Moku Lock-in Amplifier

User Manual

Table of Contents

Introduction

The Moku Lock-in Amplifier extracts and isolates a periodic signal of a known frequency, using a local oscillator as a reference. Using dual-phase demodulation, the Lock-in Amplifier can recover the magnitude and phase of weak oscillating signals, even in a noisy environment. A block diagram of the instrument is seen in Figure 1. Instrument specifications can be found in your Moku's specification sheet.

This manual is intended to help users understand the user interface and underlying architecture of the instrument. It also includes a general example in the quick start guide and a small number of in-depth examples to provide a foundation for new users.

These user manuals are tailored to the graphical interfaces available on macOS, Windows, iPadOS, and visionOS. If you'd prefer to automate your application, you can use Moku API; available for Python, MATLAB, LabVIEW, and more. Refer to the API Reference to get started.

AI-powered help is available to aid both workflows. AI help is built into the Moku application, and provides fast, intelligent answers to your questions, whether you're configuring instruments or troubleshooting setups. It draws from Moku manuals, the Liquid Instruments Knowledge Base, and more, so you can skip the datasheets and get straight to the solution.

Access AI help from the main menu

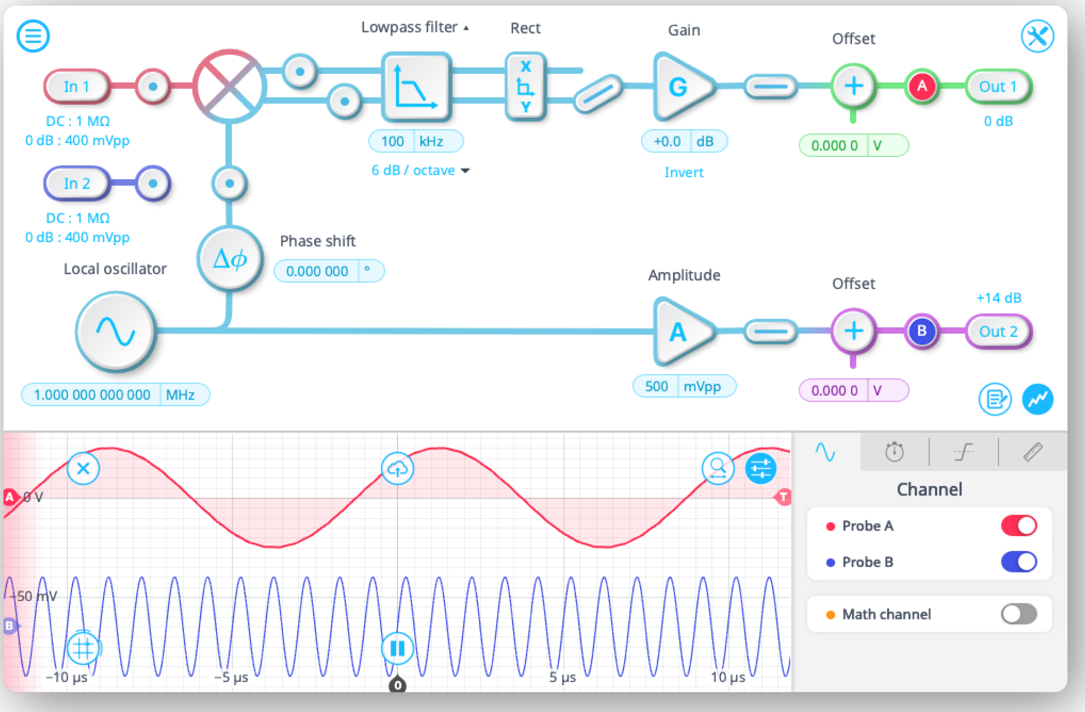


Figure 1. Lock-in Amplifier user interface showing the instrument block diagram (top), embedded oscilloscope display (bottom) and the oscilloscope settings panels (bottom right).

Quick start guide

This example explains the principle of dual-phase demodulation and highlights a typical use case of the Lock-in Amplifier.

In this example, the fluctuations of a phase modulated signal are measured with an external reference. The signal of interest is a 1 MHz, zero-mean sine wave with an amplitude of 1 mVpp, phase-modulated at 5 Hz, with a modulation depth of ±90°. The external reference is a 50% duty cycle square wave with 1 MHz repetition rate and 1 Vpp amplitude. The signal and reference were generated based on the same clock (phase-locked), with an arbitrary phase offset between them.

The signal and reference are connected to Input 1 and Input 2 on Moku, respectively.

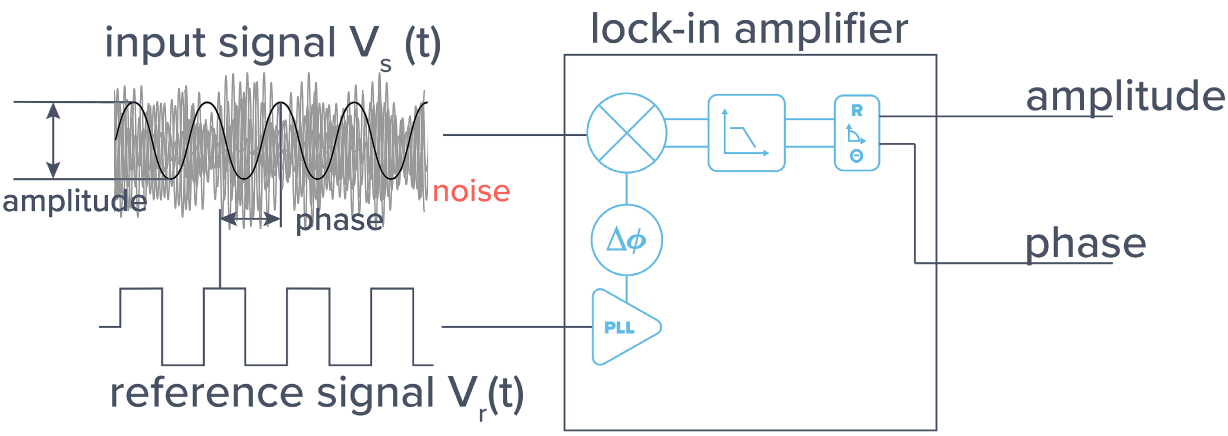


Figure 2. Phase demodulation with input and reference signals entering the Lock-in Amplifier, demodulated into amplitude (R) and phase (ϕ).

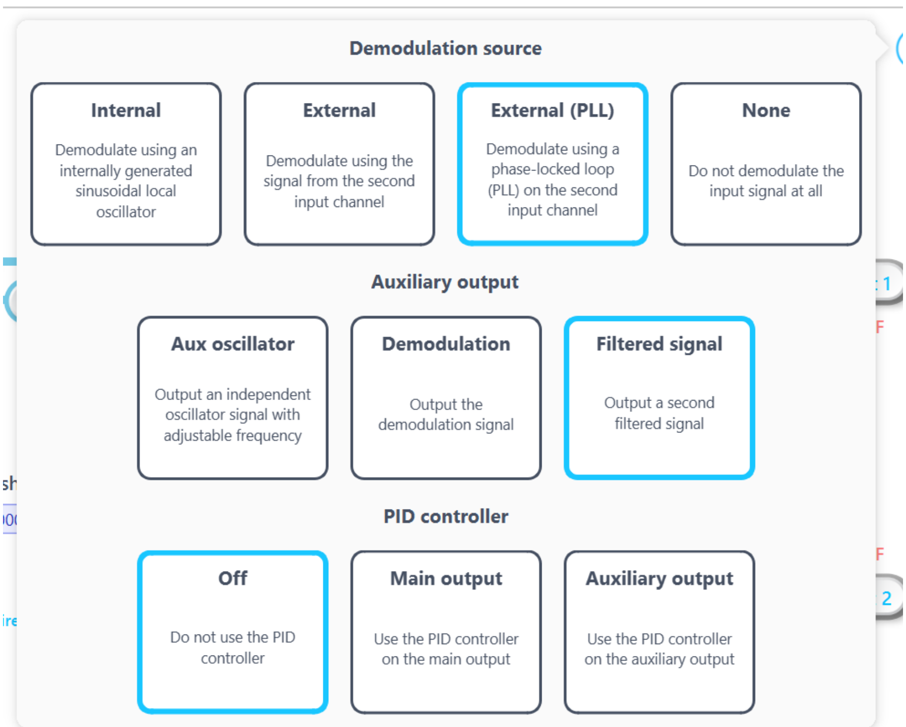


Figure 3. Lock-in Amplifier configuration for this example.

- **Step 1:** Select the Lock-in Amplifier configuration
  - Configure your lock-in setup from the icon. Select "External (PLL)" as the Demodulation source, "Filtered signal" as the Auxiliary output and the PID controller set to "OFF".
- **Step 2:** Configure the analog front end settings for the signal inputs
  - In this case both inputs have a 50 Ω input impedance to match its source, 0 dB attenuation and DC coupling.
- **Step 3:** Configure the PLL
  - Set the PLL frequency to 1 MHz with a multiplier of 1× to match the reference signal. Configure the loop bandwidth to 1 kHz to reduce noise while maintaining loop responsiveness.
- **Step 4:** Configure the lowpass filter
  - Set the demodulator lowpass corner frequency to 20 Hz with a 12 dB/octave slope. The demodulated X/Y output is a ~5 Hz sinusoid matching the 5 Hz phase modulation, so a corner frequency a few times above 5 Hz preserves the signal while providing useful noise rejection. For faster response, increase the corner to 50–100 Hz; for a smoother output, reduce it toward 10 Hz.
- **Step 5:** Configure Lock-in Amplifier output gain
  - Increase the output gain to about +40 dB to bring the signal into the ~10 mV range. To avoid saturation, the output should be less than 2 Vpp. Enable the probe points for both the X and Y paths to view the output. Click the icon to calculate quantities such as the mean and frequency of each signal. The measured signal and reference might have a significant phase offset
- **Step 6:** Adjust the phase shift of the PLL
  - The reference signal and the actual signal might have a significant phase difference. If the absolute phase shift is measured, it's important to align the phase of the Local Oscillator and signal. Align the phase difference as necessary for your application. In this example, no phase shift is needed.
- **Step 7:** Adjust polar-to-rect conversion range
  - Using the known input signal of 0.5 mV peak, the demodulator (in-phase) produces a baseband signal of $\frac{V_{peak}}{2} = 0.25mV$. Based on this amplitude, the optimal conversion range is 7.5 mVpp.
- **Step 8:** Log data
  - The embedded Oscilloscope lets users visualize the signal throughout the path, allowing for easier optimization and troubleshooting.
  - The active probe points can also be used to track long term performance and record signals with the embedded Data Logger. To log for one hour, for example, set the rate to 100 kSa/s in precision mode with "immediate" start for 01:00:00.000 (hh:mm:ss.ms). Click the red circle to start the logging.

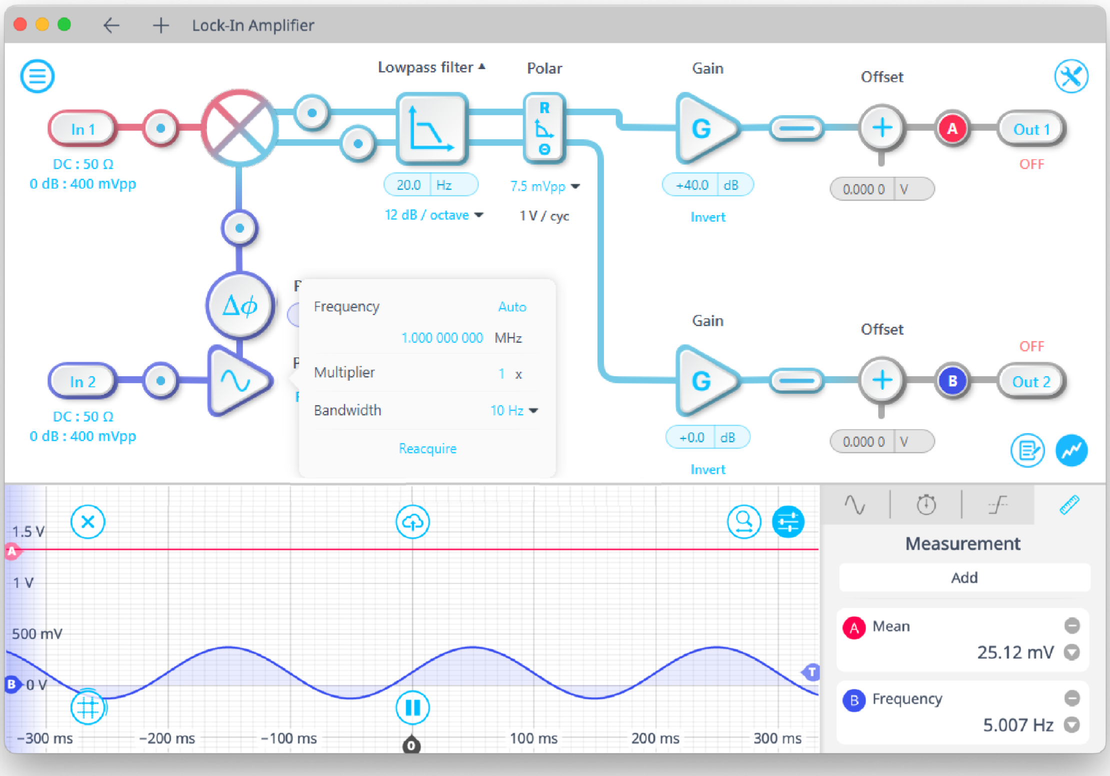


Figure 4. Lock-in Amplifier configuration, observing the amplitude R and phase ϕ of the system in the embedded oscilloscope.

