Moku Frequency Response Analyzer

User Manual

LIQUID INSTRUMENTS

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Introduction

The Moku Frequency Response Analyzer can be used to measure the transfer functions of electrical, mechanical, or optical systems by injecting a swept sine wave into the system and comparing the output voltage to the input voltage. The resulting measurements of the system's magnitude and phase response can help to optimize the closed-loop response of control systems, characterize resonant behavior in nonlinear systems, design filters, or measure the bandwidth of electronic components. 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 the 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 .

For more information on the specifications for each Moku hardware, please refer to our product documentation, where you can find the specifications and the Frequency Response Analyzer datasheets.

Figure 1. Frequency Response Analyzer user interface showing the magnitude plot (top), phase plot (bottom), and settings panel (right).

Quick start guide

In this example, we will characterize a lowpass filter to demonstrate how lowpass filters respond to a sine wave over the frequency spectrum, and how you can measure this behavior with the Moku Frequency Response Analyzer. Further, more detailed, examples may be found in the example section.

Lowpass filter characterization

In this example we characterize the magnitude and phase response of an 11 MHz lowpass filter, driven by the swept sine output of the Moku:Pro Frequency Response Analyzer.

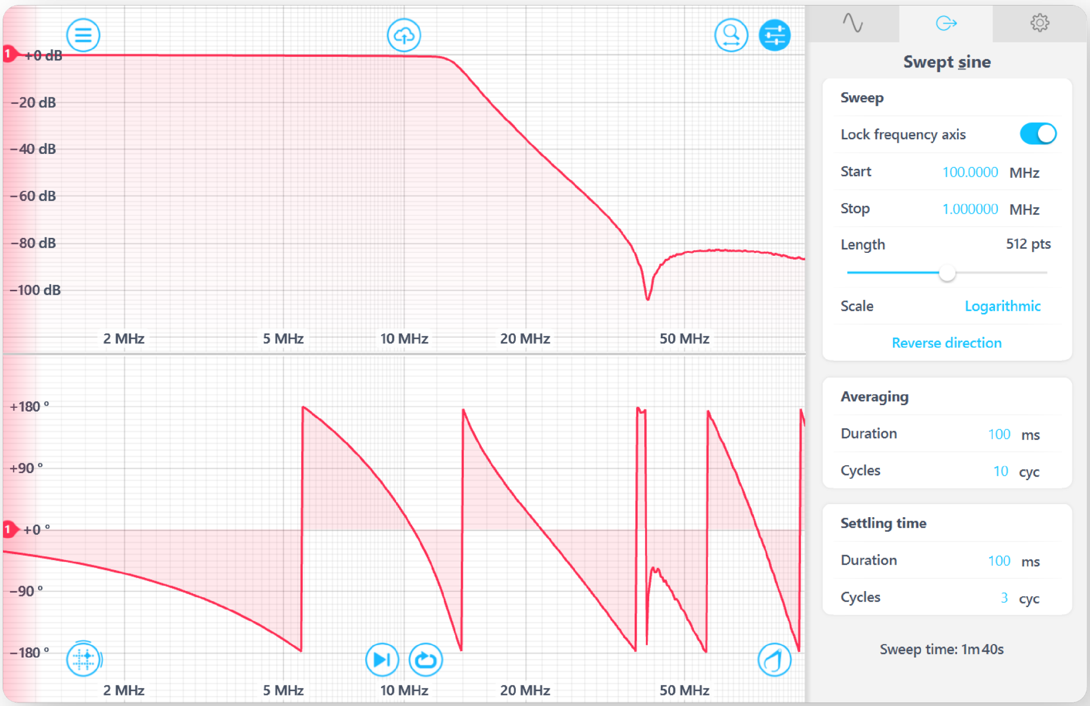

Figure 2. Screenshot of the measured magnitude (top) and phase (bottom) response of the 11 MHz lowpass filter. Magnitude response shows a flat passband, cutoff near 11 MHz, and high stopband attenuation with a transmission zero near 40 MHz. Phase response shows gradual phase lag in the passband, rapid transition near the cutoff frequency, and phase wraps at higher frequencies due to strong attenuation and a transmission zero near 40 MHz.

- **Step 1:** Select the measurement mode
  - Connect Output 1 to the input of the lowpass filter, and connect the filter output to Input 1 of your Moku device.
  - Select In ÷ Out mode, this configuration will compute the magnitude and phase response of the lowpass filter as a ratio of the input to output, across the frequency range.
- **Step 2:** Configure the analog front end and output settings
  - Configure the appropriate analog front end settings: coupling, impedance, range, and bandwidth. In this case the coupling is set to DC to include any offsets. Impedance is set to 50 Ω, to match the filter. The range is set to 400 mVpp to best measure the output amplitude. The bandwidth is set to 300 MHz as the next largest range above our output frequency.

- Configure the analog output settings: amplitude, offset, and output termination. The amplitude is set to 100 mVpp and turned ON using the button. Offset is set to 0 V, and OFF using the button, as there is no offset to compensate for. Output termination is set to 50 Ω, to match the impedance of the filter and input.
- **Step 3:** Set the swept sine output
  - From the Swept sine settings tab, set the sweep to start at 100 MHz and stop at 1 MHz.
  - To get an initial result quickly, set the sweep averaging duration to 1 cycle at 2.0 ms, and the settling time to 1 cycle of 100 µs duration. This will give an indicative result, but is less accurate, as the cycles do not have as much time to settle at each frequency point.
  - Set the length of the sweep to 512 points; this can be increased later for further precision. These settings will give a sweep time of 1.1 seconds, giving indicative sweep results quickly. Points, averaging, and settling time can all be increased for more precise measurements.
  - Select "Logarithmic" scale to see the broad range system response. Linear mode can be selected to view close-up details, if desired.
  - Lock the frequency axis to prevent accidental changes in the sweep range. Double-click on the graph area to autoscale the magnitude and phase response of the filter.
  - For repeated measurements press the repeat button . For a single measurement press the play/pause button .
- **Step 4:** Set up the advanced configurations
  - Enable automatic delay compensation to remove any phase shifts caused by a constant time delay.
  - Select the fundamental harmonic to be viewed; change this later to view subsequent harmonics.
  - Dynamic amplitude and phase differences can all be left at OFF and 0.000 degrees respectively, as they are not needed in this measurement.
- **Step 5:** Refine the measurement
  - To refine the measurement we will increase the settling and averaging settings to a 100 ms averaging duration, for 10 cycles. Set the settling time to 3 cycles with a duration of 100 ms.
  - Press for a single measurement; this pauses acquisition after the sweeps are completed. This can be measured with cursors or exported via screenshot or CSV from the button. See saving and sharing for more export options.
  - Figure 2 shows the 11 MHz lowpass filter with a flat 0 dB passband, steep roll-off beyond its 11 MHz cutoff, and strong stopband attenuation including a deep notch around 40 MHz. The phase response shows gradual phase lag in the passband, rapid transition near the cutoff frequency, and phase wrapping at higher frequencies due to strong attenuation and a transmission zero near 40 MHz.

Principles of operation

The Moku Frequency Response Analyzer measures the phase and magnitude response of a system by applying a swept sine to the system, and demodulating its response across a stepped frequency range.

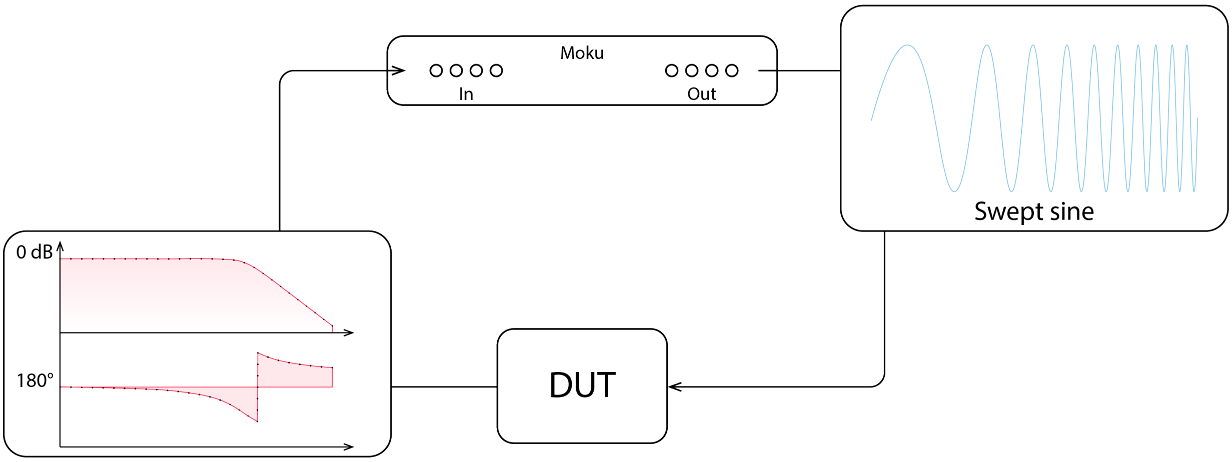

Figure 3. Frequency response measurement using a swept-sine stimulus. The Moku generates a swept sine signal that is applied to the device under test (DUT). The Moku reads the system's magnitude and phase response at each frequency point.

Swept Sine Frequency Response Acquisition

Moku Frequency Response Analyzer uses a swept sine to measure the frequency response of a system. The swept sine acquisition method involves sequentially stimulating a system with sinewaves at discrete frequency intervals over a specified bandwidth, where the bandwidth is divided into N points. Each sinewave frequency is output from the instrument for $S + A$ seconds, where S is the settling time, and A is the averaging time.

This approach gives low phase noise because the system is allowed to reach steady-state before any data is recorded, ensuring that only the stable sinusoidal response contributes to the measurement. By averaging the steady-state portion of the signal, random noise components are reduced, with the coherent response at the swept sine frequency retained. As a result, both magnitude and phase can be extracted with high precision and repeatability. Repeating this process across all frequency points of interest produces an accurate frequency response with high dynamic range and excellent signal-to-noise performance.

Using the instrument

The instrument configuration menu allows you to configure the Frequency Response Analyzer for your measurement, which will vary depending on the characteristics of the system under test. Access the instrument configuration menu by pressing the icon.

Configuring the measurement

Measurement modes

The Moku Frequency Response Analyzer supports three measurement modes, which can be used to measure the transfer function (In ÷ Out), small-signal frequency response (In ÷ In1) or the direct response (Input) of the system.

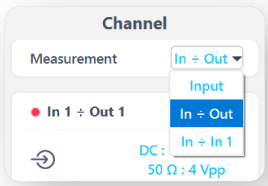

Figure 4. Measurement mode options.

