Moku Spectrum Analyzer

User Manual

LIQUID INSTRUMENTS

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Introduction

The Moku Spectrum Analyzer allows you to observe input signals in the frequency domain, viewing multiple channels of data simultaneously with a low-resolution bandwidth (RBW) over a minimum span of 100 Hz. The Spectrum Analyzer also features a multi-channel Waveform Generator for driving any device under test.

Below we provide a guide to the underlying architecture of the instrument and its user interface. We also include a general example in the quick start guide and a small number of in-depth examples to provide a foundation for new users.

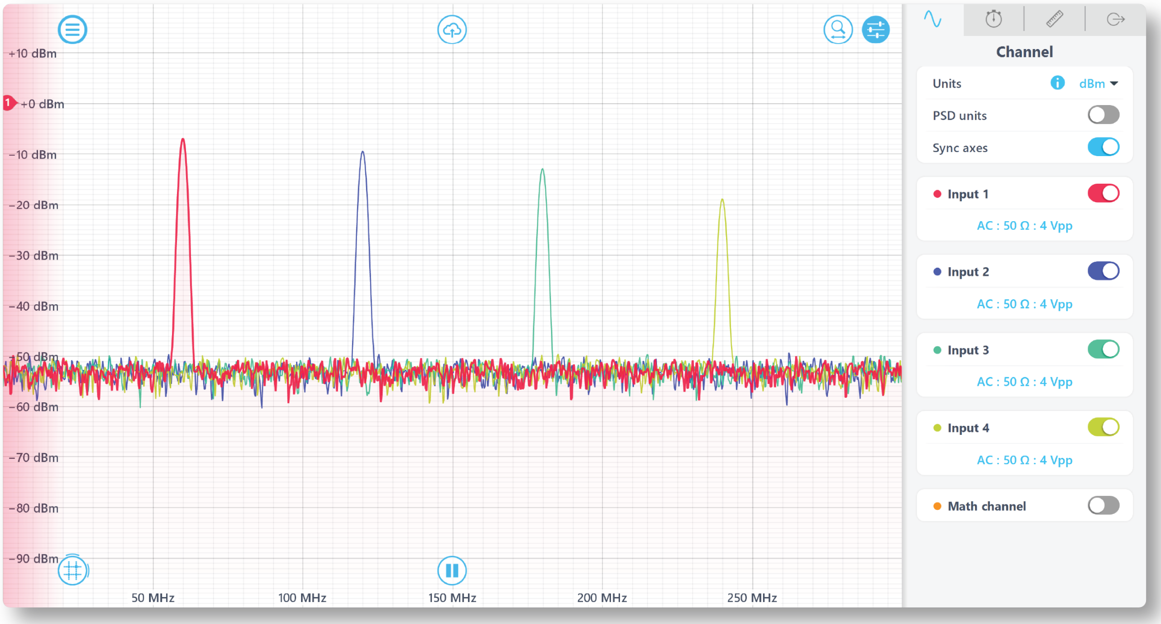


Figure 1. Moku Spectrum Analyzer user interface showing signal display area (left) and settings panel (right).

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

For more information on the specifications for each Moku hardware, please refer to our Product Documentation, where you can find the Specifications and the Spectrum Analyzer Datasheets.

Quick start guide

Here we outline the typical power measurement workflow in the frequency domain with the Spectrum Analyzer. More detailed examples may be found in the Examples section.

In this example, we used a second Moku Waveform Generator to simulate two signals; a 50 MHz 1 Vpp sine wave on Input 1 and an 80 MHz 500 mVpp square wave on Input 2. The signal on Input 2 was frequency modulated with ±10 MHz deviation at 1 kHz modulation frequency.

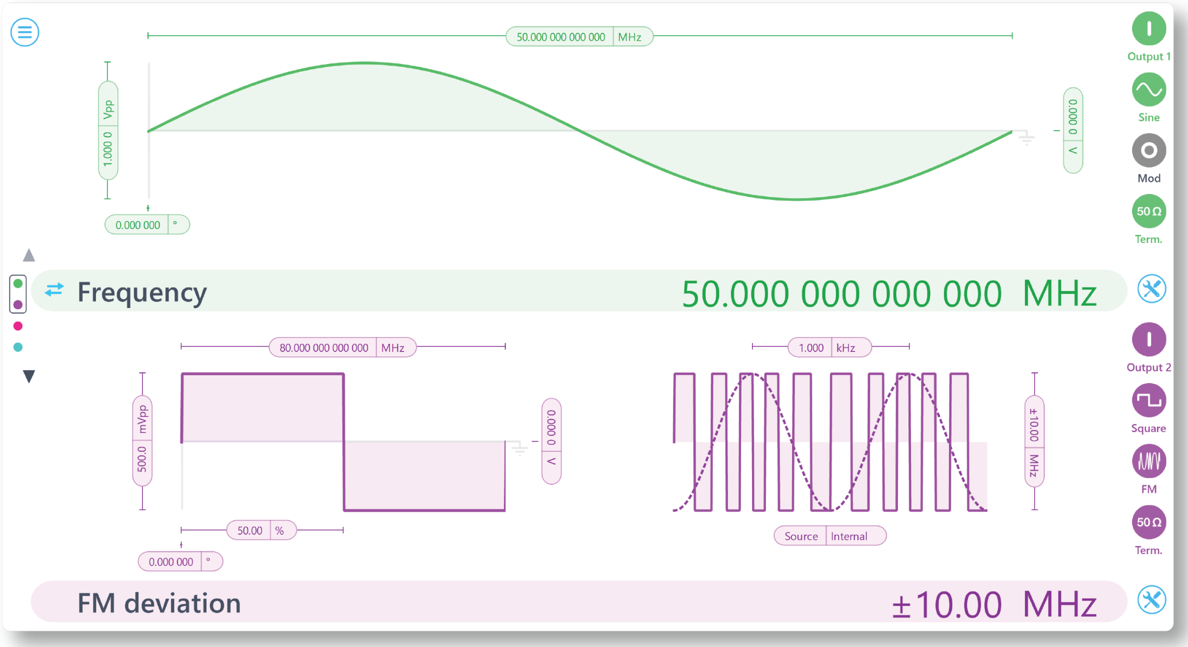


Figure 2. Setup of the Waveform Generator for the Spectrum Analyzer quick start guide showing the generated sine wave (top) and frequency modulated square wave (bottom).

- **Step 1**: Configure the channel settings to match the output impedance of the signals.
  - In the channel panel, set the units to dBm and enable sync axes.
  - Enable each input and set the frontends to DC coupling, 50 Ω impedance, and 4 Vpp range.
  - Note: These are the default settings of the instrument.
- **Step 2**: Configure the frequency and acquisition to display the signals.
  - Switch to the frequency panel and ensure the Scale is set to Linear in the sub-panel.
  - Set Start to 20 MHz and Stop to 100 MHz; this will automatically set the Centre to 60 MHz and Span to 80 MHz.
- **Step 3**: Set the resolution bandwidth to optimize the frequency resolution.
  - In the resolution bandwidth sub-panel, set the Mode to Manual and set the RBW to 1 MHz.
  - Set the window to flat top and leave the video filter off for now.
- **Step 4**: Enable averaging to increase the signal-to-Noise ratio.
  - In the averaging sub-panel, set the target frame rate to 5 /s.
  - Increase the frame averages to 35 using the slide bar or by manually entering the value.
- **Step 5**: Generate outputs to stimulate the device under test.
  - In the output panel, enable Output 1 at 10 MHz frequency, 1 Vpp amplitude, and 50 Ω termination.
  - Enable Output 2 at 1 kHz frequency, set the termination to Hi-Z then set the amplitude to 2 Vpp.

- **Step 6**: Configure measurements, math channel, and cursors to characterize the input signals.
  - In the measurements panel, select "Add a measurement", then select "In 1" and "Peak freq".
  - Add another measurement for In 2 and Peak level.
  - In the channel panel, enable the math channel and select "In 1 + In 2".
  - To add a power cursor, drag out to the right from the cursor icon.
  - To add a tracking cursor, drag the power cursor close to the peak, then right click on the cursor measurement, and select "Track peak" from the context menu.
- **Step 7**: Save and export data to record the results.
  - Select export data.
  - Save the traces, measurements, settings, and a screenshot to your device.

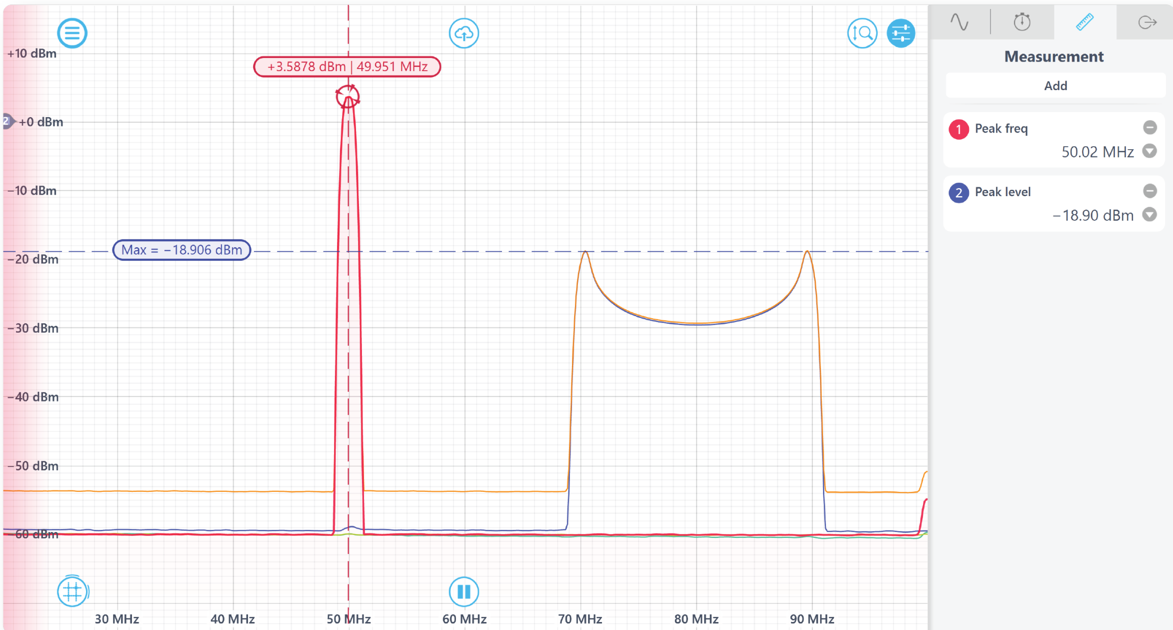


Figure 3. Screenshot of the Moku configured for a Spectrum Analyzer measurement showing the signal display area with cursors (left) and measurements panel (right).

System architecture

Spectrum Analyzers are essential test and measurement instruments in the lab. They are used to display and analyze signals in the frequency domain. Compared to the Fast Fourier Transform (FFT) function available in some Oscilloscopes, frequency-swept Spectrum Analyzers typically provide better spectral resolution while maintaining a large frequency span. However, Spectrum Analyzers can be much slower than the FFT-based approach, especially at a finer resolution. The Moku Spectrum Analyzer instrument uses a hybrid technique, which delivers the advantages of both approaches and balances the speed and frequency span.

