Moku Waveform Generator

User Manual

LIQUID INSTRUMENTS

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Introduction

The Moku Waveform Generator is designed to generate common waveforms with high accuracy and easily configurable across multiple independent output channels. The outputs are precisely adjustable for frequency, phase, and amplitude. Further, the outputs may be modulated with a variety of internally generated or external signals and triggered from flexible, programmable triggers.

The Moku Waveform Generator provides configurable sine, square, ramp, pulse, noise, and DC waveforms, along with a wide range of modulation options. These include frequency modulation (FM), amplitude modulation (AM), phase modulation (PM), pulse width modulation (PWM), burst modulation, and sweep modulation. Modulation sources can be selected from an internally generated sine wave with configurable frequency, any input, the external trigger (hardware dependent), or another output, enabling cross-channel modulation. Users can synchronize waveform phases across different channels. The Moku Waveform Generator features an ultra-stable timebase, with an external clock reference input available to further enhance stability (hardware dependent).

Below we provide a guide to the underlying architecture of the instrument. 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.

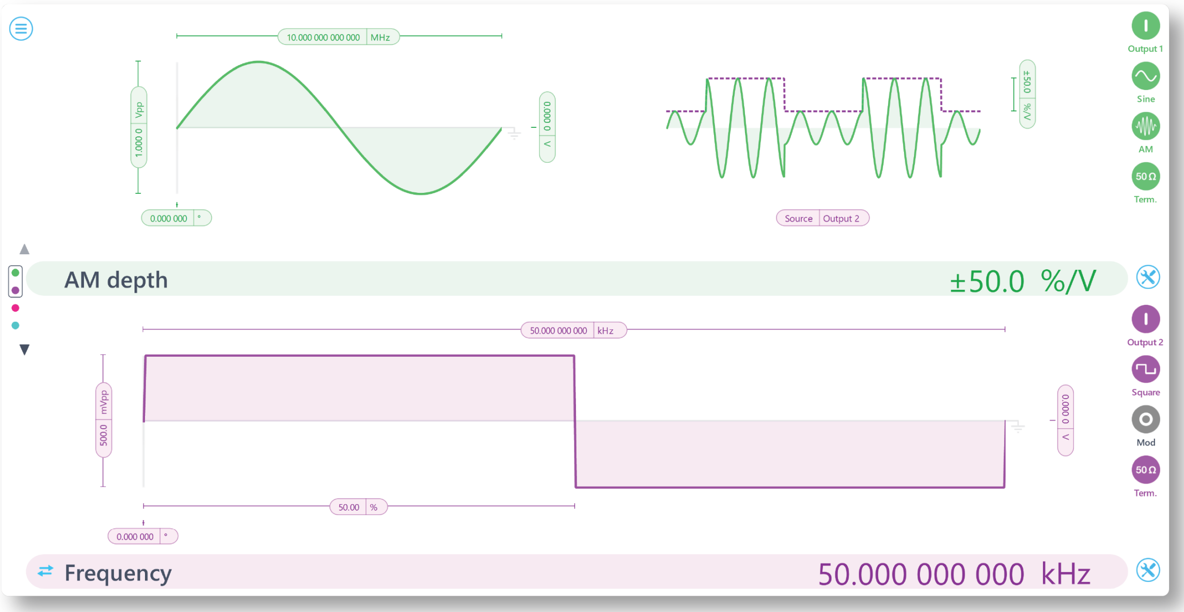


Figure 1. Moku Waveform Generator

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 Waveform Generator Datasheets.

Quick start guide

Here we outline the typical workflow of the Waveform Generator, using cross-channel frequency modulation as our example. We will use the Waveform Generator to produce a frequency-modulated sine wave on Output 1, using a square wave from Output 2 as the modulation source. Further more detailed examples can be found in the examples section.

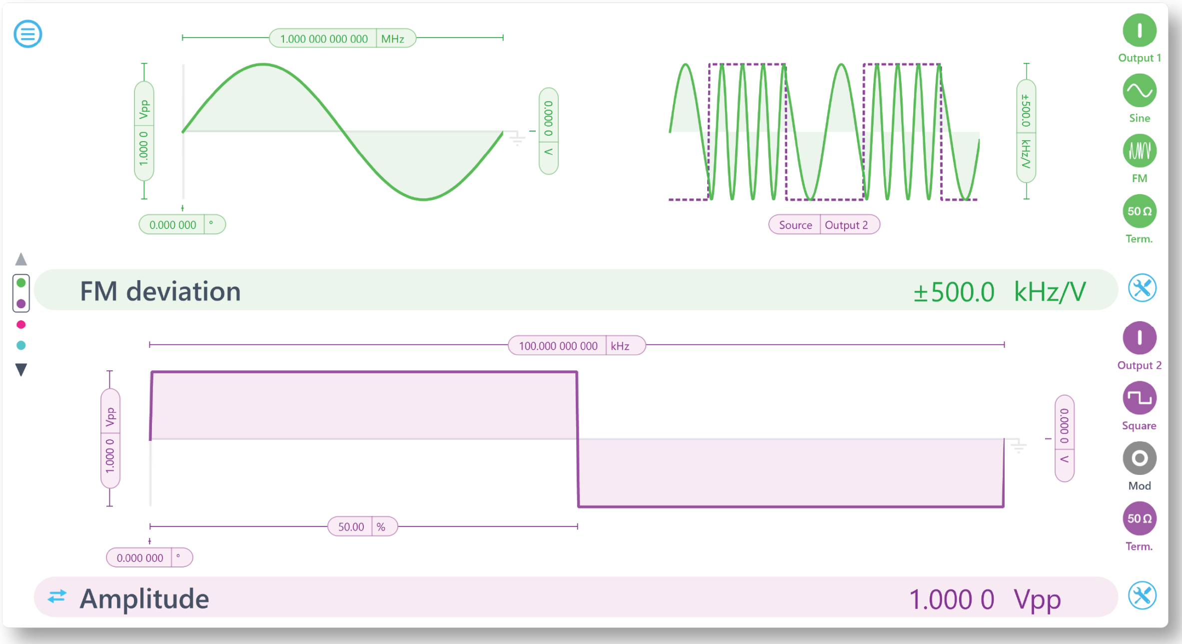


Figure 2. Waveform Generator quick start guide to frequency modulation

In this example, we use an Oscilloscope in Multi-instrument Mode to observe the output signals.

- **Step 1: Generate a sine wave and configure the frequency and amplitude**
  - On the right side of Output 1, select the sine wave option
  - Set the frequency to 1 MHz and the amplitude to 1 Vpp
  - Set the offset to 0 V and phase to 0 degrees, these are defaults
- **Step 2: Generate a square wave and configure Output 2**
  - On the right side of Output 2, select the square wave option
  - Set the frequency to 100 kHz and the amplitude to 2 Vpp
  - Set the duty cycles to 50%, offset to 0 V, and phase to 0 degrees, these are defaults
- **Step 3: Enable frequency modulation on Output 1**
  - On the right side of Output 1, select the modulation type to be frequency modulated (FM)
- **Step 4: Configure the Output 1 modulation**
  - Set the modulation source to Output 2
  - Set the FM deviation to 500 kHz/V
- **Step 5: Turn on the outputs in order**

  - Toggle Output 2 ON
  - Toggle Output 1 ON
- **Step 6: Sync the phases**
  - Click the configuration icon at the bottom right of the displayed waveform, and select "Sync phase"
- **Step 7: Observe the waveforms**
  - A preview of the waveforms will be shown in the Waveform Generator interface, as seen in Figure 2.
- **Step 8: Perform a self-test to preview the waveforms in the Moku Oscilloscope**
  - Route the signals in Multi-instrument Mode to an Oscilloscope to observe the waveform behavior, as seen in Figure 3.

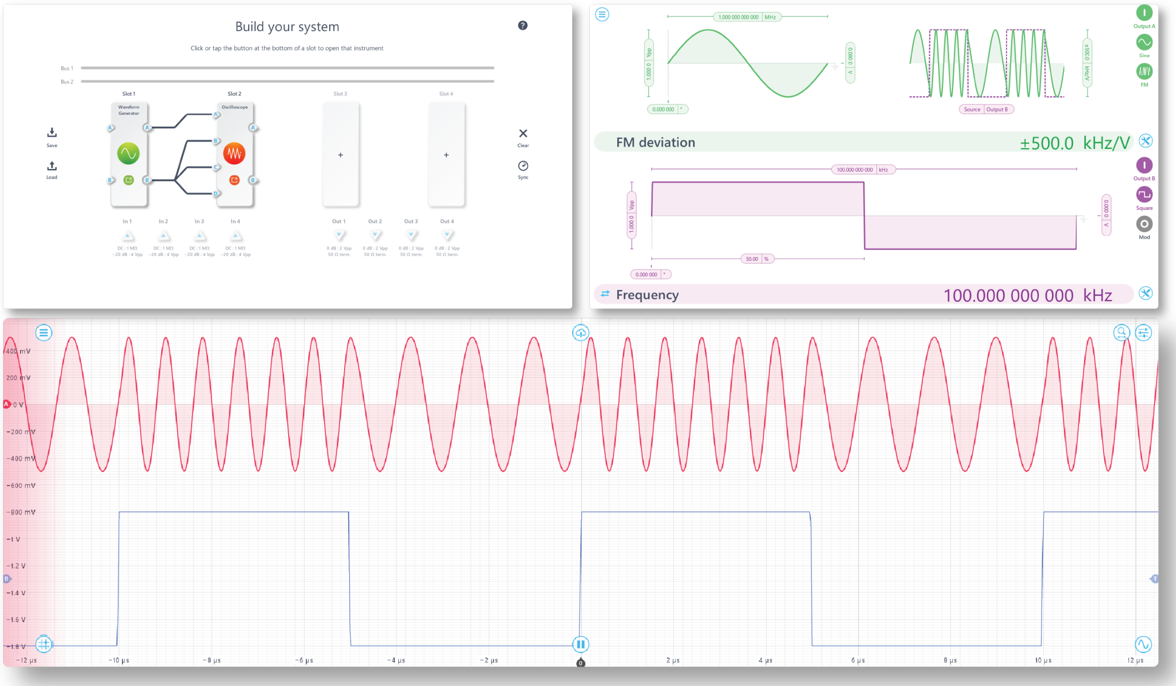


Figure 3. Multi-instrument Mode self-test setup for previewing the waveforms output from the Waveform Generator

Principles of operation

The Moku Waveform Generator is an intuitive and flexible tool for generating standard waveforms, with a range of modulation options. Key operational principles include waveform generation, modulation options, cross-channel modulation, triggering, synchronization, and integration with other instruments.

The Waveform Generator creates specific waveforms such as sine, square, and ramp, which can be customized in frequency, amplitude, phase, and offset. It offers six modulation forms; amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), pulse-width modulation (PWM), burst, and sweep. This flexibility allows for the simulation and testing of complex signal environments.

The device supports cross-channel modulation, allowing the output on one channel to be modulated by the output of another channel, offering further flexibility in signal generation. The generator includes versatile trigger options, allowing external inputs or outputs to trigger modes like burst or sweep, enhancing control over signal generation.

Outputs are synchronized to a common clock, enabling deterministically timed sequences. This feature is particularly useful in applications requiring precise timing, like quantum sensing or RF system prototyping. It can operate within a multi-instrument mode, integrating seamlessly with instruments like oscilloscopes for signal verification and testing.

Available waveforms

Table 1. Available waveform types and configurable characteristics

Wave type	Parameters	Modulation type
Sine	Frequency Amplitude Offset Phase	AM FM PM Burst Sweep
Square	Frequency Amplitude Offset Phase Duty cycle	AM FM PM Burst Sweep
Ramp	Frequency Amplitude Offset Phase Symmetry	AM FM PM Burst Sweep
Pulse	Frequency Amplitude Offset Phase Pulse width Edge time	AM FM PM PWM Burst Sweep
Noise	Amplitude Offset	AM Burst (Gated and Start mode only)
DC	DC level	None

The Moku Waveform Generator provides configurable sine, square, ramp, pulse, noise, and DC waveforms, along with a wide range of modulation options.

Difference between pulse and square waveforms

The square wave is a low-jitter waveform with variable duty cycle and high slew rates. The high analog bandwidth of the Moku can give very sharp rise and fall times, highly desirable in many applications. The pulse wave is similar to the square wave but has configurable duty cycle and edge times (rise and fall time). The trade-off is that at high frequency, the pulse wave has slightly worse edge jitter behavior compared to the square wave. Another point of difference is that pulse width modulation (PWM) is only available on pulse waveforms.

Synchronizing waveforms

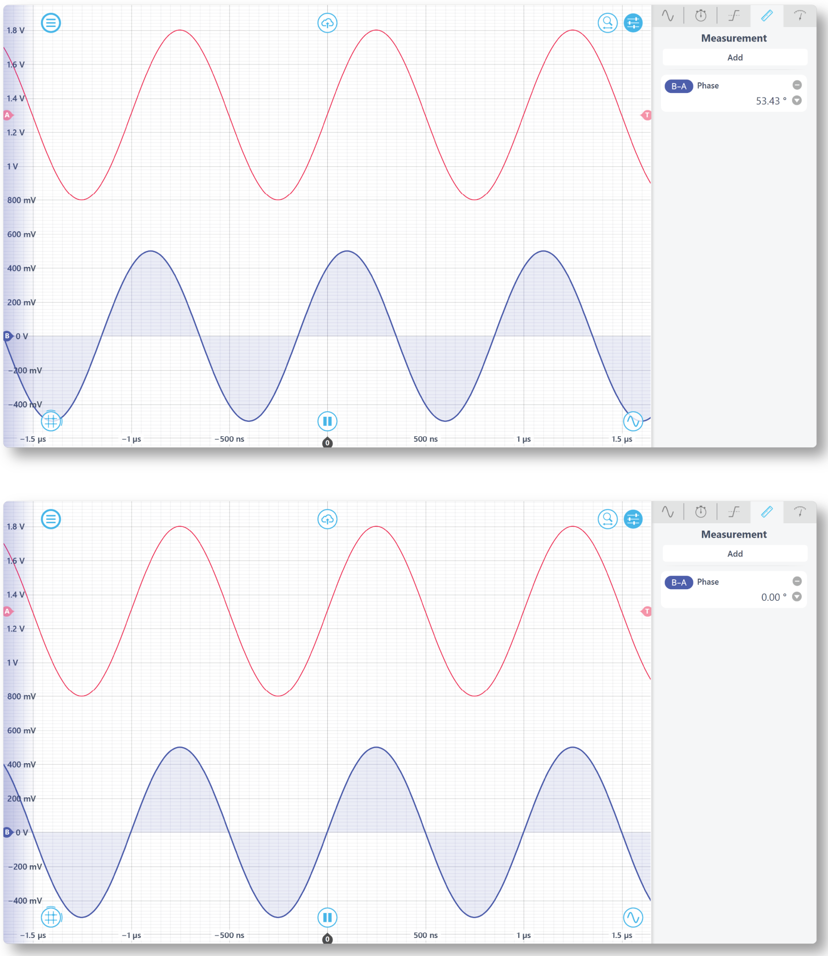


Figure 4. Sync waveforms in the Waveform Generator

The Waveform Generator channels can be phase synchronized by selecting the configuration icon, then “Sync phase”. This will ensure the phase of the Waveform Generator channels is zero.

Termination and impedance matching

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.

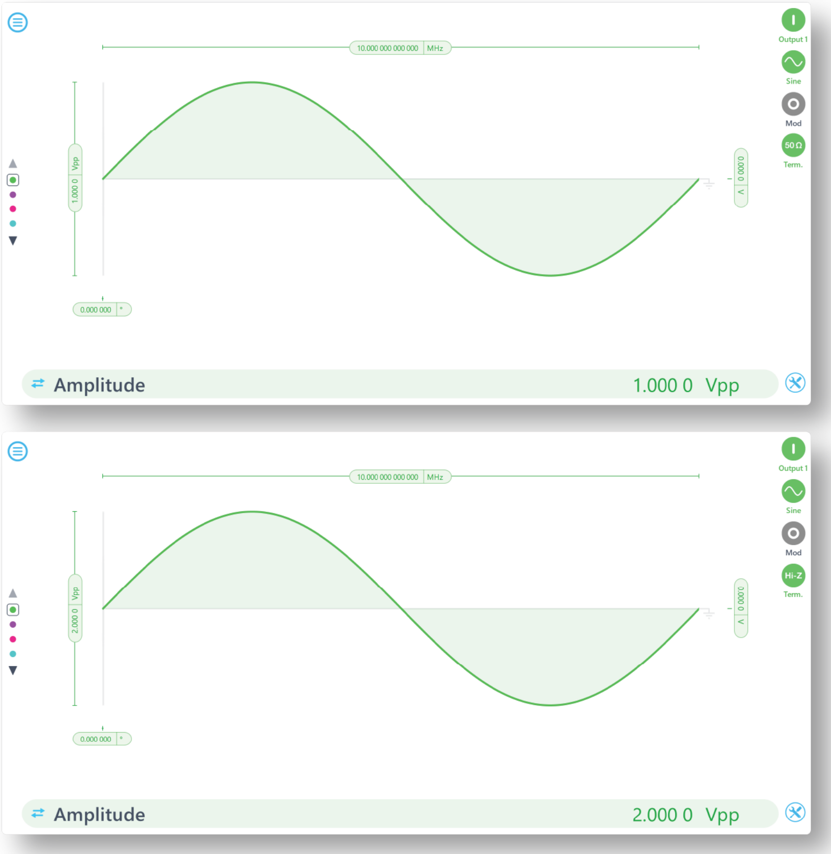


Figure 5. Relationship between termination and displayed amplitude

Changing the "Load"/"Term" 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. In the plot below, it can be seen that the "Term" is set to 50 Ω, resulting in a voltage output of 1 Vpp. When the "Term" is changed to "Hi-Z", the voltage reading changes to 2 Vpp. Although the voltage output source remains unchanged, the voltage reading in the interface is doubled because the voltage distribution on the load doubles when the load changes from 50 Ω to high impedance.

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

Difference between the Waveform Generator and Arbitrary Waveform Generator

Moku offers two waveform generation instruments: the Waveform Generator and the Arbitrary Waveform Generator. While similar in function, they are optimized for different use cases. The

Waveform Generator produces six standard waveforms and includes built-in modulation options such as AM, FM, and PM. In contrast, the Arbitrary Waveform Generator allows users to define fully custom waveforms by uploading their own coefficients. Although it doesn't offer built-in modulation, users can incorporate modulation directly into the waveform definition. In summary, use the Waveform Generator for standard signals, and the Arbitrary Waveform Generator for custom or complex waveform needs.

Waveform types

The available pre-loaded waveforms in the Waveform Generator are more standard and those in the Arbitrary Waveform Generator are more niche. All pre-loaded waveforms in the Waveform Generator are able to be generated in the Arbitrary Waveform Generator, however they may not be generated with the same optimized algorithm.