Principles of operation

Lock-in amplifiers work by multiplying an input signal $R \cdot \sin(\omega t + \phi)$ with a reference signal $\sin(\omega t)$, a frequency mixing process called demodulation.

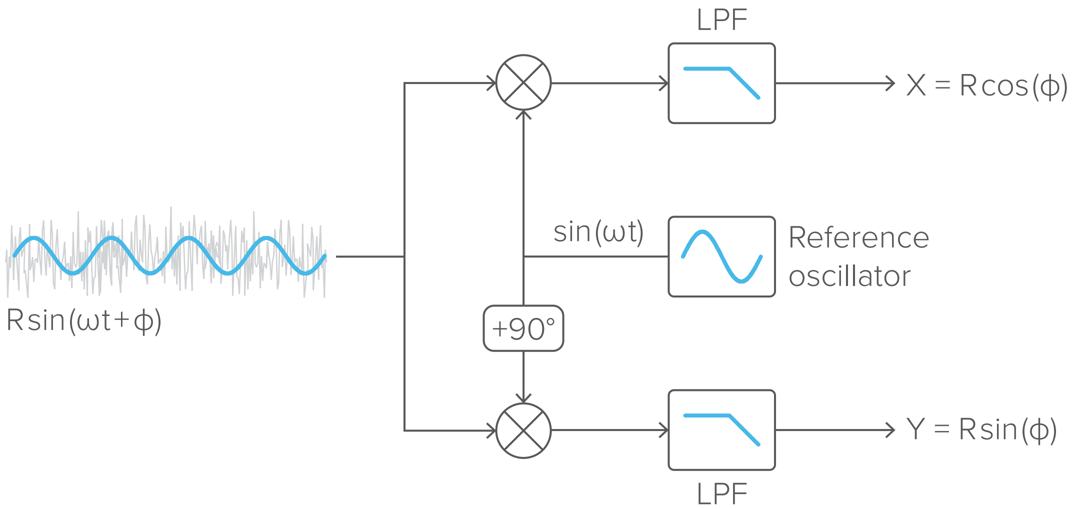


Figure 5. The Lock-in Amplifier is capable of measuring the amplitude R and the phase ϕ of a signal relative to a defined reference signal, even if the signal to noise ratio is poor.

The demodulation process produces two spectral components, called sidebands: 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 (lower sideband) 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 (upper sideband) will appear at twice the input frequency with additive phase.

A lowpass filter attenuates the upper sideband and suppresses noise. The DC output of the filter is proportional to the amplitude of the input signal scaled by the cosine of the phase difference, $X = R \cdot \cos(\phi)$.

However, this single-phase approach only measures the signal component aligned with the reference. To fully recover both the magnitude and phase of the input, the signal must also be demodulated against an orthogonal reference, as seen in Figure 5 . Using sine and cosine references produces the in-phase (X) and quadrature (Y) components, a process known as dual-phase demodulation and a standard feature of all modern lock-in amplifiers.

With X and Y, the magnitude R and phase ϕ can be calculated as

$$R = \sqrt{\left(X^2 + Y^2\right)} \quad (1)$$

and $\phi = \tan^{-1}\left(\frac{Y}{X}\right)$

For more detailed explanations, read our white paper on Implementing a phase-locked loop with Moku:Pro, our app note on Dual-frequency resonance tracking (DFRT) and more.

Advanced configuration

The Lock-in Amplifier offers a wide array of digital signal processing options to support different applications. Access the advanced configuration menu using the icon at the top right of the interface.

- Select between "Internal", "External" (straight-through), or "External (PLL)" as phase-locked demodulation references. Alternatively, you can bypass the demodulation source by selecting "None".
- Configure the Auxiliary output to determine the instrument's second output signal. Either generate an independent oscillator signal ("Aux oscillator"), output the local oscillator ("Demodulation"), or output a second filtered signal ("Filtered signal", e.g. output both X and Y).
- Choose to add a PID controller to the "Main output" (Channel 1) or the "Auxiliary output". This option is only available when the "Filtered signal" option is selected for the Auxiliary output.

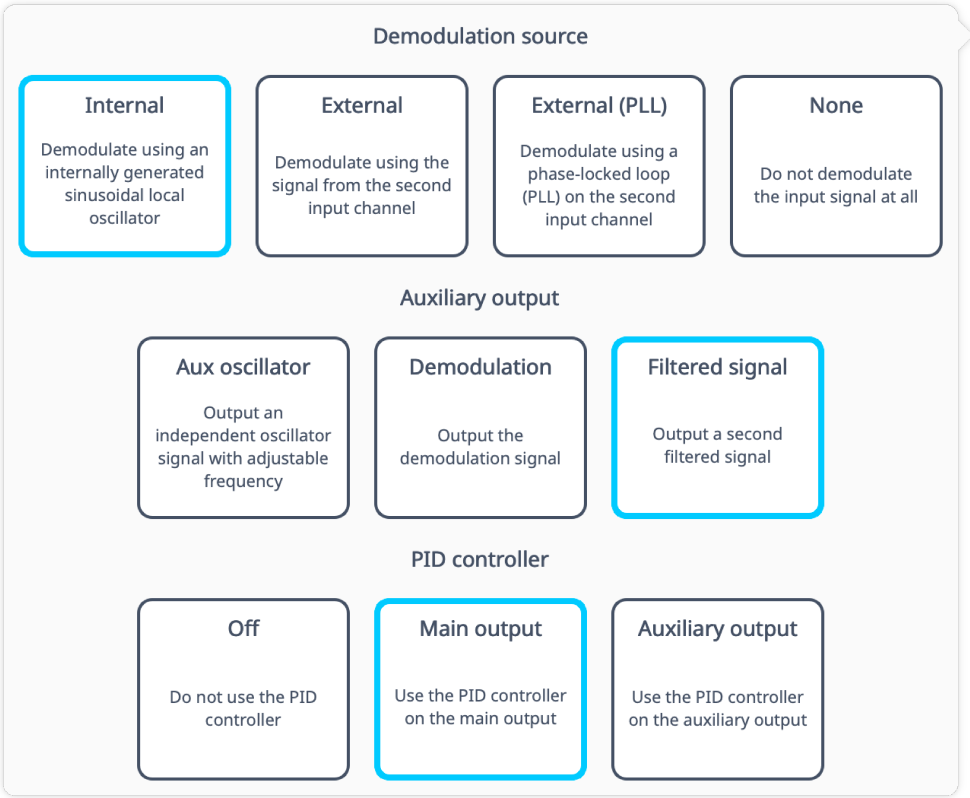


Figure 6. Demodulation sources, auxiliary outputs and PID controller options available to configure the Lock-in Amplifier.

Using the instrument

Signal input

The analog inputs to the Lock-in Amplifier allow you to change the analog frontend settings for each input. Tap the In 1 icon to configure the input settings for the signal input.

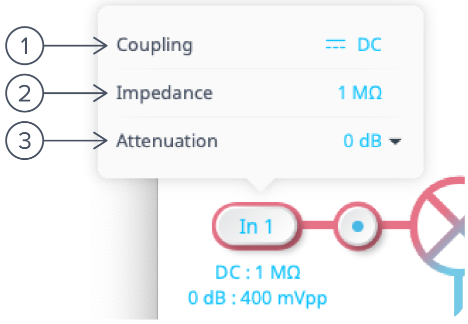


Figure 7. Signal input settings; set the coupling, impedance and attenuation for each analog input.

ID	Description
①	Select between AC and DC input coupling.
②	Select between 50 Ω and 1 MΩ input impedance (hardware dependent).
③	Select an input attenuation.

Dual-phase demodulator

Moku Lock-in Amplifier features a dual-phase demodulator with cascaded single-pole lowpass filters to attenuate the second harmonic and suppress noise in the in-phase and quadrature components.

① Select between **6, 12, 18, or 24 dB/octave** lowpass filter slopes.

② Select between **rectangular (X/Y)** and **polar (R/ϕ)** coordinate modes.

③ View the demodulated in-phase and quadrature signals prior to the lowpass filters using probe points.

④ Select which demodulated signal to route to the output. Note: your options depend on how the Lock-in Amplifier is configured.

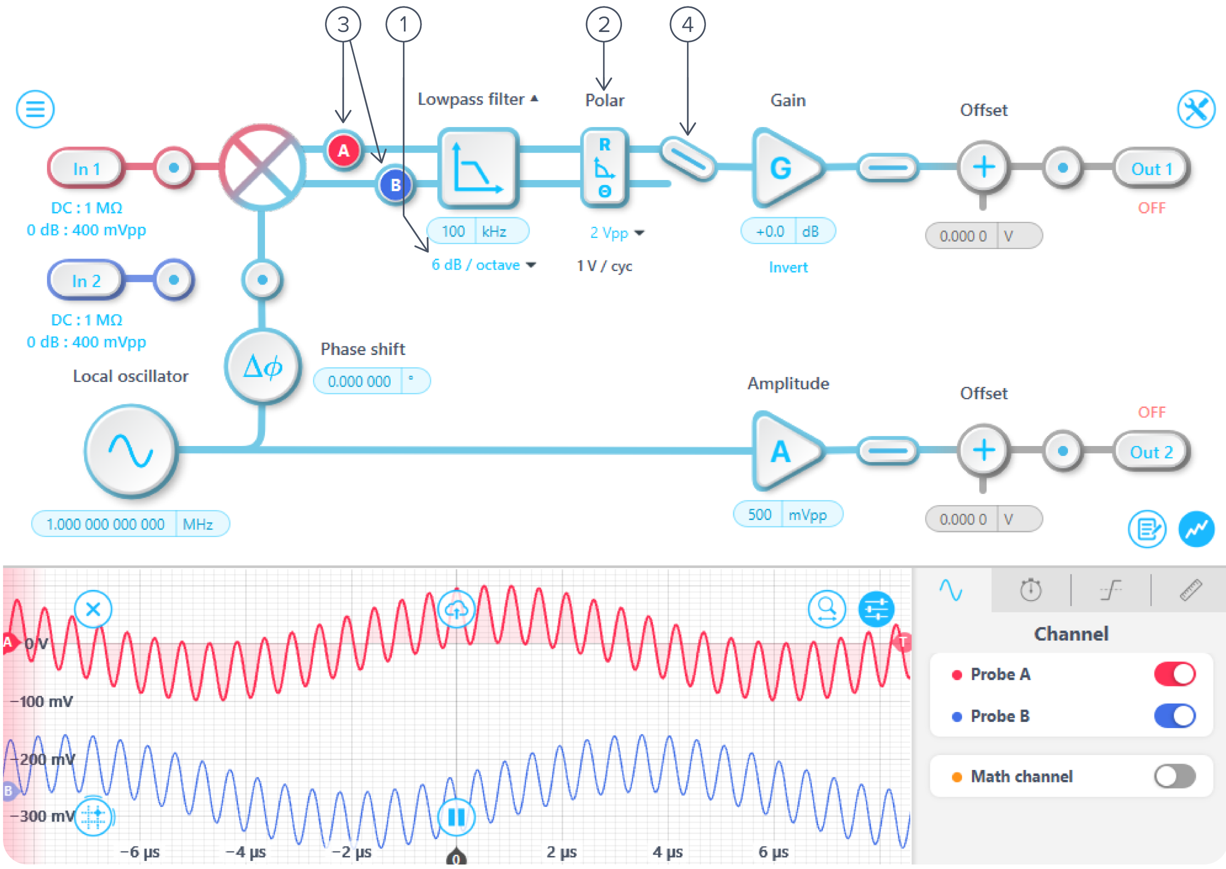


Figure 8. Block diagram (top) and embedded Oscilloscope (bottom) of the dual-phase demodulator configuration.