Frequency domain signal analysis is an essential technique used to identify and separate unwanted noise from a signal of interest. Compared to time domain analysis, it's much easier to spot the noise and optimize the system to filter out the unwanted noise with frequency domain analysis.

Fast fourier transfer

The Fast Fourier Transform (FFT) is a mathematical algorithm that computes the frequency domain responses of a signal from the time domain trace. It is a standard built-in feature for many modern digital storage Oscilloscopes and provides a good first glance of the signal in the frequency domain. However, the spectral resolution (R) of the FFT is proportional to the sampling rate (Fs) divided by the number of FFT points (N). Since the maximum frequency displayed in the FFT spectrum is limited to half the sampling rate, a larger frequency span results in poorer resolution (i.e., a larger R), as demonstrated in the equations below.

$$R \propto \frac{Fs}{N} \tag{1}$$

$$FrequencySpan \propto Fs \tag{2}$$

$$\therefore R \propto FrequencySpan \tag{3}$$

This limits the FFT-based approach in characterizing finer details at high frequencies. To overcome the limitation of the FFT based approach, Moku Spectrum Analyzer digitally mixes the signal of interest with a local oscillator (LO) to bring the frequency of interest to near DC range, as shown in Figure 4.

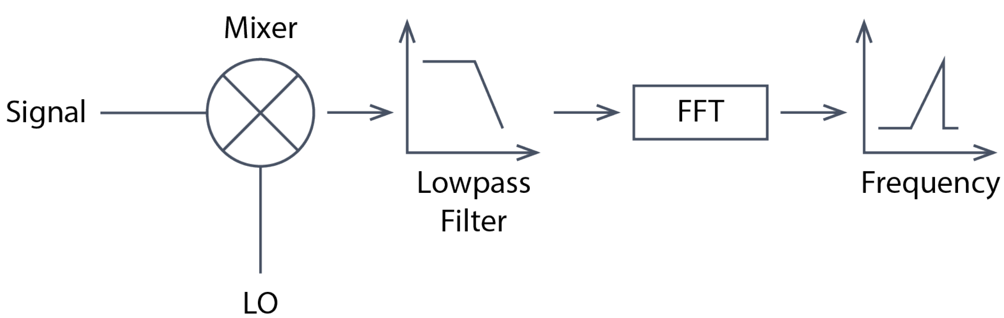


Figure 4. Signal processing flow of the Moku Spectrum Analyzer.

FFT performs best with smaller frequency spans. The pure FFT approach always starts the spectral window at 0 Hz, but the hybrid approach allows the starting point of the spectral window to be selected at any given frequency. Any part of the spectrum can then be analyzed with a narrow span. The spectral resolution is no longer limited by the upper frequency of the spectrum but rather is related to the frequency span, allowing for high resolution even at higher frequencies.

Cross correlation

Cross-correlation involves comparing two signals to identify similarities. By performing cross-correlation on two similar signals, uncorrelated noise (random noise) is effectively canceled out, while the correlated signal components are preserved. This process reduces the overall noise floor, allowing for clearer signal detection.

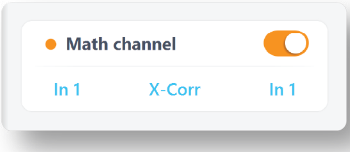


Figure 5. Math channel function cross-correlation (X-Corr) in the Moku Spectrum Analyzer.

The Moku Spectrum Analyzer has a Cross Correlation (X-Corr) function available in the math channel. A single cross-correlation is calculated as the product of the Fast Fourier Transform (FFT) of one signal and the complex conjugate of the FFT of the second signal. The calculations are performed entirely in the frequency domain, and the result has units of power while retaining phase information. There are visible effects of this when cross correlating a signal with itself i.e. **In1 X-Corr In1**; as the span increases, the noise floor shifts. There is a relationship between X-Corr and averaging; the more averages there are, the lower the noise floor, and the signal-to-noise ratio (SNR) improves.

Figure 6. Noise floor and SNR measurements (right) of the cross-correlation channel.

Essentially, cross-correlation is the measurement of how well two independent signals resemble each other, a concept also known as cross-similarity. A similar technique, called autocorrelation, applies when a signal is being matched to a lagged version of itself.

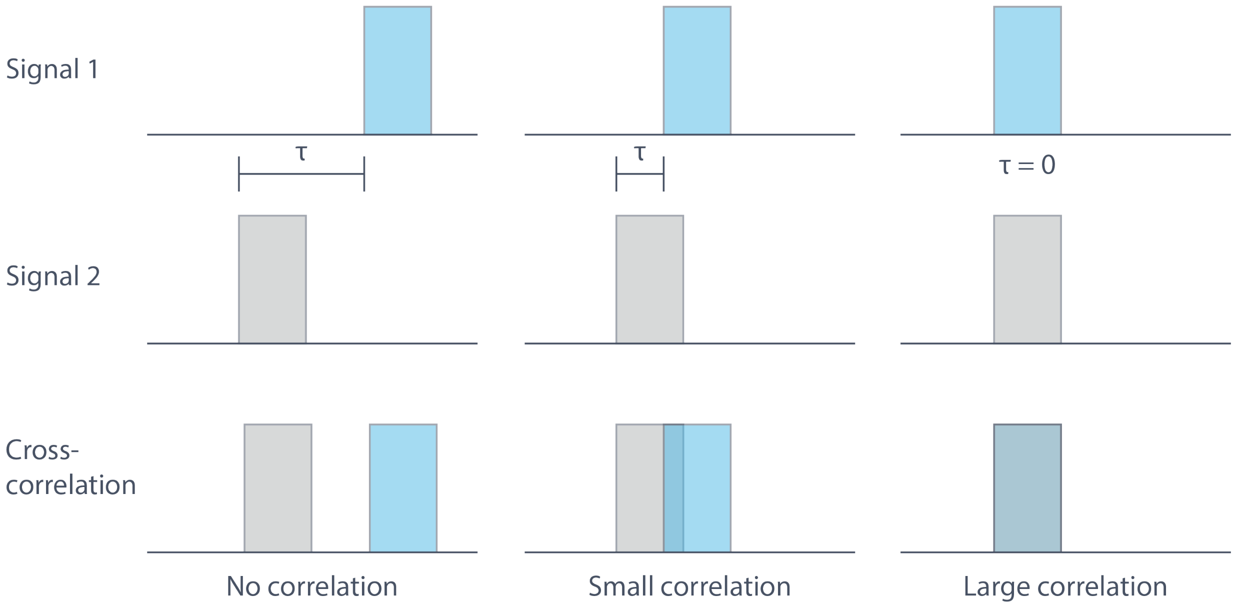


Figure 7. Correlation of signals with various time delays.

In the time domain, cross-correlation is defined as the integral of the product of two signals, with one signal typically offset by a variable time delay τ. The resulting cross-correlation is expressed as a function of this delay. Figure 7 shows a visual example for several values of τ. In the frequency domain, cross-correlation is computed by taking the FFT of each signal, multiplying one by the complex conjugate of the other to produce a cross-spectrum. This cross-spectrum retains phase information and can, in theory, be transformed back to the time domain using an inverse FFT.

Applications for cross-correlation

Phase noise analysis: The phase noise measurement of an unknown oscillator can often be limited by the added noise of the measurement electronics themselves. To solve this challenge, the device can be fed into two different demodulation channels. Performing cross-correlation analysis on the two resulting signals can remove the uncorrelated noise added by the separate local oscillators while preserving the correlated noise, which is the figure of interest. This allows for the measurement of phase noise lower than the measurement device itself.

Time-delay estimation: The cross-correlation function between two similar signals produces an amplitude maximum when the two signals are matched in time. This is a valuable feature in applications such as determining range or time-of-flight in radar measurements, or synchronizing signals in telecommunications.

Signal analysis: Use cross-correlation to analyze radar, sonar, seismic, and other signals. Comparing an incoming signal to a known template can help detect events below the noise threshold, extract information, or identify specific events.

Resolution bandwidth

The resolution bandwidth (RBW) defines the spectral resolution of the spectrum analysis. It is determined by the number of points that are used for the FFT and the window function applied to the signal prior to calculating the FFT. A narrower RBW provides better spectral resolution.

A narrower RBW can also improve the signal-to-noise ratio (SNR) by reducing the noise bandwidth, or noise floor, which helps in detecting weak signals.

Averaging

Averaging is another method to improve the signal-to-noise ratio. This method improves the signal-to-noise ratio by averaging multiple frames of data. Averaging is recommended when capturing relatively stable features and when it does not reduce the resolution of the spectra.

The video filter smooths the spectrum by averaging adjacent pixels on the displayed spectrum. It is a postprocessing technique and does not affect the on-board spectrum acquisition process. A larger video filter will produce smoother spectra at the expense of poorer frequency resolution and can reduce the amplitude of narrow spectral features.

Target frame rate

Setting the target frame rate allows for averaging calculations to be performed on the Moku. This allows for faster processing of averages compared to the frame averages slide bar. The calculation from frame speed to spectra per frame is dependent on the span and RBW, and the result can be seen in the averaging sub-panel.

Factors that influence noise floor

Reducing the noise floor of the Spectrum Analyzer improves the ability to detect weak signals that might otherwise be obscured by noise.

SNR vs noise floor: SNR is a measure of the strength of a signal relative to the background noise level. It is typically expressed in decibels (dB). The noise floor sets the baseline for the lowest signal level that can be detected. Therefore, a lower noise floor allows for the detection of weaker signals, effectively improving the SNR.

RBW: The noise floor is influenced by the RBW, which defines the width of the frequency band over which the noise power is measured. A narrower RBW results in a lower noise floor because it reduces the noise power by limiting the bandwidth over which noise is integrated.

Span: As the span decreases, so can the RBW. The frequency span determines the range of frequencies displayed by the Spectrum Analyzer. A narrower span allows for a finer RBW, which in turn lowers the noise floor. This is because the noise power is spread over a smaller frequency range, reducing the total noise power within the RBW.

Averaging: Averaging multiple measurements helps to reduce the impact of random noise. Since noise is typically random and uncorrelated, averaging tends to cancel out the noise components, leading to a lower noise floor.

Cross-correlation: In cross-correlation measurements, averaging the results of cross correlations helps to reduce the noise floor. By performing cross-correlation on two similar signals, uncorrelated noise is cancelled out and averaging these results minimizes the noise variance.

Input range: The amount of attenuation applied through the analog frontend affects the noise floor. For example, with 20 dB attenuation, the maximum detectable signal without clipping is 10x larger than in a no-attenuation scenario. This implies that the equivalent noise power also increases by a factor of 10 as the input range expands. Selecting the input range that is as close to the signal without clipping will provide the best results in reducing the noise floor whilst maintaining your signal quality.

Converting between displayed units

The Moku Spectrum Analyzer can display the spectrum amplitude in various units (dBm, Vrms, Vpp, and dBV). Additionally, you can select corresponding power spectral density (PSD) units (dBm/Hz, Vrms/√ Hz, Vpp/√Hz, and dBV/√ Hz). It is worth noting that the RBW setting only affects the measurement in PSD units.