Waveform Generator	Arbitrary Waveform Generator
• Sine • Square • Ramp • Pulse • Noise • DC	• Sine • Gaussian • Exponential Rise • Exponential Fall • Sinc • Cardiac • Equation • Custom

Modulation types

The Waveform Generator has more in-build modulation options available, however the Arbitrary Waveform Generator can load in any pre-modulated signal from a text file.

Waveform Generator	Arbitrary Waveform Generator
• Amplitude • Frequency • Phase • Pulse Width • Burst • Sweep	• Pulsed • Burst

Using the instrument

The Moku Waveform Generator is equipped with multiple output channels, which are configured in two parts. The high-level channel configuration, edited in the buttons on the right of the interface, and the waveform and modulation parameter editor, edited in the waveform preview.

User interface

If there are more channels available than visible, click the up arrow ▲ and down arrow ▼ icons to navigate between the channels.

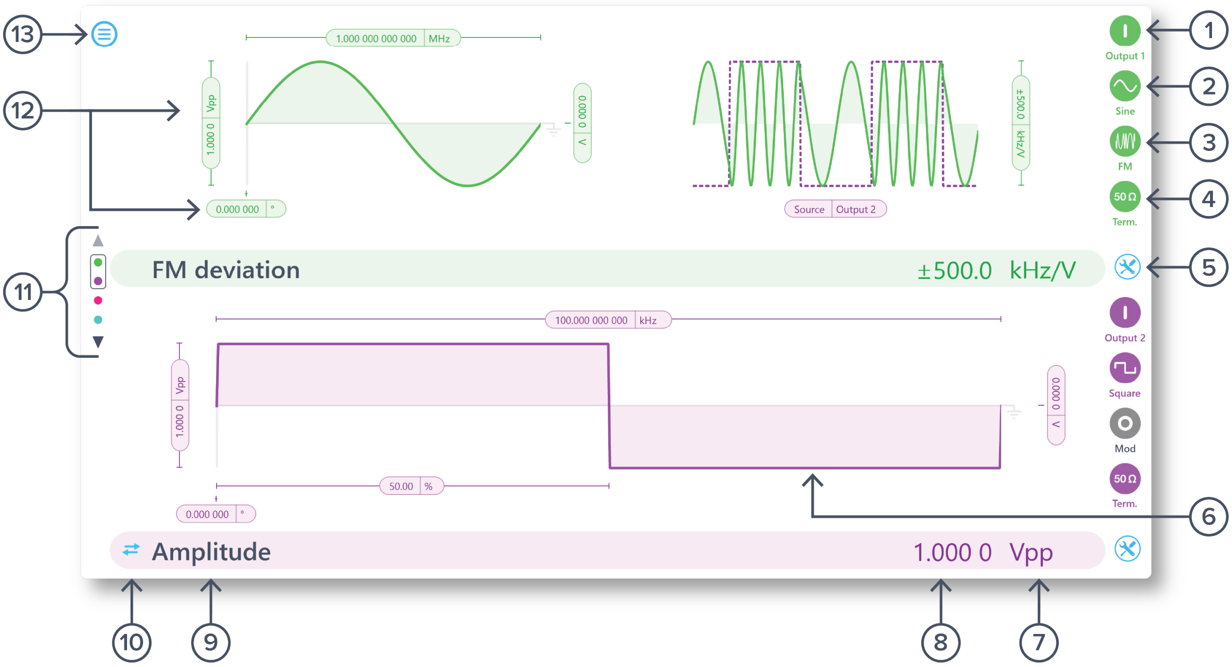


Figure 6. Waveform Generator user interface

① Toggle Output 1 ON and OFF
② Set the waveform type
③ Set the modulation type
④ Toggle the termination (hardware dependent)
⑤ Open Output 1 context menu from the configuration icon ; sync waveforms or copy settings from other channels
⑥ Waveform preview graph
⑦ Select the units of the displayed parameter
⑧ Enter the value of the displayed parameter
⑨ Label of the displayed parameter
⑩ Switch parameter representation
⑪ Click through available outputs
⑫ Click the parameter pill to configure parameters
⑬ Main menu

In the desktop app, type the letter of the metric prefix for quick selection of units. Click the frequency units and type **M** for MHz, **k** for kHz, or **H** for Hz or click the amplitude units and type **m** for mV.

Configuration

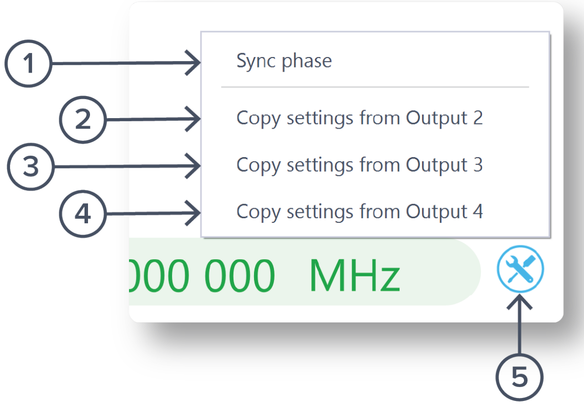
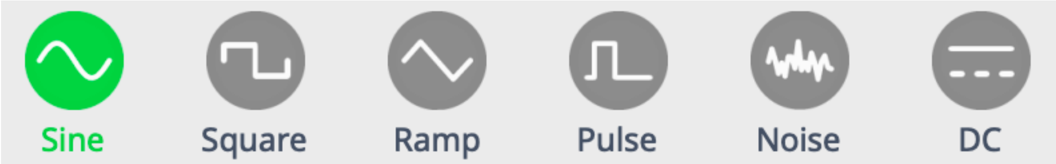


Figure 7. Waveform Generator configuration context menu

① Synchronize the phase of each waveform cross all channels
② Copy the settings from Output 2 to Output 1
③ Copy the settings from Output 3 to Output 1
④ Copy the settings from Output 4 to Output 1
⑤ Click to open configuration context menu for Output 1

Waveform types

The Moku Waveform Generator is capable of generating six different signals, each with optional modulation.



Sine wave

The sine wave is the simplest dynamic signal in the Moku. It features extremely low harmonic distortion.

The sine wave can be modulated by all available modulation types except PWM. Moreover, it forms the basis of the “Internal” selectable modulation source, providing a modulating waveform regardless of whether any channel of the Moku is currently outputting a sine wave.

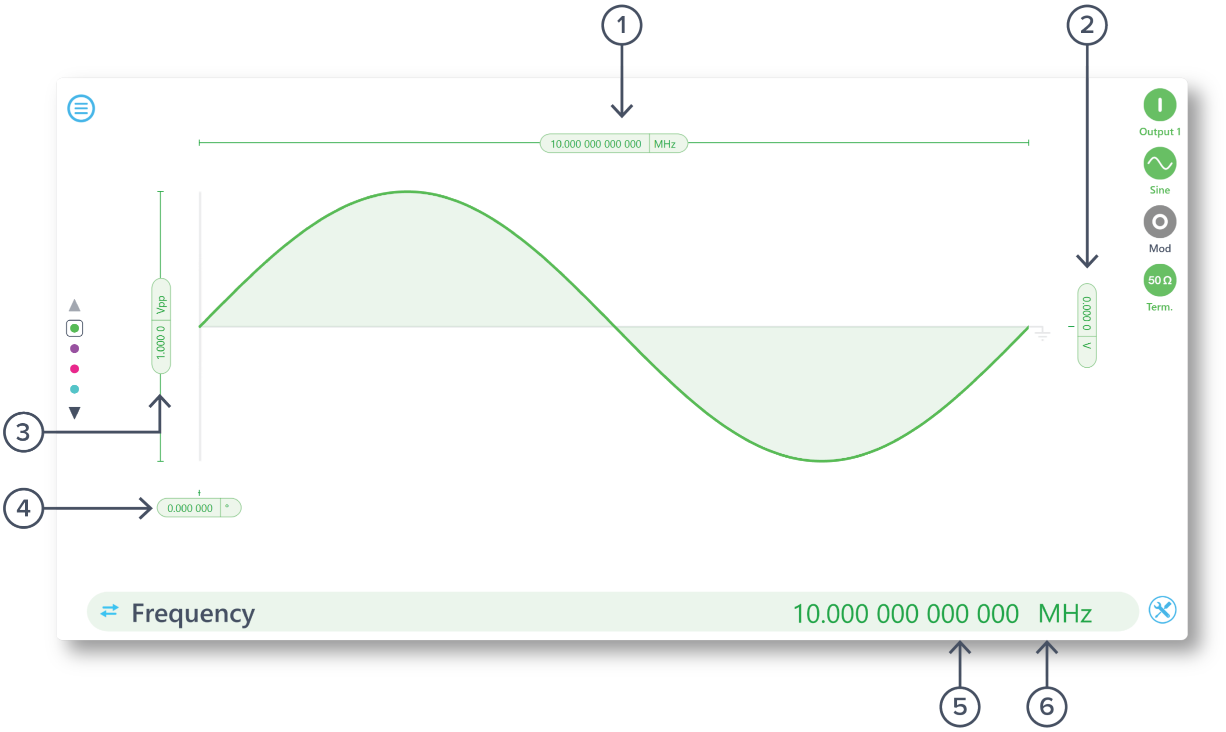


Figure 8. Waveform Generator configured for generating a sine wave

① Click to edit frequency parameter
② Click to edit offset parameter
③ Click to edit amplitude parameter
④ Click to edit phase parameter
⑤ Click to edit displayed parameter value
⑥ Click to select displayed parameter units

Square wave

The square wave is a low-jitter waveform with variable duty cycle and high slew rates. The high analog bandwidth of the Moku can give very sharp rise and fall times. If you require slew-rate limits and variable duty cycle in your application, see pulse wave below.

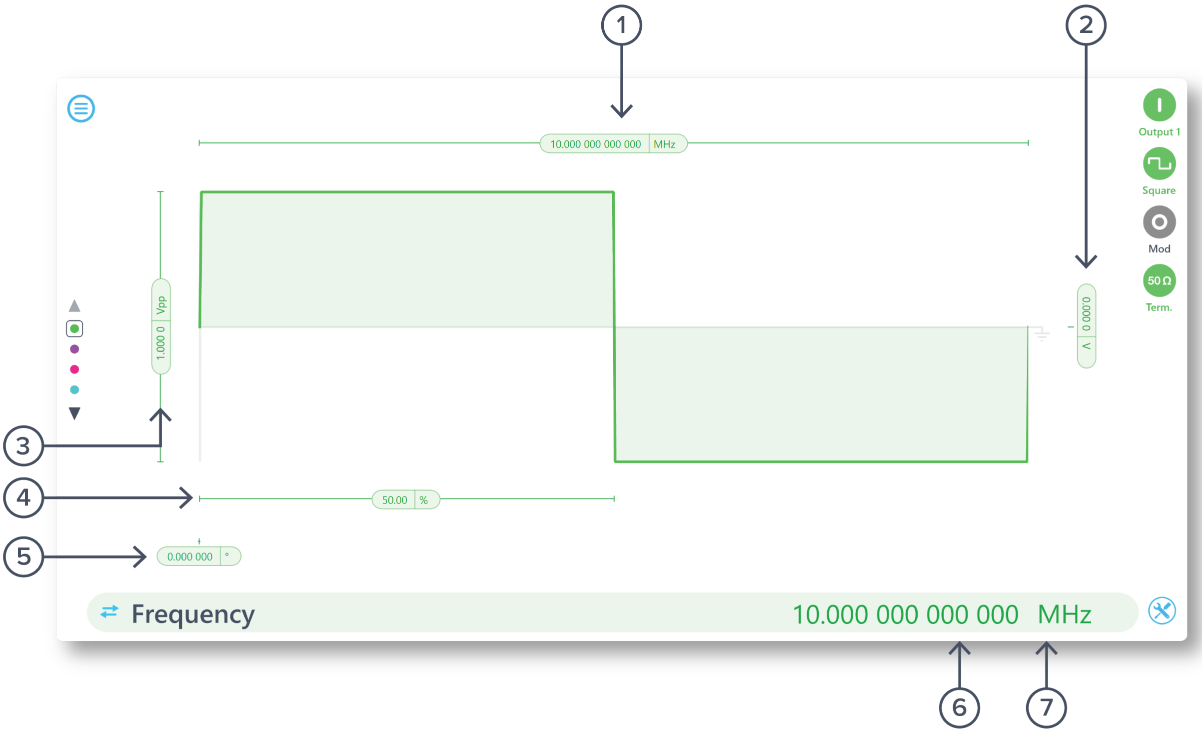


Figure 9. Waveform Generator configured for generating a square wave

① Click to edit frequency parameter
② Click to edit offset parameter
③ Click to edit amplitude parameter
④ Click to edit duty cycle parameter
⑤ Click to edit phase parameter
⑥ Click to edit displayed parameter value
⑦ Click to select displayed parameter units

Ramp wave

The ramp wave consists of linear ramps from low level to high and back again. The ratio between the time spent rising and the overall period is referred to as the symmetry. If you require configurable dwell times at the high or low levels but common rise and fall times, you may use the pulse wave with large edge times.

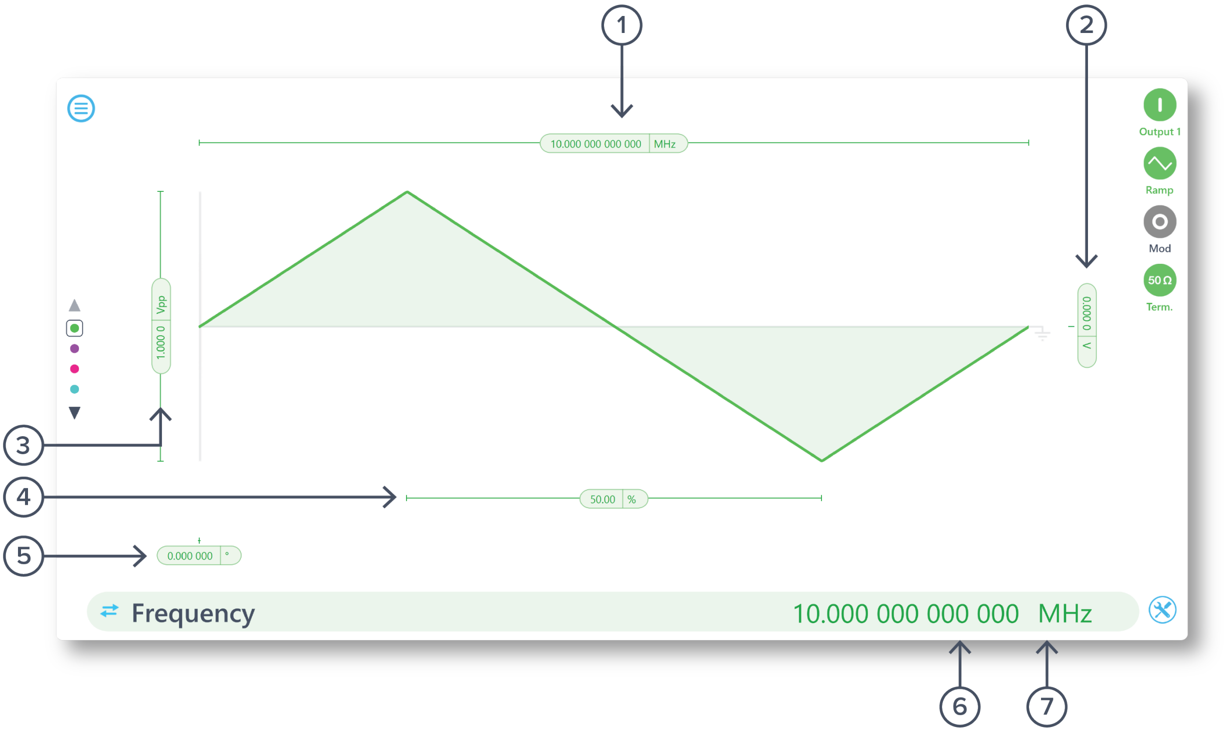


Figure 10. Waveform Generator configured for generating a ramp wave

① Click to edit frequency parameter
② Click to edit offset parameter
③ Click to edit amplitude parameter
④ Click to edit symmetry parameter
⑤ Click to edit phase parameter
⑥ Click to edit displayed parameter value
⑦ Click to select displayed parameter units

Pulse wave

The pulse wave is similar to the square wave but has configurable duty cycle and edge times (rise and fall time). The trade-off is that at high frequency, pulse has slightly worse edge jitter behavior compared to the square wave.

The pulse wave also uniquely supports pulse-width modulation (PWM). When PWM is enabled, edge times are fixed to their minimum values.

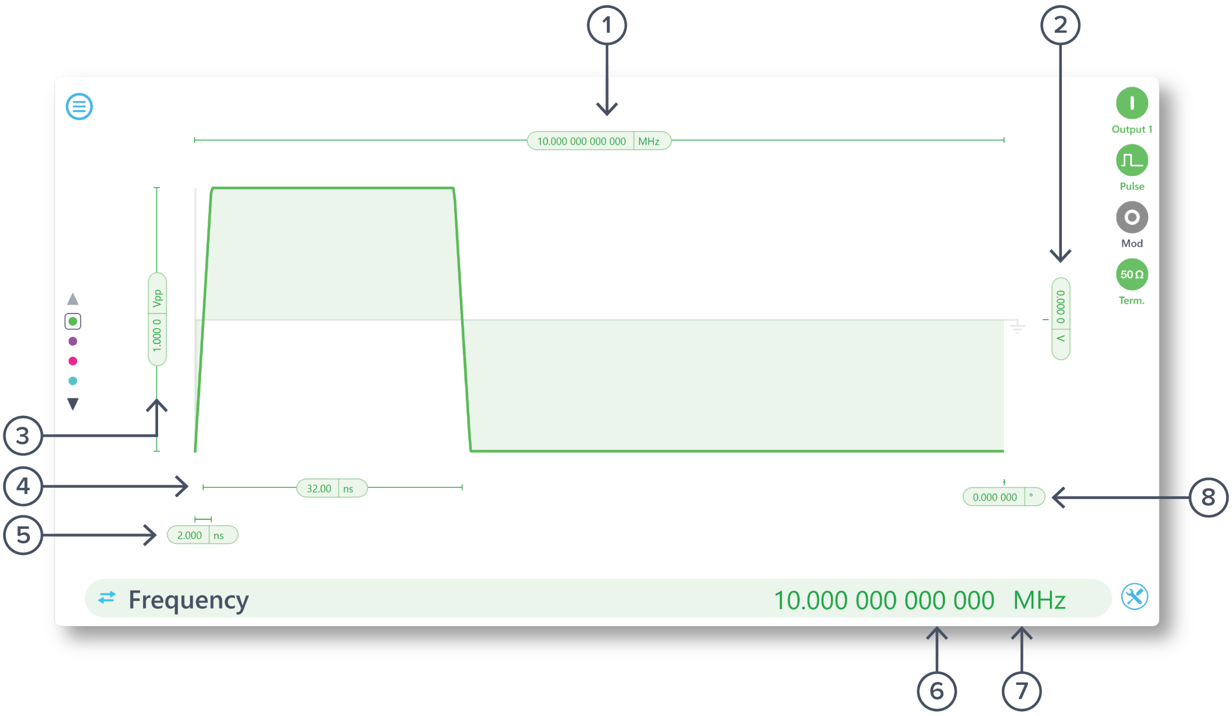


Figure 11. Waveform Generator configured for generating a pulse wave

① Click to edit frequency parameter
② Click to edit offset parameter
③ Click to edit amplitude parameter
④ Click to edit pulse width parameter
⑤ Click to edit edge time parameter
⑥ Click to edit displayed parameter value
⑦ Click to select displayed parameter units
⑧ Click to edit phase parameter

Noise

Approximately Gaussian, white noise. Noise signals can be used for simulating real-world scenarios, such as interference or background noise, in order to evaluate and test the performance of systems or circuits under noisy conditions.