Rectangular (or Cartesian) coordinate mode measures the input signal with respect to a specific quadrature of the reference signal. This can be used to decode amplitude and phase components of the signal separately when using an external local oscillator directly, for example, when modulating and demodulating QAM, QPSK, and other schemes.

Polar coordinate mode measures the amplitude and phase of the input signal with respect to the reference signal. Polar mode is not available when using the external dual-phase demodulator.

Reference signal

The reference signal for demodulating the input signal can be changed in the demodulation source from the configuration menu . The available demodulation sources are "Internal", "External", "External (PLL)" or "None".

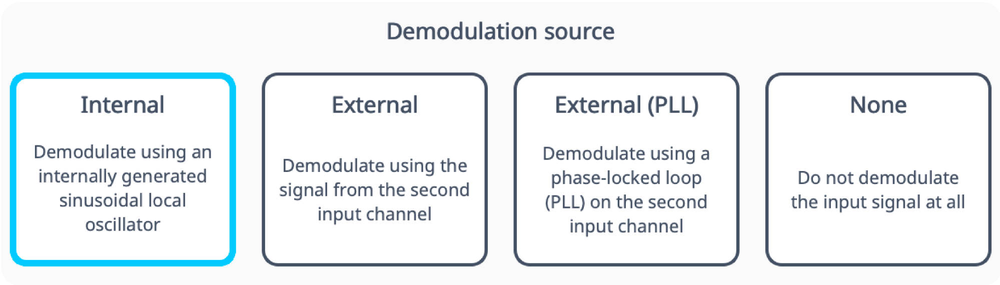


Figure 9. Demodulation Source options

Internal

The "Internal" option allows the use of the local oscillator that is generated internally. This oscillator utilizes the same timebase as the clock reference.

Note: Moku devices with an external clock reference port can be synchronized with an externally connected device. This will lock the clock of your Moku to the external reference which will also be used as the demodulation source reference, read more about the External reference.

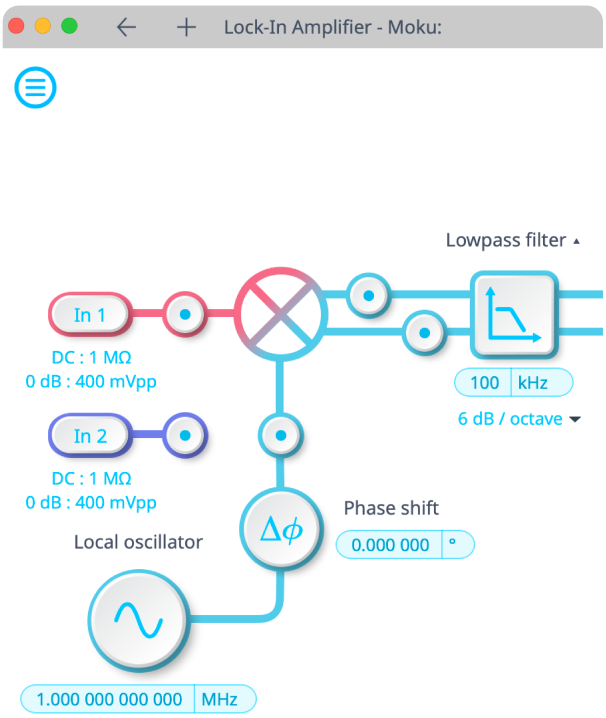


Figure 10. Internal reference signal user interface with the local oscillator passed straight to the mixer.

External (direct)

The "External" option allows the second input channel to be used as the reference oscillator. This also allows non-sinusoidal references to be used as the demodulation source, and can be used to measure correlation or recover specific components of complex input signals. As the external signal can be an arbitrary shape, it cannot be used to perform dual-phase demodulation, it can only interrogate one quadrature, X.

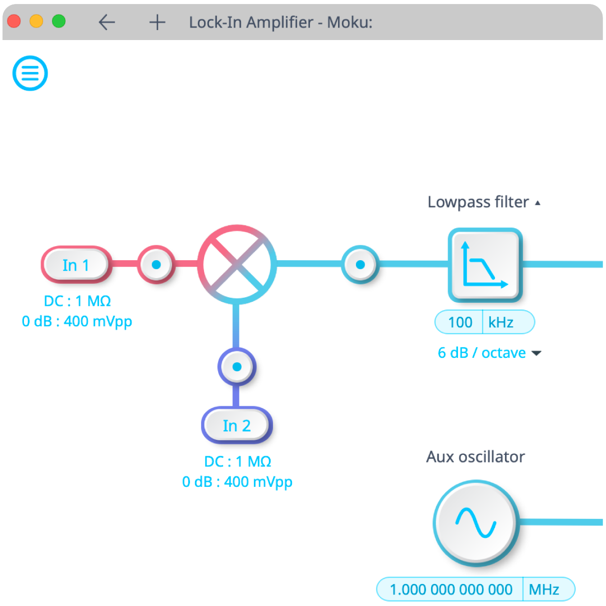


Figure 11. External reference signal user interface with the second input (In 2) used as a reference oscillator.

External (PLL)

The "External (PLL)" option allows the second input channel to be used as the reference oscillator for dual-phase demodulation. The option uses a digitally implemented phase-locked loop (PLL) to track the phase of the external reference with a user-selectable bandwidth. The PLL allows the instrument to generate synchronized in-phase and quadrature sinusoids at the same frequency, with adjustable phase and frequency multipliers. This mode enables the Lock-in Amplifier to recover both quadrature signals without sharing the same timebase as the external signal.

The user can specify a frequency to lock on to, or the device can automatically lock to the strongest component present in the external reference by using "Auto" mode. Use the "Reacquire" button to re-lock to the external reference. The multiplier in the PLL allows you to use a harmonic of the externally frequency. The multiplier can range from $0.125\times$ to $250\times$ of the tracked frequency, in steps of 0.125 (within the output bandwidth of your Moku).

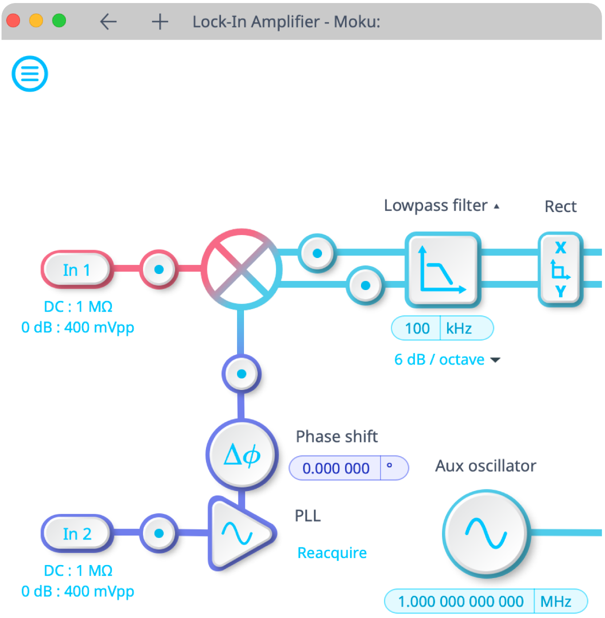


Figure 12. Block diagram of the External (PLL) reference signal.

None

The "None" option can be used to bypass the mixing operation, passing the signal directly to the lowpass filter. This is useful if the necessary signal extraction is done on an external system or another instrument in Multi-Instrument Mode, and enables modulation-free locking techniques such as DC locking, side-of-fringe locking, and tilt locking.

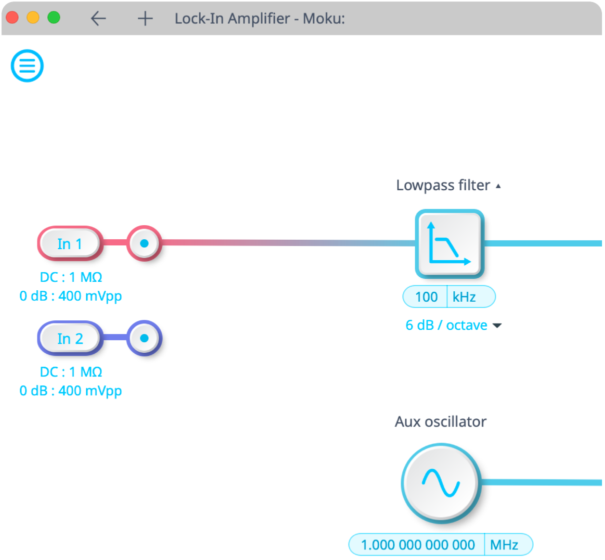


Figure 13. None reference signal user interface, passing the signal directly to the lowpass filter.

Lowpass filter

After the mixer, a filter can be used to remove the unwanted high-frequency components. The lowpass filter is made up of cascaded filters in the Lock-in Amplifier, which behave similar to a simple first-order RC filter. Increasing the order of the cascaded single-pole filters increases the "roll off" angle of the slope and improve stop-band rejection, shown in Figure 14 and selected by ① in Figure 15. The lowpass filter is typically characterized by its corner (or cutoff) frequency; the point where the output is attenuated by $3dB$. This can be seen in Figure 14.

The corner (cutoff) frequency of a single-pole lowpass filter is directly related to its time constant, τ, by Equation 2. A larger time constant results in a lower cutoff frequency, providing more smoothing, but a slower response, while a smaller time constant allows for a faster response with less filtering. Adjust this at ③ shown in Figure 15. The Moku Lock-in Amplifier lets users specify the filter in terms of either the time constant or the corner frequency, depending on preference, selected by ② in Figure 15.

$$\tau = \frac{1}{2 \cdot \pi \cdot f_C} \quad (2)$$

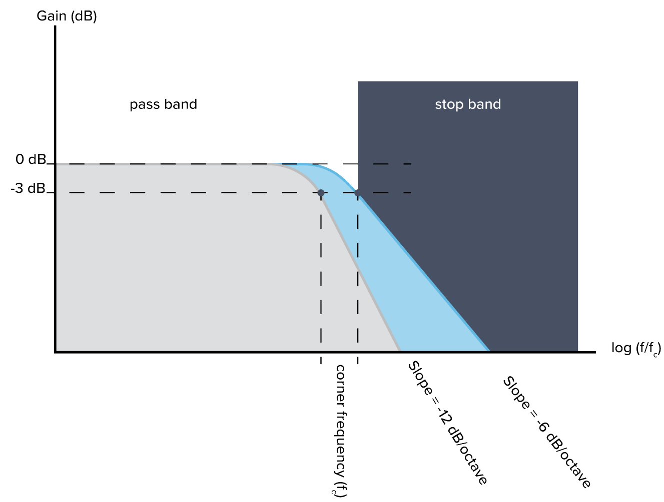


Figure 14. Frequency response of cascaded stages, showing the steeper roll off using a slope of -12 dB/octave.

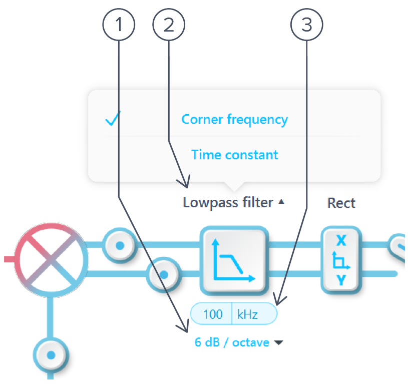


Figure 15. Lowpass filter options in the Lock-in Amplifier, indicating where to (1) select the lowpass filter slope, (2) switch between designing with the "Time constant" and "Corner Frequency", and (3) choose the time constant or cutoff frequency of the filter.

Rectangular-to-polar conversion range

The Lock-in Amplifier's demodulation process produces two orthogonal components, X (in-phase) and Y (quadrature), which together form the Cartesian representation of the signal, or its real and imaginary parts in the complex plane. These components fully describe the demodulated waveform in terms of amplitude and phase, but in some applications it is more intuitive to work in polar coordinates: magnitude (R) and phase angle (ϕ).