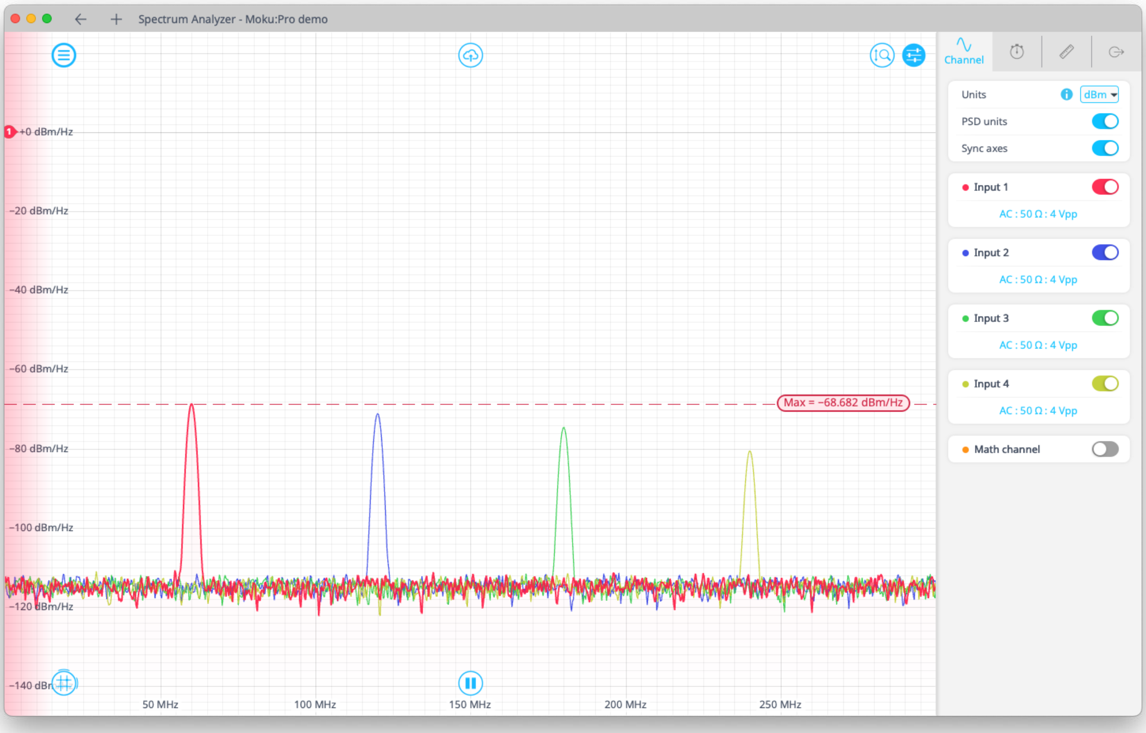


Figure 8. Spectrum Analyzer with dBm PSD units (dBm/Hz)

Figure 8 is an example from demo mode, where the channel 1 peak is shown at -68.68 dBm/Hz.

This can be converted to Vrms/√Hz by relationship

$$P[mW/Hz] = 10^{(P[dBm/Hz]/10)} \tag{4}$$

So in this case,

$$P = 1.355 \cdot 10^{-7} mW/Hz \tag{5}$$

Also, $V = \sqrt{P \cdot R}$ and here 50 Ω is the conventional nominal impedance, so $R = 50\Omega$.

Thus the spectral peak in volts, allowing for conversion from mW to W, is

$$V = \sqrt{1.35 \cdot 10^{-10} \cdot 50} = 82.31 \mu V/\sqrt{Hz} \tag{6}$$

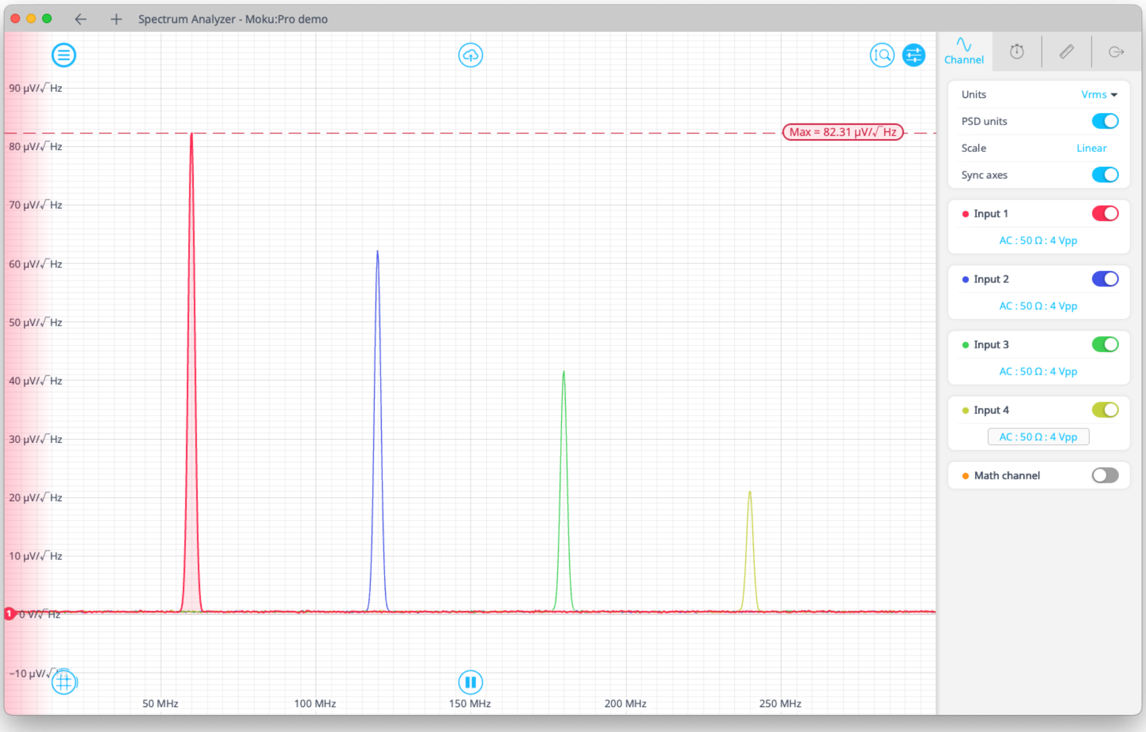


Figure 9. Spectrum Analyzer with Vrms PSD units (µV/√Hz)

In this second screenshot of the Spectrum Analyzer in demo mode, the units have been switched to µV/√Hz, where the peak measurement matches our calculation.

Using the instrument

The controls options can be accessed by clicking the icon, allowing you to reveal or hide the control drawer, giving you access to all instrument settings. The controls drawer gives you access to channel, frequency, and output settings.

User interface

Figure 10. Spectrum Analyzer user interface with an open control drawer (right).

① Main menu
② Save data
③ Controls
④ Control drawer; channels, frequency, measurements, and outputs
⑤ Play/Pause
⑥ Cursors
⑦ Signal display area
⑧ Reference position indicator

Display

This area is intended to display the spectrum of input and math channels, where the horizontal axis is the measured frequency range and the vertical axis is the power or power spectral density (PSD) in linear or log scales.

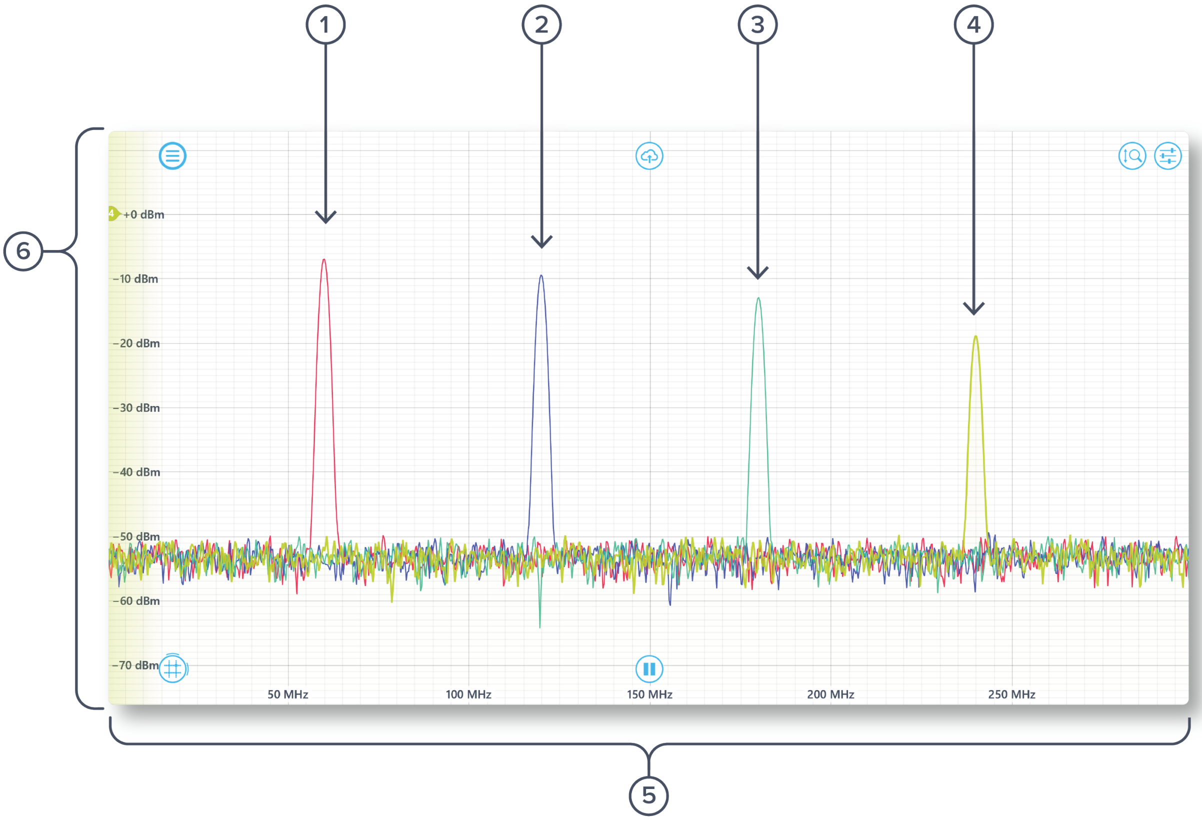


Figure 11. Spectrum Analyzer signal display area

① Spectrum for input channel 1.
② Spectrum for input channel 2.
③ Spectrum for input channel 3.
④ Spectrum for input channel 4.
⑤ Frequency axis: shows the frequency scale for all channels.
⑥ Power axis: shows the power scale for the active channel*.

The scales of both axes can be adjusted with pinching gestures on the Moku iPad app or by scrolling on the Moku desktop app.

*The shaded color near the vertical axis indicates the active channel.

Magnifying glass

Figure 12. Magnifying glass

Vertical scale

The vertical scale can be controlled using pinch and pan actions (on iPad) or click and scroll (on desktop) in the graph area while the magnifying glass is set to "Vertical zoom" .

