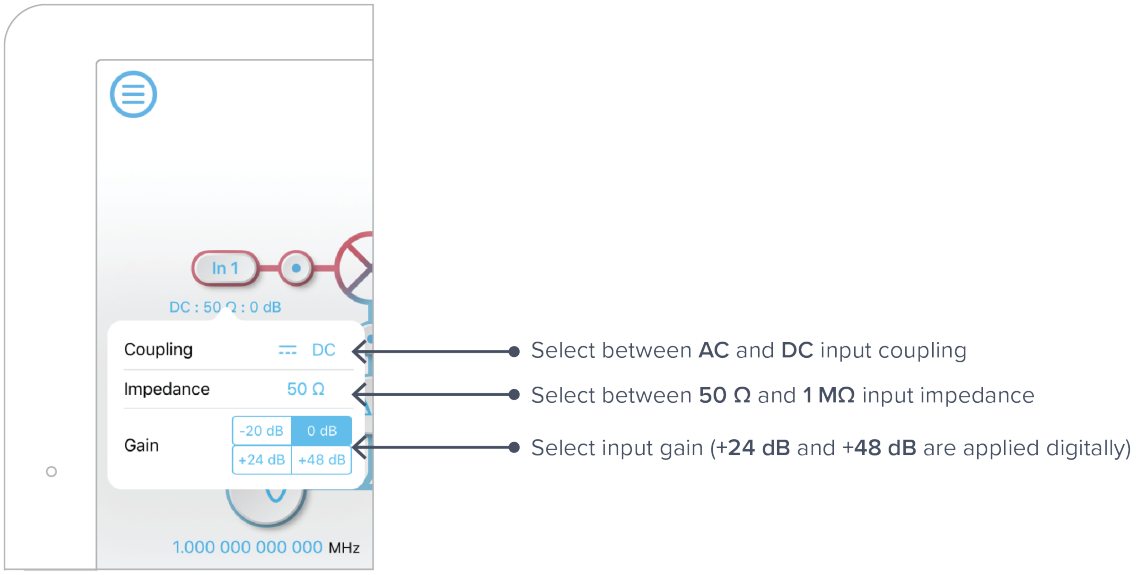
Upper user interface



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

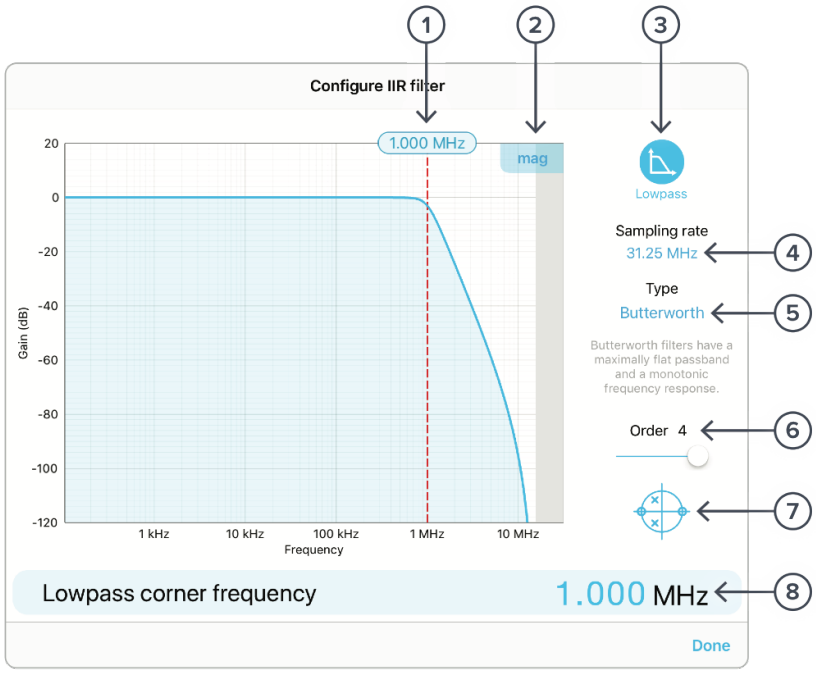
Signal Input

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.