When operating in Polar mode, the Lock-in Amplifier performs a mathematical conversion from X/Y to R/ϕ. This conversion requires defining a rect-to-polar conversion range, which sets the largest signal amplitude (R) that can be represented without saturation. The available ranges are 2 V_{pp}, 7.5 mV_{pp}, or 25 μV_{pp}. This range is applied after the IQ mixer stage, so it does not directly correspond to the raw input signal amplitude, but rather the amplitude of the demodulated signal.

For best performance, select the smallest range that still accommodates your signal without clipping. Using a range that is too large, unnecessarily reduces the effective resolution and increases measurement noise. Using too small a range will cause saturation and inaccurate readings.

For example, if the measured signal has an amplitude of 2.5 mVpp after the IQ mixer, the 7.5 mVpp range would be the most suitable range; if a signal has an amplitude of 1 Vpp, the 2 Vpp range would be the ideal range.

In Polar mode, phase is converted to voltage at a fixed scale of 1 V per cycle. For reference, 1 V per cycle corresponds to 2.78 mV per degree, or 159 mV per radian.

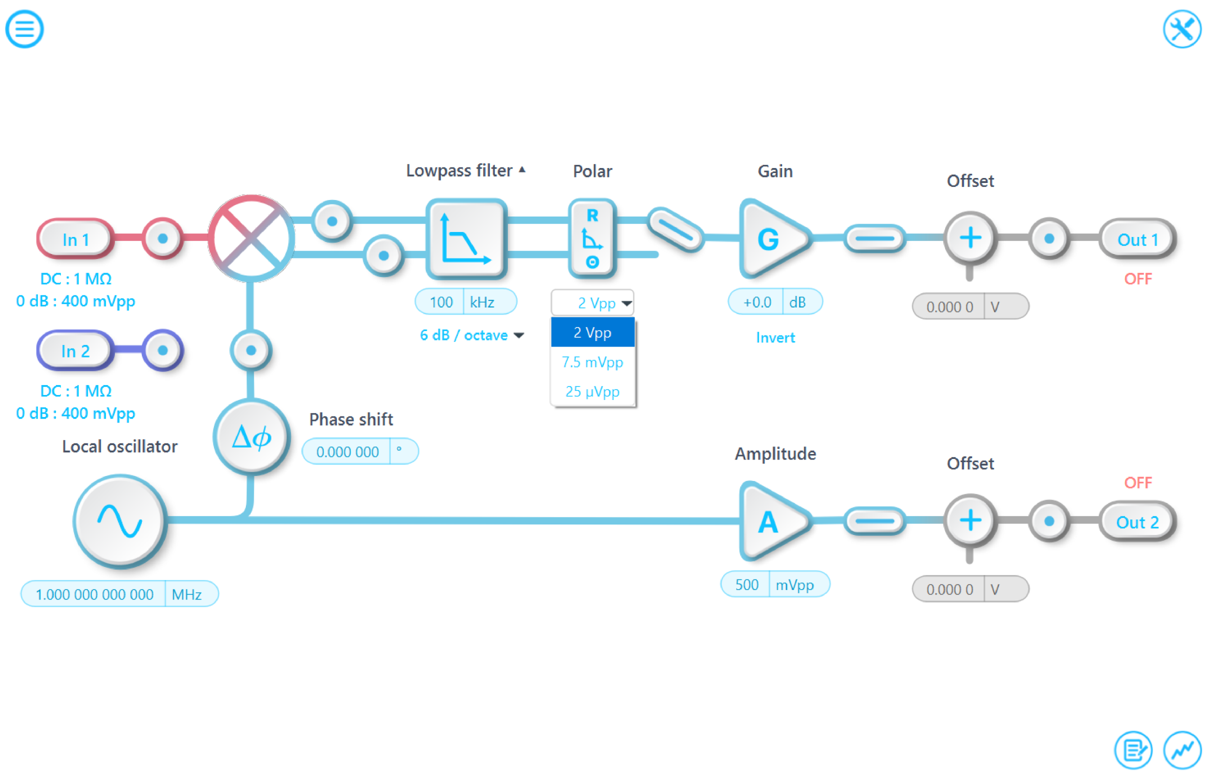


Figure 16. The drop down menu allows you to select the conversion range (2 Vpp, 7.5 mVpp, or 25 µVpp) corresponding to the maximum magnitude R that can be represented without saturation.

Output conditioning

The instrument outputs can be conditioned using gain, attenuation, or voltage offset. The gain block can optionally be replaced with a PID controller for feedback applications. These can be configured on both the main and auxiliary outputs from the configuration menu.

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

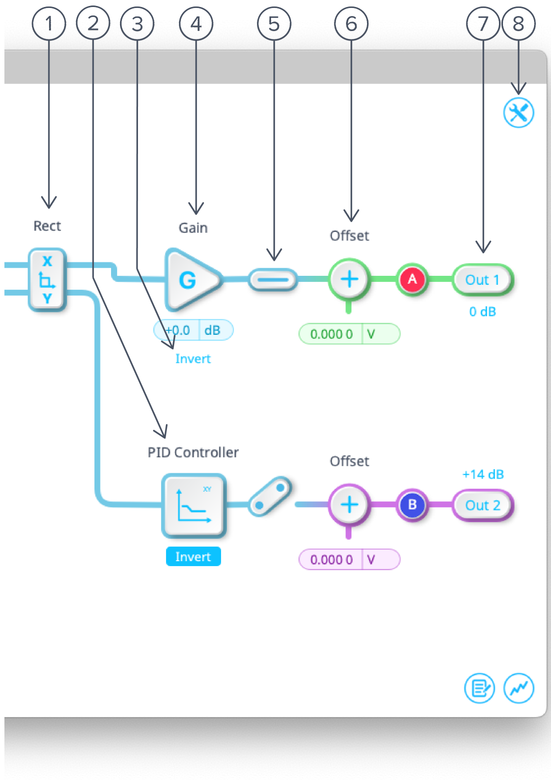


Figure 17. Lock-in Amplifier output conditioning.

① Select Rectangular or Polar coordinate mode.

② Click on the PID Controller to adjust.

③ Optionally, invert the output signal.

④ Adjust the amplitude of the sine wave by applying a gain or attenuation.

⑤ Click to open and close the output to send a 0 V or DC (using the offset) signal.

⑥ Add a voltage offset to your signal output.

⑦ Click to turn on the output, selecting the output gain, if available.

⑧ Open the instrument configuration panel (shown above).

Gain

In general, set the output gain as high as possible without causing saturation. Internally, the Lock-in Amplifier processes signals at a much higher bit depth than the instrument's physical outputs. As long as there's no saturation, applying gain increases the output amplitude and makes better use of the instrument's available resolution. This is illustrated in Figure 18.

When using polar coordinates, choose the smallest rectangular-to-polar conversion range that accommodates your signal to further optimize resolution.

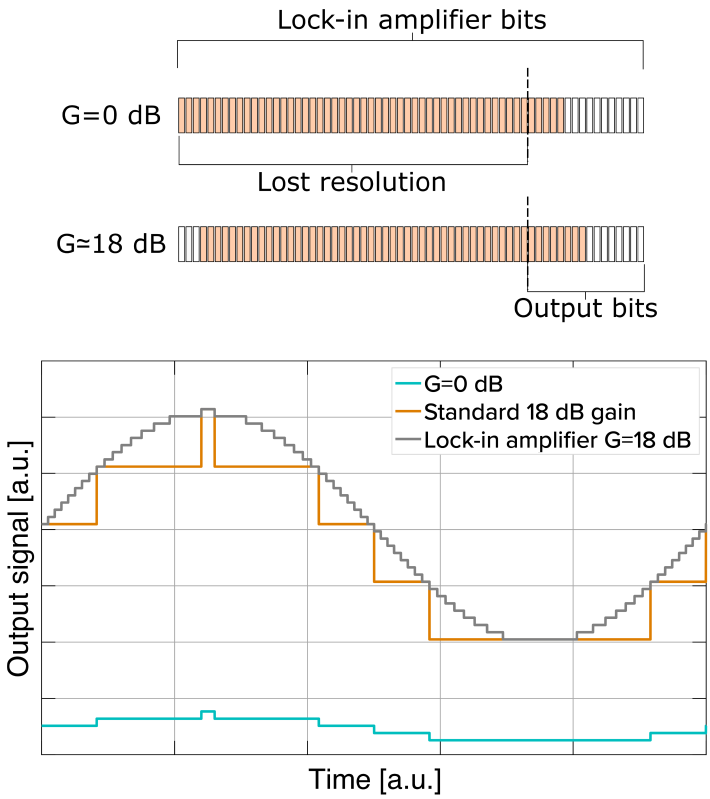


Figure 18. Flat 18 dB gain (orange) versus Lock-in Amplifier with +18 dB gain (gray) block on the output, preserving finer waveform detail.

Auxiliary output

In the Lock-in Amplifier, Output 2 can be configured to be used as an additional auxiliary oscillator signal, output the demodulated signal or output a second filtered signal (e.g. X/R to Output 1 and Y/ϕ to Output 2).

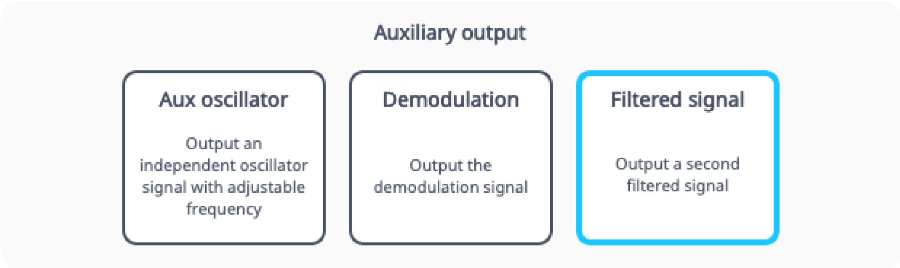


Figure 19. Auxiliary output configuration options.

Aux Oscillator

Use the second output as an extra oscillator. The extra oscillator is an independent generator and can be set at a different frequency to the demodulating frequency.

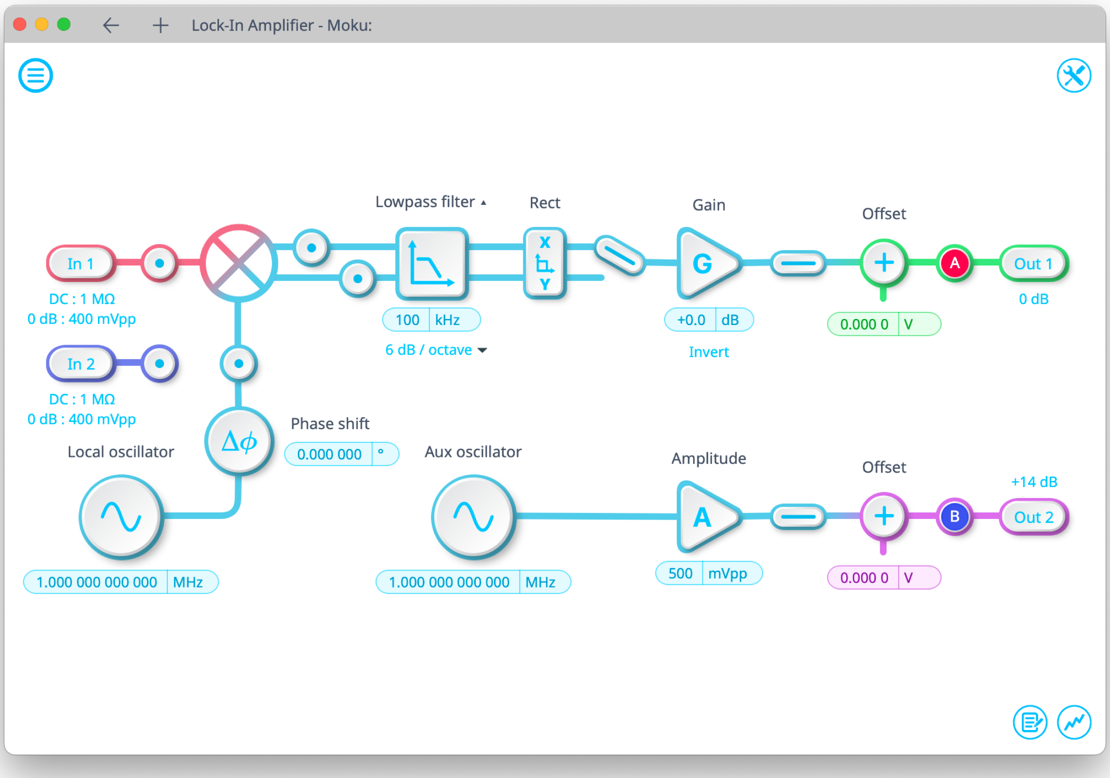


Figure 20. Auxiliary Oscillator attached to the secondary output (Out 2).