Horizontal scale

The horizontal scale can be controlled using pinch and pan actions (on iPad) or click and scroll (on desktop) in the graph area while the magnifying glass is set to "Horizontal zoom" .

Rubber-band zoom

Both the vertical and horizontal axes can be set simultaneously, allowing you to select the area you would like to zoom to by selecting "Rubber-band zoom" and drawing a rectangle around the area.

Channels

The channels pane ∿ allows you to change the input settings for each ADC channel, adjust the input scales and coupling, and enable/disable the math channel.

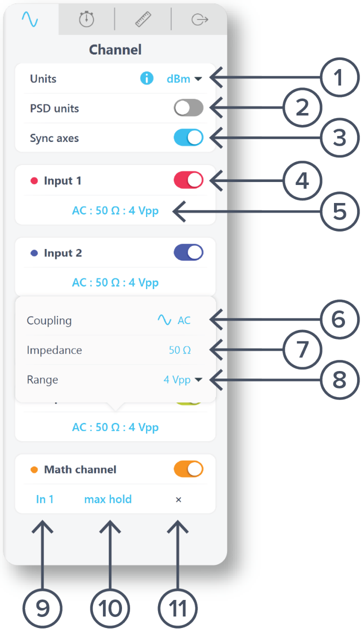


Figure 13. Channel settings panel.

① Select the vertical axis scale (dBm, Vrms, Vpp, dBV), see Converting between displayed units.
② Toggle to enable or disable PSD units (dBm/Hz, Vrms/√ Hz, Vpp/√Hz, and dBV/√ Hz).
③ Toggle to sync the vertical axes.
④ Toggle to enable/disable the input spectrum for Input 1.
⑤ Click to change the frontend settings of Input 1.
⑥ Select the input coupling of the input channel (DC or AC).
⑦ Select the input impedance of the input channel (50 Ω or 1 MΩ).
⑧ Select the input range of the input channel.
⑨ Select input for the math channel.
⑩ Select operations.
⑪ Click to reset hold.

Math channel

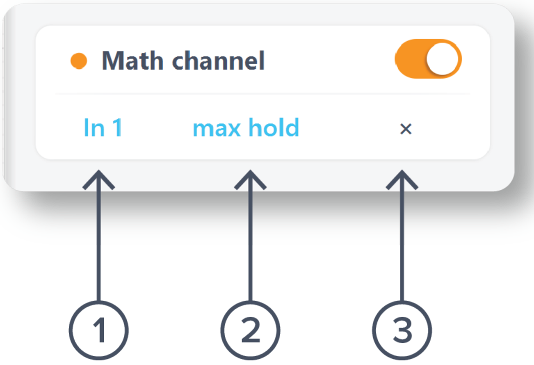


Figure 14. Spectrum Analyzer math channel.

① Select input.
② Select operations.
③ Click to reset hold.

Five operations are currently supported on the Spectrum Analyzer math channel: +, ×, min hold, max hold and X-Corr. To read more about cross-correlation, see Cross correlation.

Frequency

The frequency panel allows you to change parameters related to the frequency domain (horizontal axis), including frequency span, RBW, and video bandwidth.

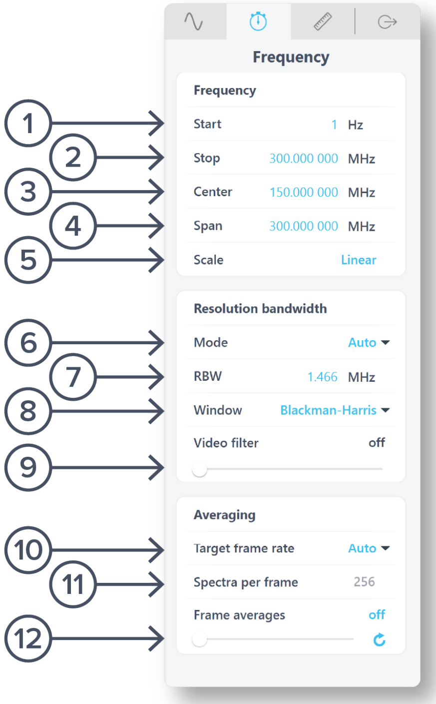


Figure 15. Frequency settings panel.

① Enter the start/lower frequency of the Spectrum Analyzer measurement.
② Enter the stop/higher frequency.
③ Enter the center frequency.
④ Enter the span of the frequency.
⑤ Select between a linear or logarithmic scale for the horizontal axis.
⑥ Select the RBW mode (Auto, Manual, or Min)*.
⑦ Click to manually set the desired RBW value.
⑧ Select the window function**.
⑨ Move the slider to set the corner of the video filter.
⑩ Select the target frame rate, Auto or manually.
⑪ Spectra per frame.
⑫ Move the slider to set the number of frame averages.

Note that [Start, Stop] and [Center, Span] in the frequency panel are equivalent representations of the measured frequency range. Moku will automatically update the other pair if one is changed.

* Auto: determines the best resolution based on the span; Manual: manually sets the RBW of the Spectrum Analyzer; Min: uses the smallest RBW available.

** Available options: Blackman-Harris, Flat top, Rectangular, Bartlett, Hamming, Hann, Nuttall, Gaussian, and Kaiser.

Output

The output panel allows you to configure the integrated sine wave generator for the Spectrum Analyzer.

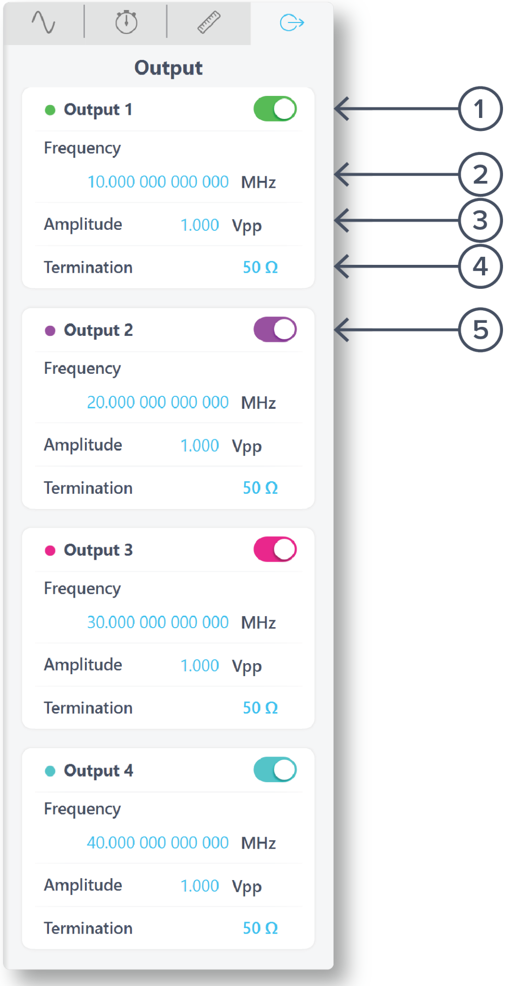


Figure 16. Output settings panel.

① Toggle to enable output sinusoidal signal on Output 1.
② Enter the frequency of the output signal.
③ Enter the amplitude of the output signal.
④ Toggle the output termination.
⑤ Toggle to enable output sinusoidal signal on Output 2.

Spectrum trace

Right click the spectrum trace to reveal additional viewing options:

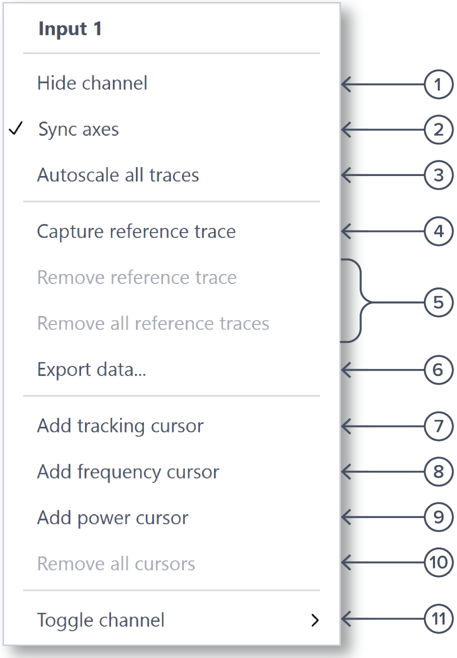


Figure 17. Channel spectrum context menu

① Click to hide the spectrum trace
② Toggle sync vertical axes
③ Click to auto scale all traces on the vertical axes
④ Click to set and display the current spectrum as a reference trace
⑤ Select to update, remove or remove all reference traces
⑥ Click to export the trace data
⑦ Click to add a tracking cursor
⑧ Click to add a frequency cursor
⑨ Click to add a power cursor
⑩ Click to remove all cursors
⑪ Select to toggle the displayed channels

Spectrum trace (iPad only)

Press and hold the spectrum trace to reveal additional viewing options.

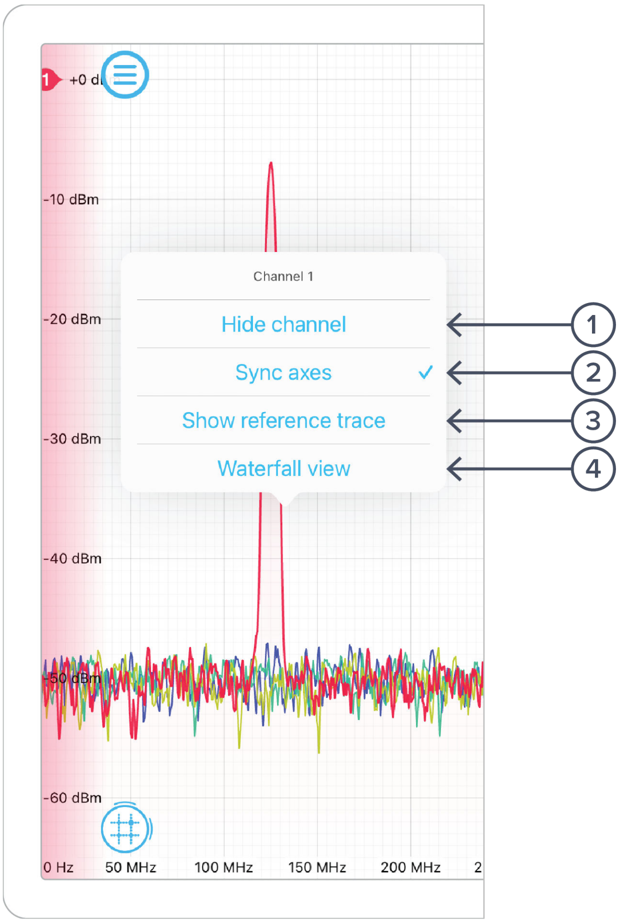


Figure 18. Channel spectrum context menu (iPad only)

① Tap to hide the spectrum trace.
② Tap to toggle sync vertical axes.
③ Tap to set and display the current spectrum as a reference.
④ Tap to show the waterfall view.

Waterfall view (iPad only)

Use the waterfall view to visualize the spectrum variation over time. Use finger gestures to adjust the scales and viewing angle.