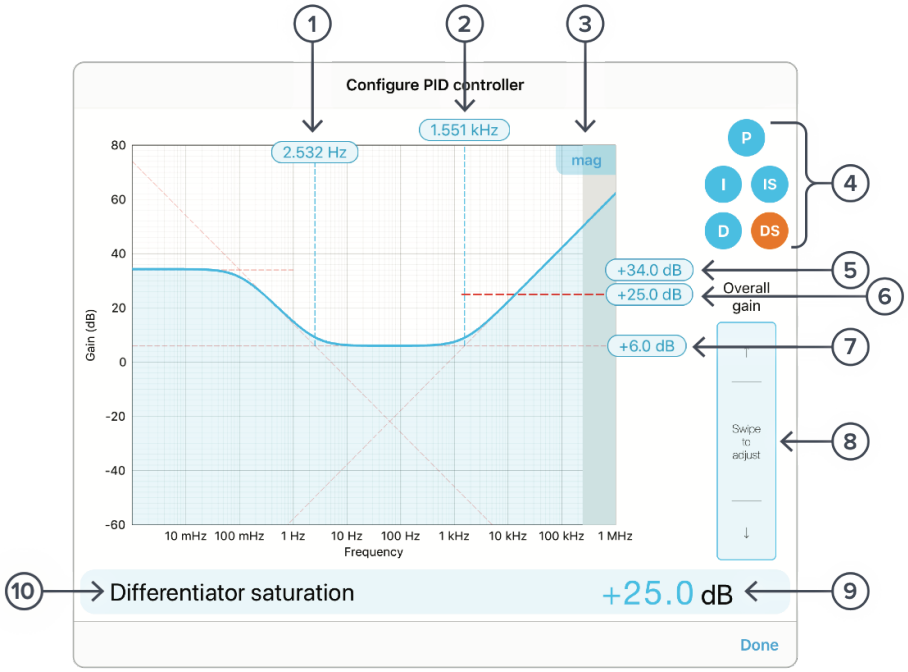
ID	Description	ID	Description
1	Configure lowpass filter corner frequency, tap to enter frequency or touch and drag	5	Tap to select filter type
2	Toggle between magnitude or phase plots	6	Tap to select filter order
3	Fixed function of low pass filter	7	Toggle view of poles/zeroes of filter
4	Fixed sample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

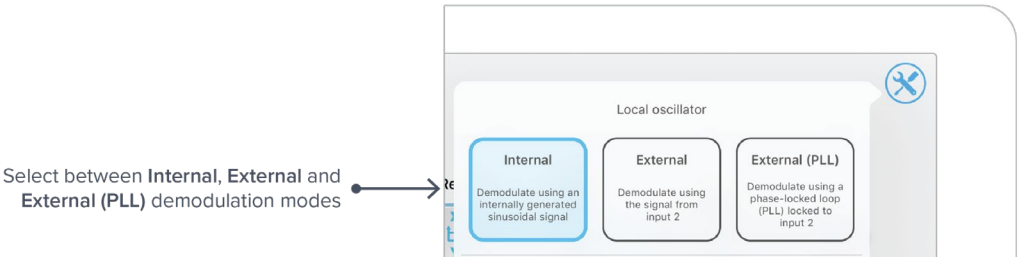
The PID controller provides full control over proportional, integral and derivative gain profiles with saturation levels available for the integral and derivative components. The PID's transfer function is updated in real-time.



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.