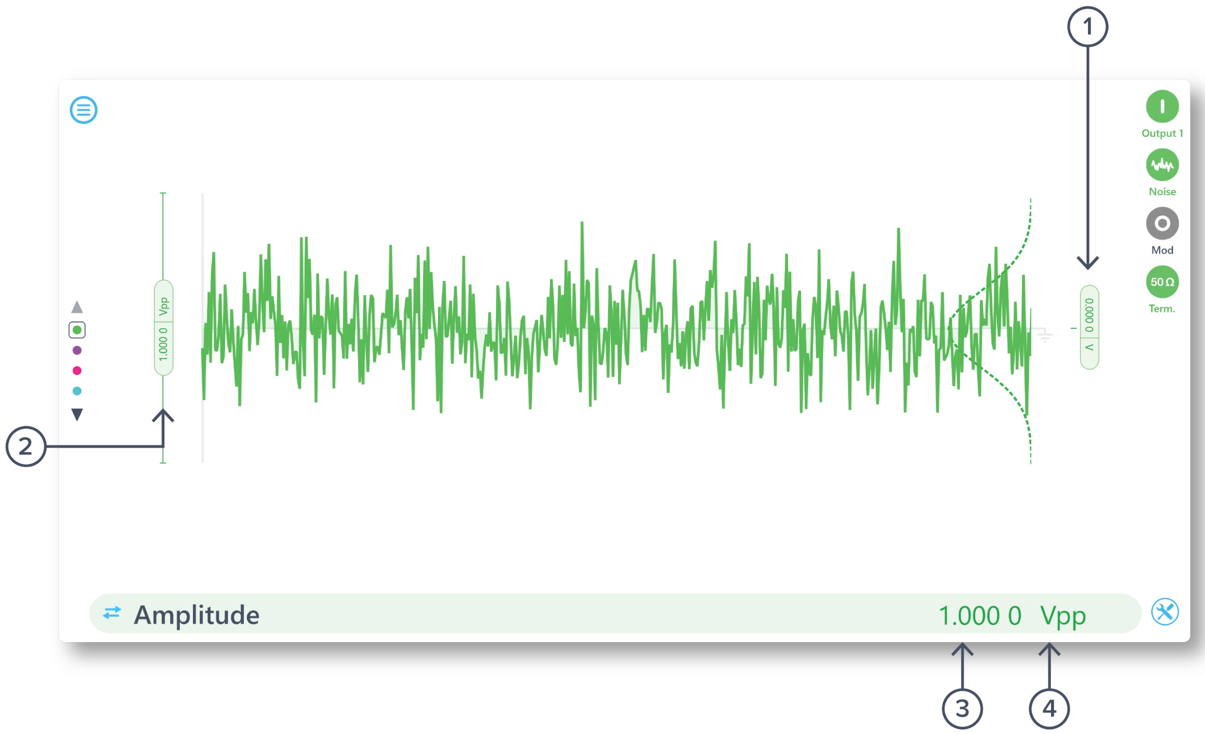


Figure 12. Waveform Generator configured for generating noise

① Click to edit offset parameter
② Click to edit amplitude parameter
③ Click to edit displayed parameter value
④ Click to select displayed parameter units

DC

Provides a high precision, fixed reference voltage at the output.

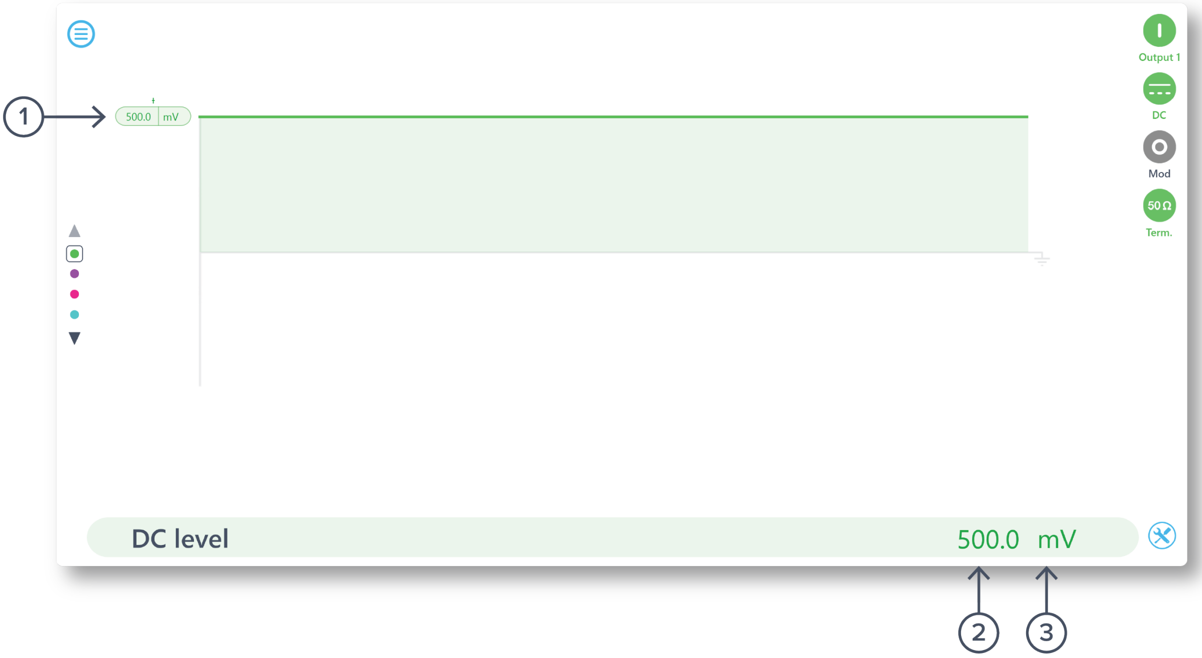


Figure 13. Waveform Generator configured for generating a DC signal

① Click to edit DC level parameter
② Click to edit displayed parameter value
③ Click to select displayed parameter units

Waveform parameters and controls

There are a number of parameters that are applicable to certain waveforms. These parameters are frequency, amplitude, offset, phase, symmetry, duty cycle, pulse width, edge time, and DC level.

Frequency

Applicable to: sine, square, ramp, pulse

Specified in hertz, the frequency can also be represented as period (specified in seconds). Click the frequency pill then the toggle arrows in the parameter bar ⇄ to switch between the two representations.

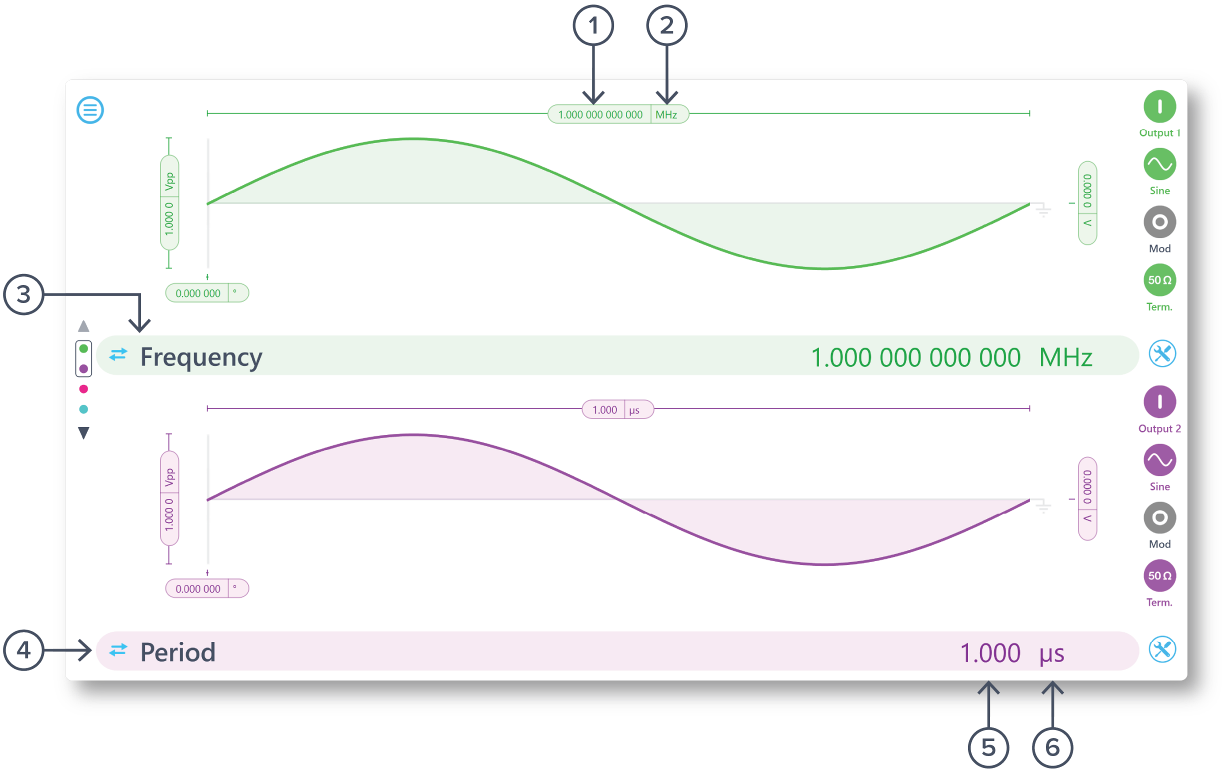


Figure 14. Waveform Generator frequency parameter

① Click to edit frequency parameter value
② Click to select frequency parameter units
③ Frequency representation parameter bar
④ Period representation parameter bar
⑤ Click to edit parameter value
⑥ Click to select parameter units

Switching between the parameter representations can define the parameter in a way that is most straightforward for your measurement. For example, consider a waveform with a frequency of 125 kHz. The period of this waveform will be the inverse of the frequency, $frequency^{-1} = period = \left(125 \cdot 10^{3}\right)^{-1} = 8 \cdot 10^{-6} = 8\mu s$.

Amplitude

Applicable to: sine, square, ramp, pulse, noise

Amplitude is specified as a peak-to-peak value; that is, the high level minus the low level. If you wish to specify the high and low levels explicitly, click the amplitude pill then the toggle arrows in the parameter bar ⇄ to switch between the two representations.

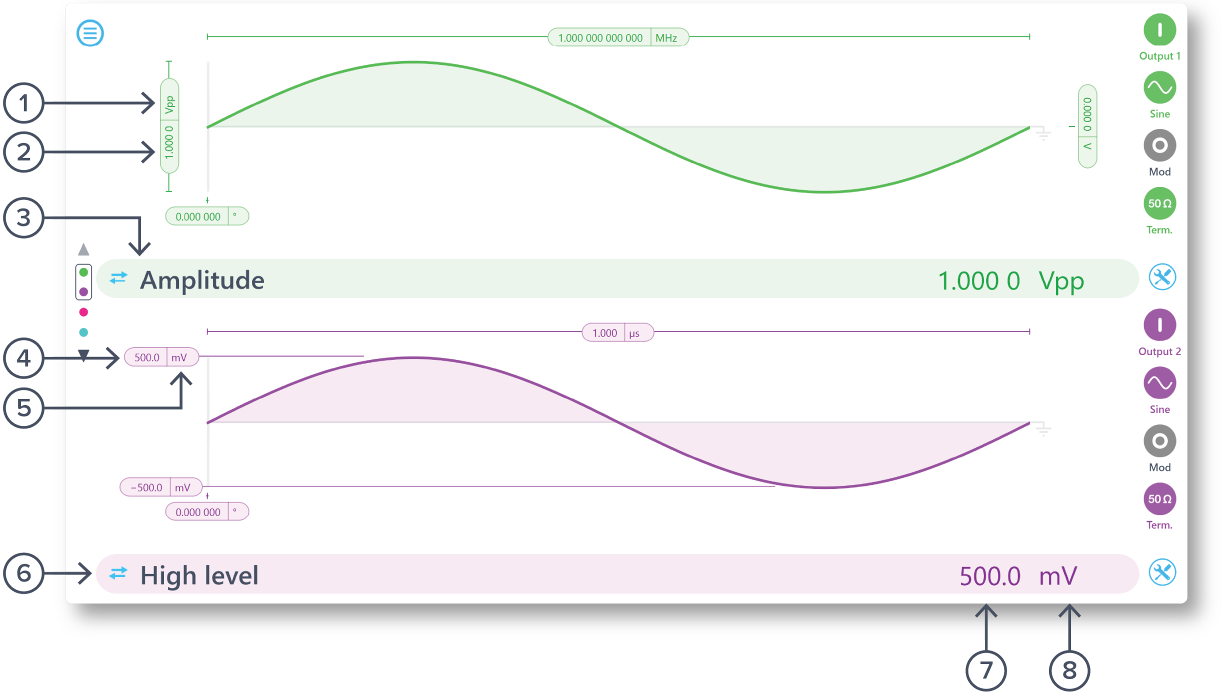


Figure 15. Waveform Generator amplitude parameter

① Click to select amplitude parameter units
② Click to edit amplitude parameter value
③ Amplitude representation parameter bar
④ Click to edit high level value
⑤ Click to select high level units
⑥ High level representation parameter bar
⑦ Click to edit parameter value
⑧ Click to select parameter units

Offset

Applicable to: sine, square, ramp, pulse, noise

Average value of the sine wave over time. The alternative representation of this parameter is low level, which combined with high level also specifies amplitude. Click the offset pill then the toggle arrows in the parameter bar ⇄ to switch between the two representations.

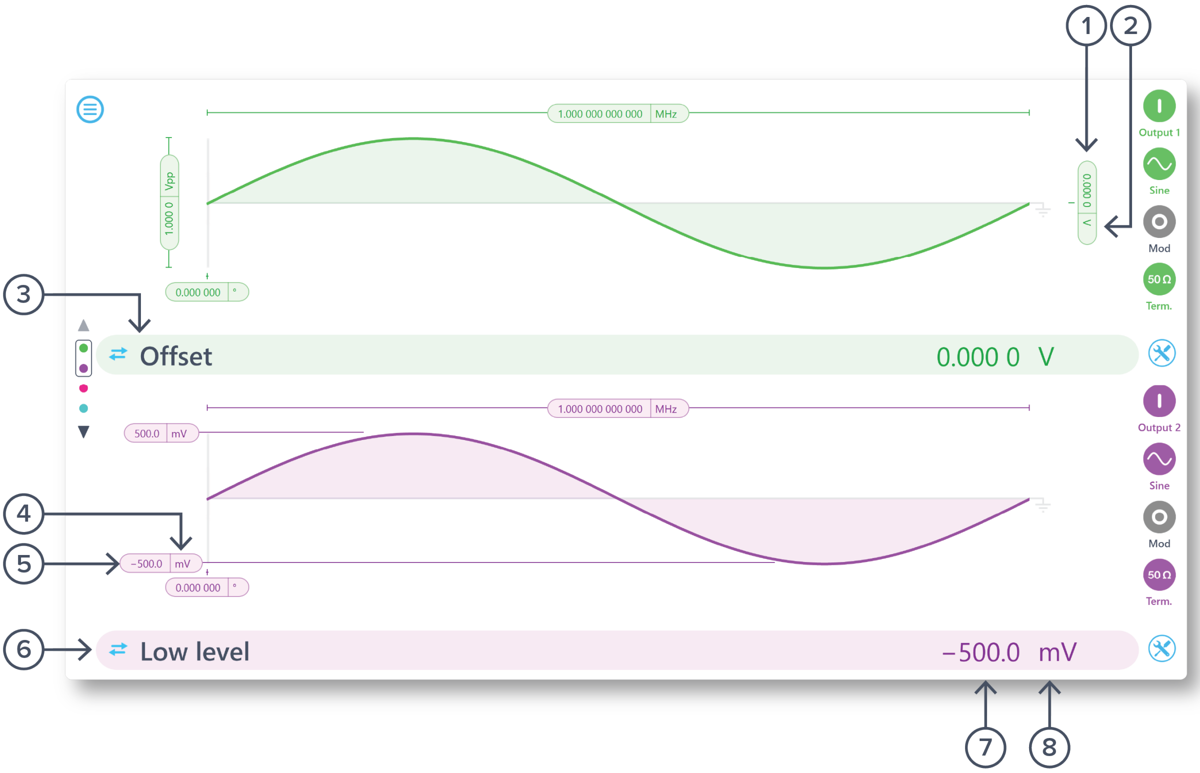


Figure 16. Waveform Generator offset parameter

1. Click to edit offset parameter value
2. Click to select offset parameter units
3. Offset representation example
4. Click to select low level parameter units
5. Click to edit low level parameter value
6. Low level representation example
7. Click to edit parameter value
8. Click to select parameter units

Phase

Applicable to: sine, square, ramp, pulse

Adjust the phase offset of the waveform with respect to the internal reference clock of the Moku device.