In ÷ Out

In ÷ Out is the most commonly used measurement mode, otherwise known as the transfer function mode, it measures the complex frequency response between a stimulus swept sine signal and a measured response by forming a ratio between the two channels.

$$H(jw) = \frac{\text{Measured input}}{\text{Swept sine output}} \quad (1)$$

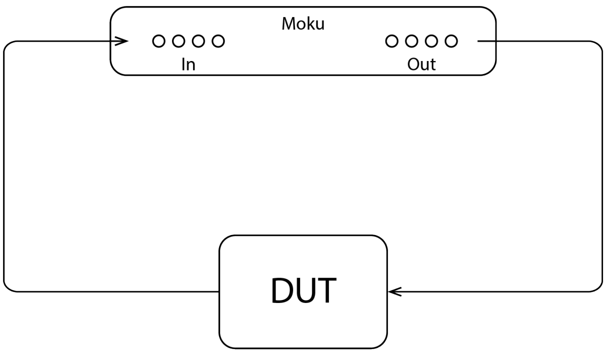

Figure 5. Device setup for In ÷ Out mode, with the Output X attached to the DUT, which is in turn, connected to Input X.

In ÷ Out measures the gain (magnitude) versus frequency, or phase shift at each frequency. This mode provides high immunity to absolute amplitude errors and is the recommended mode for most frequency response measurements.

Best used for the following applications:

- Op-amp closed-loop frequency response
- Amplifier gain and bandwidth
- Filter characterization
- General system frequency response measurement

In ÷ In 1

In ÷ In 1 mode can be used to measure the small-signal frequency response of a feedback loop. This is done by driving the greater system with the swept sine output and measuring the response of the sub-system by measuring the response between two points in the system, as shown in Figure 6.

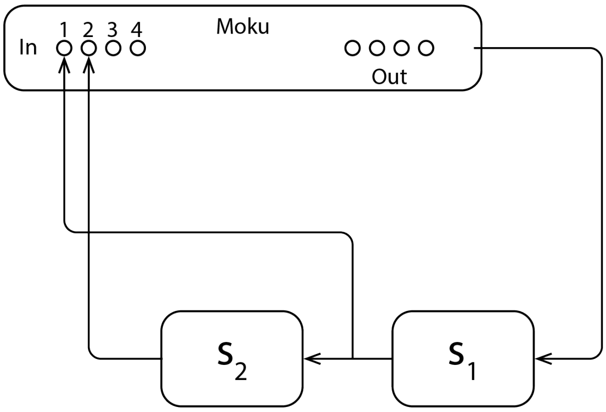

Figure 6. Device setup for In ÷ In 1 mode, with the Output X attached to the beginning of the system. Input 1 is connected to just before the sub-system under test, the output of which is connected to Input 2 to measure the response of s_2.

In ÷ In 1 measures the loop gain magnitude and phase, and can derive stability metrics (gain and phase margin). Only the linearized small-signal AC response is measured, from which gain and phase margin can be calculated. Because the injected signal is small, the measurement only captures the linearized small-signal behavior around the operating point, not large-signal or nonlinear effects, assuming that the system is linear around a fixed bias point. Therefore, In ÷ In 1 mode is best used for the following applications:

- Op-amp stability analysis
- Control loop compensation verification
- Power supply and regulator control loops
- Feedback system design validation

Input

Single-channel response mode measures the absolute magnitude and phase of a single input channel; this is not compared to a reference signal. Typically, the system will be driven by an external reference signal used to generate the stimulus, but it may still be driven by the Frequency Response Analyzer swept sine output.

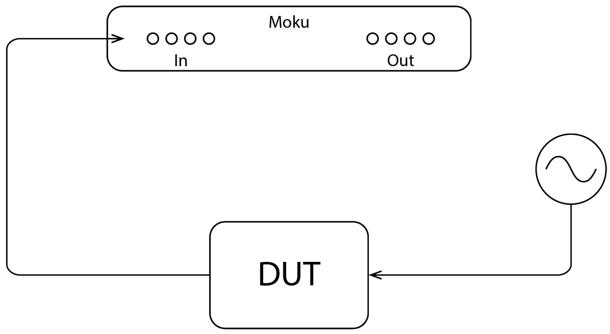

Figure 7. Device setup for Input mode, with an arbitrary voltage source supplying the stimulus, this can be the Moku output or an external source. The output of the DUT is connected to the input of the Moku. The complete magnitude and phase response is shown in the Frequency Response Analyzer, with no difference to the system input shown.

Input mode measures the absolute magnitude versus frequency and the phase; no channel ratio is calculated in this mode. Absolute amplitude accuracy depends on the measurement channel configuration.

Best used for the following applications:

- Resonance and peak detection
- Signal integrity verification
- Preliminary or diagnostic measurements
- Systems where only one measurement point is accessible

In Input mode, the Moku Frequency Response Analyzer displays absolute signal amplitude, which may be expressed in voltage-based (dBVpp, dBVrms) or power-based (dBm) units depending on the measurement context.

- **dBVrms (decibels relative to 1 V RMS):** Displays the measured signal amplitude relative to 1 V RMS and is commonly used for small-signal and frequency-domain analysis of linear systems, as RMS voltage directly relates to signal power in resistive loads.
- **dBm (decibels relative to 1 mW):** Displays the measured signal level as power relative to 1 mW and is used for power-based measurements and RF-style comparisons. Note the value assumes a defined load impedance of 50 Ω, if the system impedance differs the measurement may not represent true delivered power.
- **dBVpp (decibels relative to 1 V peak-to-peak):** Displays the measured signal amplitude relative to 1 V peak-to-peak and is typically used for intuitive voltage-level inspection and signal integrity checks, noting that it reflects peak-to-peak voltage rather than RMS or power.

Configuring channels

You can change the view and measurement of the input by changing the range or impedance, bandwidth, or coupling. Adjust the output setting with the amplitude, offset, or output termination.

The channel panel allows you to toggle channels ON/OFF and change the analog frontend settings for each ADC channel and configure the Math channel. The Math channel allows you to perform simple operations on your input channel signals and view the result.

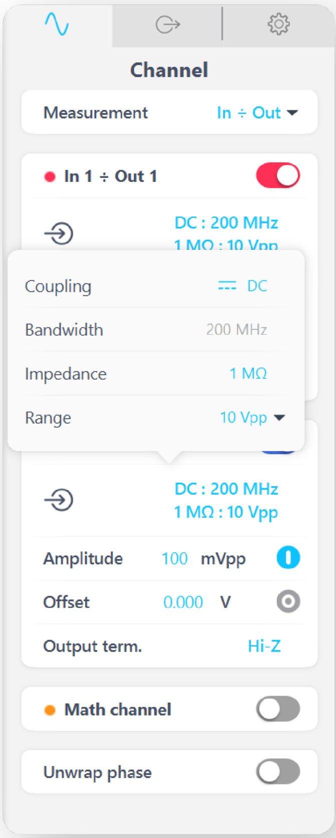

Figure 8. Channel settings panel

Coupling Use AC coupling to eliminate any DC offset in your signal, and DC coupling to capture all DC and AC components.

Bandwidth Select the bandwidth of the signal input for the channel.

Impedance Toggle between 1 MΩ and 50 Ω impedance, depending on your circuit and device hardware.

Range Choose to "Auto" set or manually set the input range.

Amplitude Select the amplitude of the output signal for the channel.

Offset Optionally add a DC offset to the swept sine output for the channel.

Output term. Match the output termination (if available) for the channel.

Math channel Add a channel displaying real-time math operations, across two channels.

Unwrap phase Display an estimate of the total accumulated phase of the system.

Analog front end settings

Coupling

- **DC coupling** shows all of the input signal, including any alternating waveforms as well as any DC offsets present in the measured signal.
- **AC coupling** will remove any DC offset present in the signal with a highpass filter, showing only the signal's AC component. This can attenuate low frequency signals in the process, such as low frequency signals.

For most applications, DC coupling is the preferred option; this does not filter or modify the signal in any way. AC coupling is best used when your signal is relatively small compared to its DC offset, such as a small ripple along a DC power supply, so you can utilize the full range and resolution of the ADC.

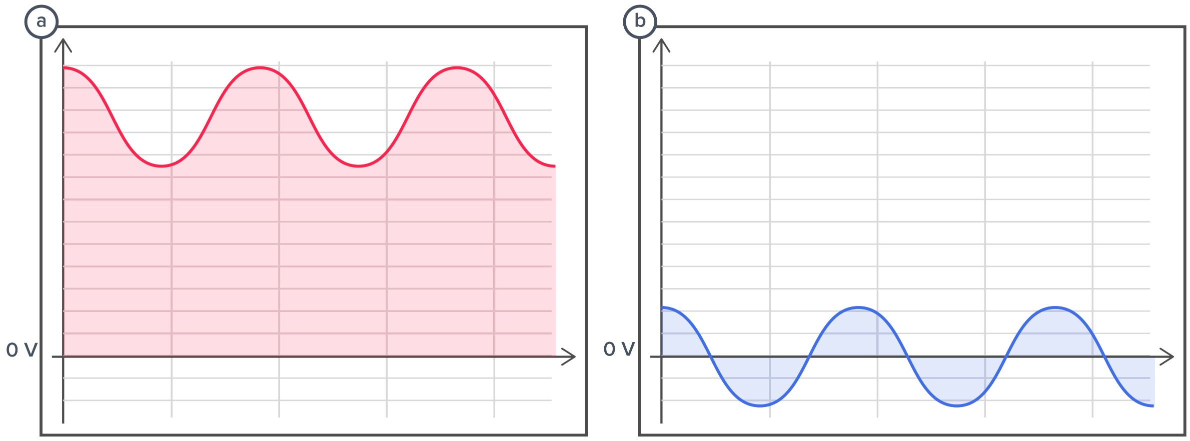

Figure 9. DC (a) and AC (b) coupled signals

Input impedance

Input impedance is effectively the resistance from the signal line to ground. For high-frequency measurements, it is important that the impedance on your Moku matches that of the device under test. This matching maximizes power transfer and minimizes signal reflections. If the impedances are mismatched, part of the signal will reflect back toward the source, which can distort the measurement and, in some high-power or sensitive systems, potentially damage the source equipment.

High-impedance mode (1 MΩ) is used where Moku is observing a signal that is already terminated elsewhere (e.g. between two high-speed devices), or where absolute voltage measurement accuracy is required, and the signal is low enough frequency that reflections from the measurement equipment do not significantly interfere with the original signal.

The input impedance also forms a voltage divider with the signal's source impedance, which can reduce or increase the apparent voltage if the impedances do not match.

Range

The range settings are used to ensure the ADC utilizes all its bits of resolution, giving you the most accurate signal reconstruction at all times. The Frequency Response Analyzer applies attenuation or gain (hardware dependent) to the incoming signal so that it is always scaled appropriately for the ADC, irrespective of the input signal amplitude. The best approach is to use the smallest input range that can fully represent your signal.

If the input range is set too small, the signal will be clipped at the ADC. If the range is set too large, the ADC will use too few bits of resolution, making the signal appear noisy. The ideal case is when the signal is correctly scaled to match the ADC input range. These scenarios are illustrated in Figure 10.