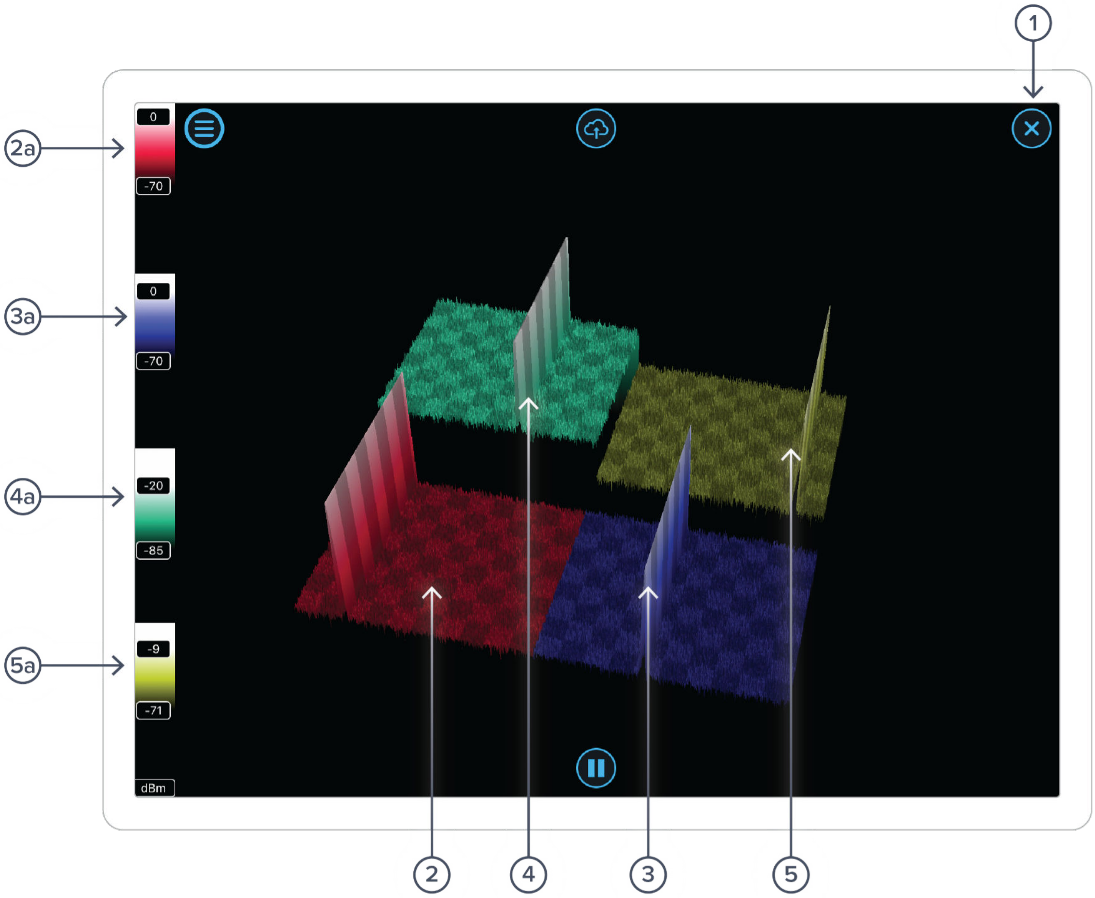


Figure 19. Waterfall view user interface.

① Tap to close the waterfall view.
② Waterfall view for input 1.
(2a) Color scale for input 1.
③ Waterfall view for input 2.
(3a) Color scale for input 2.
④ Waterfall view for input 3.
(4a) Color scale for input 3.
⑤ Waterfall view for input 4.
(5a) Color scale for input 4.

Measurements and cursors

Measurements

The measurements can be accessed by clicking the icon in the controls drawer of the desktop app, or pressing the icon in the bottom right corner of the iPad app, allowing you to add/remove measurements to probe a spectra's peak level, peak frequency, power, etc. The measurement function operates on a per channel or per markers basis.

Figure 20. Measurements desktop

① Click to add measurements.
② Source channel.
③ Measurement type.
④ Measurement reading.
⑤ Click to show measurements statistics.
⑥ Statistics include mean, minimum, maximum, standard deviation, and count.
⑦ Click to remove measurement card.

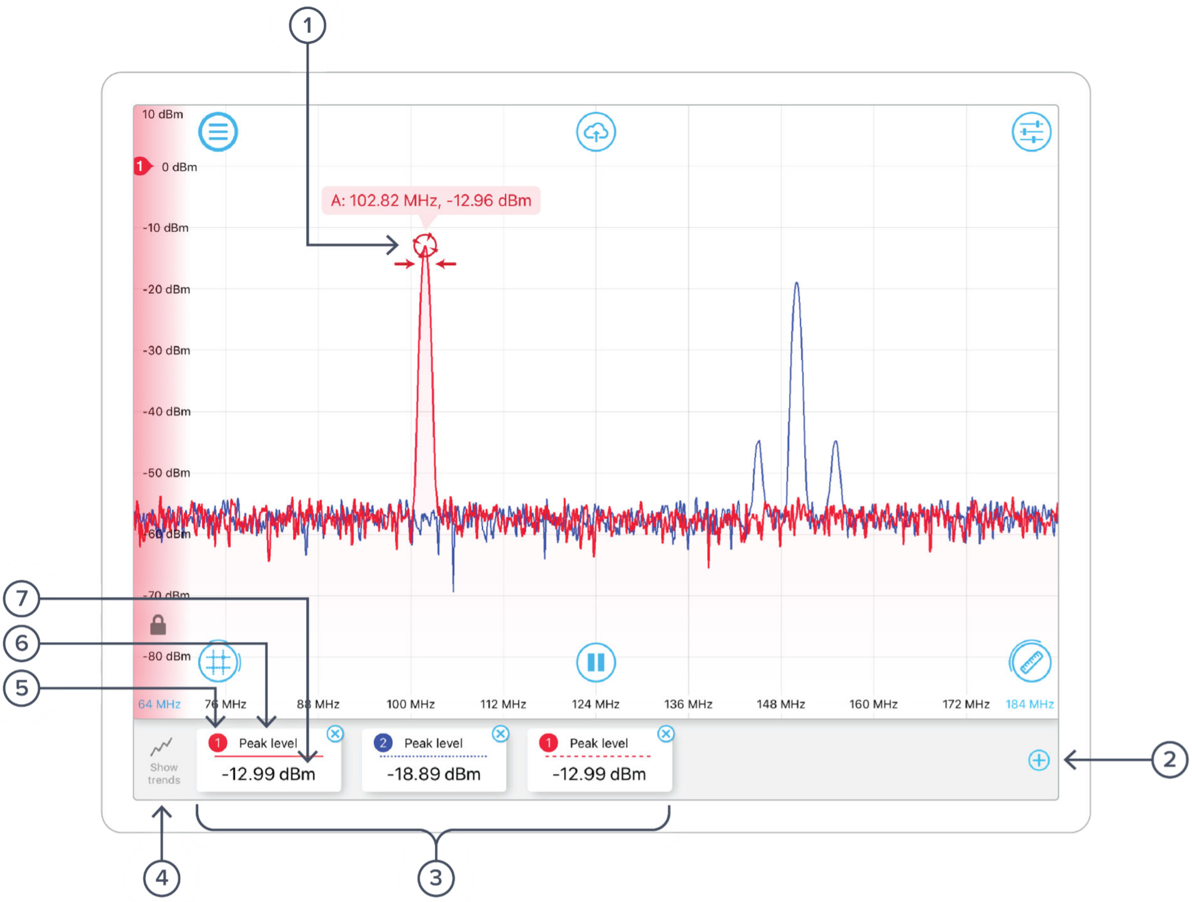


Figure 21. Measurements iPad

① Measurement marker, tap to reveal additional options.
② Tap to add measurements.
③ List of current measurement cards, tap to reveal additional options.
④ Tap to show measurements trends.
⑤ Source channel.
⑥ Measurement type.
⑦ Measurement reading.

Additional measurements (iPad only)

Note that measurement markers can be added by dragging the measurement icon to snap on the input signal. In addition, a plot of measurements vs. time can be accessed by tapping the "show trends" button.

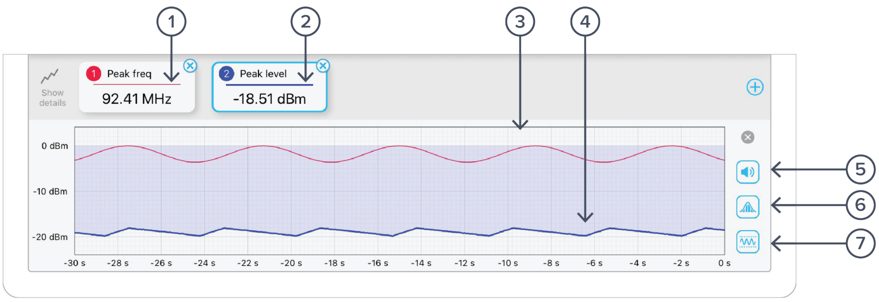


Figure 22. Additional iPad measurements.

① Trend line style for tile 1.
② Trend line style for tile 2.
③ Trend line for tile 1.
④ Trend line for tile 2.
⑤ Tap to enable/disable audio.
⑥ Tap to enable/disable statistics.
⑦ Tap to enable/disable adjusted Y-axis scale.

Measurement tile options

Measurement tile options can be revealed by simply clicking or tapping the tile. Users can select to measure peak level, peak frequency, noise level, peak signal-to-noise ratio (peak SNR), and occupied bandwidth (occupied BW) of a selected channel or marker.

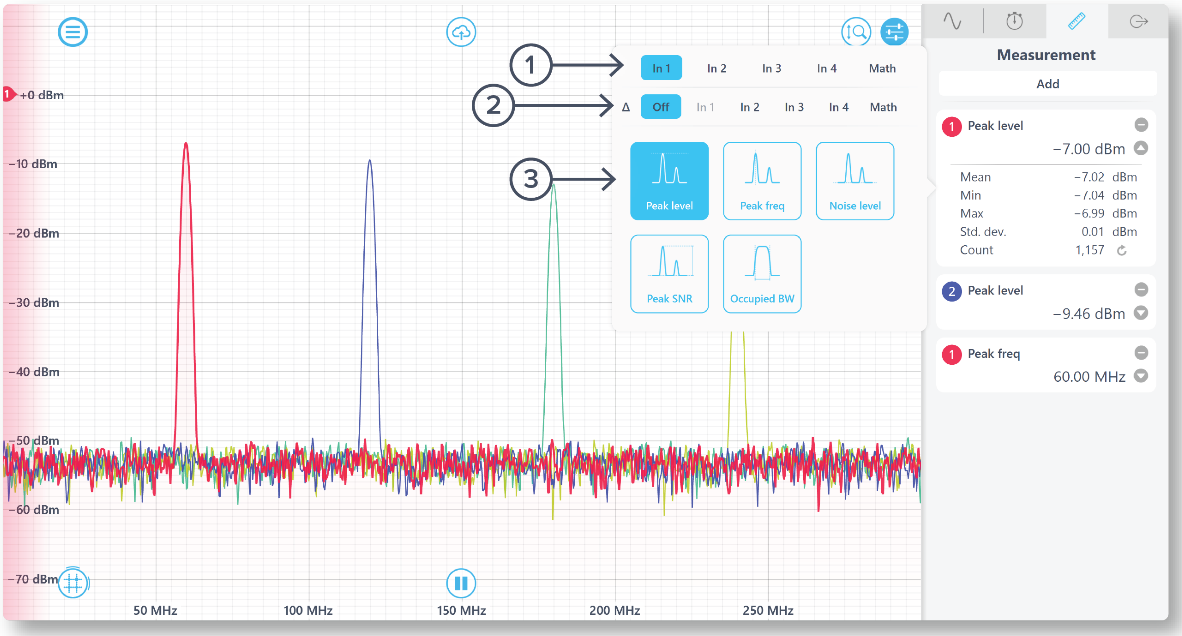


Figure 23. Options for measurements from channels for desktop

① Select measurement source.
② Select to measure the difference between channels.
③ Select measurement type.