By selecting the toolbox icon, then “Sync phase”, this phase also becomes relative to the other output channels. See Synchronizing waveforms

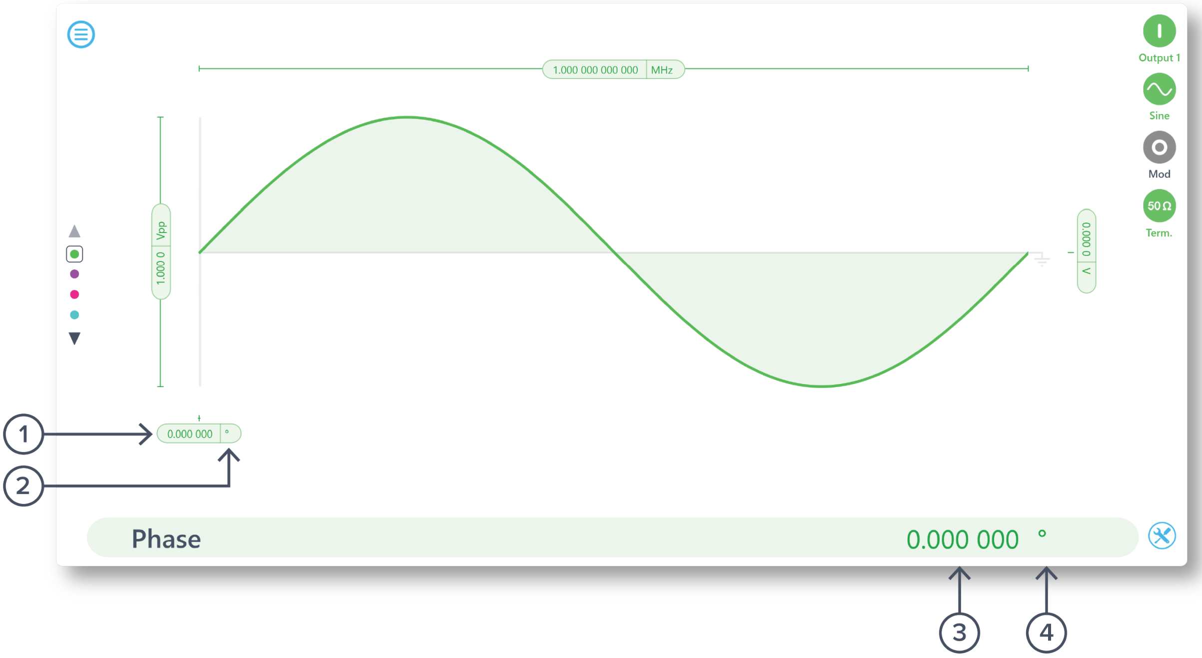


Figure 17. Waveform Generator phase parameter

① Click to edit phase parameter value
② Displayed units of phase parameter
③ Edit parameter value
④ Displayed units of selected parameter

Symmetry

Applicable to: ramp

Ratio, in percent, between the time spent on the rising edge and the overall period. As symmetry approaches 0% or 100%, the ramp wave becomes a sawtooth (minimum rise and fall times, respectively).

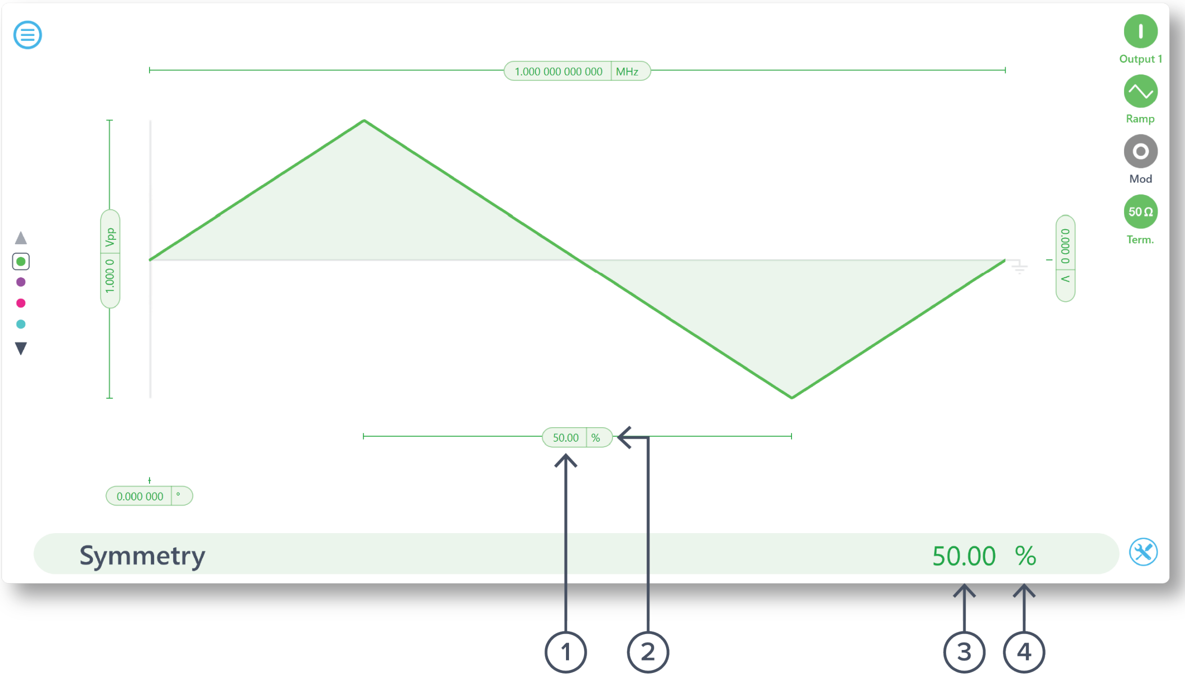


Figure 18. Waveform Generator symmetry parameter

① Click to edit symmetry parameter value
② Click to select symmetry parameter units
③ Edit parameter value
④ Select parameter units

Duty cycle

Applicable to: square

Ratio, in percent, of the time spent above the median value to the total period. For instance, a duty cycle of 50% means that the signal is high for half of the time and low for the other half during each cycle.

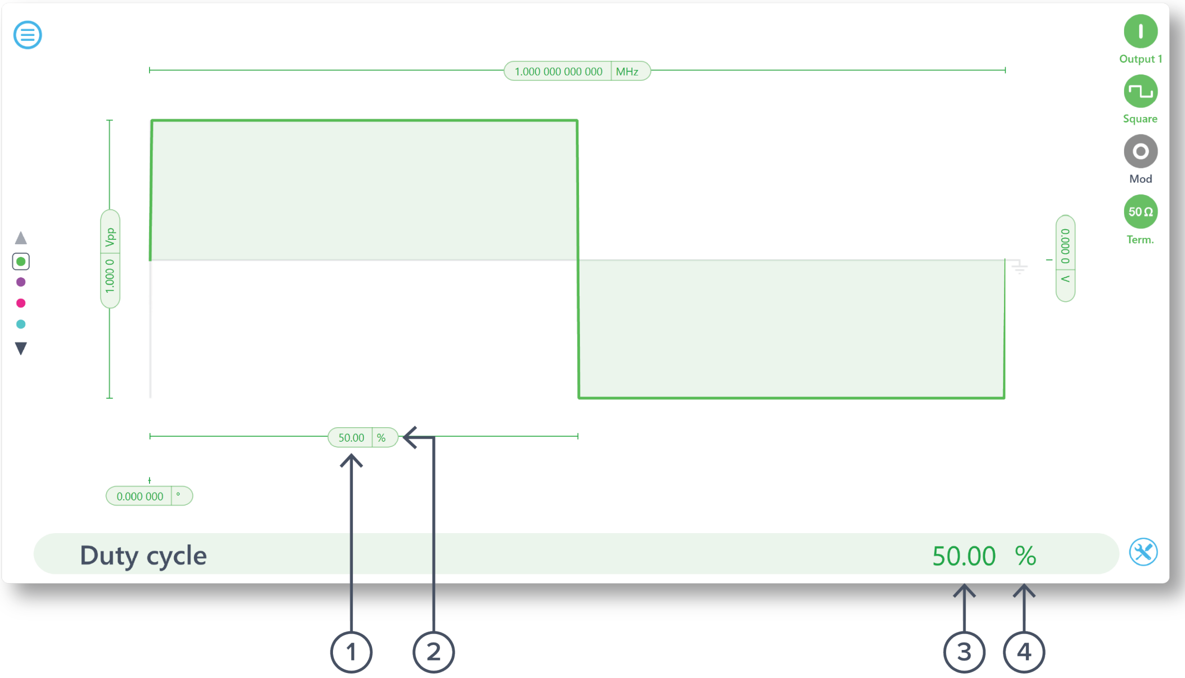


Figure 19. Waveform Generator duty cycle parameter

① Click to edit duty cycle parameter value
② Click to select duty cycle parameter units
③ Edit parameter value
④ Select parameter units

Pulse width

Applicable to: pulse

Width of the pulse during which the signal is at a higher voltage. Any specified edge time is split equally between the pulse width and the rest of the cycle; that is, duty cycle is preserved when altering edge time.

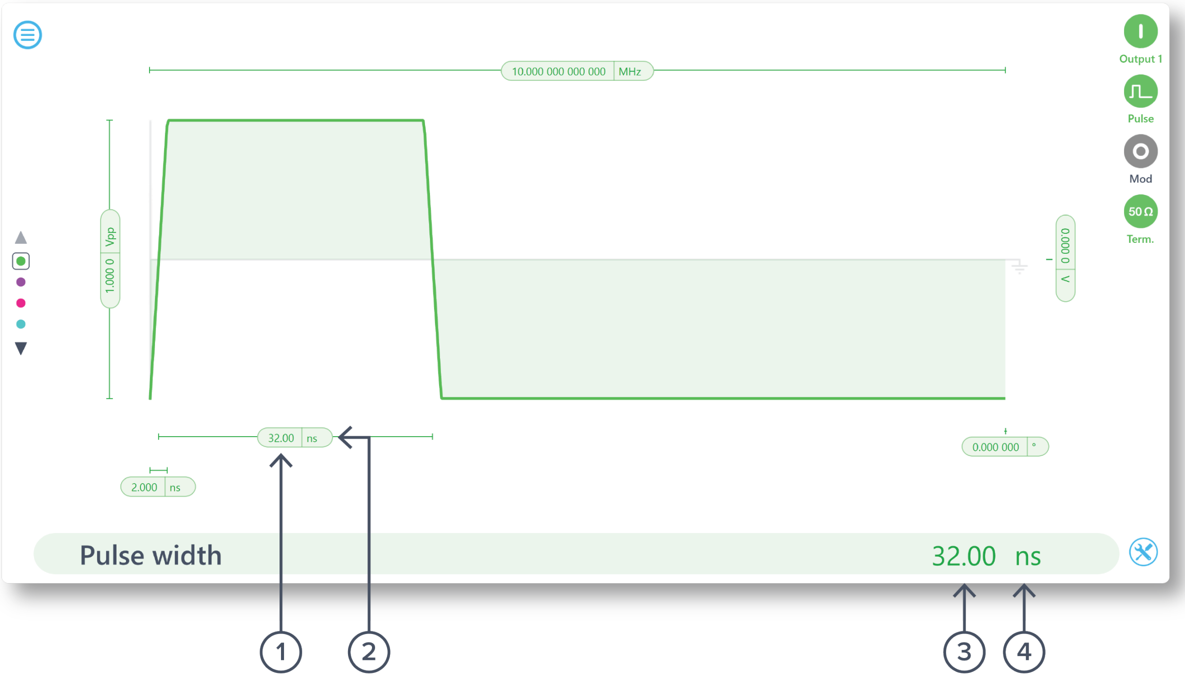


Figure 20. Waveform Generator pulse width parameter

① Click to edit pulse width parameter value
② Click to select pulse width parameter units
③ Edit parameter value
④ Select parameter units

Edge time

Applicable to: pulse

Time taken to transition from low level to high and vice-versa. This limits the slew rate of the signal which can be advantageous in some applications. Edge time is split between high and low time equally, preserving duty cycle. Edge time cannot be adjusted when the pulse wave is pulse width modulated (PWM).

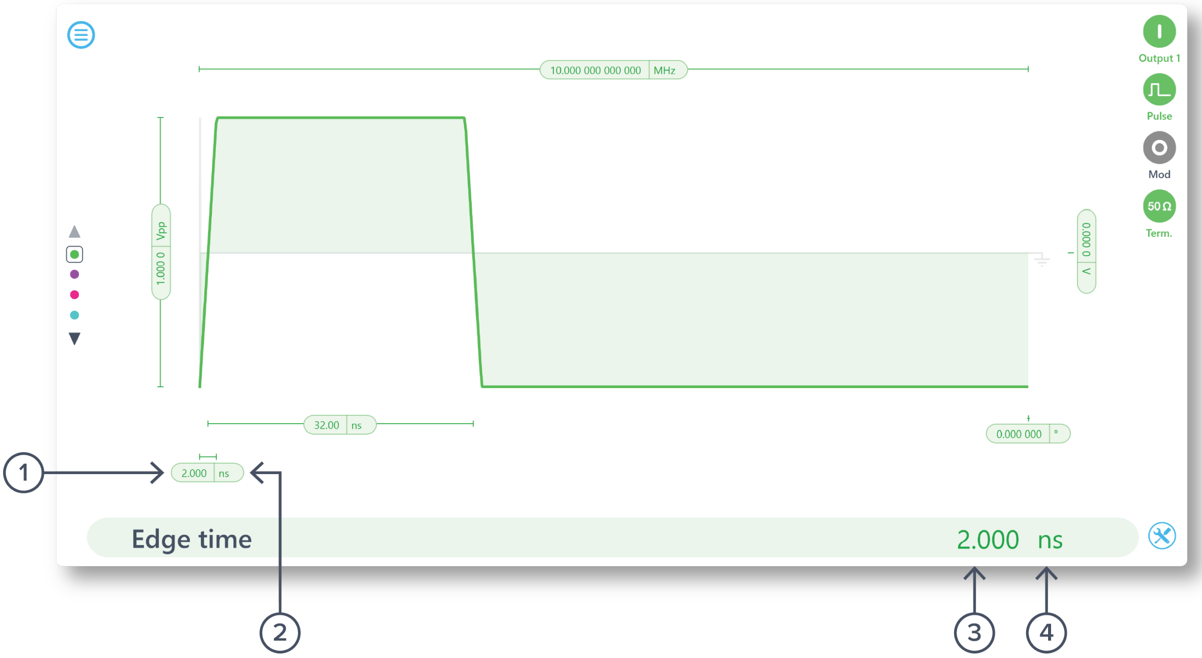


Figure 21. Waveform Generator edge time parameter

① Click to edit edge time parameter value
② Click to select edge time parameter units
③ Edit parameter value
④ Select parameter units

DC level

Applicable to: DC

Fixed voltage to output.

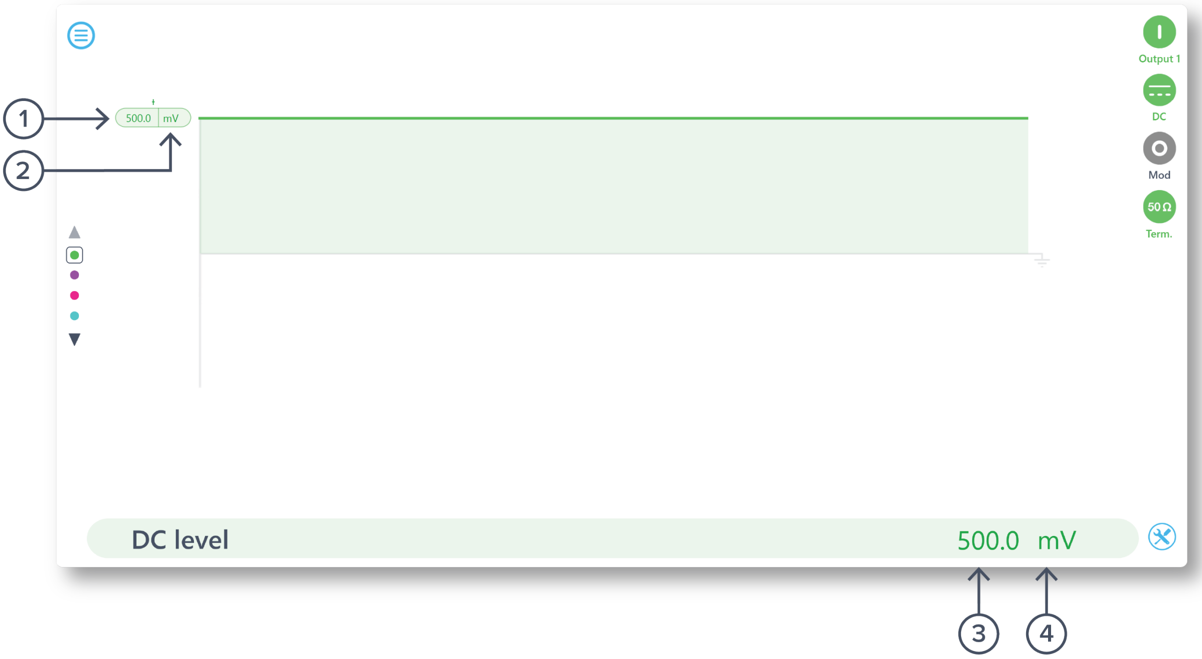


Figure 22. Waveform Generator DC level parameter

① Click to edit DC level parameter value
② Click to select DC level parameter units
③ Edit parameter value
④ Select parameter units

Modulation types

The Moku Waveform Generator can modulate waveform and offers a range of options, including amplitude modulation, frequency modulation, phase modulation, pulse width modulation, burst modulation, and sweep modulation.

Figure 23. Waveform Generator modulation types

Modulation sources

Each modulation type can be driven by one of three sources.

Internal

Modulation is driven by an internally generated sine wave of configurable frequency. The amplitude of this wave is “full range.” It will modulate to the depth specified when configuring the modulation type.

Input

Modulation is driven by an analog input. The depth is specified *per volt on* the input. When this source is selected, the range and coupling of the corresponding input can also be selected.

Output

Modulation is driven by another output channel (i.e. Output 1 may be modulated by the waveform on Output 3). This allows the user to multiply-modulate a signal by modulating a signal on one channel, then using that signal to modulate the another in turn. This is useful, for example, when you wish to generate an “ideal” modulated signal on one channel, but then perturb the phase, frequency, or amplitude in order to test a system’s response.

Modulation parameters

The modulation parameters will change for each source that is selected. An example of what this may look like for amplitude modulation is below.