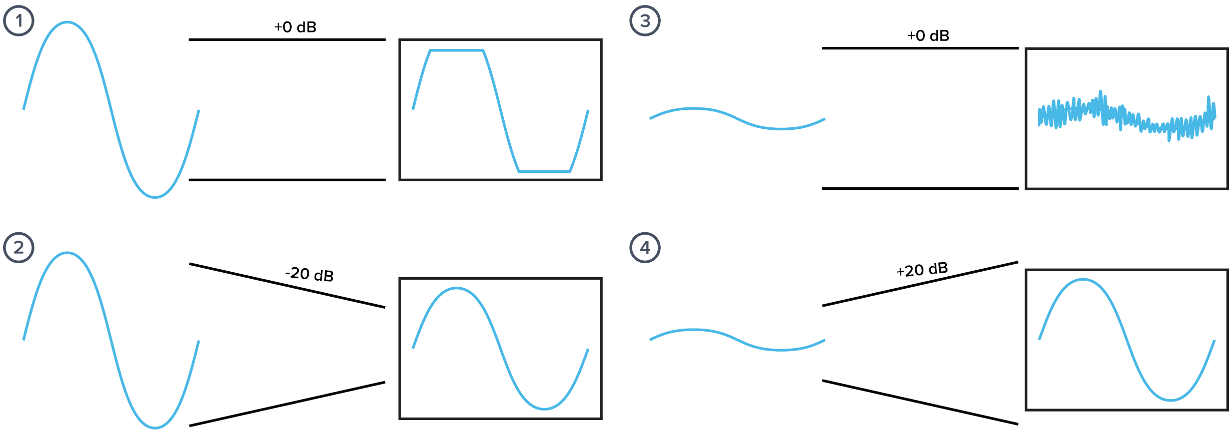

Figure 10. Illustration of Frequency Response Analyzer range scaling. (1) Input range too small, causing signal clipping at the ADC, (2) the correctly scaled input range, ensuring accurate signal capture, (3) input range too large, reducing ADC resolution and making the signal appear noisy, and (4) the correctly scaled input range.

See dynamic amplitude setting for more help.

Overvoltage protection

It is always recommended to operate within the specified input range of your Moku to protect the device and ensure accurate measurements. However, some Moku devices are equipped with built-in overvoltage protection to help safeguard the hardware in case of unexpected signal spikes. Overvoltage protection in the input will automatically switch to 1 MΩ mode to reduce current and power dissipation through the device.

Amplitude

Choose the amplitude for the output's swept sine output. Select an amplitude that is representative of the device under test's operating conditions.

Offset

The offset adds a DC bias to the output stimulus, adjusting the mean value of the output over time. Adjust the offset to bias a device under test at a specific operating point or remove a bias in the system.

Output termination

Moku:Lab, Moku:Pro, and Moku:Delta outputs, or Digital to Analog Converters (DACs), have a fixed 50 Ω load. When you connect the output to a 50 Ω device, the output voltage distributes to the internal load and external load equally. When you connect the output to a high impedance (Hi-Z) device, most of the voltage distributes to the external load.

Changing the "Load" or "Output termination" on the user interface does not affect the actual driving voltage. Instead, it only changes the scale for the display to reflect the voltage drop across the external load. The displayed voltage under the high load is twice the displayed number under the 50 Ω load. For example, when the output termination is set to 50 Ω, a resulting voltage of 1 Vpp is output. When the Output termination is changed to "Hi-Z", the voltage will measure 2 Vpp. Although the voltage output source remains unchanged, the voltage output is effectively doubled because the voltage distribution on the load doubles when the load changes from 50 Ω to high impedance.

Read about the importance of impedance matching in the input impedance section.

Moku:Go has a fixed 200 Ω output load and therefore the termination is fixed as Hi-Z in the interface.

Unwrap phase

Enabling unwrapping will display an estimate of the total accumulated phase of the system. This is useful when there are large delays in the measured system as it will show the continuous accumulated phase without jumps.

When phase unwrapping is enabled, the difference to the previous sample is computed for each element. This difference is mapped into the principal range around zero (±180°) (normal operation) then reconstructs the current phase as the previous value + wrapped change. The effect is to remove 360° jumps between consecutive samples so the phase sequence is continuous.

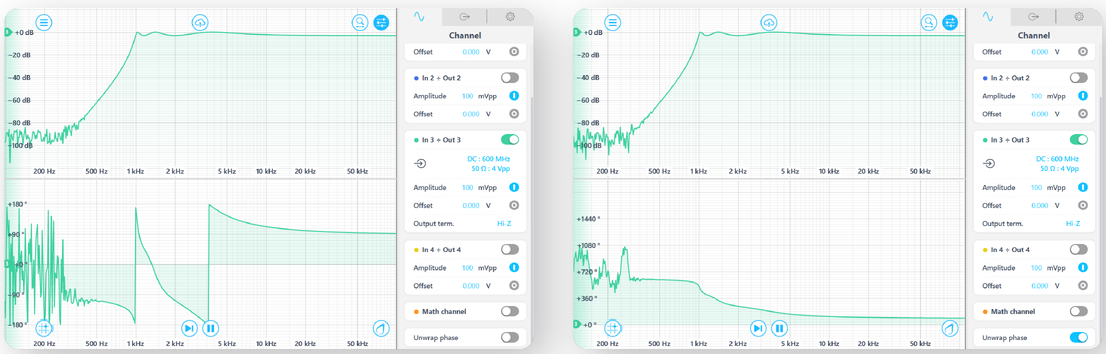

Figure 11. (a) Phase of a discontinuous phase response, and (b) the same signal with unwrapped, continuous phase.

Acquisition modes

The Frequency Response Analyzer can acquire continuously or in single sweeps, pausing after each acquisition.

Press to acquire a single sweep and pause the acquisition at its completion. This mode is useful when capturing data.

Press to acquire continuously, beginning a new sweep at the completion of the previous sweep. This mode can be used to view transient behavior, or to view the frequency response when configuring the measurement.

Swept sine

Adjust the swept sine output frequency range and parameters, set the sweep start and stop frequencies. The sweep time affects the displayed measurement and can take hours to days to complete. It is recommended that you begin your measurement with fewer points in the sweep, lower averaging and settling times to get an indicative result before refining in a longer, more accurate sweep measurement.

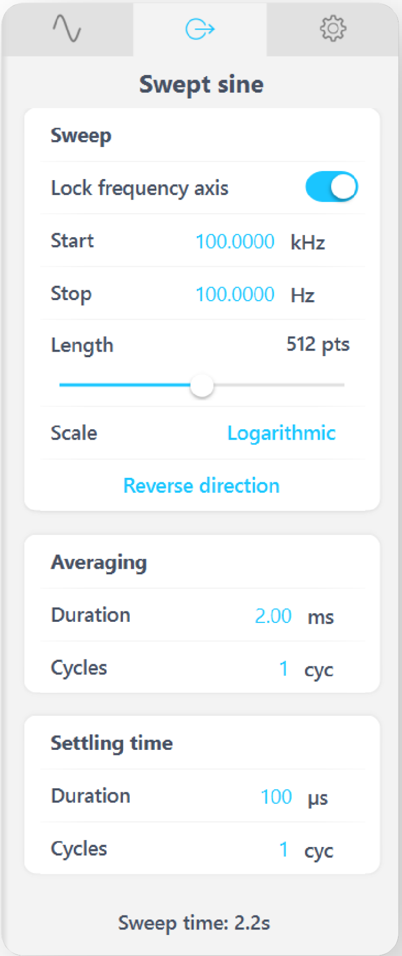

Figure 12. Swept sine settings.

Swept sine settings

Lock frequency axis to keep the measurement over same frequency range; this also avoids changing and restarting measurements when interacting with the graph area

Start Configure sweep start frequency

Stop Configure sweep stop frequency

Length Select number of sweep points; more points increases the sweep time

Scale Select Linear or Log scale to display the phase and magnitude graphs

Reverse direction Reverse the direction of the sweep

Averaging duration Configure the duration of each averaging cycle

Averaging cycles Configure the number of averaging cycles

Settling duration Configure the settling time

Settling cycles Configure the number of settling cycles

Sweep time Total sweep time based upon selected parameters

Sweep points

Increasing the number of points in the sweep increases frequency resolution of the measurement, allowing narrower features to be detected over a wider frequency range, but will increase the total measurement duration.

Sweep scale

Select whether the discrete points in the swept sine output are spaced linearly or logarithmically. Logarithmic sweeps provide greater measurement resolution at lower frequencies.

Averaging

Measurements at each point in the frequency sweep are averaged to improve accuracy and precision. You can configure the period over which each measurement is averaged in order to control signal-to-noise ratio. Longer averaging times result in higher signal-to-noise ratios (SNR), allowing small features to be detected with greater precision. Shorter averaging times result in lower SNR measurements but the reduce total sweep time.

The total averaging time is determined based on the **duration** and **number of cycles** over which each point in the sweep is averaged. The Moku Frequency Response Analyzer averages for the greater of the two values rounded up to the nearest number of integer cycles in order to avoid spectral leakage.

Settling time

The settling time determines how long the Frequency Response Analyzer waits before performing measurements at each frequency in the sweep. Settling time is important when characterizing resonant systems with high Q-factors in order to allow excitations to settle between measurements.

The total settling time is determined based on the **duration** and **number of cycles** over which the instrument will wait before beginning a measurement at each frequency in the sweep. The Frequency Response Analyzer will wait for the greater effective duration of the two settings before beginning a measurement at each point in the sweep.

Normalization

The Moku Frequency Response Analyzer features a normalization tool that can be used to normalize for subsequent measurements. Normalization is useful for comparing different devices under test (DUT); measure the inital DUT, then normalize and measure the second DUT to view the difference of the two frequency responses.

The frequency axis is locked when a normalization trace is active. Remove the trace to adjust the frequency sweep range.

Normalizing the measurement pauses acquisition. Press to run the acquisition sweep once, or to run continuous acquisition. Further, changes to normalization take effect immediately, even when acquisition is paused.

Open the normalization menu by tapping the icon, right-clicking the trace (Desktop), or long press on the trace (iPad).

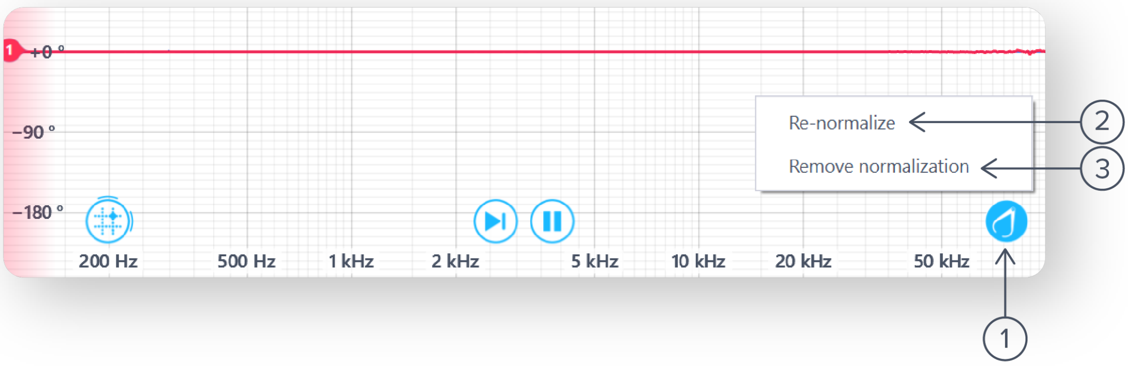

Figure 13. Normalization context menu.