Measurement tile options (iPad only)

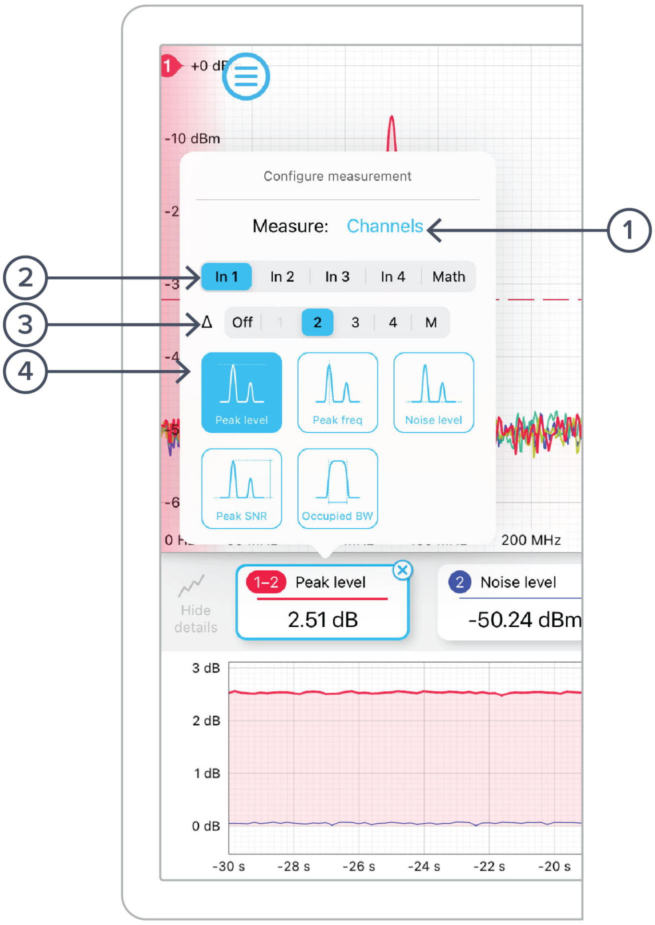


Figure 24. Options for measurements from channels for iPad

① Tap to switch to measurements from markers.
② Tap to select measurement source.
③ Tap to measure the difference channels.
④ Tap to select measurement type.

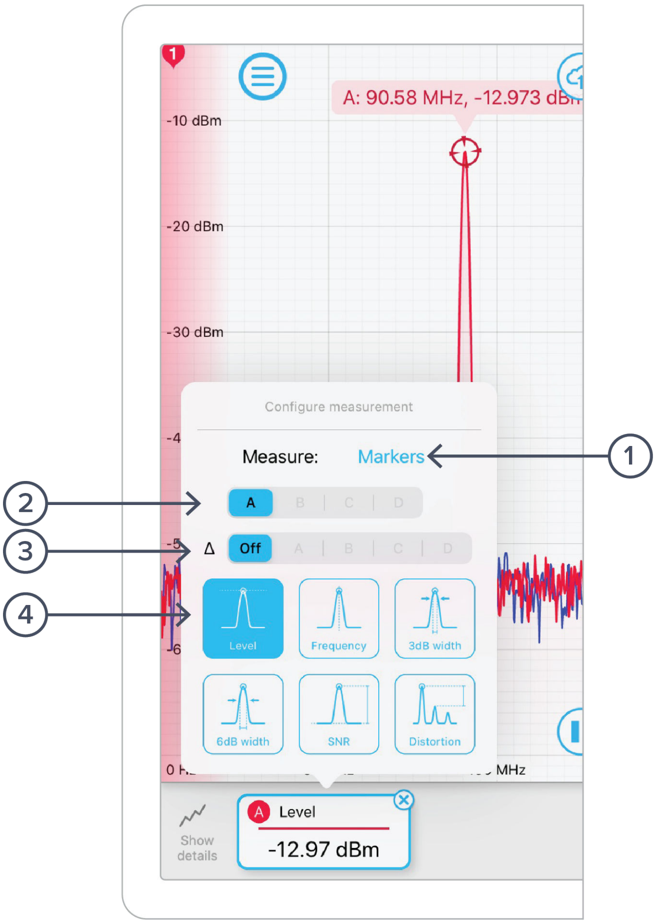


Figure 25. Options for measurements from markers (iPad only)

① Tap to switch to measurements from channel (iPad only).
② Tap to select measurement source.
③ Tap to measure the difference between markers.
④ Tap to select measurement type.

Measurement marker options (iPad only)

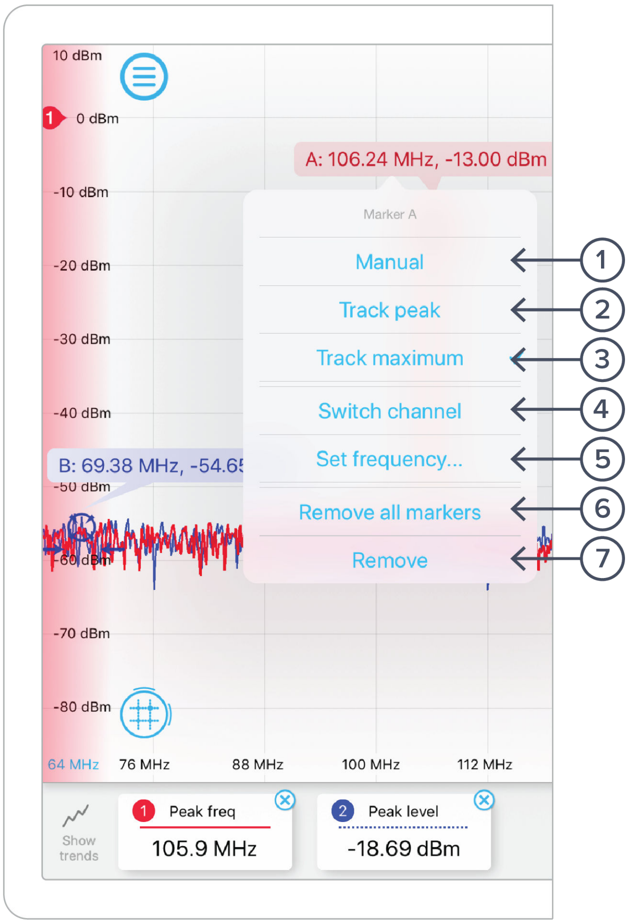


Figure 26. Measurement marker context menu. (iPad only)

Measurement marker options can be revealed by simply tapping the markers. Users can select to set the marker to track the peak, track the maximum, and other options.

① **Manual** Tap to set marker position manually.
② **Track peak** Tap to set marker to the frequency of the closest peak / spur.
③ **Track maximum** Tap to set marker to the frequency of the maximum power. The marker is updated in real-time.
④ **Switch channel** Tap to switch the channel that the marker measures.
⑤ **Set frequency** Tap to set the marker to measure the amplitude of a particular frequency.
⑥ **Remove all markers** Tap to remove all active markers.
⑦ **Remove** Tap to remove the currently selected marker.

Cursors

The cursors can be accessed by clicking the icon, allowing you to add power or frequency cursors on the display.

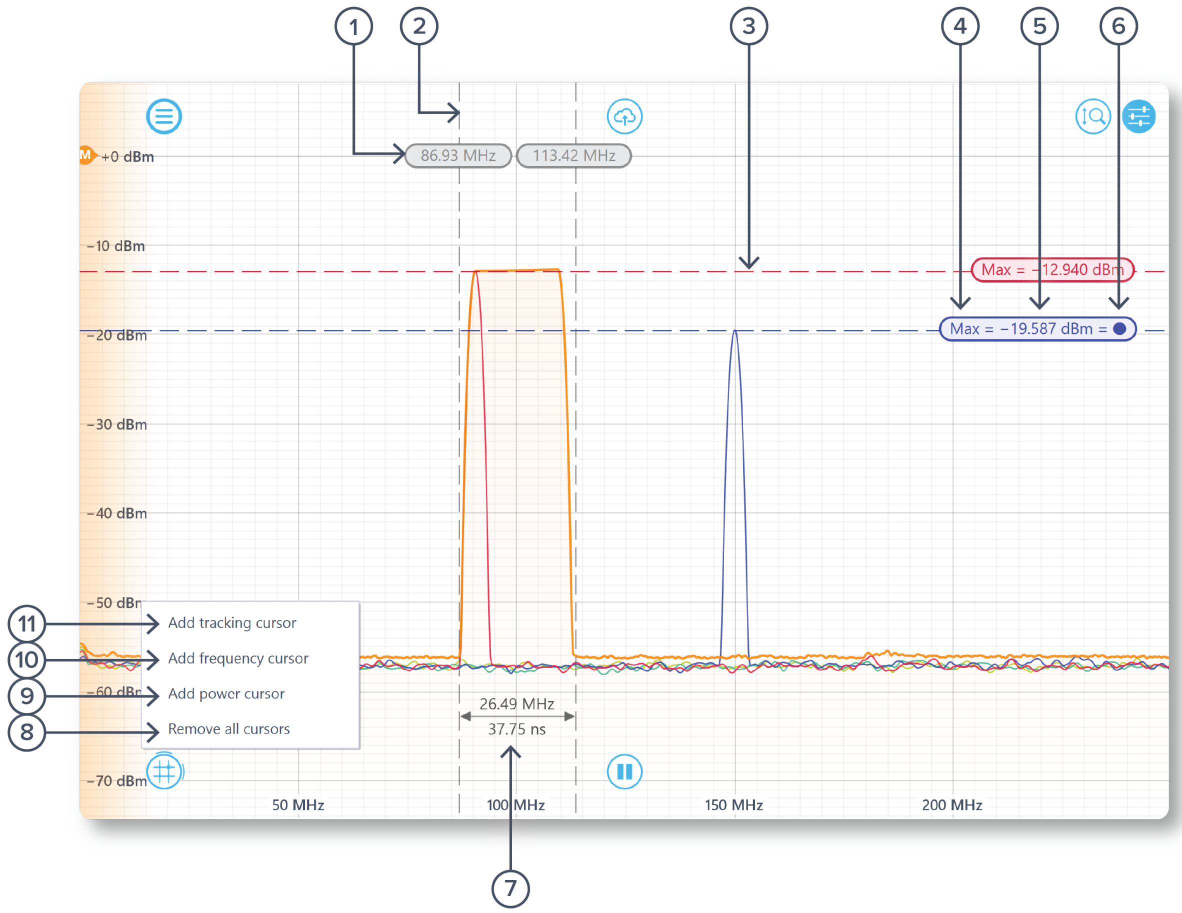


Figure 27. Cursor actions and context menu.