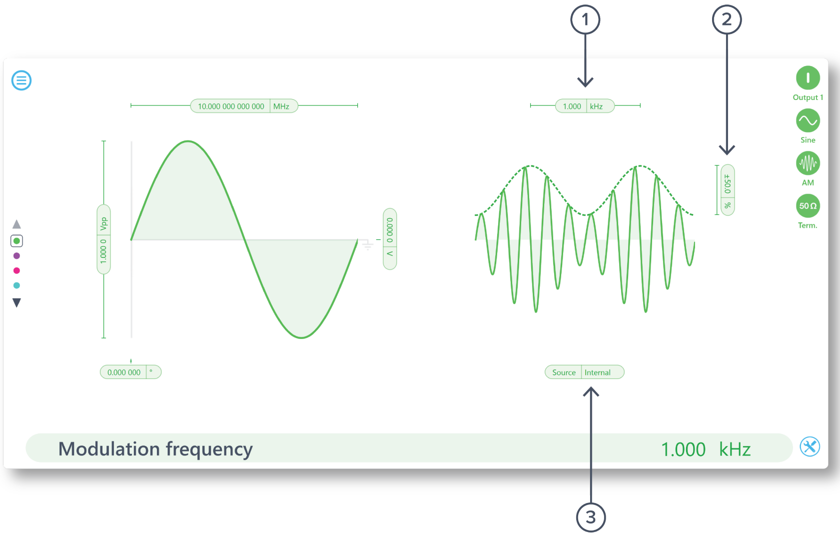


Figure 24. Waveform Generator amplitude modulation (AM) internal

① Edit modulation frequency parameter
② Edit AM depth parameter
③ Select modulation source

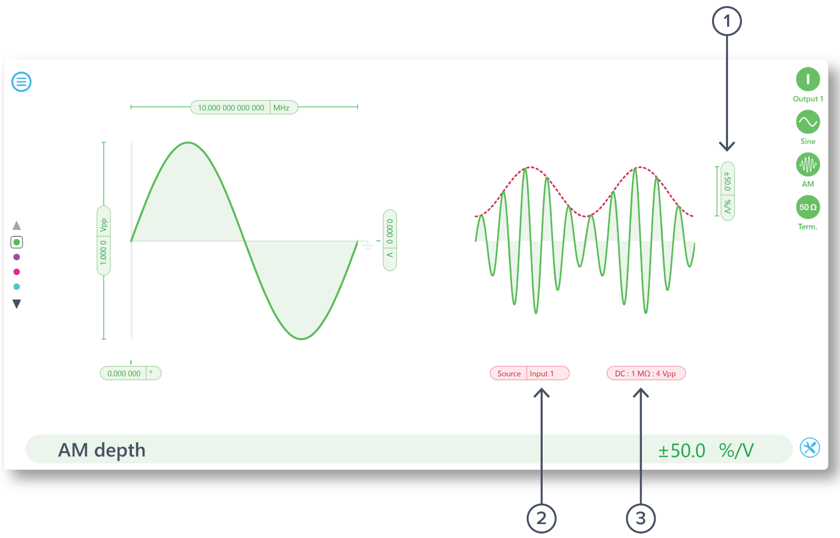


Figure 25. Waveform Generator amplitude modulation (AM) input

① Edit AM depth parameter
② Select modulation source
③ Edit selected input frontend settings

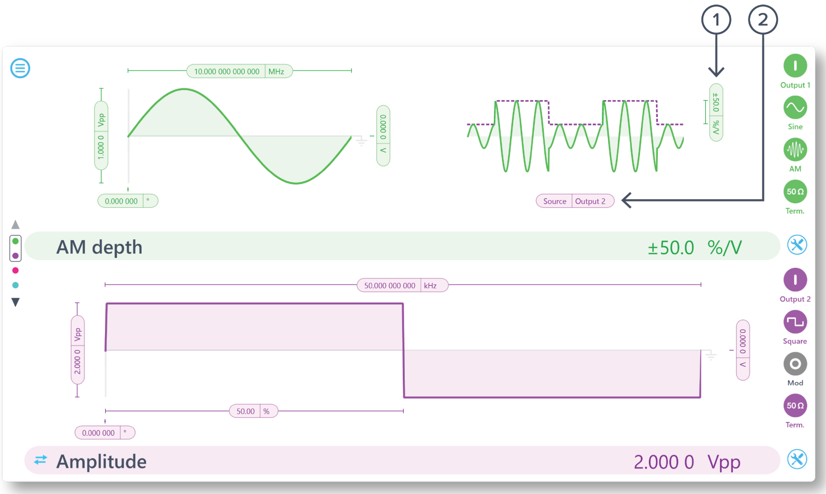


Figure 26. Waveform Generator amplitude modulation (AM) output

① Edit AM depth parameter
② Select modulation source

Amplitude modulation (AM)

Applicable to: sine, square, ramp, pulse, noise

Amplitude modulation will change the amplitude of the generated signal proportionally to the modulation input. The actual proportion changed is called the modulation depth, the units of which depend on the modulation source (see discussion of sources above).

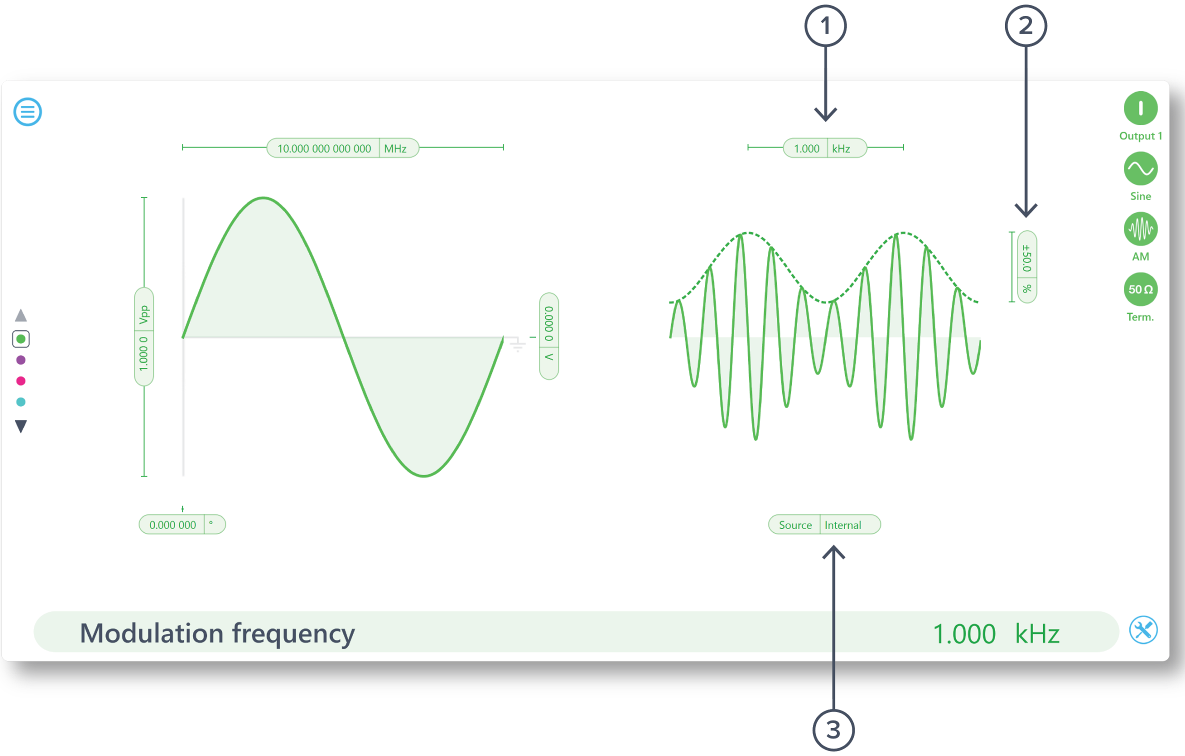


Figure 27. Waveform Generator amplitude modulation (AM) internal

① Edit modulation frequency parameter
② Edit AM depth parameter
③ Select modulation source

Frequency modulation (FM)

Applicable to: sine, square, ramp, pulse

Frequency modulation will change the frequency of the generated signal proportionally to the modulation input. The change in frequency caused by a given input is called the modulation depth and has units of hertz or hertz per volt depending on the modulation source used.

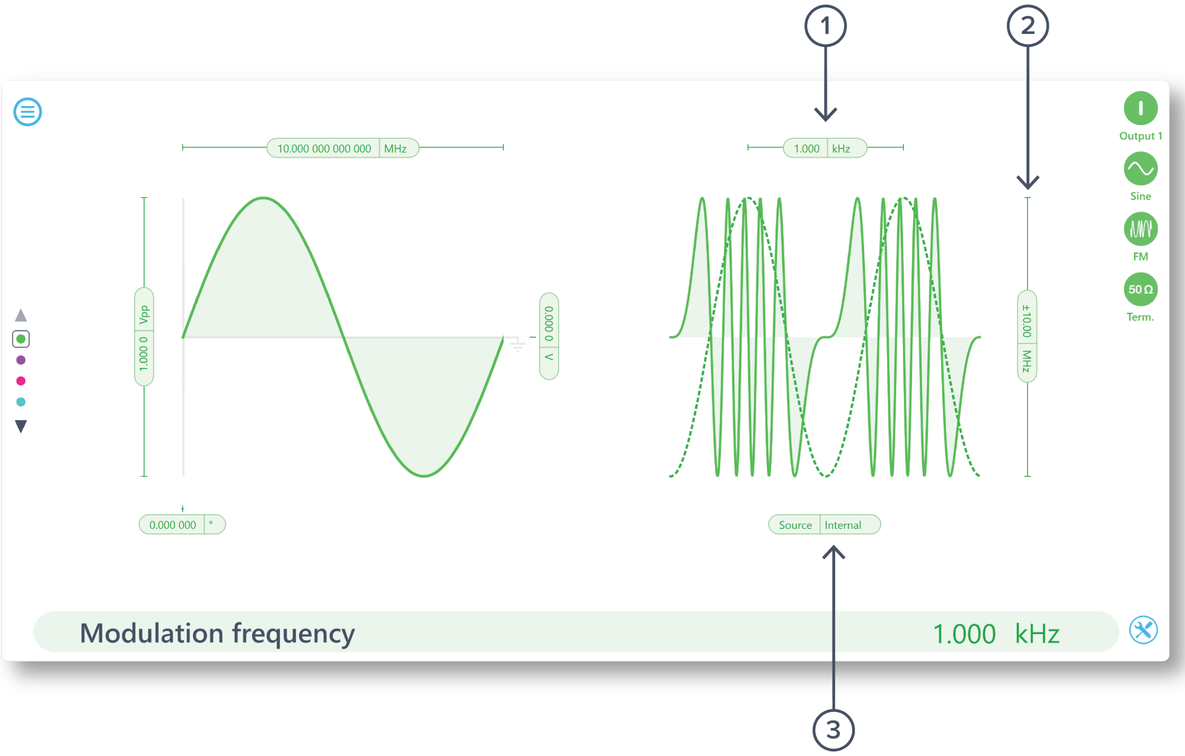


Figure 28. Waveform Generator frequency modulation (FM) internal

① Edit modulation frequency parameter
② Edit FM deviation parameter
③ Select modulation source

Phase modulation (PM)

Applicable to: sine, square, ramp, pulse

Phase modulation will change the phase of the generated signal proportionally to the modulation input. The change in frequency caused by a given input is called the modulation depth and has units of degrees or degrees per volt depending on the modulation source used.

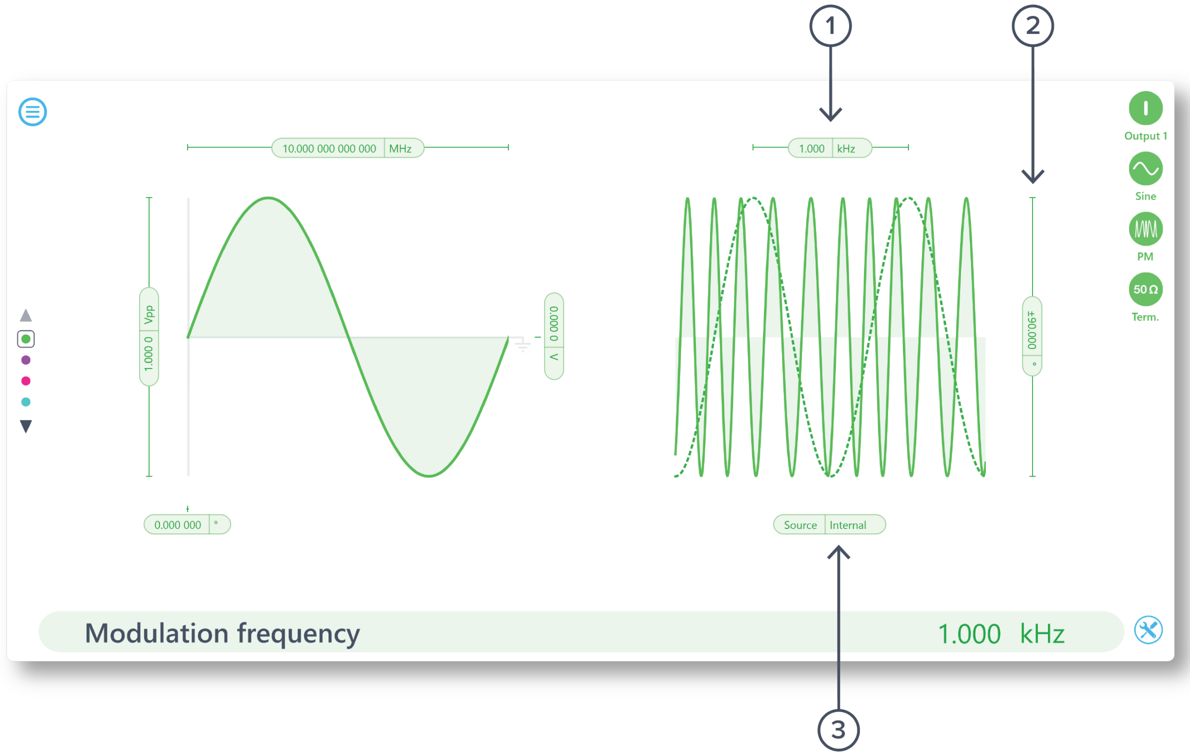


Figure 29. Waveform Generator phase modulation (PM) internal

① Edit modulation frequency parameter
② Edit PM shift parameter
③ Select modulation source

Pulse-width modulation (PWM)

Applicable to: pulse

Pulse-width modulation (PWM) changes the width of the high-level portion of the pulse wave. If the modulation depth is set appropriately, then this can produce traditional 0-100% duty cycle PWM, but it can also produce pulse trains suitable for driving servo motors, electronic speed controllers (ESCs), etc.

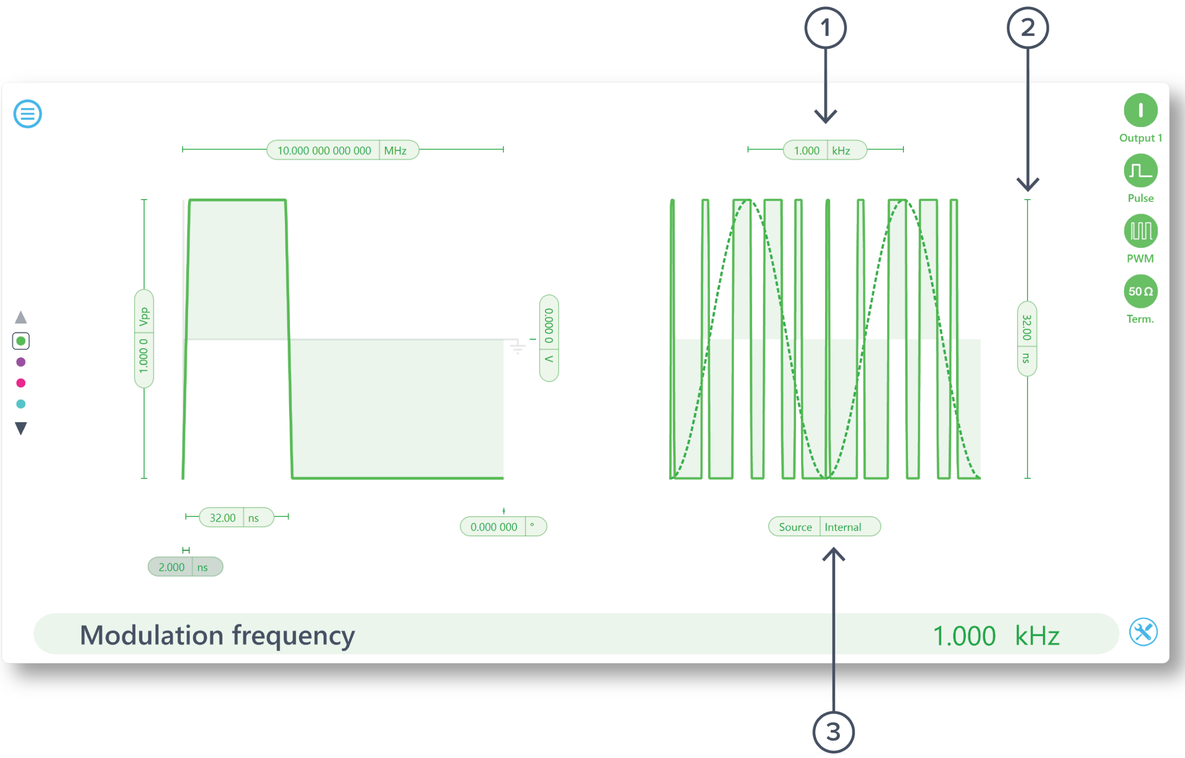


Figure 30. Waveform Generator pulse width modulation (PWM) internal

① Edit modulation frequency parameter
② Edit pulse width deviation parameter
③ Select modulation source

Trigger output modes

Burst and sweep modes depend on the detection of a trigger event. There are three possible sources for this event.

Internal

The trigger event is generated automatically at a given rate (specified period).

External

A rising edge on the back-panel external trigger input is used as the trigger source. For trigger level and precision characteristics, refer to the technical specifications available at liquidinstruments.com/resources/supporting-material/product-documentation/.

Input

The specified analog input is monitored for a rising edge past the specified voltage.

Output

Another analog output channel is monitored for a rising edge past the specified voltage. Combined with the fact that the other outputs can in turn be modulated from a variety of sources, this provides extremely flexible control of the trigger period (included for example changing period based on an external voltage).

Burst mode

Applicable to: sine, square, ramp, pulse, noise

In burst mode, a trigger event causes the given output to begin generating its configured waveform either continuously, for a set number of cycles, or for a set duration. Burst requires you to specify a sub-mode that defines if or when the generation ends.

N-Cycle: When triggered, the waveform will be generated for the set number of cycles. The waveform will stop after the specified number of cycles, at which time it will re-arm for a new trigger. Not available for noise, which is a continuous waveform and is not defined in cycles.

Gated: The waveform will continue to be generated while the trigger signal is high (level-triggered).

Start: The waveform generation begins on a trigger signal but will continue indefinitely.