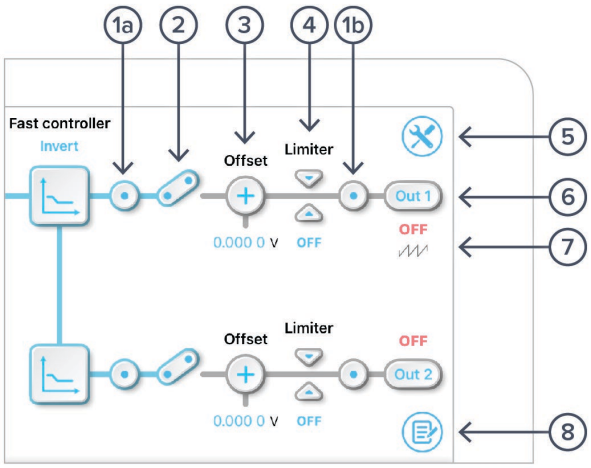
External (PLL)

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 .

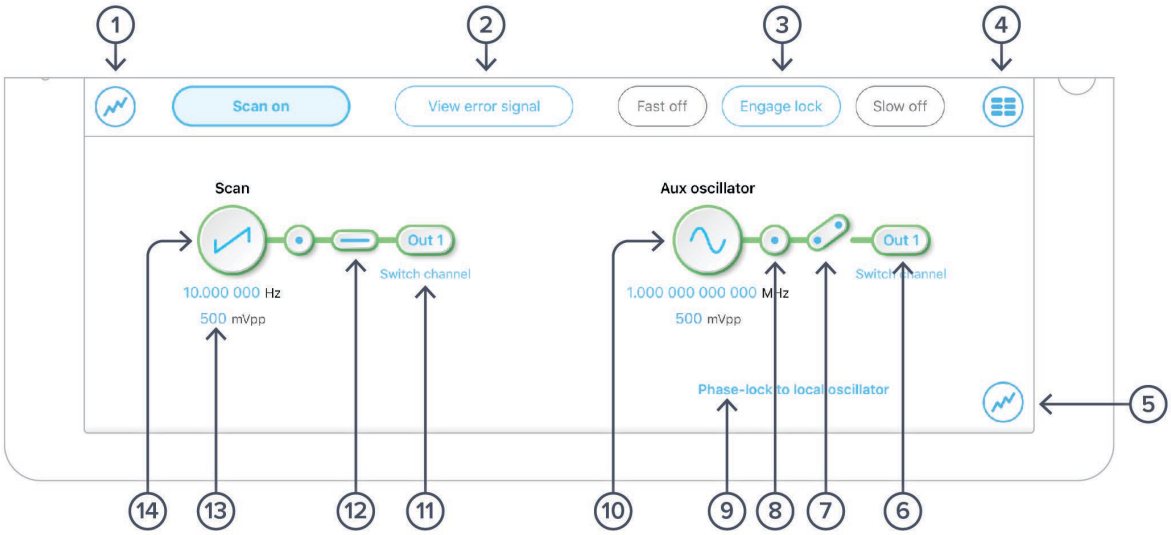


ID	Description	ID	Description
1a,b	Drop point for oscilloscope	5	Tools to configure local oscillator
2	Tap to enable PID controller output	6	Turn output 1 on/off
3	Enable & set a fixed offset	7	Indicates scan active on output 1
4	Enable & set output limiter	8	Select datalogger instrument

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.