① **Frequency reading** Click to enter frequency, right-click to reveal frequency cursor options.
② **Frequency cursor** Drag left or right to set positions.
③ **Power cursor** Drag up or down to set positions. Color represents the channel of the measurement.
④ **Cursor function** Indicates the current cursor function (max, min, max hold, etc).
⑤ **Power reading** Click to enter power, right-click to reveal power cursor options.
⑥ **Reference indicator** Indicates the cursor is set as reference.
⑦ **Frequency difference** Represents the frequency difference between two cursors. This will show up automatically when you have two frequency cursors placed.
⑧ **Remove all cursors** Click to remove all power and frequency cursors.
⑨ **Add power cursor** Click to add a cursor measuring the vertical position.
⑩ **Add frequency cursor** Click to add a cursor measuring the horizontal position.
⑪ **Add tracking cursor** Click to add a cursor measuring the horizontal position, frequency, whilst tracking the vertical position, power value, at that frequency.

Power cursor

Select the cursor reading to enter a power value. Right click the cursor reading to reveal additional power cursor options.

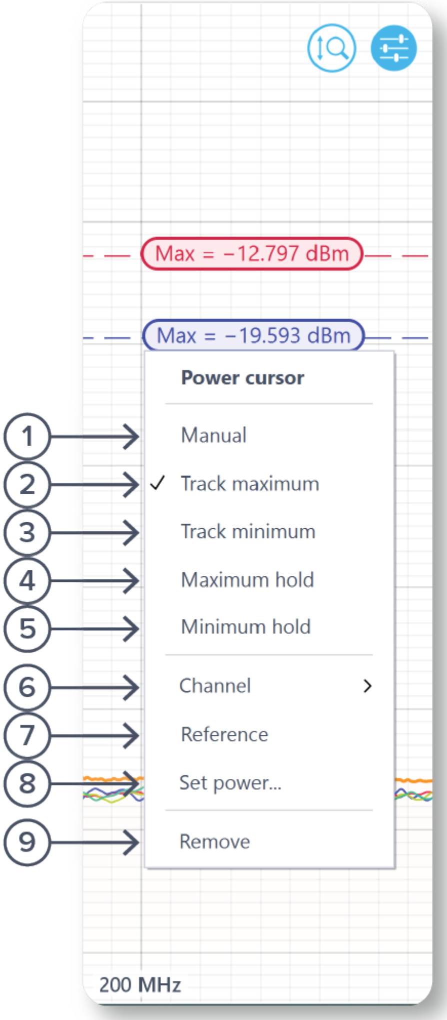


Figure 28. Power cursors and context menu.

① **Manual** Click to manually set the vertical position of the cursor.
② **Track maximum** Click to set the cursor to track the maximum power.
③ **Track minimum** Click to set the cursor to track the minimum power.
④ **Maximum hold** Click to set the cursor to the maximum power of previous traces.
⑤ **Minimum hold** Click to set the cursor to the minimum power of previous traces.
⑥ **Channel** Select to change the channel that the cursor measures.
⑦ **Reference** Click to set the cursor to act as a vertical reference value. When this option is selected, all other cursors will display the difference between the cursor and the reference cursor's value.
⑧ **Set power** Click to set the power cursor at specific power.
⑨ **Remove** Click to remove the selected cursor.

Frequency cursor

Select the cursor reading to enter a frequency value, right click the cursor reading to reveal additional frequency cursor options.

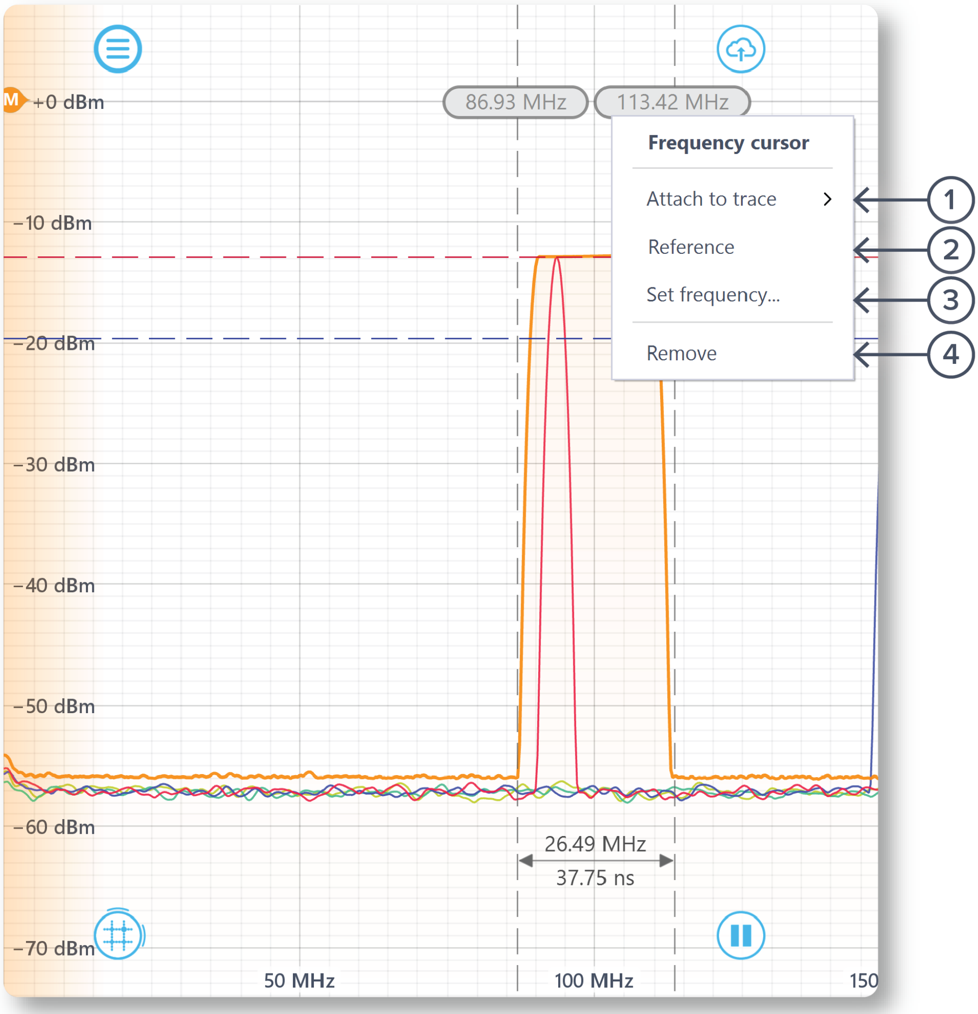


Figure 29. Frequency cursors and context menu.

① **Attach to trace** Create a tracking cursor that displays the power of the selected trace at the specified frequency.
② **Reference** Click to set the cursor to act as a horizontal reference value. When this option is selected all other cursors will display the difference between the cursor and the reference cursor's value.
③ **Set frequency** Click to position the cursor at the entered frequency.
④ **Remove** Click to remove the cursor from display.

Examples

Cross correlation example

Here we outline how to perform a cross correlation measurement in the Spectrum Analyzer. This example will showcase how cross correlation can reduce the noise floor and increase the signal-to-noise ratio (SNR).

In this example, we used a second Moku Waveform Generator to simulate two signals; a 200 MHz, 1 Vpp sine wave was used as the signal on Input 1, and a 200 MHz, 500 mVpp sine wave was used as the signal on Input 2.

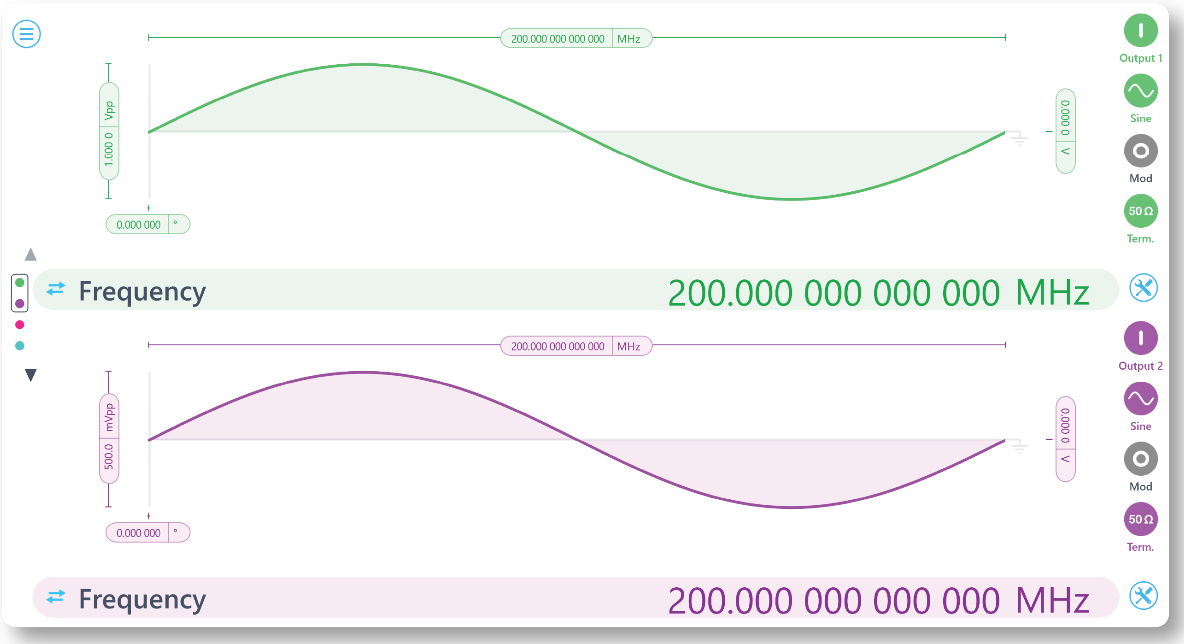


Figure 30. Signals for cross-correlation

- **Step 1: Configure the channel settings**
  - In the channel panel, set the units to dBm and enable sync axes.
  - Enable each input and set the frontends to AC coupling, 50 Ω impedance, and 4 Vpp range.
  - Note: These are the default settings of the instrument.
- **Step 2: Configure the frequency and acquisition**
  - Switch to the frequency panel and ensure the scale is set to "Linear" in the sub-panel.
  - Set start to 0 Hz and stop to 300 MHz; this will automatically set the centre to 150 MHz and span to 300 MHz.
  - Note: These are the default settings of the instrument.
- **Step 3: Configure the math channel to enable cross-correlation**
  - In the channel panel, enable the math channel and select "In 1 XCorr In 2".
- **Step 4: Configure measurements to analyze the signal**
  - In the measurements panel, select "Add a measurement".
  - Click on the measurement tile then select "In 1" and "Peak SNR". Repeat this for In 2 and the math channel.