Demodulation

Send the local oscillator signal to the second output, ensuring that both the mixing oscillator signal and the generated output operate at the same frequency.

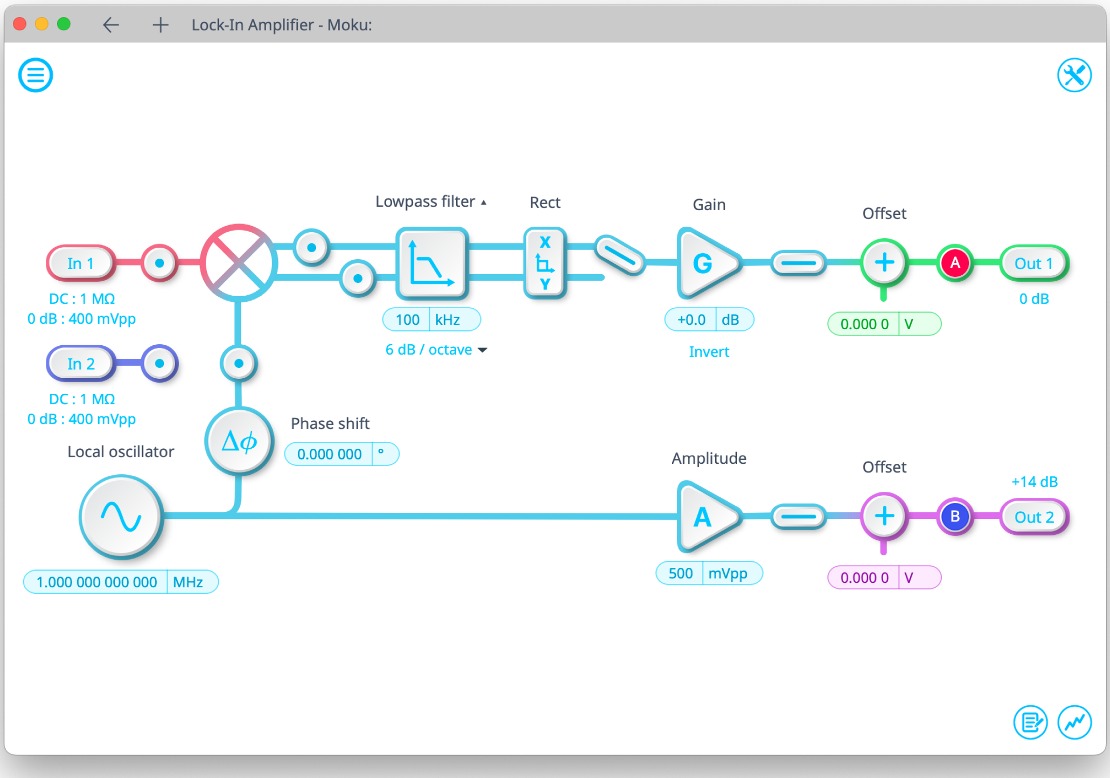


Figure 21. Local oscillator sent to the second output (Out 2).

Filtered Signal

Use the second output to view both components of either the X/Y or R/ϕ signals simultaneously, and record both quadratures for further processing.

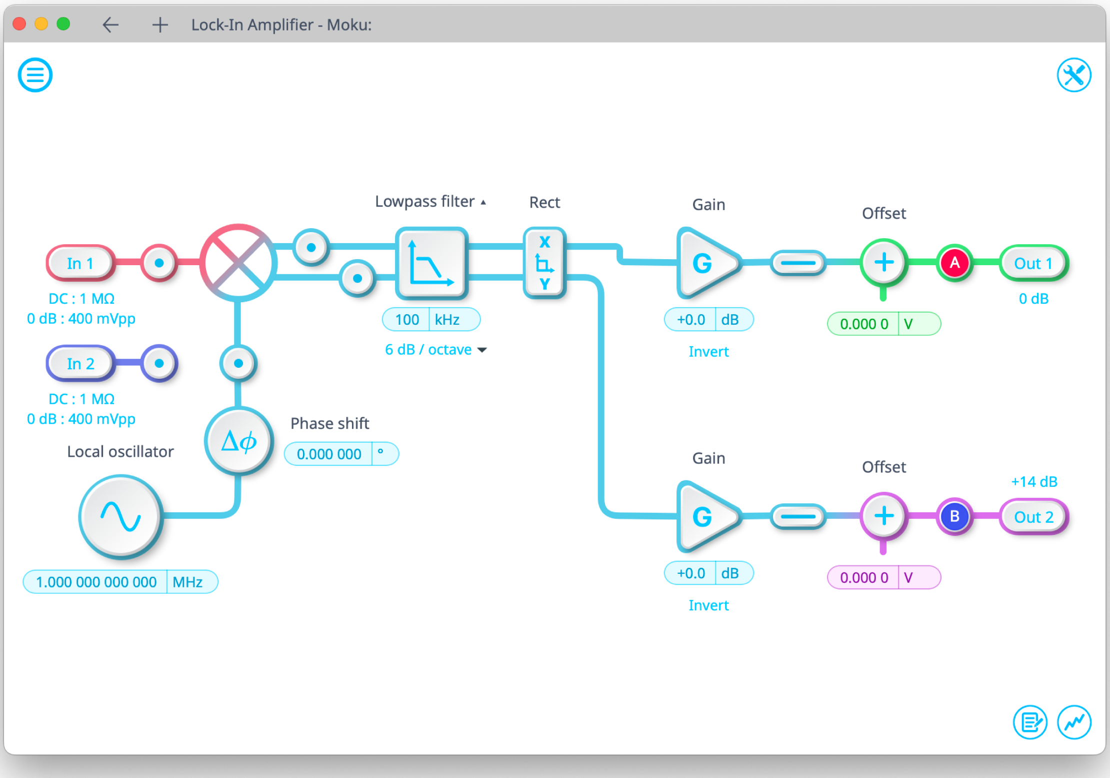


Figure 22. Filtered signal setup with the Y signal attached to the secondary output (Out 2).

PID controller

The Lock-in Amplifier can be incorporated into a feedback system by providing both the sensor and controller stages within a single instrument. The controller stage uses a configurable PID controller to meet your system's stability requirements.

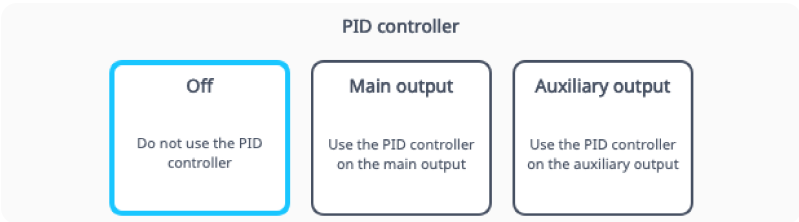


Figure 23. PID controller configuration options.

The PID controller provides full control over proportional, integral, and derivative gain profiles with saturation levels available for the integral and derivative controllers. Changing the parameters in the PID Controller updates the transfer function in real-time.

The gain of each control path can be adjusted individually. The following example shows a proportional-integral (PI) controller with a unity gain crossover frequency at 3.1 kHz. The overall gain control on the left allows you to scale all paths together, increasing or decreasing the controller's strength while keeping the crossover frequency fixed. Find more details about the PID controller in the PID Controller user manual.

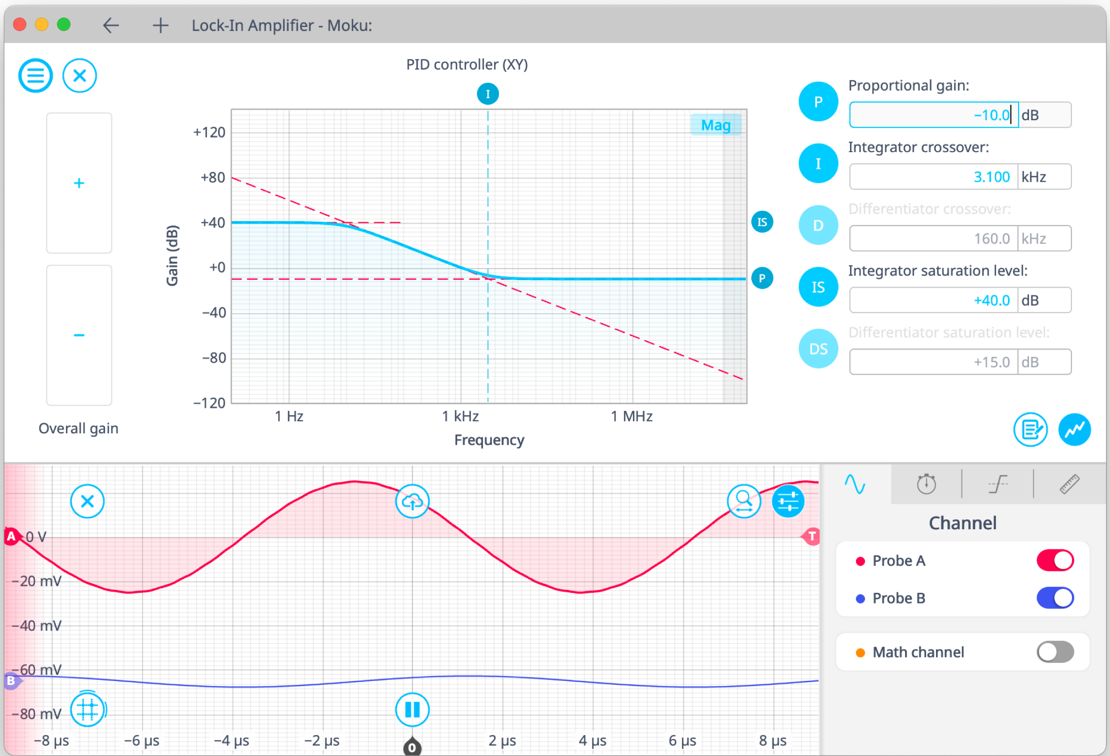


Figure 24. PID controller settings editor, implementing a proportional-integral (PI) controller with a unity gain crossover frequency at 3.1 kHz.

Note: The Lock-in Amplifier can only implement a single PID Controller at a time. This means that when you configure the instrument's Auxiliary output to generate a voltage signal proportional to the Y or ϕ, the PID Controller can be used on either X/R or Y/ϕ, but not both. This can be selected from the instrument configuration menu.

Probe points

The Moku Lock-in Amplifier has an integrated Oscilloscope and Data Logger that can probe the signal at various stages of the demodulation process. Select the probe points by tapping the icon, in the block diagram. Add up to four probe points to monitor or log data, depending on your device hardware.

Embedded Oscilloscope

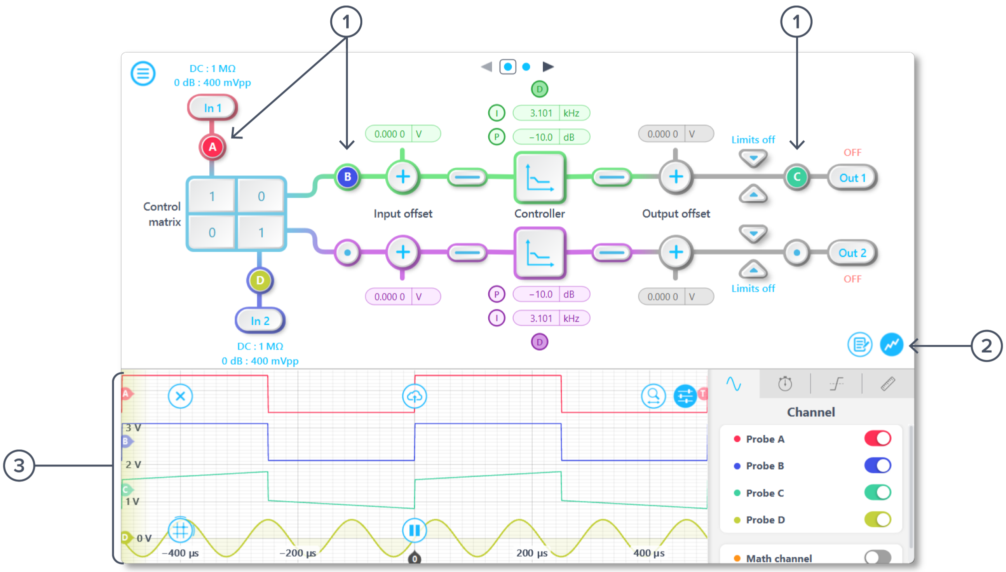


Figure 25. Probe point signals viewed in the embedded Oscilloscope.