① **Normalize menu**

② **Re-normalize** replace the current normalization trace with a new one

③ **Remove normalization** erases all stored normalization settings and cannot be undone

Advanced

The Advanced settings panel provides additional controls that improve measurement accuracy, dynamic range, and flexibility when characterizing complex devices. These features are particularly useful when characterizing systems with large gain variation, resonant behavior, nonlinear response, or significant signal delay.

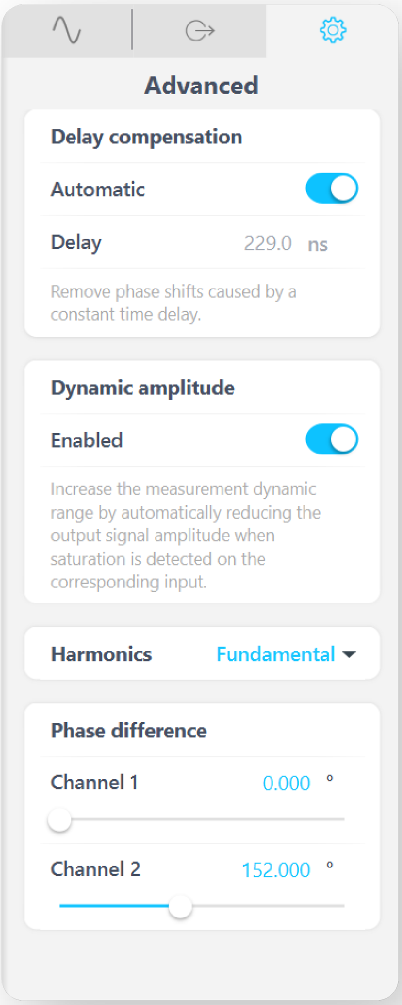

Figure 14. Advanced settings panel.

Delay compensation

Delay compensation removes the effect of constant time delay from the measured phase response. Systems with long cables, digital processing stages, or significant propagation delay introduce a linear phase slope proportional to frequency. When **Automatic** delay compensation is enabled, the analyzer estimates the constant delay component and subtracts it from the phase measurement. This reveals the intrinsic phase behavior of the DUT and simplifies interpretation of phase plots, particularly when analyzing filters or resonant systems. **Delay** can be manually entered if it is known.

Delay compensation should be disabled if the objective is to measure the actual propagation delay of the system.

Dynamic Amplitude

Enabling dynamic amplitude maximizes the dynamic range of the measurement by automatically reducing the output signal amplitude when saturation is detected on the corresponding input channel. This can be very useful when measuring devices whose amplitude response varies strongly with frequency, making it difficult to measure the frequency response with high dynamic range using a constant driving source.

Dynamic amplitude scaling automatically adjusts the swept sine output amplitude to maximize dynamic range while preventing input saturation. In frequency response measurements, a constant drive amplitude can lead to clipping in high gain regions or poor signal-to-noise ratio (SNR) in highly attenuated regions. When dynamic amplitude is enabled, the instrument monitors the input signal level and reduces the output amplitude if saturation is detected. This allows the largest possible excitation signal to be used without distortion, improving measurement quality across the entire sweep range. If saturation occurs, a pop-up warning appears in the user interface, and an orange exclamation icon provides additional details about which frequencies are affected along with suggested corrective actions (Figure 15).

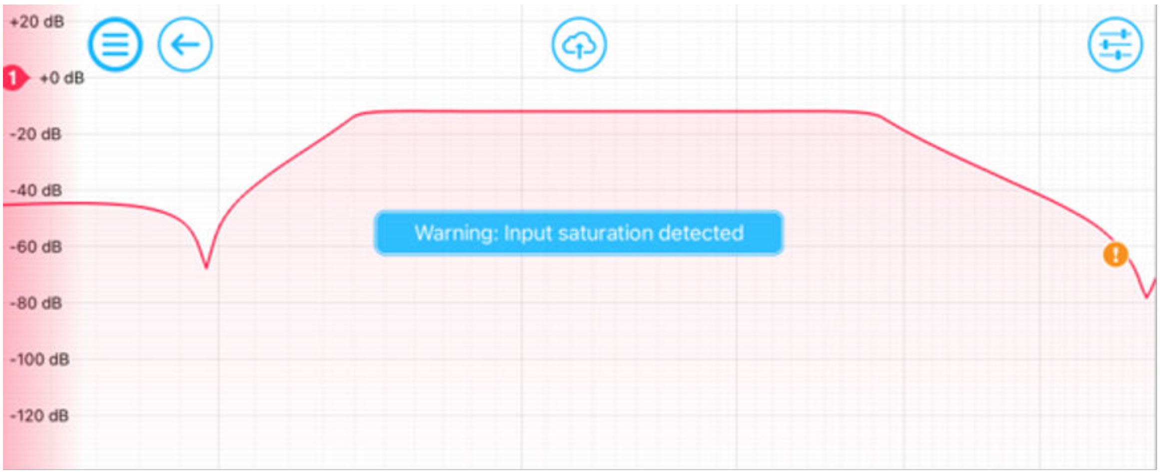

Figure 15. Saturation popup warning message

Clicking the orange exclamation icon on the right-hand side of the graph will provide additional information regarding which frequencies are saturated and possible solutions, including enabling dynamic amplitude mode.

Harmonics

Select a harmonic to measure the frequency response of the swept sine. This will affect all channels and measurements. As the fundamental frequency has the most power, subsequent harmonics have more noise for the same settings. Refine your swept sine output signal settings to reduce this noise.

The Harmonic selection feature allows measurement of the frequency response at harmonics of the swept sine instead of only the fundamental frequency. By default, the analyzer measures the fundamental component, which provides the highest signal power and best SNR. However, selecting higher harmonics enables characterization of nonlinear behavior, such as harmonic distortion generated by the device under test. Because harmonic components typically have lower amplitude, measurements at higher harmonics may require increased averaging or higher drive levels to maintain adequate SNR.

Phase difference

Set the phase difference between the output and local oscillator. Phase difference adjustments allow you to define the phase relationship between the output signal and the internal reference (local oscillator). This can be used to compensate for known fixed phase offsets, align channels in multi-channel measurements, or optimize phase alignment for specific setups. Adjusting the phase reference does not change the DUT response itself, but rather shifts the measurement reference used for comparison.

Using the math channel

Real-time math operations, across two different channels, can be performed using the Math channel. A wide range of math operations are available:

Operation	Symbol	Description
Addition	+	Sum of two channels.
Subtraction	-	Difference of two channels.
Multiplication	x	Product of two channels. The two channels can be the same, giving a squaring of the signal values.
Division	÷	Ratio of two channels.
User entered function	f(A,B,...)	A user-defined math function, edited in the input box. See user defined function for more information.

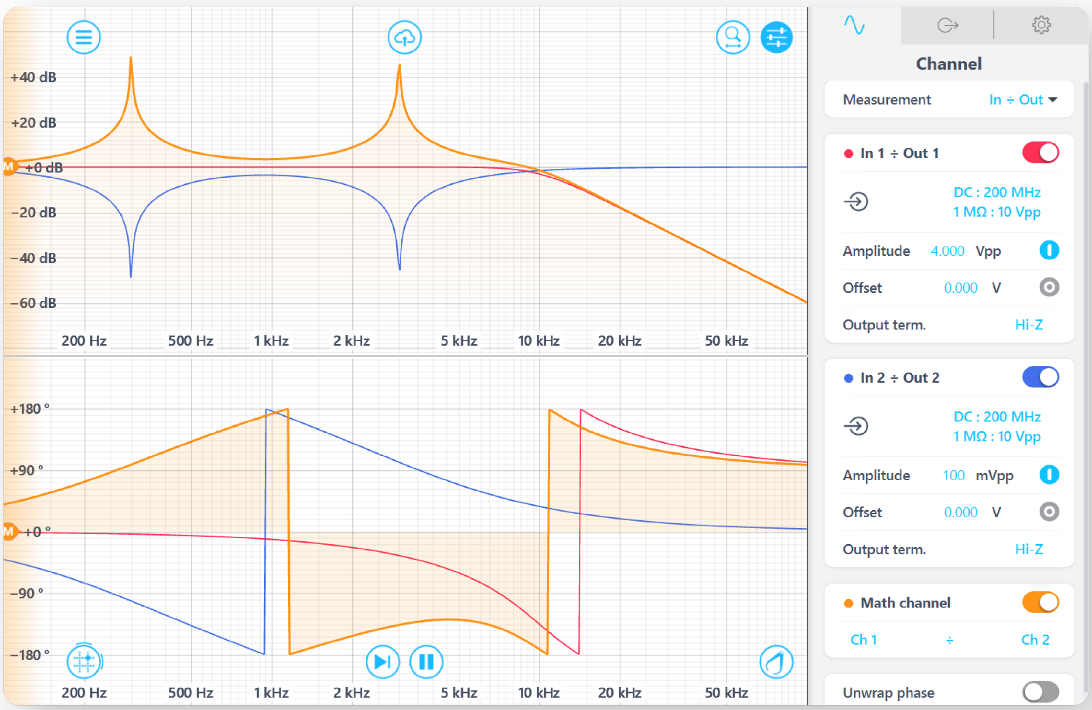

Figure 16. The Math channel calculates the product of Channel A and Channel B.

In the Frequency Response Analyzer plots, magnitude is displayed in decibels (dB), to help express a large logarithmic scale with 0 dB for unity gain. Because dB is a logarithmic scale, it does not follow linear arithmetic rules. As a result, adding two equal magnitude values in dB does not double the dB value. The magnitude plot axis is in decibels, to help express a large logarithmic scale with 0 dB for unity gain and simple notches typically every 10 dB.

For example, doubling a signal's linear amplitude increases its magnitude by 6 dB, regardless of its original level. This occurs because the dB scale converts multiplication in linear space into addition in logarithmic space. Therefore, dB values may be added directly only when combining cascaded system gains, where linear gains multiply.

The math channel cannot be routed to an analog port. If you want to perform real-time math operations for signal output, use an instrument with a cross-over matrix, such as the PID Controller, to perform basic math operations; otherwise consider Moku Compile, see some existing Moku Compile examples.

User defined function

The math channel can plot a user-entered function of all input channels. The channels are represented by the variables **A**, **B**, etc.