N-Cycle

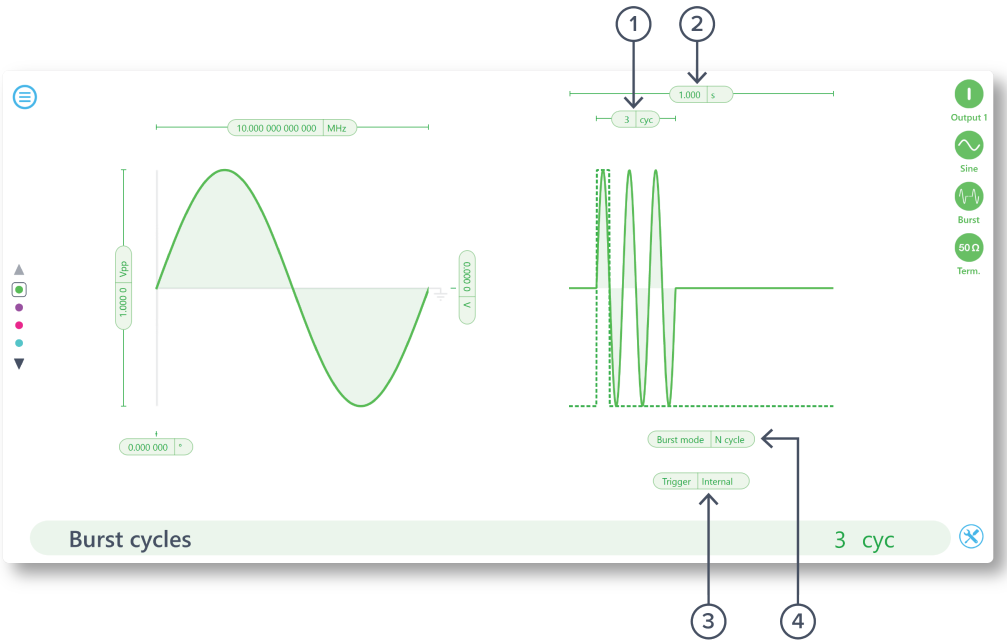


Figure 31. Waveform Generator N-cycle burst modulation internal

① Edit burst cycles parameter
② Edit burst period parameter
③ Select trigger source
④ Select burst mode

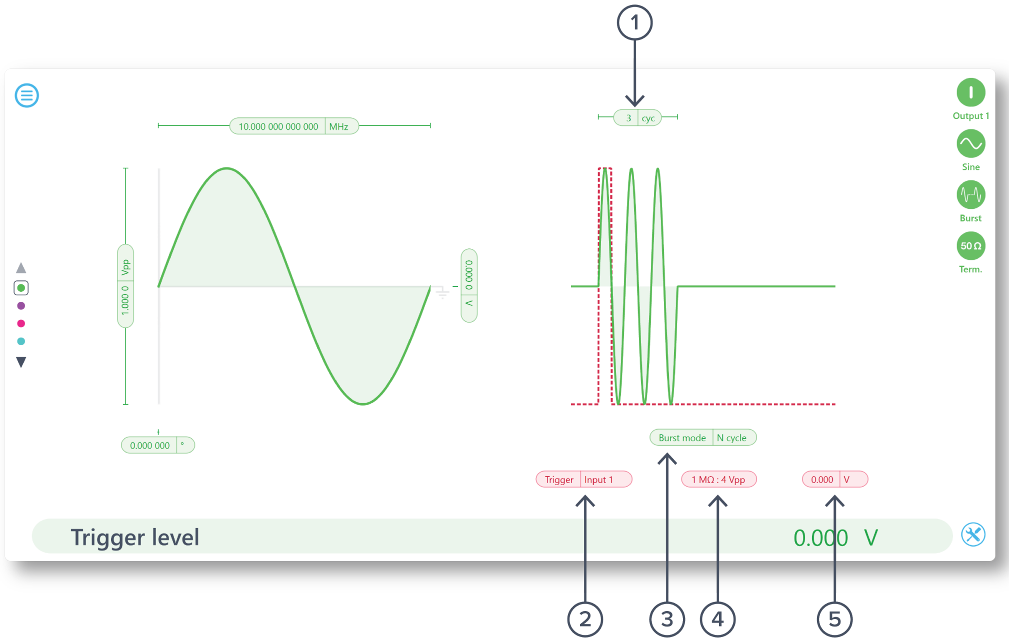


Figure 32. Waveform Generator N-cycle burst modulation input

① Edit burst cycles parameter
② Select trigger source
③ Select burst mode
④ Edit selected input frontend settings
⑤ Edit trigger level parameter

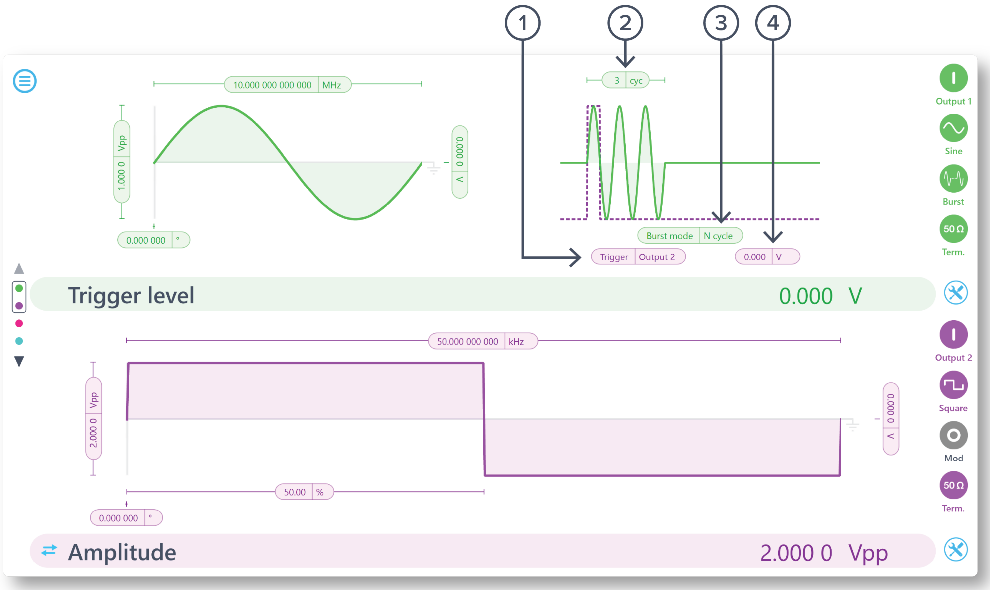


Figure 33. Waveform Generator N-cycle burst modulation output

① Select trigger source
② Edit burst cycles parameter
③ Select burst mode
④ Edit trigger level parameter

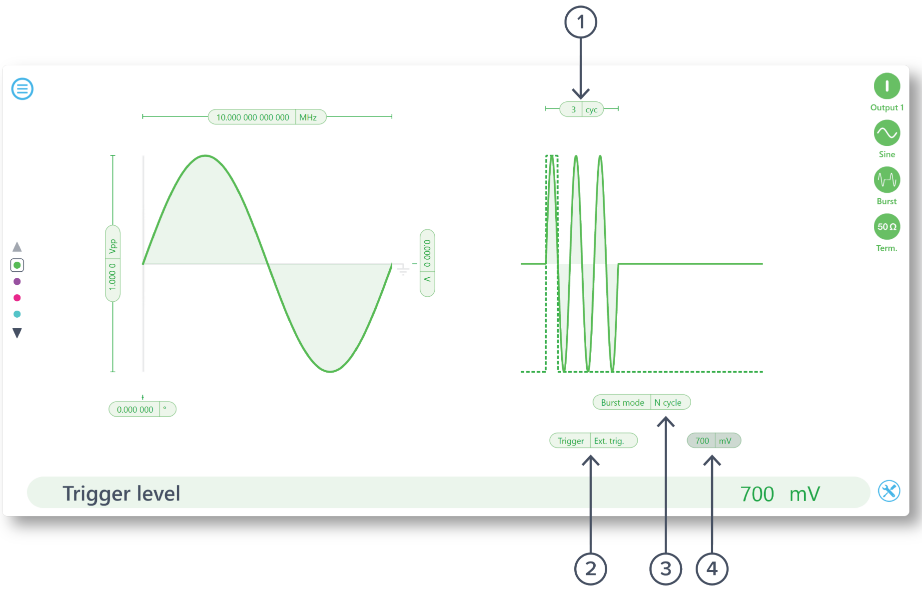


Figure 34. Waveform Generator N-cycle burst modulation external trigger

① Edit burst cycles parameter
② Select trigger source
③ Select burst mode
④ Fixed external trigger level

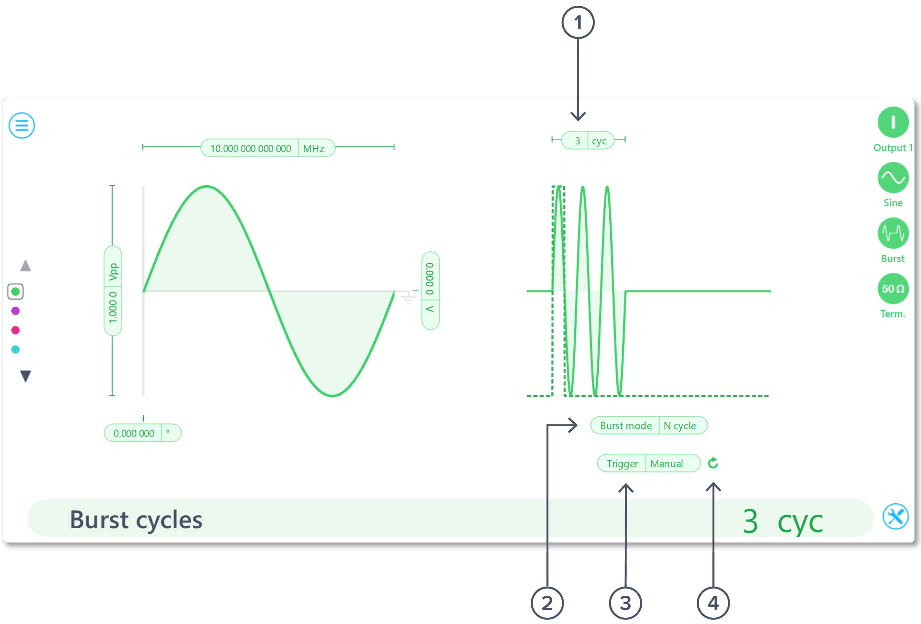


Figure 35. Waveform Generator N-cycle burst modulation manual

① Edit burst cycles parameter
② Select burst mode
③ Select trigger source
④ Click to provide manual trigger

Gated

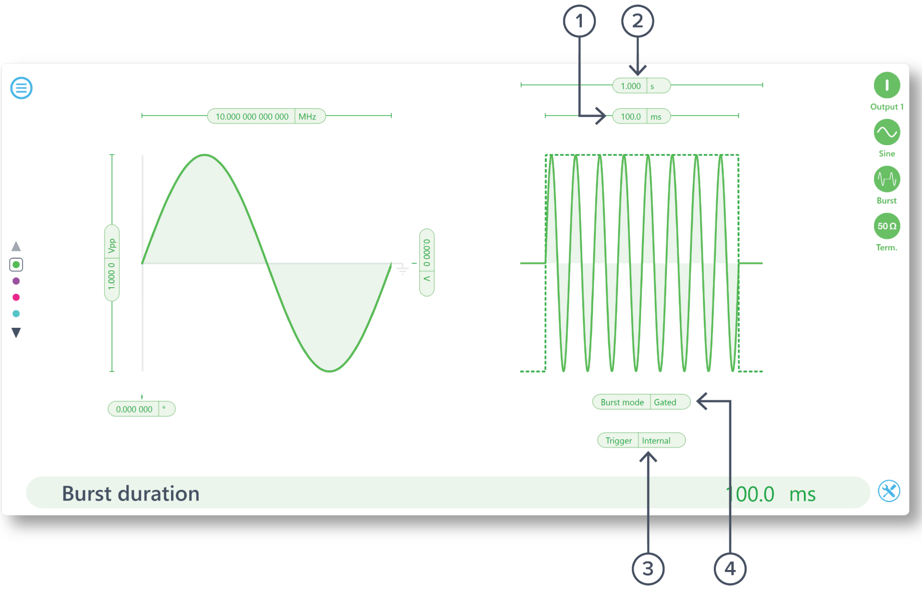


Figure 36. Waveform Generator gated burst modulation internal

① Edit burst duration parameter
② Edit burst period parameter
③ Select trigger source
④ Select burst mode

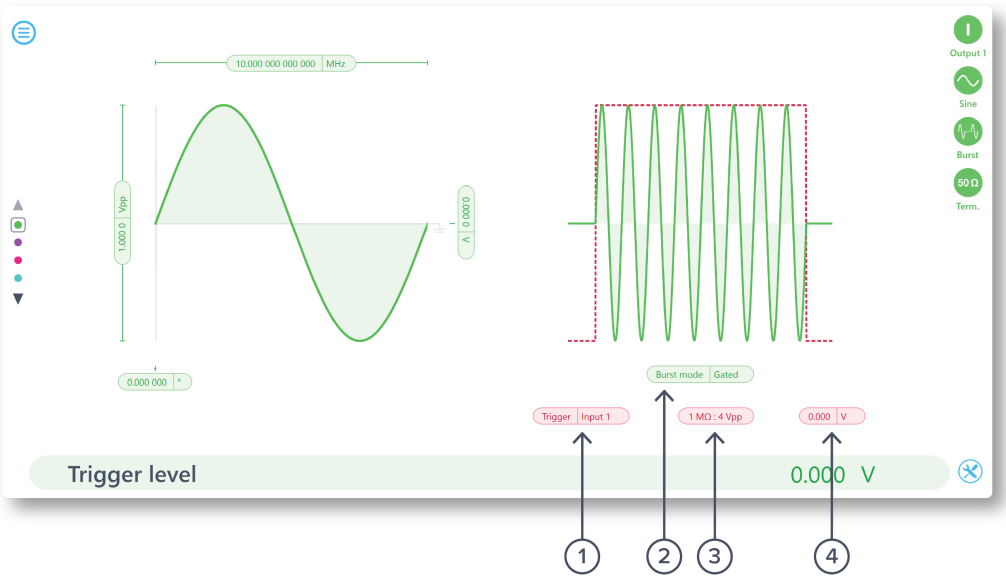


Figure 37. Waveform Generator gated burst modulation input

① Select trigger source
② Select burst mode
③ Edit selected input frontend settings
④ Edit trigger level parameter

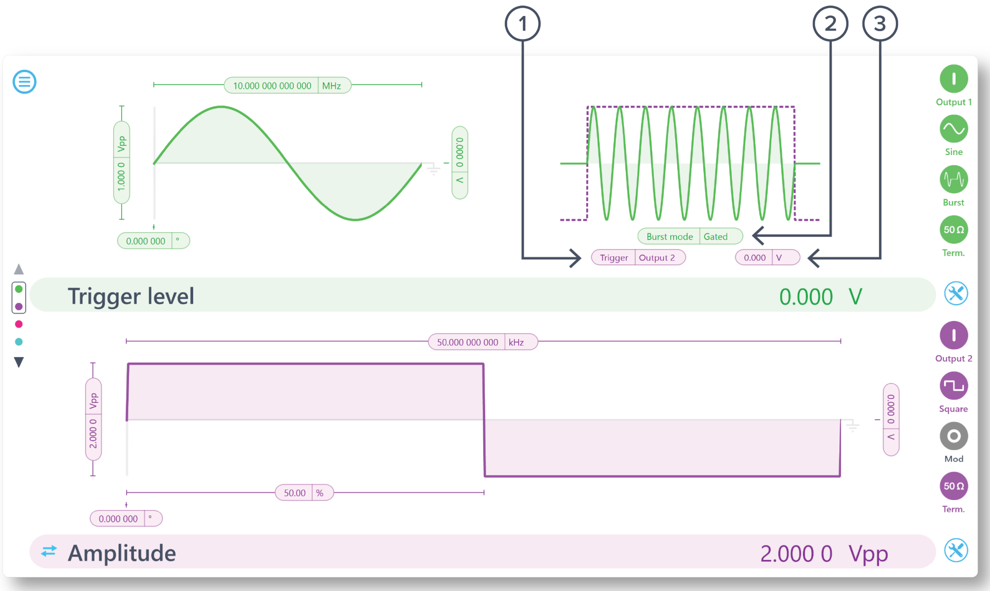


Figure 38. Waveform Generator gated burst modulation output

① Select trigger source
② Select burst mode
③ Edit trigger level parameter

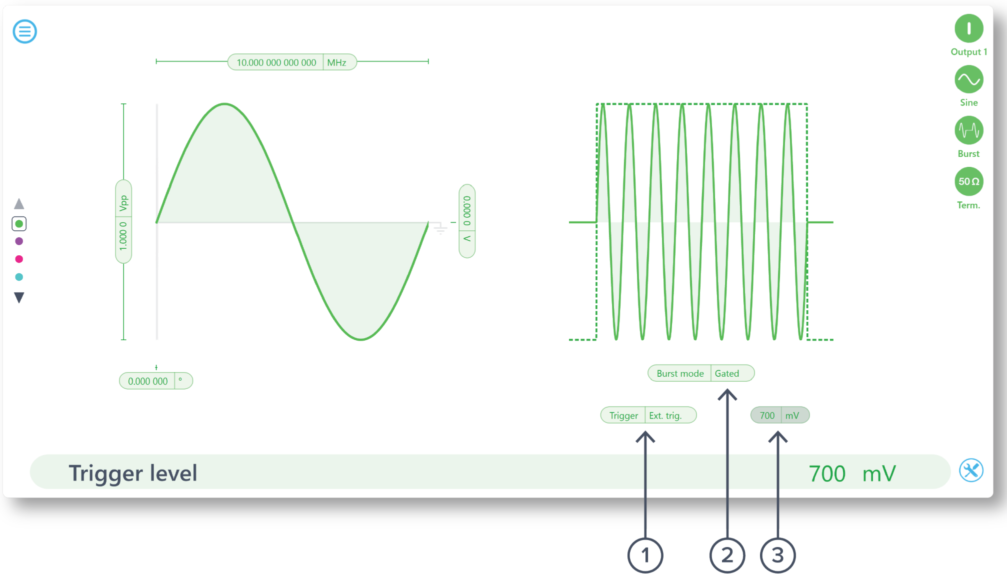


Figure 39. Waveform Generator gated burst modulation external trigger

① Select trigger source
② Select burst mode
③ Fixed external trigger level

Start

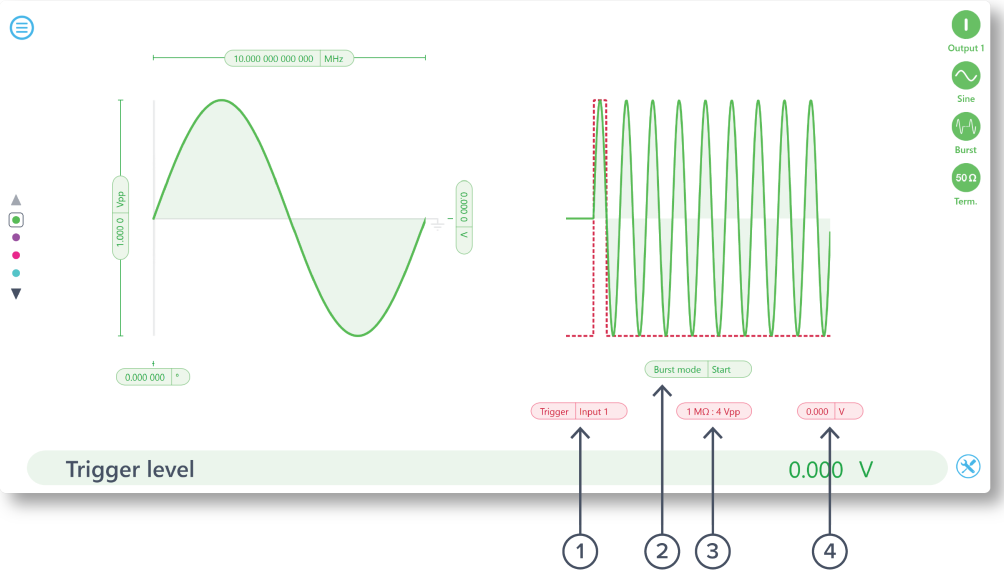


Figure 40. Waveform Generator start burst modulation input

① Select trigger source
② Select burst mode
③ Edit selected input frontend settings
④ Edit trigger level parameter