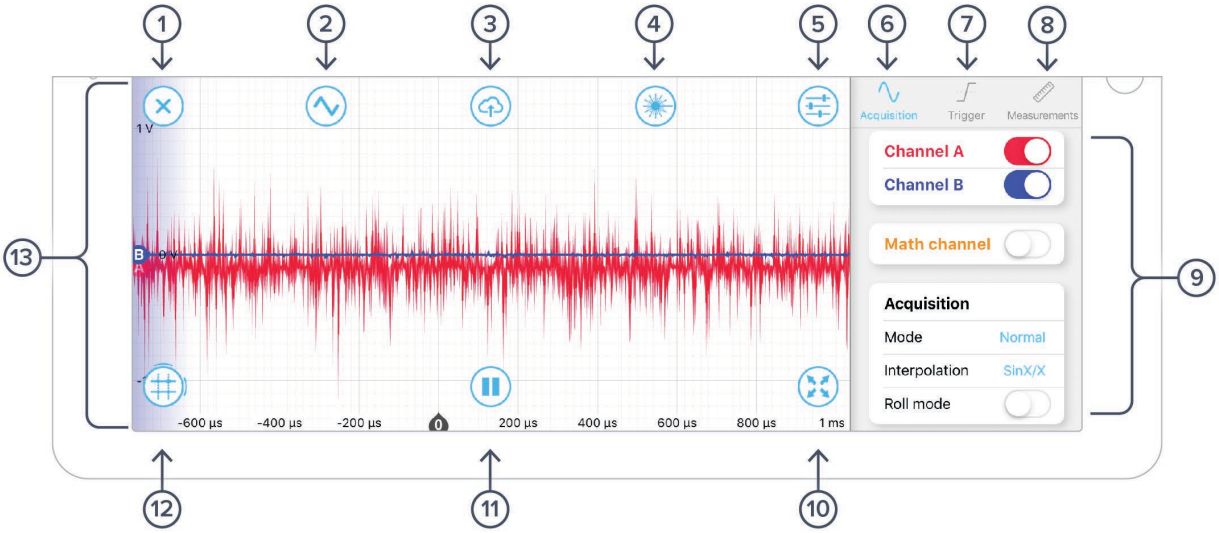
Scan and aux oscillator



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.

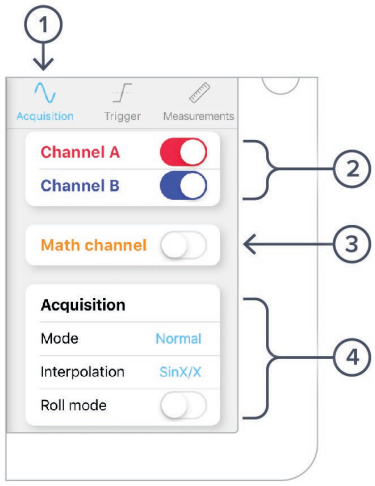
Full Screen Mode

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

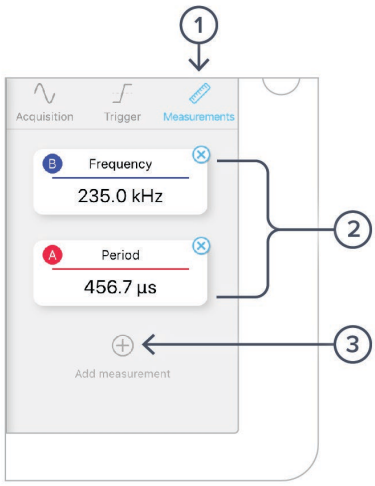
*Normal mode down-samples by discarding points between those needed. Precision mode down-samples by averaging, increasing precision and reducing noise.