When using this function, the units can be changed from volts to amps, watts or ohms. You can connect other types of probes to the oscilloscope inputs and compute the probed current, power, and resistance.

Measuring signals

Sweep modes

Single Tapping the icon will enable single sweep mode, which will pause the swept sine source at the end of the next full sweep. The swept sine signal will be turned off after the sweep completes and displayed data will not be updated.

Continuous Tapping the icon will enable continuous sweep mode, which will perform a new measurement as soon as the previous one has finished. This mode is commonly used to monitor systems with transfer functions that may change over time (e.g., control loops).

Pause / Restart Tapping the icon will immediately pause the current sweep. While paused, you can zoom in on features for more details, but no new data will be captured. Pressing the icon will also pause capture.

Tapping the or icons will restart the sweep.

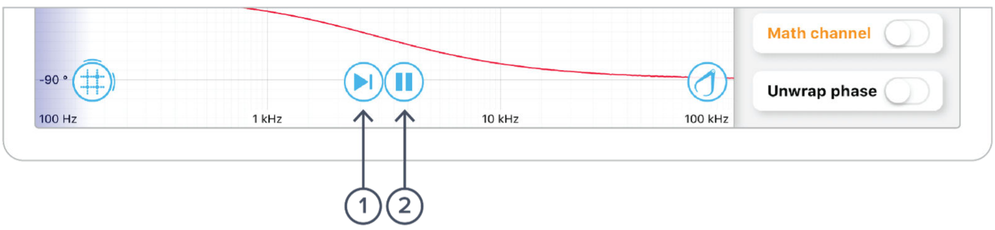

Figure 17. Sweep mode icons.

① Start single sweep

② Pause / start sweep

Cursors and measurements

Cursors

Cursors are managed from the cursor icon. Drag up from the button to insert a **magnitude / phase** cursor, drag to the right to insert a **tracking cursor** (desktop), or a **time** cursor (iPad). Click the cursor icon to manage cursors, including adding a tracking cursor, or remove all cursors. On desktop, cursors can also be added from the context menu, by right clicking the graph.

Cursors can also be positioned to measure unique events by magnitude, phase, frequency or by channel tracking, as shown in Figure 18. Cursors attached to a channel will track the magnitude or phase scale of that channel.

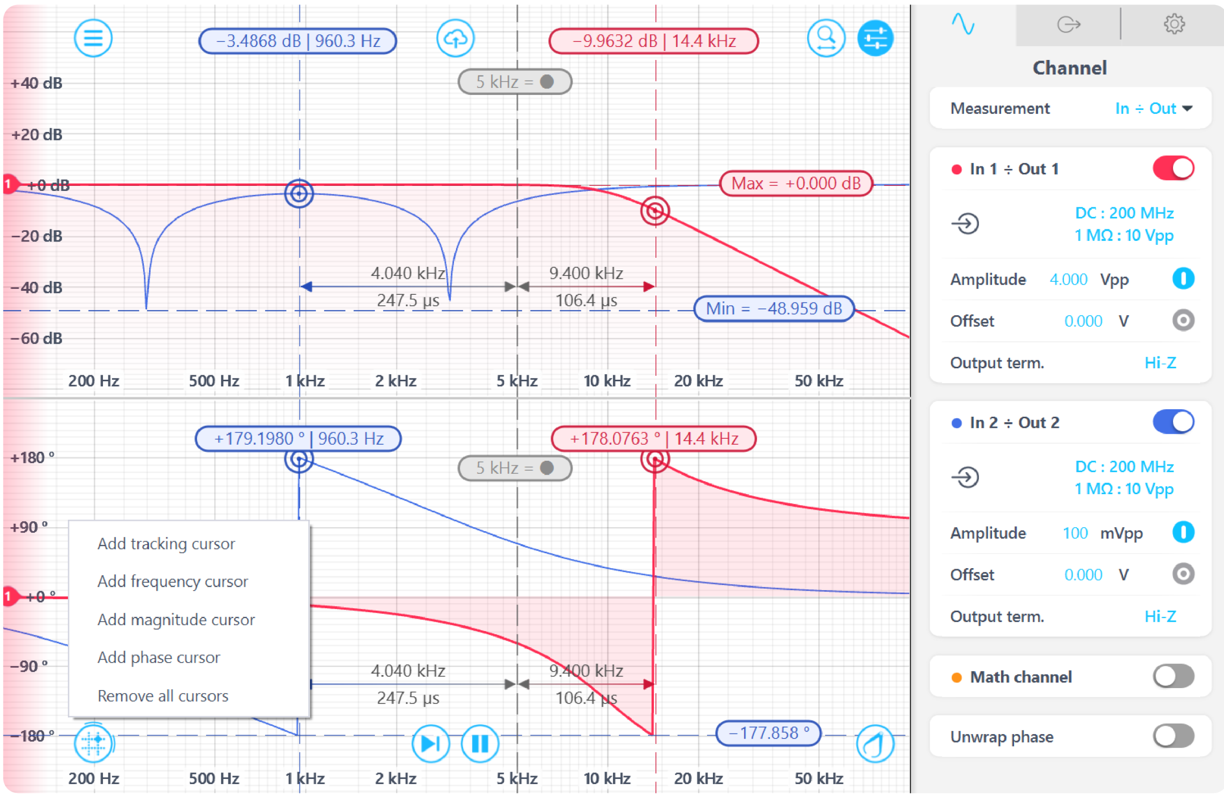

Figure 18. Cursors measuring the phase and magnitude (red, blue) with frequency cursor (gray) and with cursors.

Tracking cursor

Tracking cursors automatically follow a selected signal trace as it moves or changes with each captured data frame, maintaining its relative position on that trace. This allows you to dynamically measure parameters such as time or voltage as the waveform changes, without needing to reposition the cursor manually.

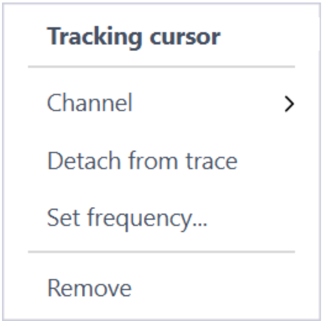

Figure 19. Tracking cursor context menu.

- **Channel** Assign the voltage cursor to a specific channel.
- **Detach from trace** Detach the cursor from the trace, turning it into a time cursor.
- **Set frequency...** Set the frequency of the cursor to a given value.
- **Remove** Remove the tracking cursor.

Frequency cursor

Frequency cursors reference and measure the frequency between other frequency cursors, without being attached to a specific trace. Right-click (secondary click) on a frequency cursor to reveal the frequency cursor options.

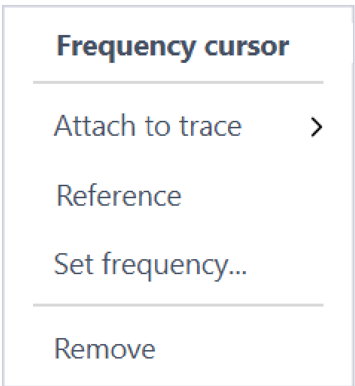

Figure 20. Frequency cursor context menu.

- **Attach to trace** Assign the frequency cursor to a specific trace, turning it into a tracking cursor.
- **Reference** Set the cursor as the reference cursor.
- **Set frequency...** of the cursor to a given value.
- **Remove** the frequency cursor.

Magnitude cursor

Magnitude cursors reference and measure the magnitude between other magnitude cursors, without being attached to a specific trace. Right-click (secondary click) on a magnitude cursor to reveal the magnitude cursor options.

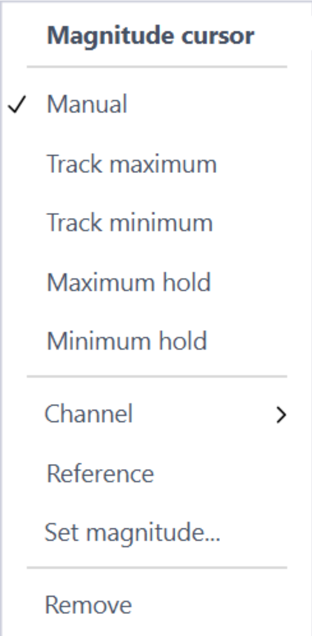

Figure 21. Magnitude cursor context menu.

- **Manual** Position the cursor manually by dragging it to a feature of interest.
- **Track maximum** Track the maximum magnitude.
- **Track minimum** Track the minimum magnitude.
- **Maximum hold** Set the cursor to hold the maximum magnitude level.
- **Minimum hold** Set the cursor to hold the minimum magnitude level.
- **Channel** Assign the magnitude cursor to a specific channel.
- **Reference** Set the cursor as the reference cursor.
- **Set magnitude...** Set the magnitude of the cursor to a given decibel value.
- **Remove** Remove the magnitude cursor.

Phase cursor

Phase cursors reference and measure the phase between other phase cursors, without being attached to a specific trace. Right-click (secondary click) on a phase cursor to reveal the phase cursor options.

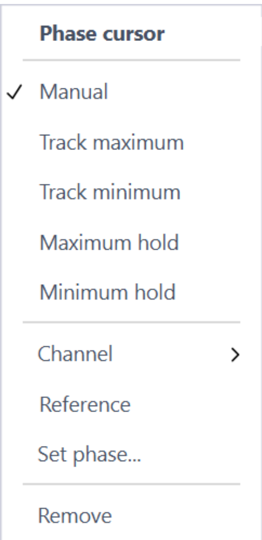

Figure 22. Phase cursor context menu.

- **Manual** Position the cursor manually by dragging it to a feature of interest.
- **Track maximum** Track the maximum phase.
- **Track minimum** Track the minimum phase.
- **Maximum hold** Set the cursor to hold the maximum phase level.
- **Minimum hold** Set the cursor to hold the minimum phase level.
- **Channel** Assign the phase cursor to a specific channel.
- **Reference** Set the cursor as the reference cursor.
- **Set phase...** Set the phase of the cursor to a given phase value.
- **Remove** Remove the phase cursor.

Saving and sharing data

Access data export options by clicking , this allows you to export data in a number of different formats. Opening this window will automatically pause the display and acquisition. Restart acquisition by pressing for a single sweep, or for continuous acquisition.