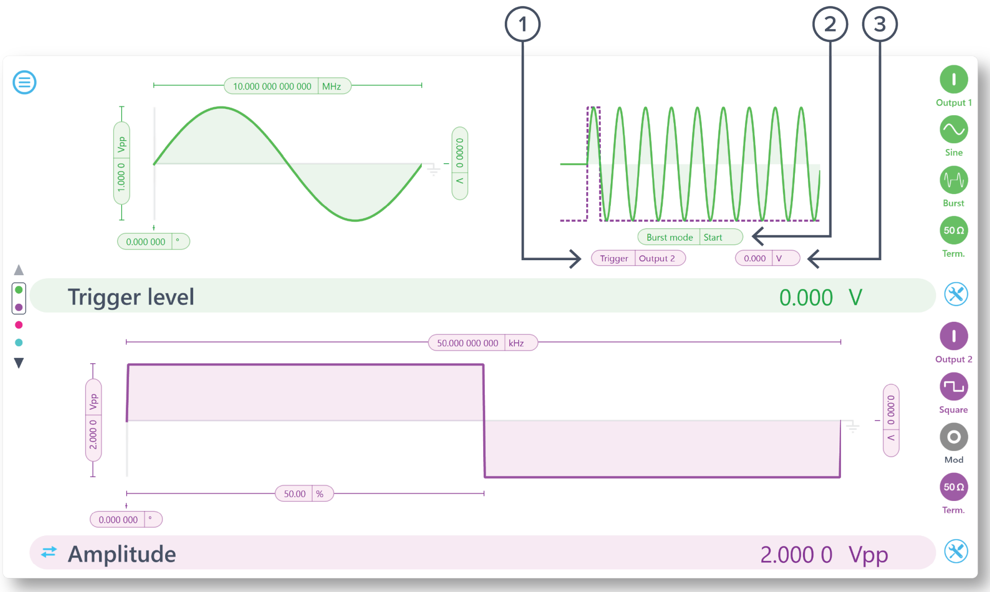


Figure 41. Waveform Generator start burst modulation output

① Select trigger source
② Select burst mode
③ Edit trigger level parameter

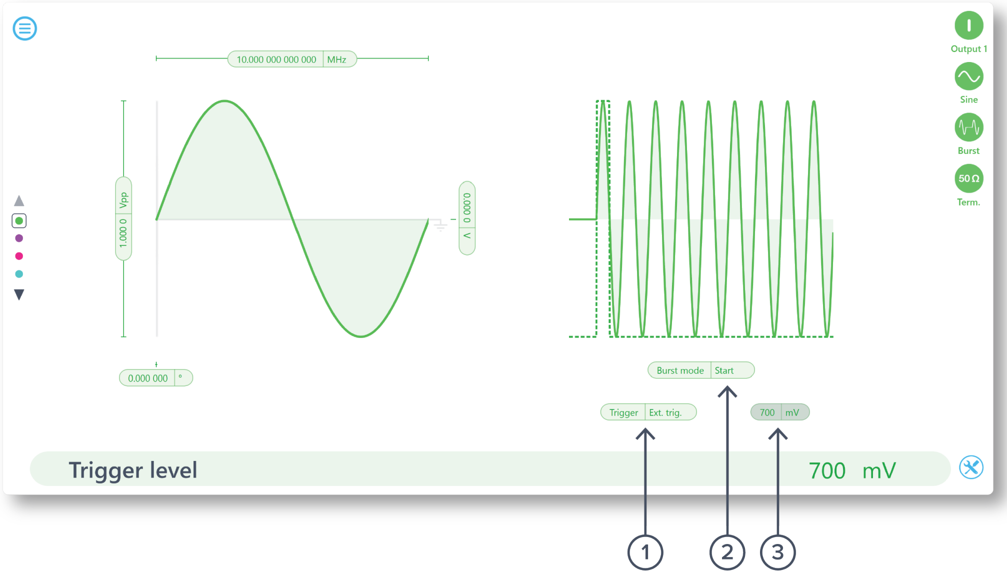


Figure 42. Waveform Generator start burst modulation external trigger

① Select trigger source
② Select burst mode
③ Fixed external trigger level

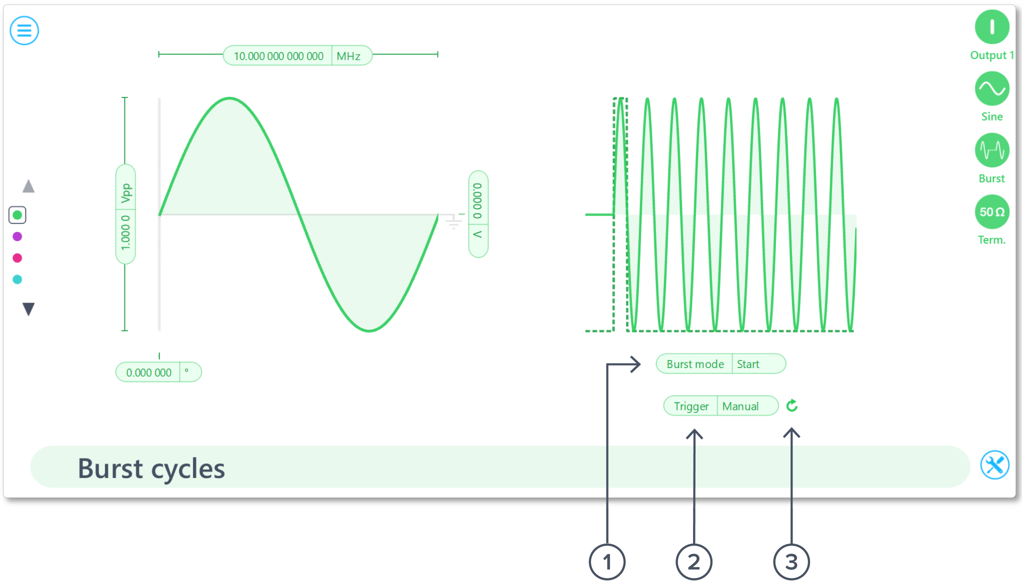


Figure 43. Waveform Generator start burst modulation manual

① Select burst mode
② Select trigger source
③ Click to provide manual trigger

Sweep mode

Applicable to: sine, square, ramp, pulse

Sweep mode provides a frequency modulation of the output waveform, where the modulation waveform is a ramp wave that begins generation on the detection of a trigger signal. That is, when a trigger is detected, waveform generation will begin at the start frequency and sweep (or “chirp”) to the end frequency over a given duration.

Sweep mode has three configurable parameters:

Start frequency: Initial frequency of the output waveform, immediately on detection of a trigger. The start frequency is the frequency of the unmodulated wave.

End frequency: Final frequency of the output waveform, reached *duration* seconds after the trigger has been detected.

Duration: The time taken to sweep from start to end frequency. Upon completion of the sweep, the sweep circuit will re-arm and be ready to receive a new trigger input. Note: When the trigger source of the sweep is set to internal, the sweep will continually loop.

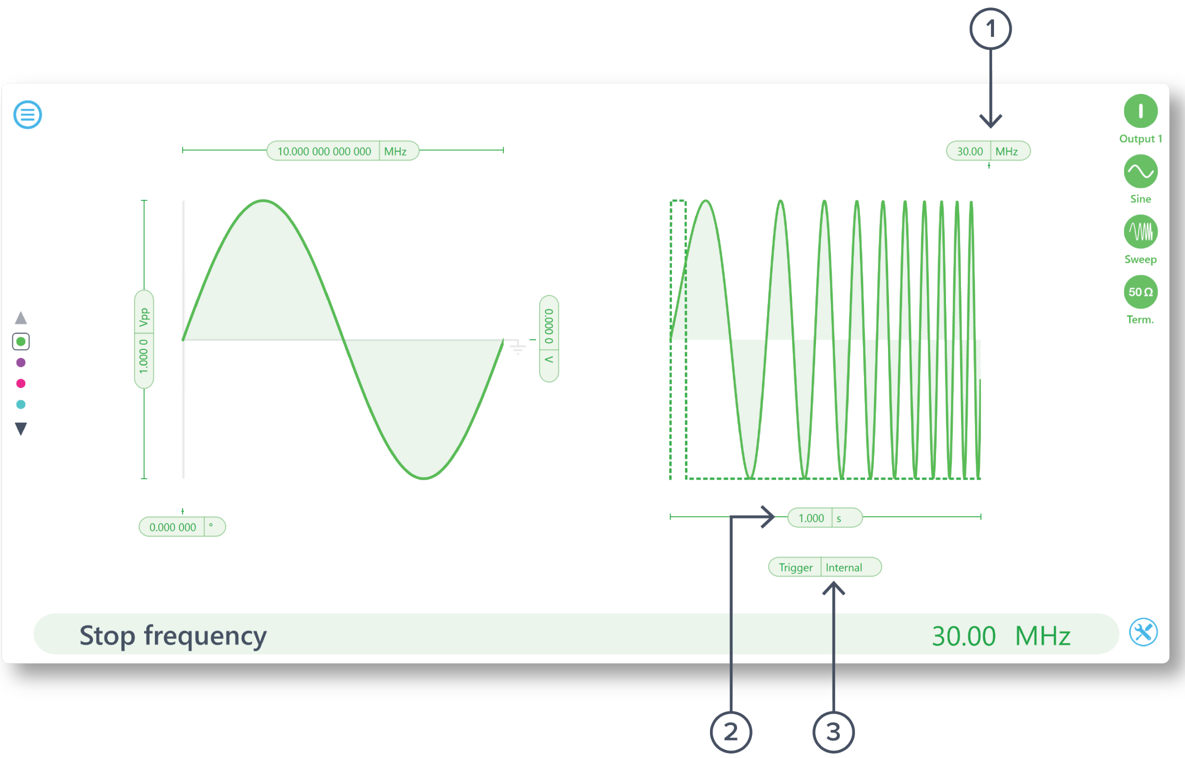


Figure 44. Waveform Generator sweep modulation internal

① Edit stop frequency parameter
② Edit sweep time parameter
③ Select trigger source

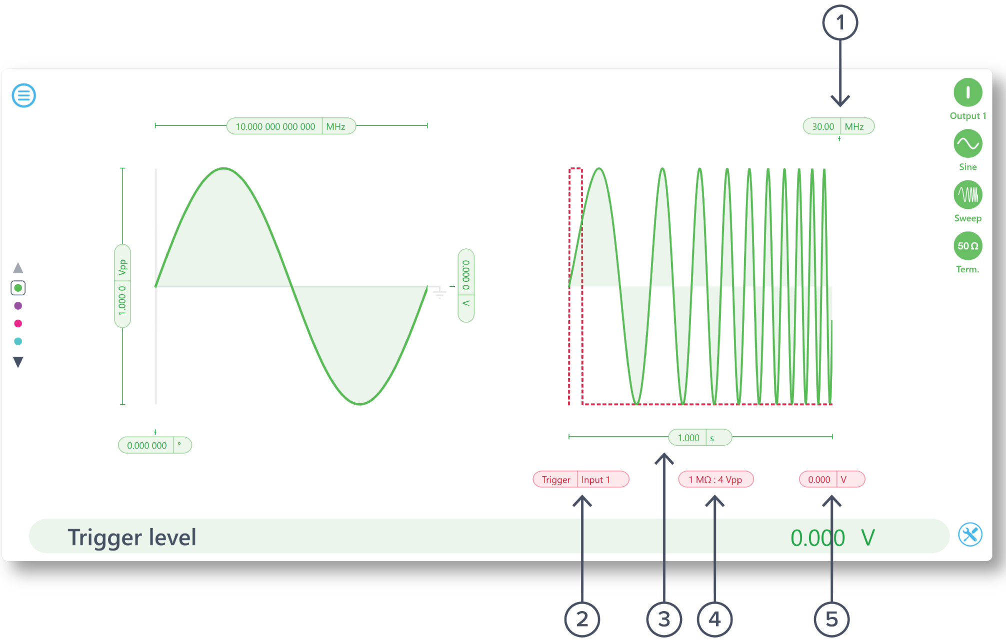


Figure 45. Waveform Generator sweep modulation input

① Edit stop frequency parameter
② Select trigger source
③ Edit sweep time parameter
④ Edit selected input frontend settings
⑤ Edit trigger level parameter

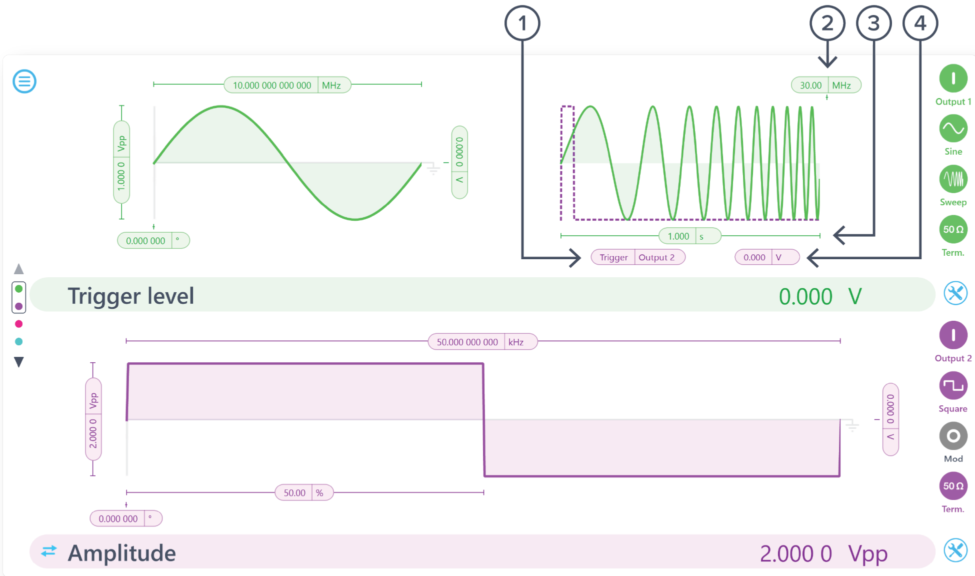


Figure 46. Waveform Generator sweep modulation output

① Select trigger source
② Edit stop frequency parameter
③ Edit sweep time parameter
④ Edit trigger level parameter

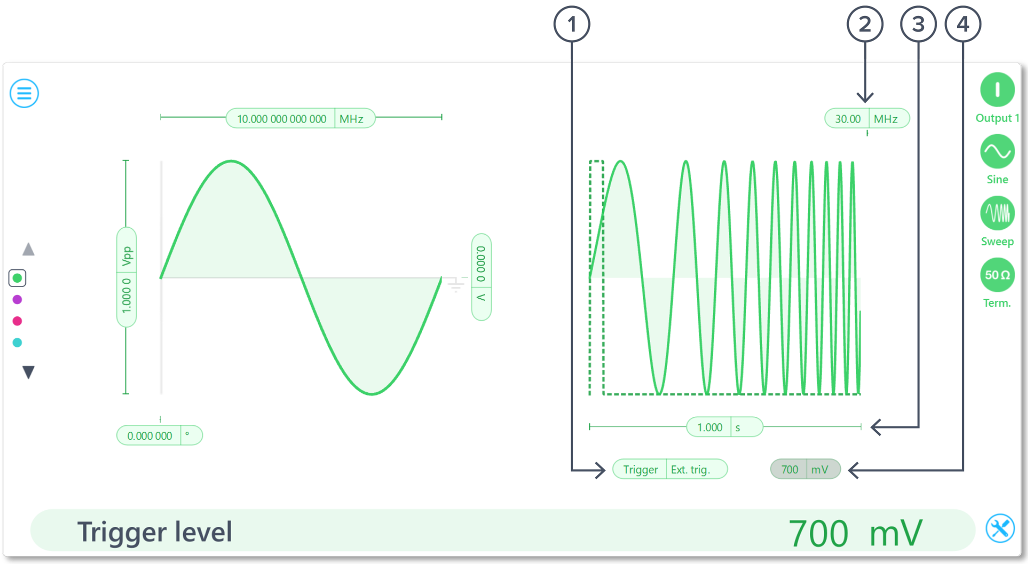


Figure 47. Waveform Generator sweep modulation external trigger

① Select trigger source
② Edit stop frequency parameter
③ Edit sweep time parameter
④ Fixed external trigger level

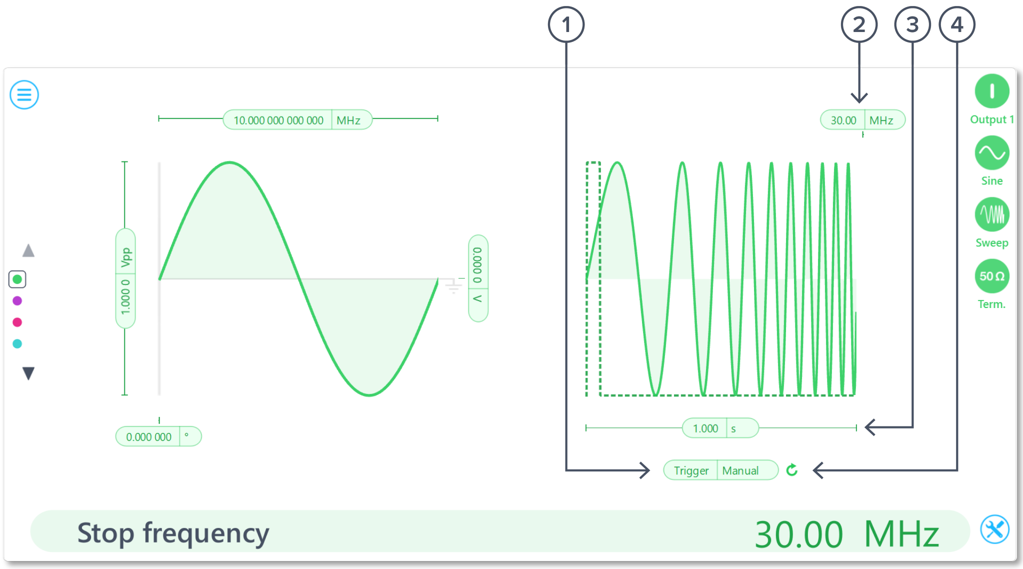


Figure 48. Waveform Generator sweep modulation manual

① Select trigger source
② Edit stop frequency parameter
③ Edit sweep time parameter
④ Click to provide manual trigger

Performance self-test

Using Multi-instrument Mode, your waveforms can be quickly performance tested to ensure the waveforms are output as expected. This is a good idea if your system is very sensitive or if it is your first time using the waveform.