- Add another measurement then select "In 1" and "Noise floor" . Repeat this for In 2 and the math channel.
- **Step 5: Interpret the results**
  - Observing the measurements, the cross correlation channel has a lower noise floor than channel 1 and channel 2. The signal to noise ratio (SNR) is also higher for the math channel than it is for either input.

Table 1. Cross-correlation results

	Input 1	Input 2	X-Corr
Peak SNR (dB)	62	56	70
Noise Level (dBm)	-58	-58	-68

- Select Export data .
- Save the traces, measurements, settings, and a screenshot to your device.

Figure 31. Moku Spectrum Analyzer cross correlation measurement

Additional controls

Live data

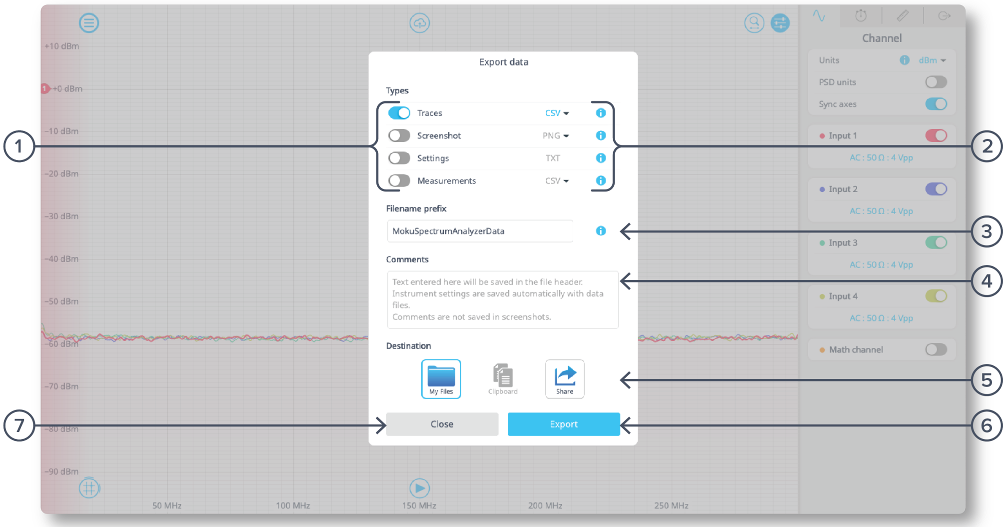


Figure 32. Live data exporting user interface and settings.

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.
- **Measurements** Saves the active measurement values, in either a CSV or MAT-file format.

② Select the **export format**.

③ Select the **Filename Prefix** for your export. This is defaulted to “MokuSpectrumAnalyzerData” and can be changed to any filename of alphanumeric characters and underscores. A timestamp and the data format will be appended to the prefix to ensure the filename is unique.

For example: “MokuSpectrumAnalyzerData_YYYYMMDD_HHMMSS_Traces.csv”

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

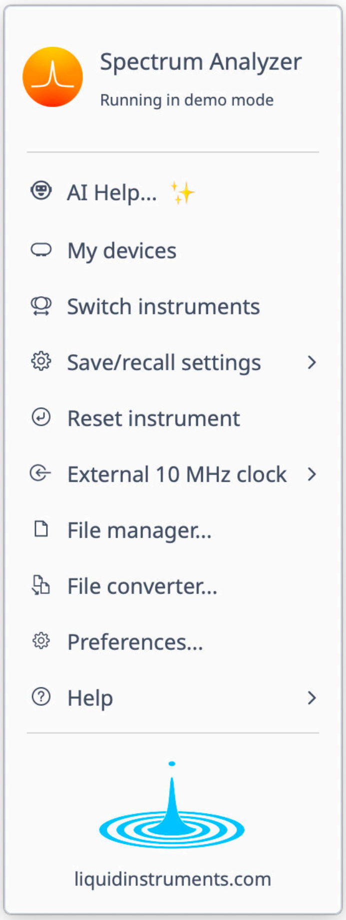
⑤ Select the export **Destination** on your local computer. If "My files" or "Share" is chosen, the exact location is selected when the Export button is clicked. Multiple export types can be exported simultaneously using My Files and Share, but only one export type can be exported to the clipboard at a time.

⑥ **Export** the data, or

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

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.

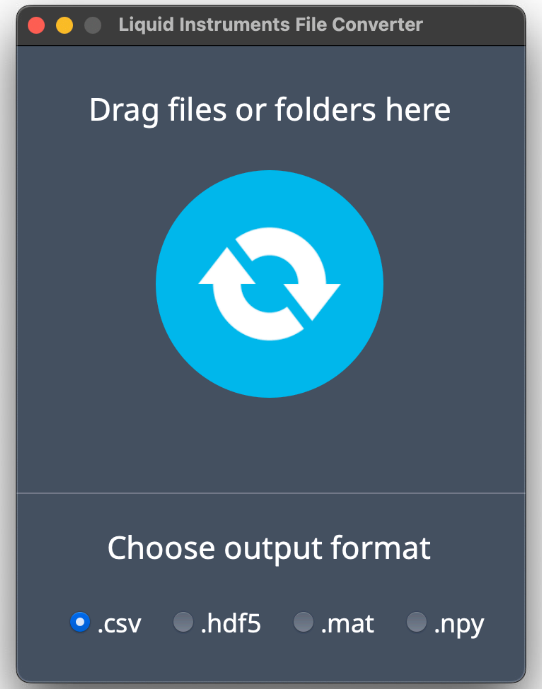


Figure 32: File Converter user interface.

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.

File manager

The File manager allows you to download the saved data from your Moku device to the local computer, with optional file format conversion. Once a file is transferred to the local computer, an icon appears next to the file.

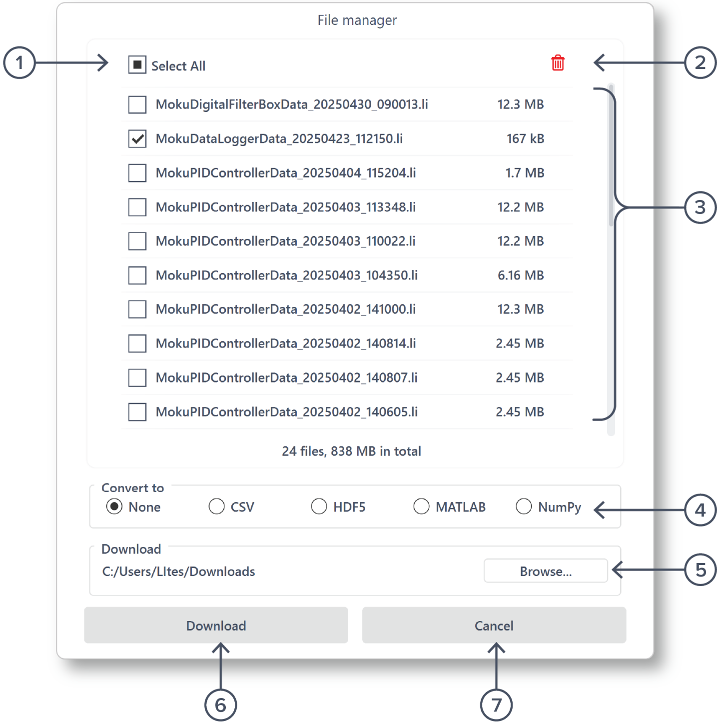


Figure 33. File exporting User Interface and settings.

To save logged data:

① **Select all** files logged to the device's memory, to download or convert.
② **Delete** all 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.

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.

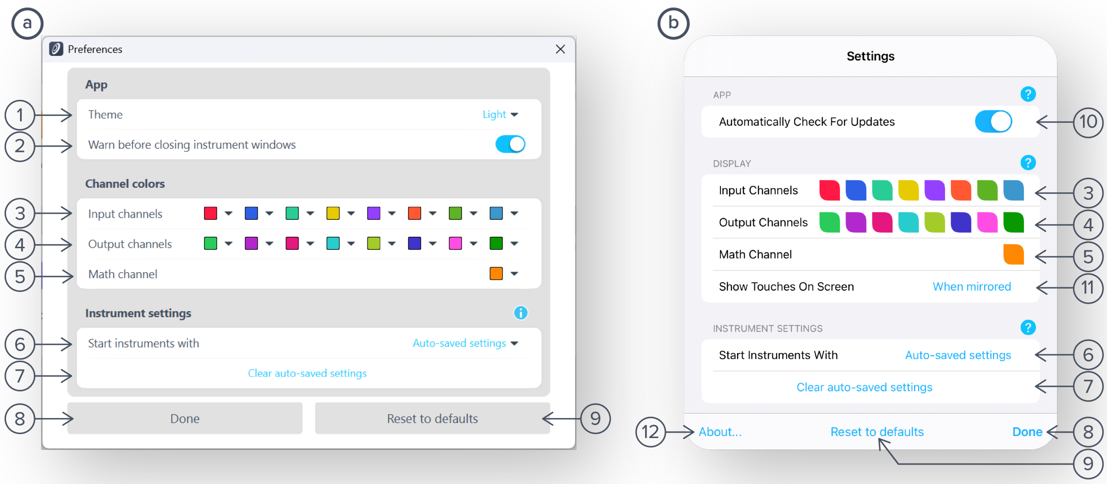


Figure 34. Preferences and settings for the Desktop (a) and for the iPad (b) App.

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.

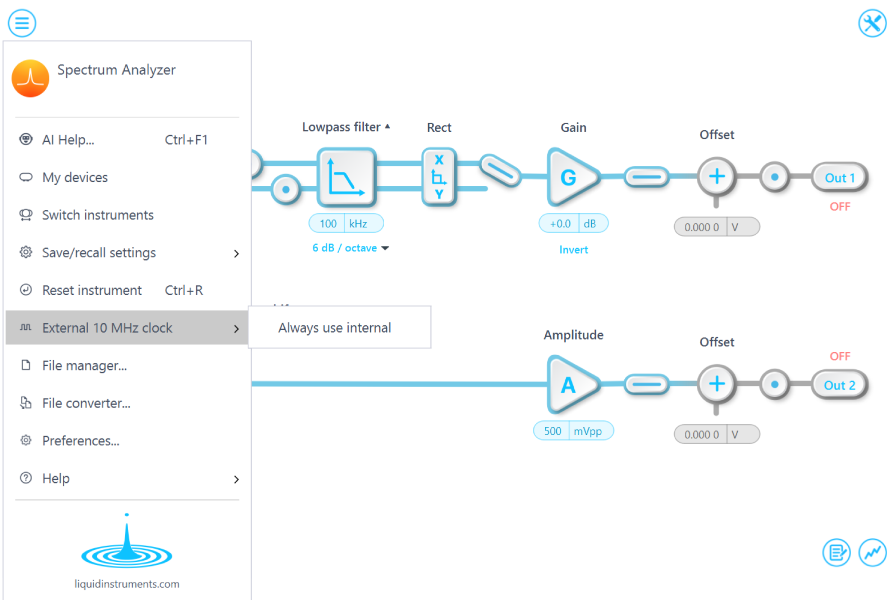


Figure 35. Moku main menu with "Always use internal" reference disabled and using an external reference.

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 36, 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 36. 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).