Live data

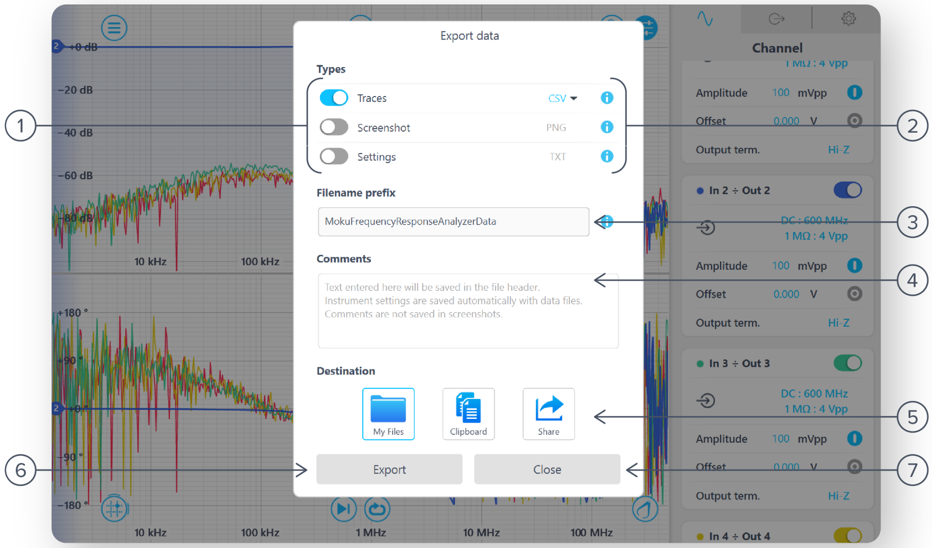

Figure 23. Live data exporting user interface and settings.

① Select the type of data to export:

- **Traces** Saves the trace data for all visible signal traces, in either a CSV or MAT-file format.
- **Screenshots** Saves the app window as an image, in either a PNG or JPG format.
- **Settings** Saves the current instrument settings to a TXT file.

② Select the **export format**.

③ Select the **Filename prefix** for your export. The default "MokuFrequencyResponseAnalyzerData" can be changed to any filename of alphanumeric characters and underscores. A timestamp and the data format are appended to the prefix.

For example: "MokuFrequencyResponseAnalyzerData_YYYYMMDD_HHMMSS_Traces.csv"

④ Enter additional **Comments** to be saved in any text-based file header.

⑤ Select the export **Destination** on your local computer. Multiple data export types can be exported simultaneously using My Files and Share, but only one data type can be exported to the clipboard at a time.

⑥ **Export** the data, or

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

Examples

Power supply rejection ratio

In this example, we will characterize the transfer function of the input ripple of a voltage regulator. This will demonstrate how to measure the power supply rejection ratio and how you can measure this behavior with the Moku Frequency Response Analyzer.

In this example we measure how well the output of a power delivery device can reject variations in its DC input voltage (the power supply rejection ratio). The power supply rejection ratio is measured by intentionally injecting a low amplitude AC signal (a ripple) onto a DC input signal and measuring the power of the ripple on the input and the output of the device under test (DUT). Equation 2 shows the relationship between the power supply rejection ratio (PSRR) and the measured input and output ripple signals.

$$PSRR = 20\log_{10}\left(\frac{V_{in}}{V_{out}}\right) \tag{2}$$

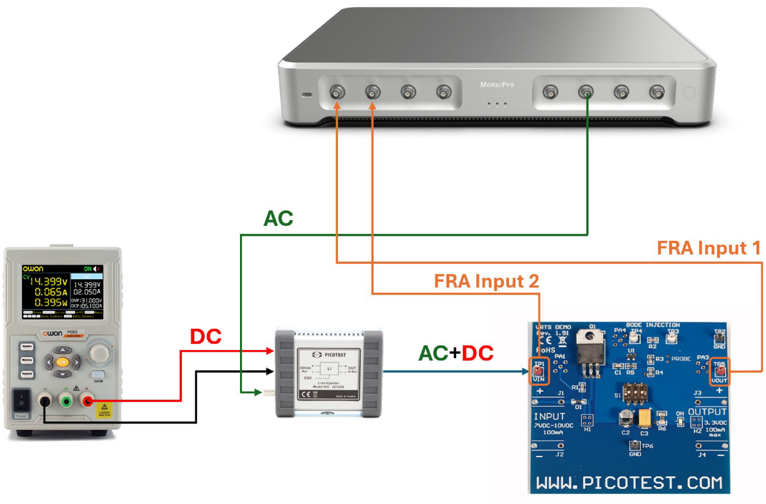

Figure 24. Test setup: A line injector takes in a DC signal from the DC power supply and an AC signal from the Moku Frequency Response Analyzer output and outputs the perturbed DC signal to the VRTS regulator board. The Moku:Pro Frequency Response Analyzer takes in the voltage input and output of the regulator board.

- **Step 1:** Select the measurement mode
  - Connect the Moku, power supply and voltage regulator board as shown in Figure 24.
  - In ÷ In1 mode is used in this configuration to compute the rejection response of the power supply.
- **Step 2:** Configure the analog front end and output settings
  - Configure the appropriate analog front end settings: coupling, impedance, range, and bandwidth. In this case the coupling is set to DC to include any offsets. Impedance is set to 50 Ω, to match the regulator. The range is set to 400 mVpp to best measure the output amplitude. The bandwidth is set to 300 MHz as the next largest range above our output frequency.
  - Configure the analog output settings: amplitude, offset, and output termination. The amplitude is set to 100 mVpp and turned ON using the button. Offset is set to 0 V,

and OFF using the button, as there is no offset to compensate for. Output termination is set to 50 Ω, to match the impedance of the regulator and input.

- **Step 3:** Set the swept sine output
  - From the Swept sine settings tab, set the sweep to start at 100 MHz and stop at 100 Hz.
  - To get an initial result quickly, set the sweep averaging duration to 1 cycle at 10.0 ms, and the settling time to 1 cycle of 100 µs duration. This will give an indicative result, with a quick sweep time, but is less accurate, as the cycles do not have as much time to settle at each frequency point.
  - Set the length of the sweep to 512 points, this gives a large number of frequency points to measure, while keeping the sweep time short.
  - Select "Logarithmic" scale to see the broad range system response.
  - Lock the frequency axis to prevent accidental changes in the sweep range. Double-click on the graph area to autoscale the magnitude and phase response of the regulator.
  - For repeated measurements press the repeat button . For a single measurement press the play/pause button .
- **Step 4:** Set up the advanced configurations
  - Enable automatic delay compensation to remove any phase shifts caused by a constant time delay.
  - Select the fundamental harmonic to be viewed; change this later to view subsequent harmonics.
  - Dynamic amplitude and phase differences can all be left at OFF and 0.000 degrees respectively, as they are not needed in this measurement.

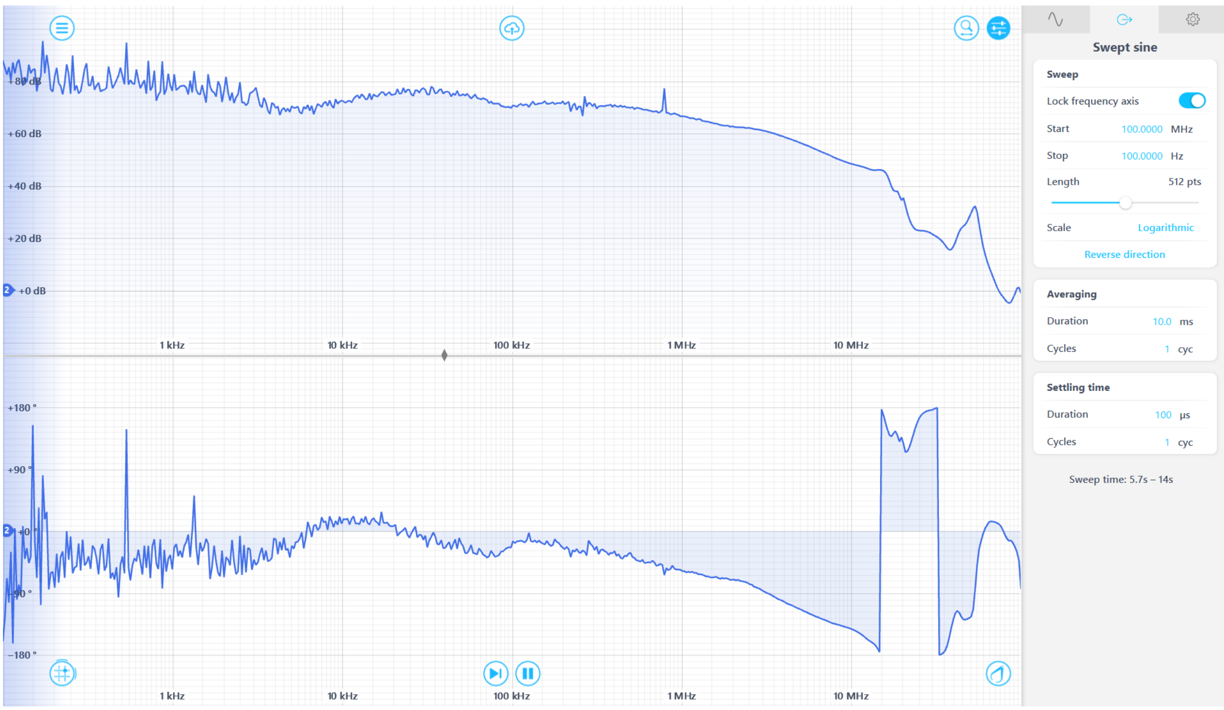

Figure 25. Initial measurement of the power board with capacitors 1 and 2 attached on the output.

- **Step 5:** Refine measurement settings
  - Increase the averaging duration to 100 ms, as shown in Figure 26, which shows significantly reduced noise, particularly at the lower frequencies.

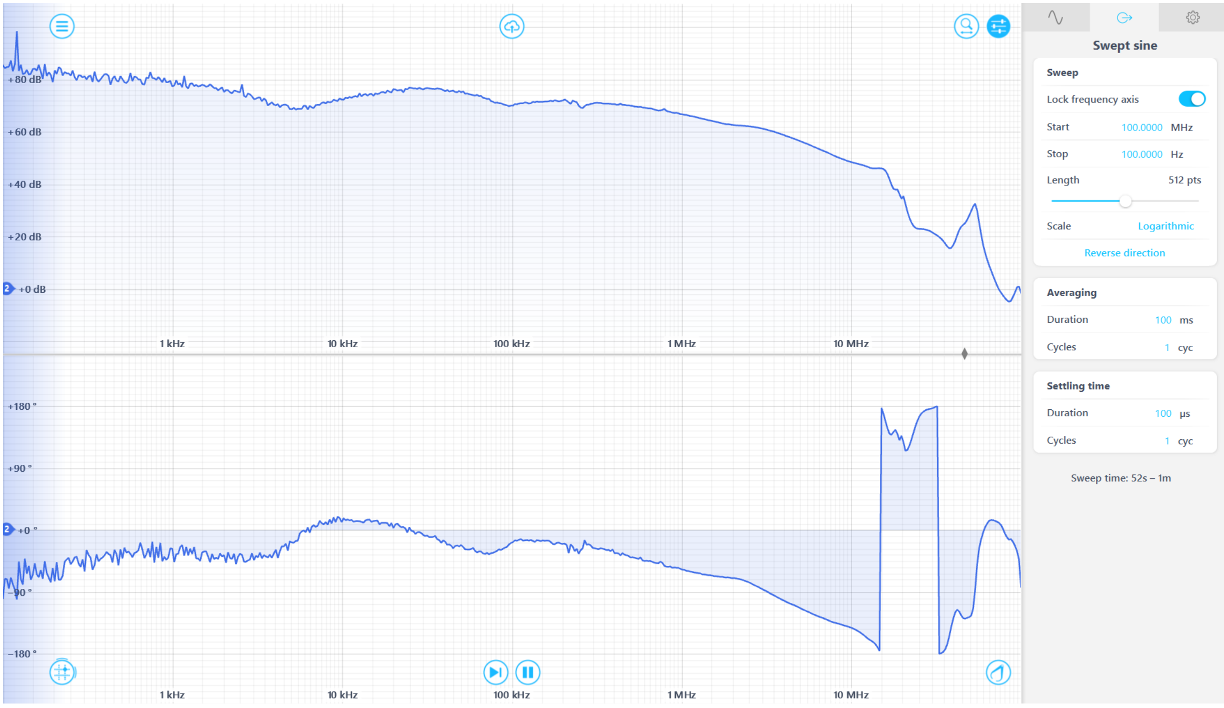

Figure 26. Refined measurement of the power board with capacitors 1 and 2 attached on the output.