ID	Parameter	Description
①	Probe points	Click to place the probe point, the number available is device dependent.
②	Open embedded Oscilloscope and Data Logger	Open and close the embedded Oscilloscope and Data Logger.
③	Oscilloscope	Refer to the Oscilloscope user manual for the details.

Embedded Data Logger

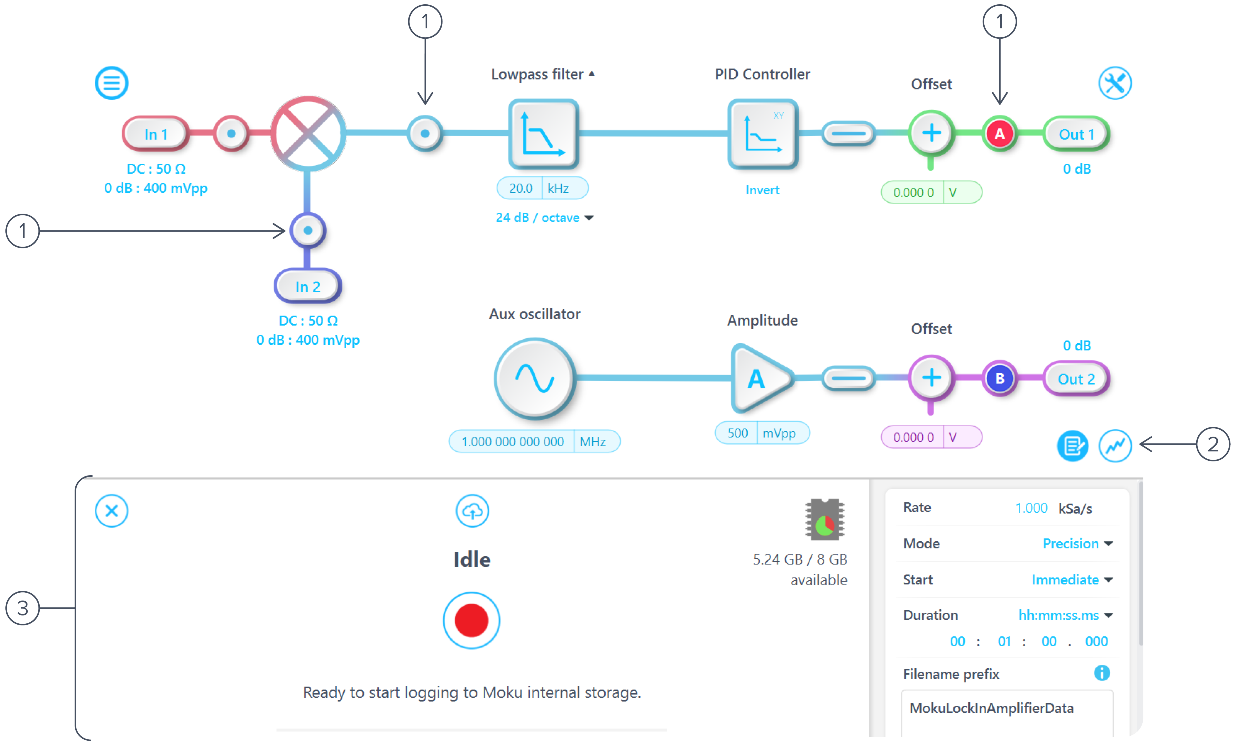


Figure 26. Embedded Data Logger in the Lock-in Amplifier.

ID	Parameter	Description
1	Probe points	Click to place the probe point, the number available is device dependent.
2	Open the embedded Oscilloscope or Data Logger	Open and close the embedded Oscilloscope and Data Logger.
3	Data Logger	Refer to the Data Logger user manual for the details.

The embedded Data Logger can stream over a network or save data to the onboard storage of your Moku. For details, refer to the Data Logger user manual. More streaming information is in our API Reference.

Share data

Export data by clicking the share icon. Any active probe points will be captured in the live data export or logging. Open the embedded Oscilloscope or Data Logger to export live and logged data, respectively.

Logged data

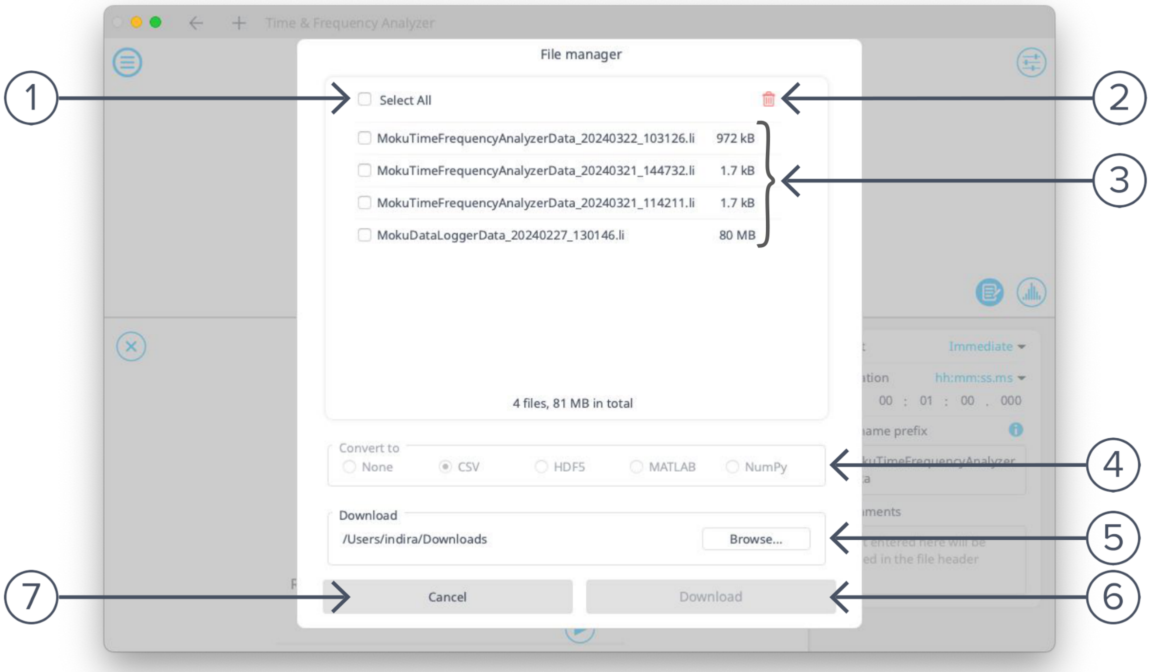


Figure 27. File exporting User Interface and settings.

To save logged data:

① **Select all** files logged to the device's memory, to download or convert.

② **Delete** the selected file/s.

③ Browse and **select file/s** to download or convert.

④ Select an optional **file conversion format**.

⑤ Select a **location** to export your selected files to.

⑥ **Export** the data.

⑦ **Close** the export data window, without exporting.

Lock-in Amplifier examples

Weak signal detection

Use the Lock-in Amplifier to measure the amplitude and phase of a low-SNR, phase modulated 1 MHz signal. In this example, the signal is phase modulated at a steady 5 Hz. The narrow bandwidth provides better noise rejection without attenuating any frequency components of the signal itself.

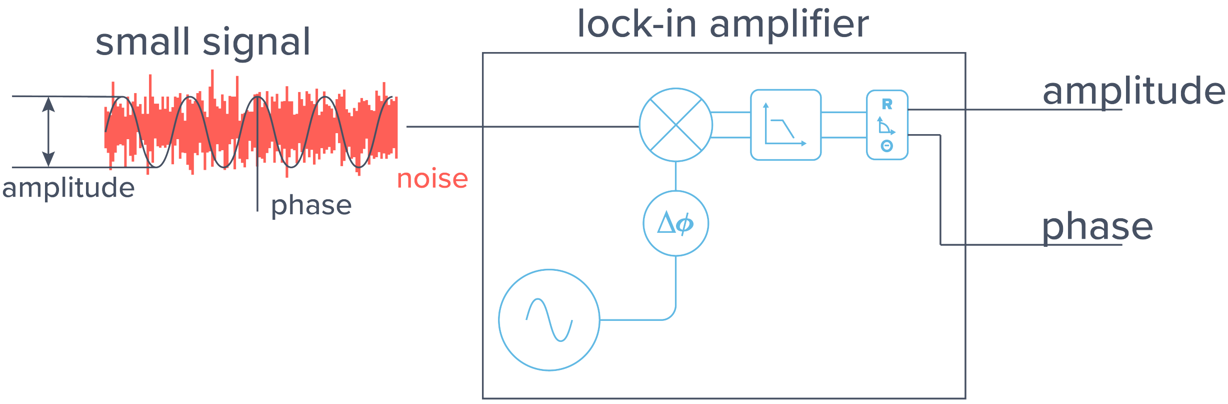


Figure 28. Weak signal detection using a Lock-in amplifier.

Set up your Lock-in Amplifier as shown below:

- **Step 1:** Select the Lock-in Amplifier configuration
  - Click the icon to configure your Lock-in setup. Select "Internal" as the demodulation source, "Filtered Signal" as the the Auxiliary output and set the PID controller to "OFF".
- **Step 2:** Configure the analog front end settings for the signal inputs
  - In this case both inputs have a 50 Ω input impedance to match its source, 0 dB attenuation and use DC coupling.
- **Step 3:** Configure the local oscillator
  - Set the frequency of the local oscillator to 1 MHz to match the input signal.
- **Step 4:** Configure the lowpass filter
  - Set the filter bandwidth to 110 Hz with a 18 dB/Octave slope.
- **Step 5:** Configure the polar coordinates
  - Change the output from X/Y mode to R/ϕ mode and adjust the rect-to-polar conversion range. Optimal performance is achieved by choosing the smallest range which can accommodate your signal without saturating. In this example, the optimal conversion range settings should be 7.5 mVpp.
- **Step 7:** View the signal phase and magnitudes
  - Select the probe points next to Outputs A and B to view the demodulated signals for R (magnitude) and ϕ (phase).

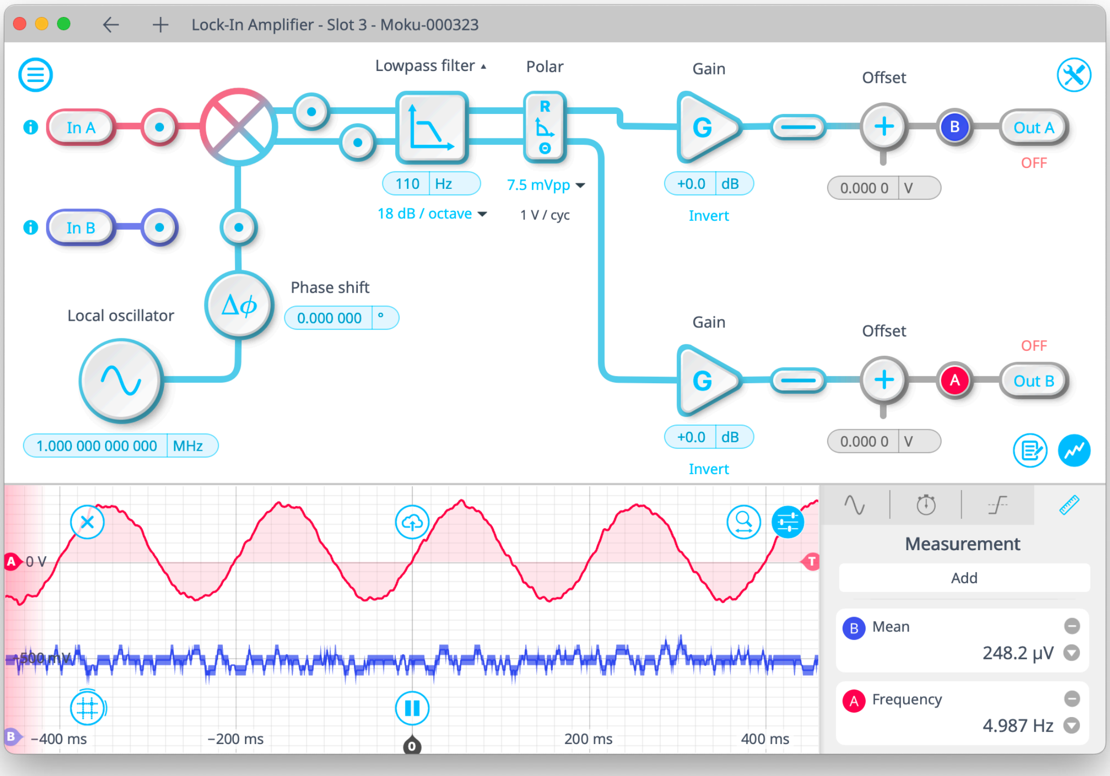


Figure 29. Screenshot of the Lock-in Amplifier setup for small signal detection.