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

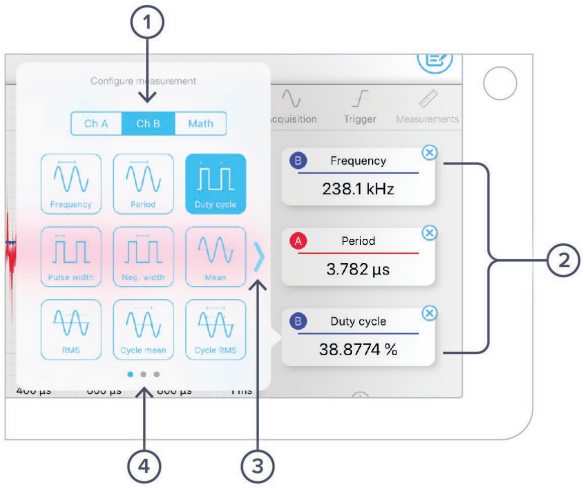
Measurements



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

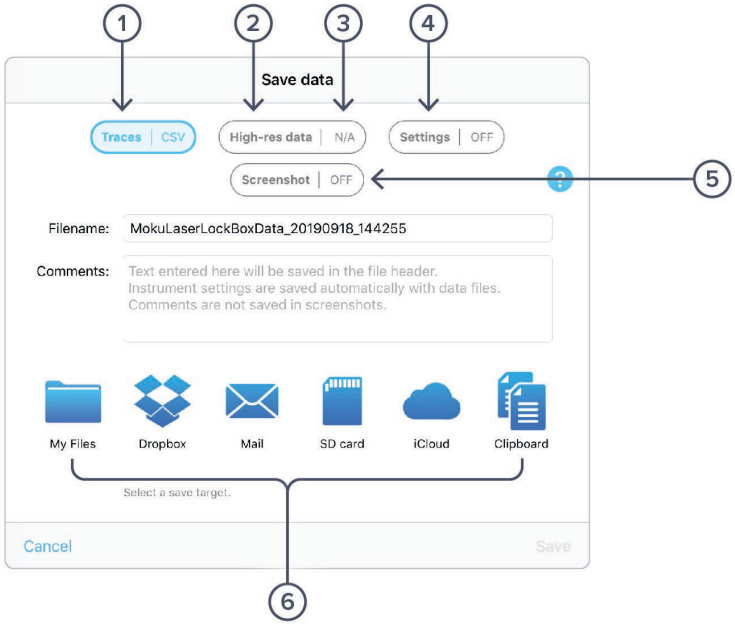
Measurement setup



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



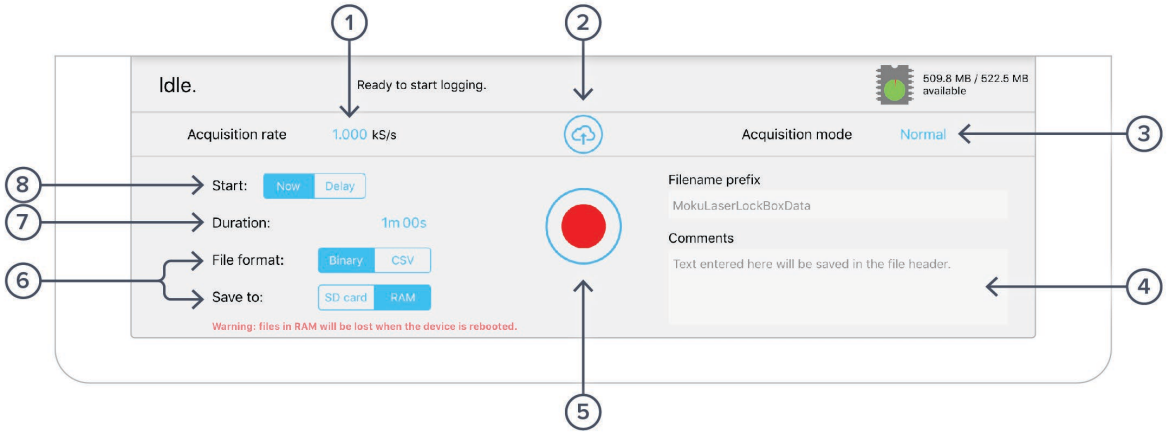
ID	Description	ID	Description
1	Save traces, CSV or MATLAB formats	4	Save Laser Lock box instruments settings to TXT file
2	Save High res data	5	Save screenshot, JPG or PNG formats
3	High res data format	6	Select save data destination