S-parameter measurement

In this example, we will characterize the S-parameters of a two-port bandpass filter. This will demonstrate how to measure the forward transmission, reverse transmission, and input/output return loss of an RF filter and how you can perform these measurements using the Moku Frequency Response Analyzer.

In this example we measure the scattering parameters S_{12}, S_{11}, S_{22}, and S_{21} of a bandpass filter (BPF) using a swept sine excitation. The forward transmission (S_{21}) describes the insertion loss and passband response of the filter, while the reverse transmission (S_{12}) characterizes isolation. The reflection coefficients (S_{11}, S_{22}) describe the impedance match at the input and output ports, respectively. By exciting one port at a time and terminating the opposite port in 50 Ω, the Frequency Response Analyzer measures the ratio of incident, transmitted, and reflected signals across frequency to compute the filter's complete two-port response.

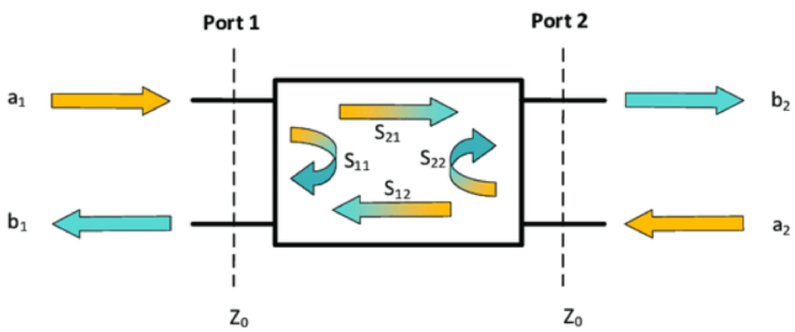

Figure 27. S-parameter representation in a 2-port network.

Four measurements will be made, one each for the S-parameters S_{12}, S_{11}, S_{22}, S_{21}. Figure 28 shows the measurement configurations taken with a Moku:Lab, the 2-port filter (BPF) and RF coupler (Mini Circuits ZFDC-10-21), and a 50 Ω terminator. The 50 Ω terminator is connected in series with the filter to preserve impedance match when measuring S11 and S22 parameters.

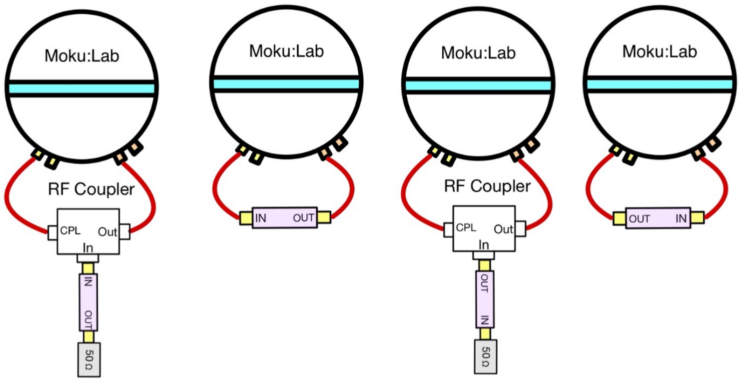

Figure 28. Configurations for each of the S-parameter measurements; from left to right the S_{11}, S_{21}, S_{22}, S_{12} configurations are shown.

- **Step 1:** Select the measurement mode
  - Configure the inputs and outputs with the filter and termination, as shown in Figure 28.
  - Select In ÷ Out mode, this configuration will compute the magnitude response of the bandpass filter as a ratio of the input to output, across the frequency range.
- **Step 2:** Configure the analog front end settings for the signal input and outputs
  - Configure the appropriate analog front end settings: coupling, impedance, range, and bandwidth. In this case the coupling is set to DC to include any offsets. Impedance is set to 50 Ω, to match the filter. The range is set to 400 mVpp to best measure the output amplitude. The bandwidth is set to 300 MHz as the next largest range above our output frequency.
  - Configure the analog output settings: amplitude, offset, and output termination. The amplitude is set to 100 mVpp and turned ON using the button. Offset is set to 0 V, and OFF using the button, as there is no offset to compensate for. Output termination is set to 50 Ω, to match the impedance of the filter and input.
- **Step 3:** Set the swept sine output
  - From the Swept sine settings tab, set the sweep to start at 200 MHz and stop at 10 MHz.
  - To get an initial result quickly, set the sweep averaging duration to 1 cycle at 10.0 ms, and the settling time to 1 cycle of 100 µs duration. This will give an indicative result, with a quick sweep time, but is less accurate, as the cycles do not have as much time to settle at each frequency point.
  - Set the length of the sweep to 512 points, this gives a large number of frequency points to measure, while keeping the sweep time short.
  - Select "Logarithmic" scale to see the broad range system response. Linear mode can be selected to view close-up details, if desired.
  - Lock the frequency axis to prevent accidental changes in the sweep range. Double-click on the graph area to autoscale the magnitude and phase response of the filter.
  - For repeated measurements press the repeat button . For a single measurement press the play/pause button .
- **Step 4:** Set up the advanced configurations
  - Enable automatic delay compensation to remove any phase shifts caused by a constant time delay.

- Select the fundamental harmonic to be viewed; change this later to view subsequent harmonics.
- Dynamic amplitude and phase differences can all be left at OFF and 0.000 degrees respectively, as they are not needed in this measurement.

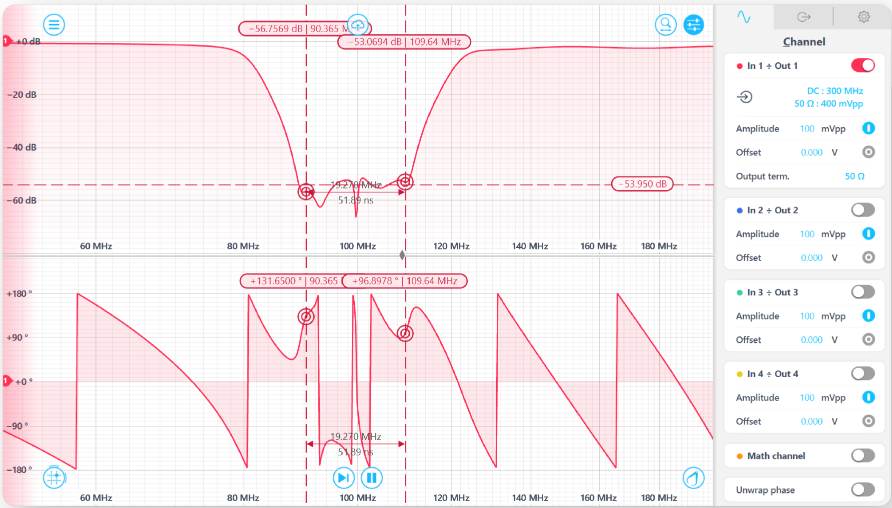

Figure 29. Measured S_{12} plot.

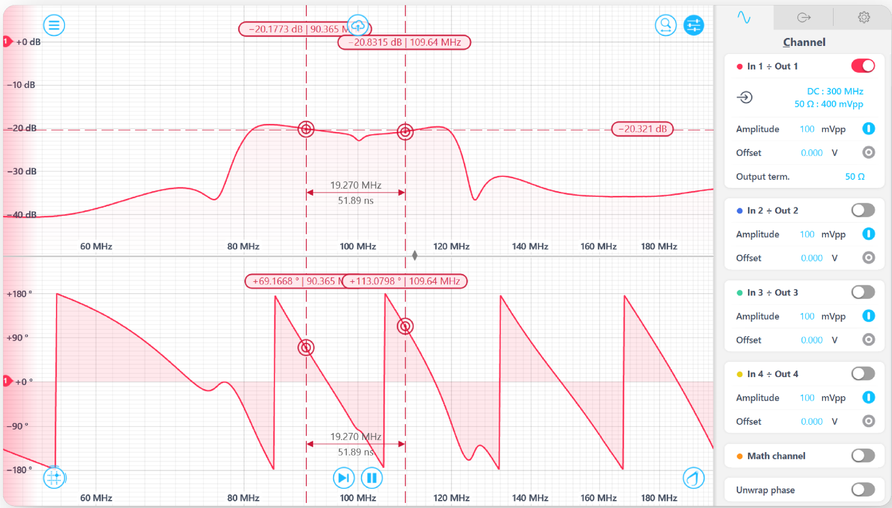

Figure 30. Measured S_{11} plot.

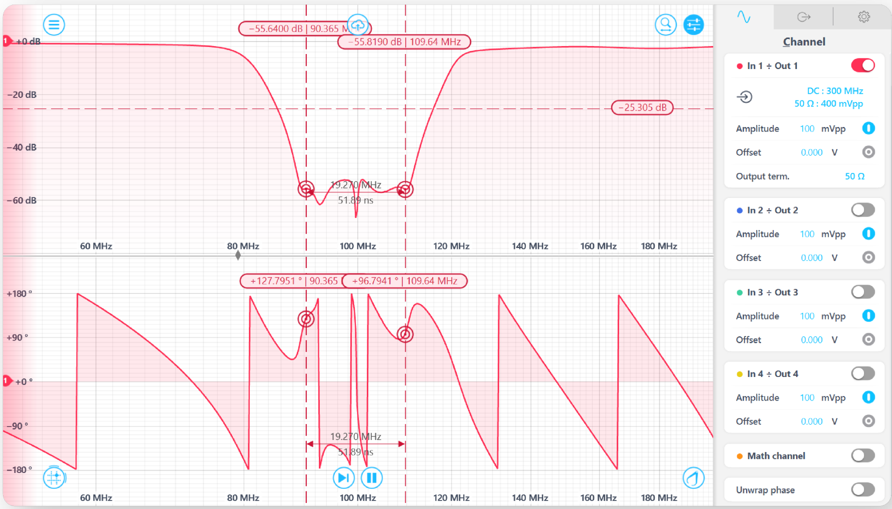

Figure 31. Measured S_{21} plot.