Multi-frequency lock-in detection

To perform multiple-frequency lock-in detection, use the Moku Lock-in Amplifier in Multi-Instrument Mode. In this example, Moku will demodulate three different frequencies and display the outputs in the Oscilloscope.

Multi-Instrument Mode lets multiple instruments run entirely within the FPGA, keeping signals in the digital domain. This allows high data rates and ultra-low latency without the SNR degradation that can occur with analog-to-digital or digital-to-analog conversions in separate hardware.

The signals of interest are a 50 kHz fundamental and its harmonics at 150 kHz (3rd harmonic) and 250 kHz (5th harmonic). Connect the measured signal to Input 1 and the stable 50 kHz reference to Input 2. The built-in phase-locked loop (PLL) tracks the phase and frequency of the 50 kHz component and generates two phase-locked, orthogonal sinusoids for dual-phase demodulation.

Set up your Moku in Multi-Instrument Mode as shown below

- **Step 1:** Configure the slots
  - Place a Lock-in Amplifier in Slots 1, 2 and 3, and an Oscilloscope in Slot 4.
- **Step 2:** Connect the slot inputs and outputs
  - Connect In 1 to Input A of Slots 1, 2, 3 and Input D of Slot 4.
  - Connect In 2 to Input B of Slots 1, 2 and 3.
  - Send the Output A of Slot 1 to Bus 1 and the Output A of Slot 2 to Bus 2.
  - For the Oscilloscope in Slot 4, send Bus 1 to Input A, Bus 2 to Input B and In 1 to Input D. Finally, send the Output A from Slot 3 to Input C.

- **Step 3:** Configure the analog front end settings for the signal inputs
  - Set the analog front end settings for the input. In this case all inputs have a 50 Ω input impedance to match its source, 0 dB attenuation and DC coupling.
- **Step 4:** Apply changes and sync
  - Press [Apply Changes] to apply these changes and synchronize the instrument clocks by clicking "Sync instrument slots" in the main menu.

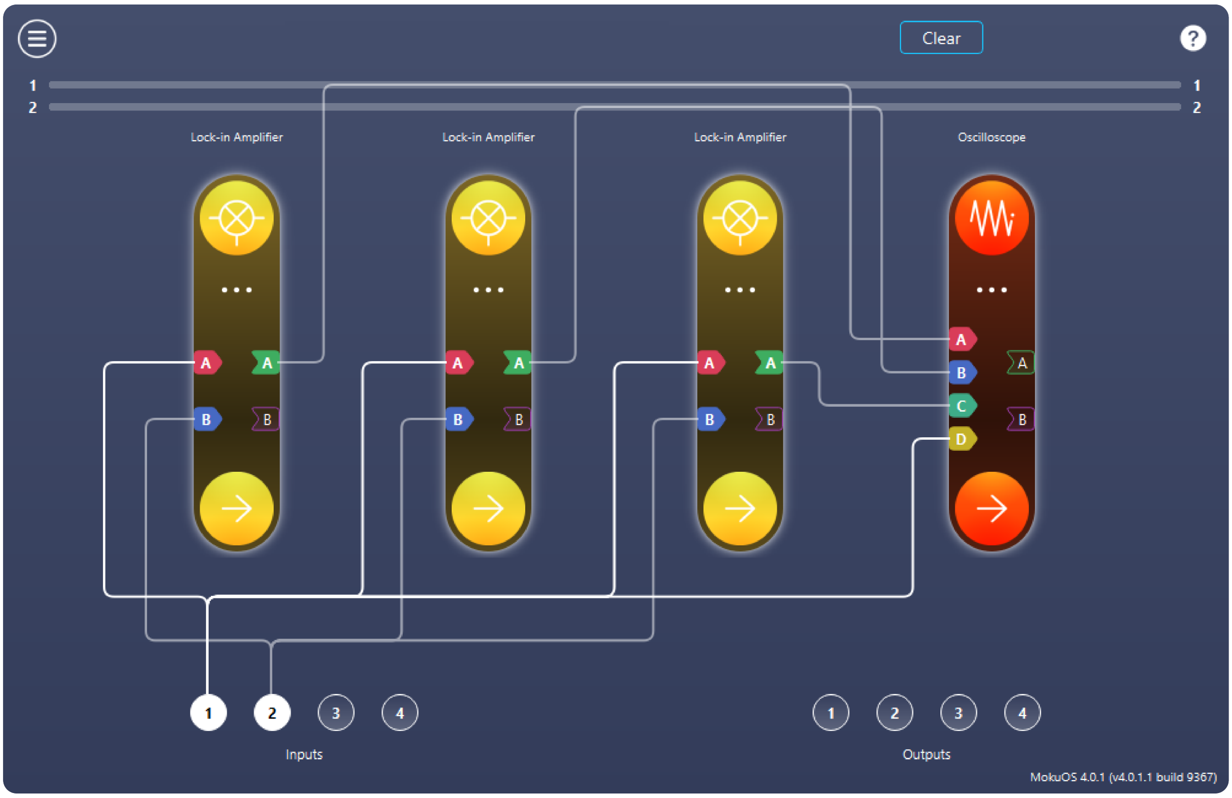


Figure 30. Multi-Instrument Mode setup for multi-frequency detection.

Setup your Lock-in Amplifiers (in slot 1, 2 and 3) as shown in Figure 31:

- **Step 1:** Select the Lock-in Amplifier configuration
  - Configure your Lock-in setup from the button icon. Select the "External (PLL)" demodulation source, "Filtered signal" as the Auxillary output and "OFF" for the PID controller.
- **Step 2:** Configure the PLL
  - Configure the PLLs all with a bandwidth to 100 Hz.
  - Configure each of the Lock-in Amplifiers to demodulate at harmonics of 50 kHz. Set the PLL frequency to 50 kHz for all Lock-in Amplifiers, and set the multiplier of each to 1x, 3x, and 5x, respectively.
- **Step 3:** Configure the lowpass filter
  - Set the filter bandwidth to 200 Hz with a 12 dB/octave slope. In this measurement, a relatively steady sinusoidal output is expected from the source, so a narrow bandwidth is used, to provide better noise rejection without rejecting any high-frequency components of the signal itself.
- **Step 4:** Configure the Lock-in Amplifier output gain
  - Increase the output gain so the output of the 1st harmonic has an amplitude of a few hundred millivolts. In this example +60 dB was added to reach this. Enable the probe points

for the X/Y output to view the signal. You can press the icon to view measurements, e.g. for the mean of each signal.

- **Step 5:** Adjust the phase shift of the PLL
  - The reference signal and the actual signal might have a significant phase difference. If the absolute phase shift is measured, it is important to align the phase of the LO and signal. The phase shift of the PLL is adjusted to make the Y component as small as possible, aligning the phase between the LO and the signal.
- **Step 6:** Adjust polar-to-rect conversion range
  - Change the output from X/Y mode to R/ϕ mode and adjust the rect-to-polar conversion range. Optimal performance is achieved by choosing the smallest range which can accommodate your signal without saturating. Based on the X/Y mode, the output amplitude is expected to be around 1 V. In this example, the optimal conversion range settings should be 2 Vpp.
- **Step 7:** Condition the output signal
  - Turn on Output A by clicking on it. Gain and offset can be left at 0 dB and 0 V.
- **Step 8:** View the signal phase and magnitudes
  - At any time during the setup of your Lock-in amplifiers you can click on a probe point to view and troubleshoot your signals.
  - View all of the signals side-by-side in the Oscilloscope, as shown in Figure 32. Measurements can be added from the settings menu .

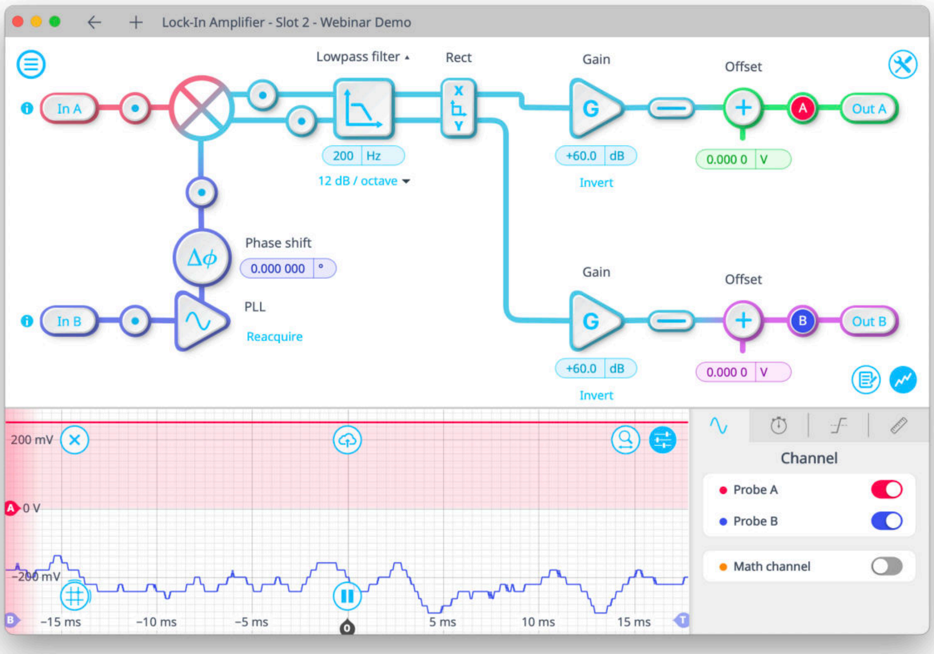


Figure 31. Screenshot of the Lock-in Amplifier setup to demodulate each harmonic of the 50 kHz square wave of interest, shown is the demodulation of the 3rd harmonic.