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



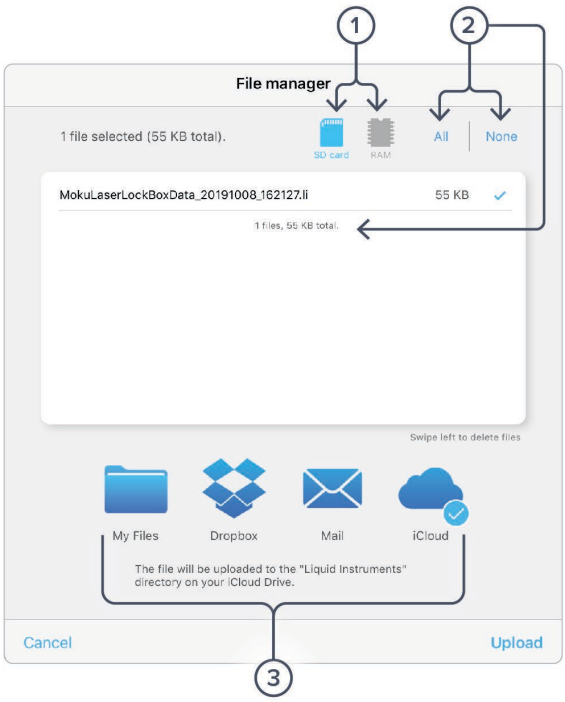
ID	Description
1	Select the sampling rate at which your measurement is recorded
2	Upload saved data
3	Select between **Normal** and **Precision** acquisition modes
4	Add comments to your measurement
5	Record a new measurement
6	Select the file format and destination of the recorded measurement data
7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

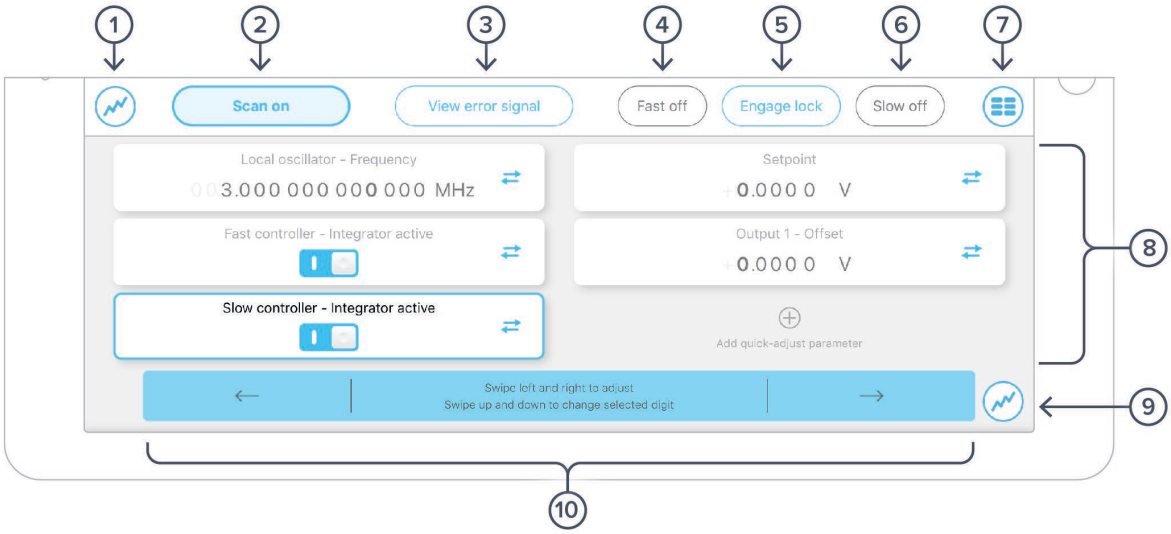
- Upload files to SD card by inserting a compatible FAT32 formatted drive into the Moku:Lab's SD card slot, located on the rear of the device next to the power connector.

Dropbox

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

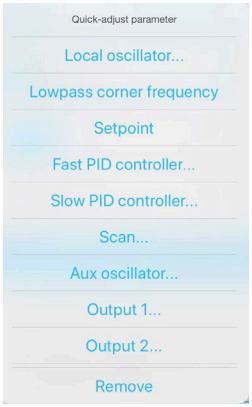
Parameter controls panel

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 .



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