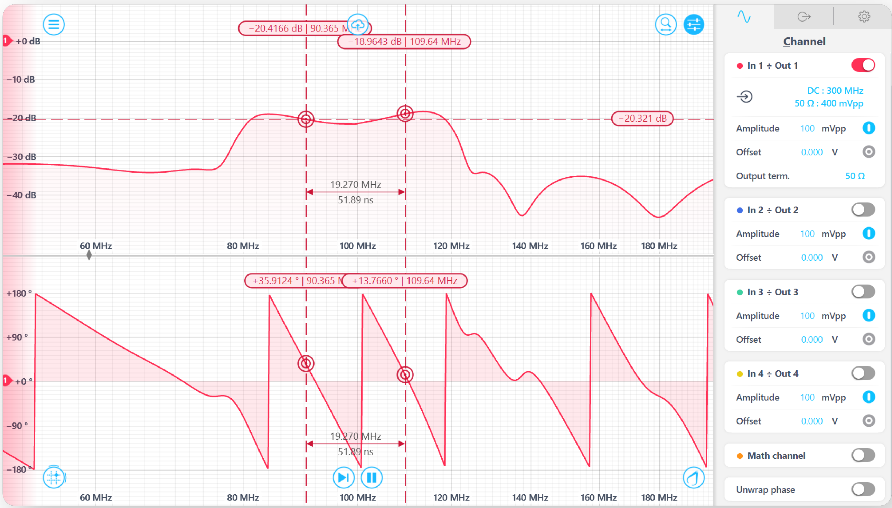

Figure 32. Measured S_{22} plot.

Additional Controls

Main Menu

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

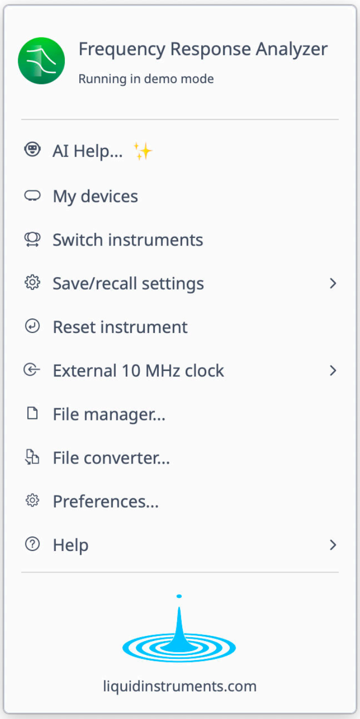

Figure 34. Main menu options for the Frequency Response Analyzer.

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.

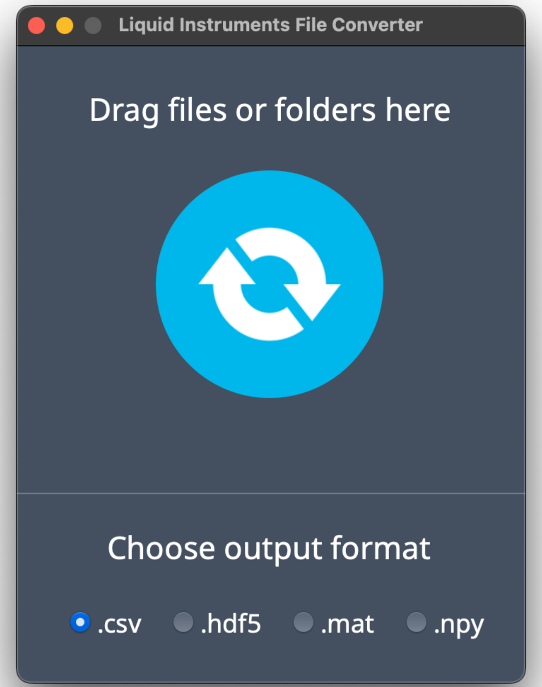

Figure 34. File Converter user interface.

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.

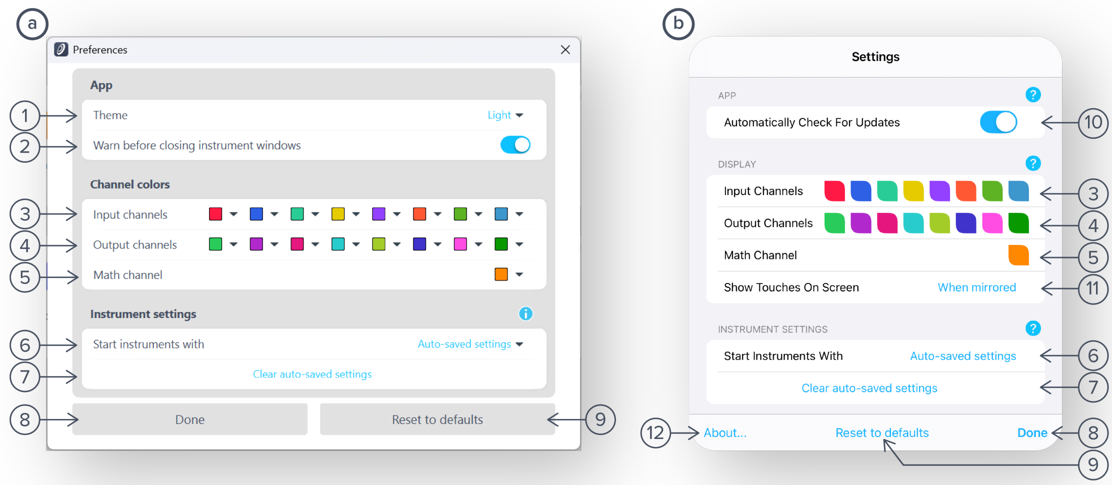

Figure 35. Preferences and settings for the Desktop (a) and for the iPad (b) App.

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.

Shortcuts

Shortcuts are integrated to speed up your workflow on Moku. This includes graph zoom and scrolling, autoscaling, cursor, measurement, instrument, and general shortcuts. They are available from the main menu, as shown in Figure 36, or use the shortcut `Ctrl + H` to open the shortcuts dialog.

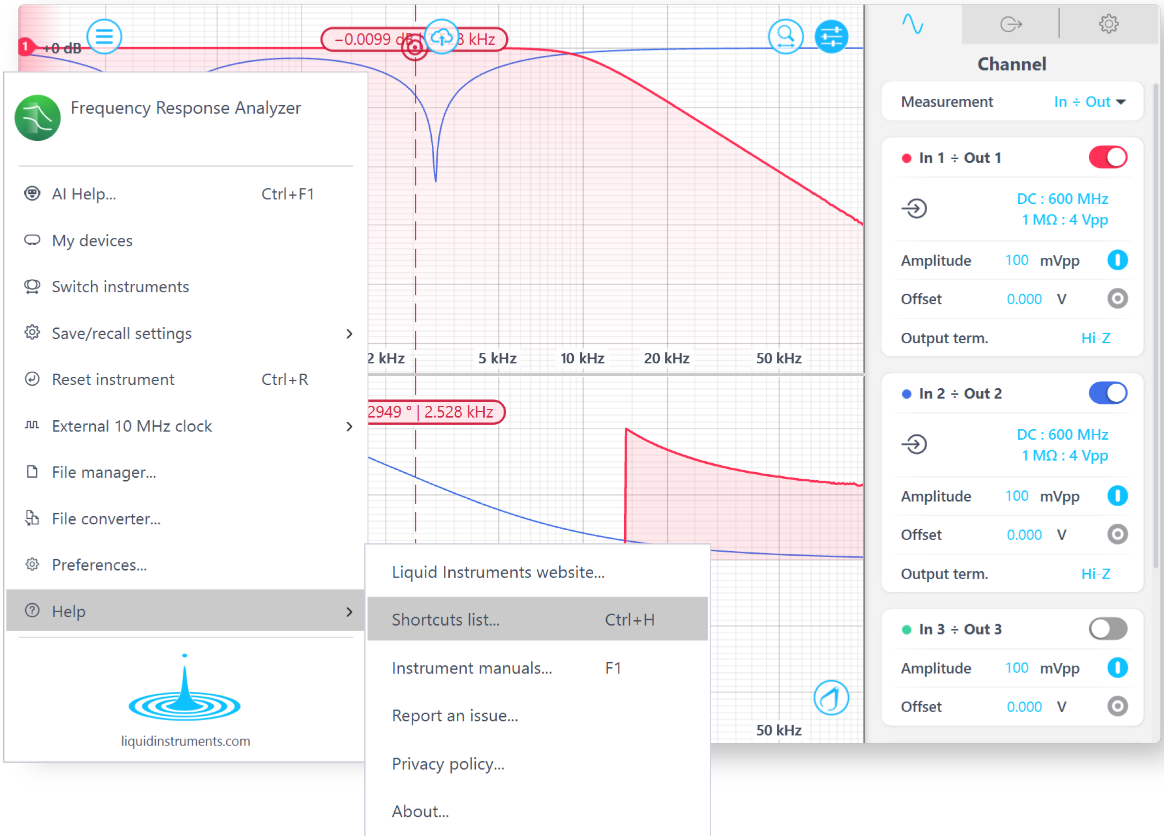

Figure 36. Main menu to access the help > shortcuts list.

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.

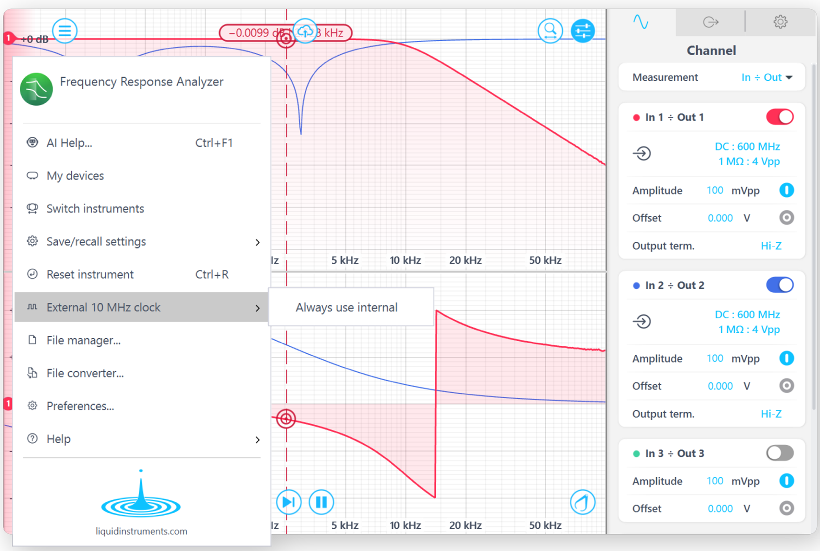

Figure 37. Moku main menu with "Always use internal" reference disabled and using an external reference.

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 38, 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 38. Moku clock blending configuration dialog with an external 10 MHz frequency reference 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).