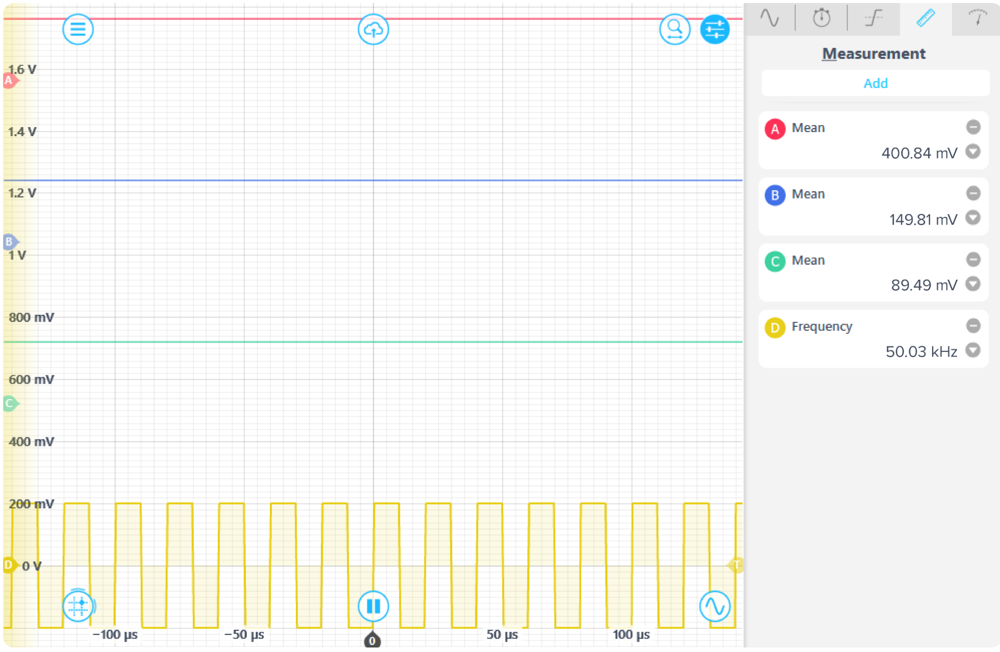
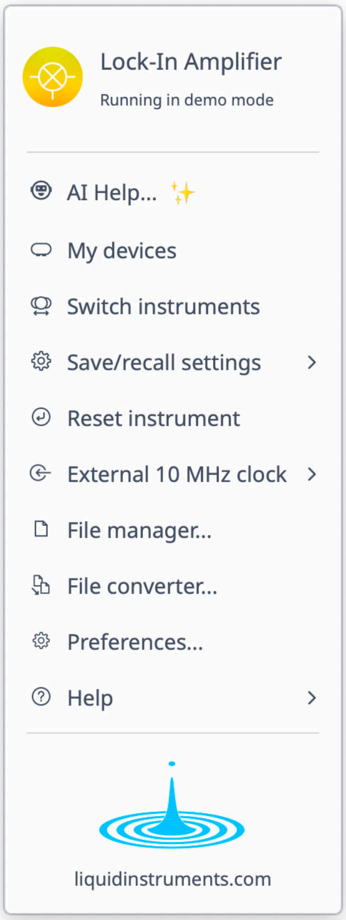


Figure 32. Screenshot of the Oscilloscope setup to view the detection results together. Channel A corresponding to a 400.84 mV 1st harmonic at 50 kHz, Channel B corresponding to the 3rd harmonic at 150 kHz with a magnitude of 149.81 mV, and Channel C corresponding to the 5th harmonic at 250 kHz with a magnitude of 89.49 mV. Channel D shows the original signal that was demodulated.

Additional tools

Main menu

The main menu can be accessed by clicking the icon on the top-left corner.



AI Help... Opens a window to chat to an AI trained to provide Moku-specific help (Ctrl/Cmd+F1)
My Devices returns to device selection screen
Switch instrument to another instrument
Save/recall settings

- Save current instrument state (Ctrl/Cmd+S)
- Load last saved instrument state (Ctrl/Cmd+O)
- Show the current instrument settings, with the option to export the settings

Reset instrument to its default state (Ctrl/Cmd+R)
Sync Instrument slots in Multi-Instrument Mode*
External 10 MHz clock selection determines whether the internal 10 MHz clock is used.
Clock blending configuration opens the clock blending configuration pop-up *
Power Supply access panel*
File Manager access tool
File Converter access tool
Preferences access tool
* If available using the current settings or device.

Help

- **Liquid Instruments website** opens in default browser
- **Shortcuts list** (Crtl/Cmd+H)
- **Manual** Open the user manual in your default browser (F1)
- **Report an issue** to the Liquid Instruments team
- **Privacy Policy** opens in default browser
- **Export diagnostics** exports a diagnostics file you can send to the Liquid Instruments team for support
- **About** Show app version, check for updates or licence information

File converter

The File converter can be accessed from the main menu .

The File converter converts a Moku binary (.li) format on the local computer to either .csv, .mat, .hdf5 or .npy format. The converted file is saved in the same folder as the original file.

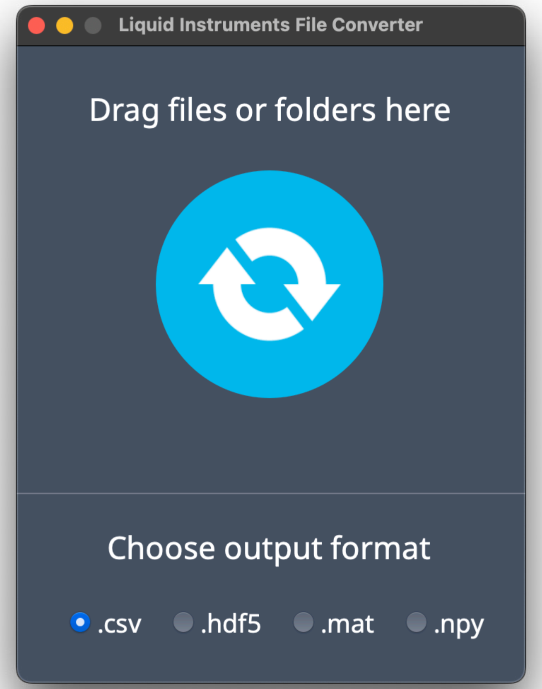


Figure 32: File Converter user interface.

To convert a file:

1. Select a file type.
2. Open a file (Ctrl/Cmd+O) or folder (Ctrl/Cmd+Shift+O) or drag and drop into the File converter to convert the file.

Preferences and settings

The preferences panel can be accessed via the Main Menu . In here, you can reassign the color representations for each channel, switch between light and dark mode, etc. Throughout the manual, the default colors are used to present instrument features.

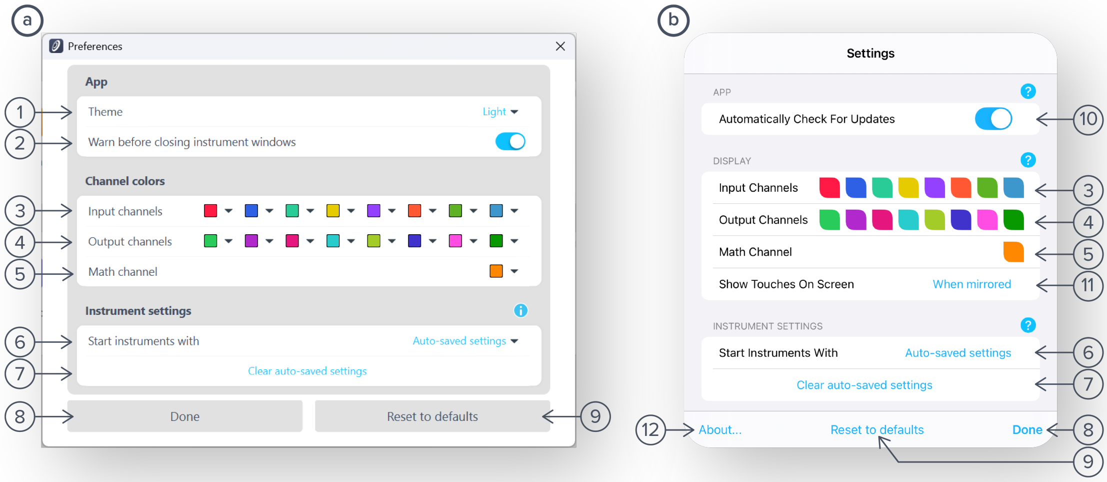


Figure 33. Preferences and settings for the Desktop (a) and for the iPad (b) App.

① Change the App theme, between dark and light mode.
② Choose if a warning opens before closing any instrument windows.
③ Tap to change the color associated with the input channels.
④ Tap to change the color associated with the output channels.
⑤ Tap to change the color associated with the math channel.
⑥ Select if instruments open with the last used settings, or default values each time.
⑦ Clear all auto-saved settings and reset them to their defaults.
⑧ Save and apply settings.
⑨ Reset all application preferences to their default state.
⑩ Notify when a new version of the app is available. Your device must be connected to the internet to check for updates.
⑪ Indicate touch points on the screen with circles. This can be useful for demonstrations.
⑫ Open information about the installed Moku application and license.

External reference clock

Your Moku may support the use of an external reference clock, which allows Moku to synchronize with multiple Moku devices, other lab equipment, lock to a more stable timing reference, or integrate with laboratory standards. The reference clock input and output are on the rear panel of the device. Each external reference option is hardware dependent, review the available external reference options for your Moku.

Reference Input: Accepts a clock signal from an external source, such as another Moku, a laboratory frequency standard, or an atomic reference (for example, a rubidium clock or a GPS-disciplined oscillator).

Reference Output: Supplies the Moku internal reference clock to other equipment that require synchronization.

If your signal is lost, or is out of frequency, your Moku will revert to using its own internal clock until the reference signal returns. If this occurs, check the source is enabled, and that the correct impedance, amplitude, tolerance, frequency, and modulation are attached to the reference. Check the required specifications in the device specsheets.

When the reference returns within range, status changes to "validating" and then "valid" once lock is re-established.

10 MHz external reference

To use the 10 MHz external reference function, ensure "always use internal" is disabled in the Moku application, found in the main menu under "External 10 MHz clock". Then, when an external signal is applied to your Moku reference input and your Moku has locked to it, a pop up will show in the app. On some devices, the external reference information will be shown in the LED status as well, more information can be found in your Moku Quick Start Guide.

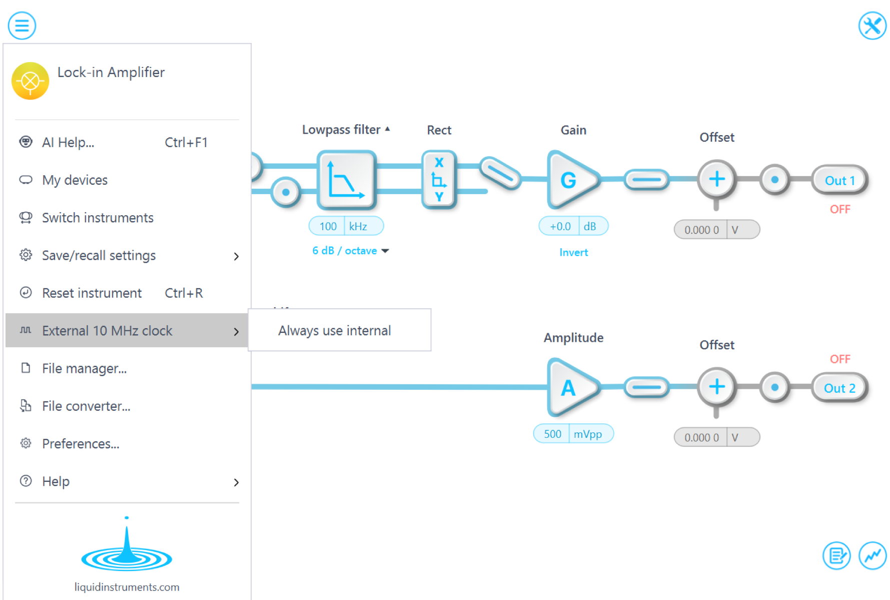


Figure 34. Moku main menu with "Always use internal" reference disabled and using an external reference.

Clock blending configuration

If available, Moku blends up to four clock sources simultaneously for more accurate phase, frequency, and interval measurements across all time scales. A low phase-noise Voltage-Controlled Crystal Oscillator (VCXO) is blended with a 1 ppb Oven-Controlled Crystal Oscillator (OCXO) for optimal wide-band phase noise and stability, which can be blended further with an external frequency reference and GPS disciplining to synchronize Moku with your lab and UTC.

The VCXO and OCXO will always be used for the clock generation signal. The external and 1 pps references are optional and can be enabled or disabled in the “Clock blending configuration...” settings from the main menu ☰. The loop bands are adjusted based on the different possible clock source configurations, shown in Figure 35, where the frequencies of the bands represent where each oscillator's phase noise dominates.

Read how the clock blending works on Moku:Delta for more details.

Figure 35. Moku clock blending configuration dialog with an external 10 MHz frequency reference and GNSS enabled.

① **VCXO jitter reference** is always used for clock generation, handling high frequency jitter with the lowest noise.

② **OCXO jitter reference** is always used for clock generation, ensuring moderate term stability.

③ **External 10/100 MHz frequency reference** uses a "10 MHz" or "100 MHz" external reference to correct drift in the local oscillator, noting your Moku will have to be restarted after each change between a 10 MHz and 100 MHz source.

④ **1 pps synchronization reference** uses an "External" or "GNSS" reference to sync with UTC and correct drift in the local oscillator. The estimated clock stability is a measure of how much the reference performance deviates relative to the local OCXO/VCXO timebase (as currently blended and, if enabled, steered by the external 10 / 100 MHz External reference).