Connect the output of the Waveform Generator to the input of the Oscilloscope. Load and turn on your waveform into the Waveform Generator and view its signal in the Oscilloscope. Its signal characteristics can be measured in the measurement panel, accessed by the measurements button .

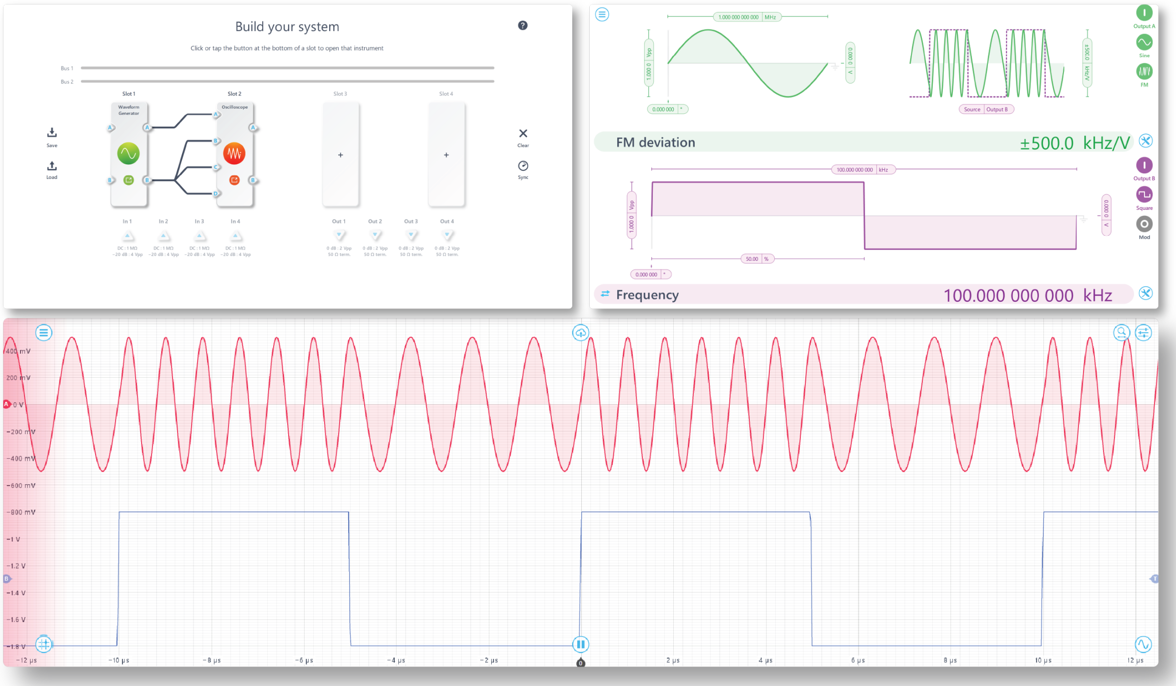


Figure 49. Multi-instrument Mode self-test setup for previewing the waveforms output from the Waveform Generator

Examples

Pulse width modulation (PWM) example

Here we outline the typical workflow of the Waveform Generator, using pulse width modulation (PWM) as our example. We will use the Waveform Generator to produce a pulse-width-modulated Pulse wave on Output 1, using an internal oscillator as the modulation source. We will use Multi-instrument Mode to view the resulting signal in the Time & Frequency Analyzer.

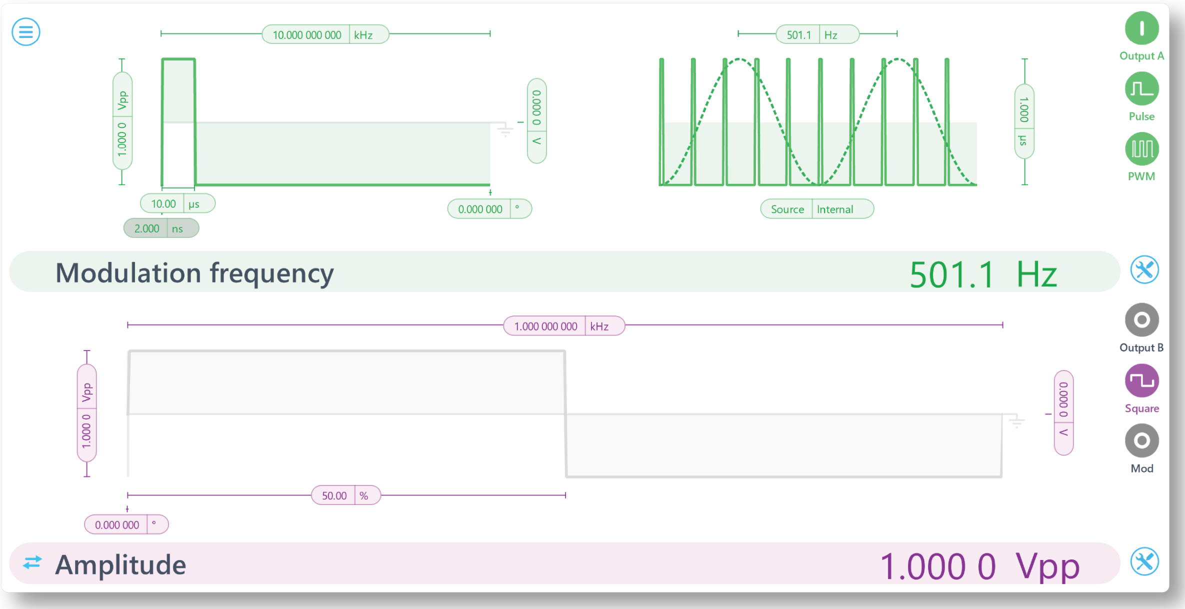


Figure 50. Waveform Generator guide to pulse width modulation

In this example, we use the Time & Frequency Analyzer in Multi-instrument Mode to observe the output signals.

- **Step 1: Step up Multi-instrument Mode.**
  - Deploy the Waveform Generator in slot 1 and the Time & Frequency Analyzer in slot 2.
  - We don't need to make any changes to the default connection map.
  - Click apply changes and open the Waveform Generator in a new window.
- **Step 2: Generate a pulse wave and configure the frequency and amplitude.**
  - On the right side of Output 1, select the pulse wave option.
  - Set the frequency to 10 kHz and the amplitude to 1 Vpp.
  - Set the pulse width to 10 µs and leave the edge time at the default.
  - Set the offset to 0 V and phase to 0 degrees, these are defaults.
- **Step 3: Enable the output.**
  - Toggle Output 1 ON.
- **Step 4: Configure the Time & Frequency Analyzer.**
  - Go back to the Multi-instrument Mode window and open the Time & Frequency Analyzer in a new window.
  - Open the events side panel, set "Event A" to trigger on the rising edge of "Input A" at 0 V.
  - Set "Event B" to trigger on the falling edge of "Input A" at 0 V.

- Switch to the intervals side panel ⏱, disable "Interval B".
- Set "Interval A" to to start on "Event A" and stop on "Event B", this will record the time between the rising and falling edge of "Input A", in other words, the pulse width.

- **Step 5: Observe the waveform in the Time & Frequency Analyzer**
  - Set the acquisition mode to continuous.
  - Click on the current statistic measurement, select "Interval A" and "Mean", this will show 10 µs.
  - Click on clear to flush out past data and open the histogram.
  - Double click on the horizontal axis of the histogram to auto scale.
  - You can now observe there is very little deviation in the pulse width from 10 µs.
- **Step 6: Enable pulse width modulation (PWM) modulation on Output 1.**
  - Go back into the Waveform Generator.
  - On the right side of Output 1, select the modulation type to be pulse width modulation (PWM).
  - Set the modulation source to internal.
  - Set the pulse width deviation to 1µs.
  - Set the modulation frequency to something arbitrary, i.e. 501.1 Hz.
- **Step 7: Observe the waveforms in the Time & Frequency Analyzer.**
  - Go back into the Time & Frequency Analyzer.
  - Click on clear to flush out past data.
  - Double click on the horizontal axis of the histogram to auto scale.
  - You can now observe the pulse width spreading across 9 µs to 11 µs.
  - Add statistics, click on the panel and set it to display the minimum of "Interval A", add another and set it to display the maximum of "Interval A".
  - The statistics will show the pulse width averaging at 10 µs and spanning from 9 µs to 11 µs.

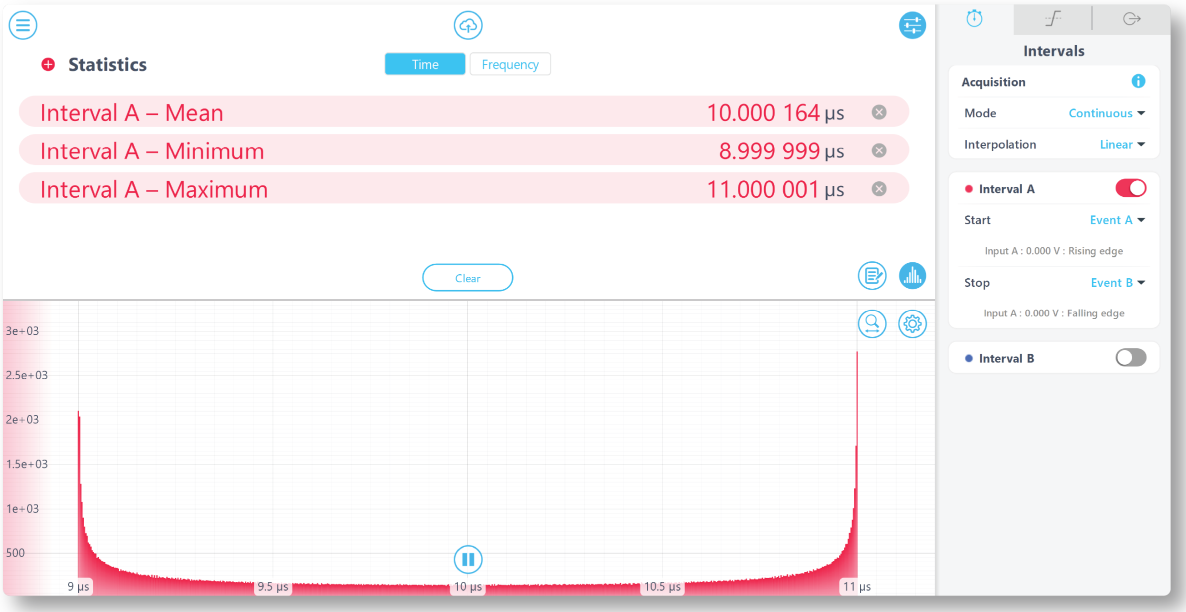


Figure 51. Multi-instrument Mode self-test setup for previewing the waveforms output from the Waveform Generator

AM example

Here we outline the typical workflow of the Waveform Generator, using cross-channel amplitude modulation (AM) as our example. We will use the Waveform Generator to produce an amplitude-modulated sine wave on Output 1, using a square wave from Output 2 as the modulation source.

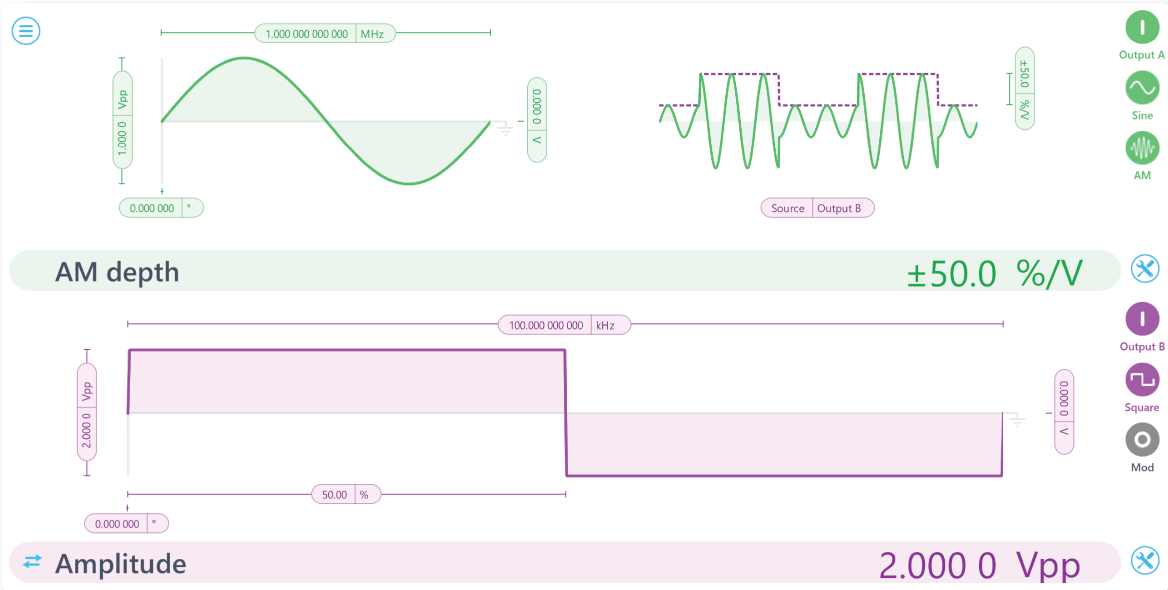


Figure 52. Waveform Generator guide to amplitude modulation

In this example, we use an Oscilloscope in Multi-instrument Mode to observe the output signals.

- **Step 1: Generate a sine wave and configure the frequency and amplitude**
  - On the right side of Output 1, select the sine wave option
  - Set the frequency to 1 MHz and the amplitude to 1 Vpp
  - Set the offset to 0 V and phase to 0°, these are defaults
- **Step 2: Generate a square wave and configure Output 2**
  - On the right side of Output 2, select the square wave option
  - Set the frequency to 100 kHz and the amplitude to 2 Vpp
  - Set the duty cycles to 50%, offset to 0 V, and phase to 0°, these are defaults
- **Step 3: Enable amplitude modulation on Output 1**
  - On the right side of Output 1, select the modulation type to be amplitude modulated (AM)
- **Step 4: Configure the Output 1 modulation**
  - Set the modulation source to Output 2
  - Set the AM deviation to 50%/V
- **Step 5: Turn on the outputs in order**
  - Toggle Output 2 ON
  - Toggle Output 1 ON
- **Step 6: Sync the phases**
  - Click the configuration icon at the bottom right of the displayed waveform, and select "Sync phase"
- **Step 7: Observe the waveforms**

- A preview of the waveforms will be shown in the Waveform Generator interface, as seen in Figure 52.
- **Step 8: Perform a self-test to preview the waveforms in the Moku Oscilloscope**
  - Route the signals in Multi-instrument Mode to an Oscilloscope to observe the waveform behavior, as seen in Figure 53.

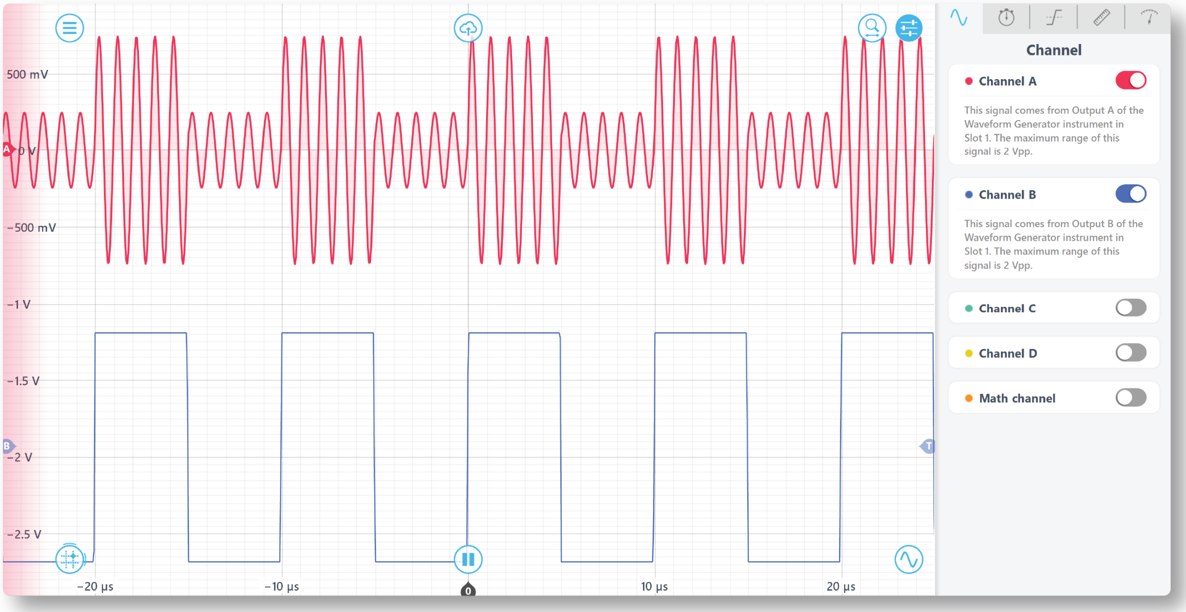
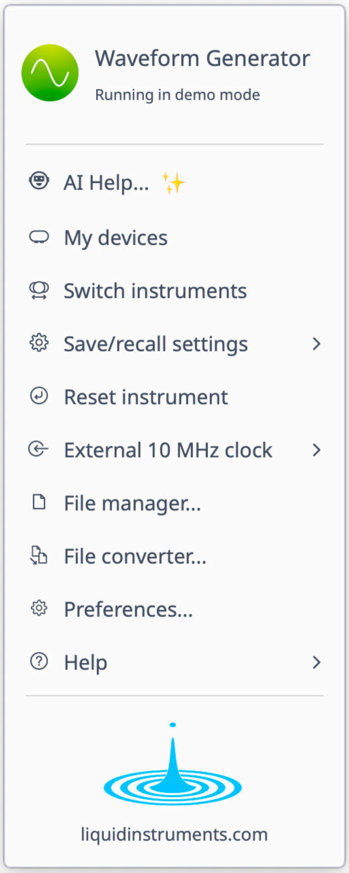


Figure 53. Multi-instrument Mode self-test setup for previewing the waveforms output from the Waveform Generator

Additional Controls

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.

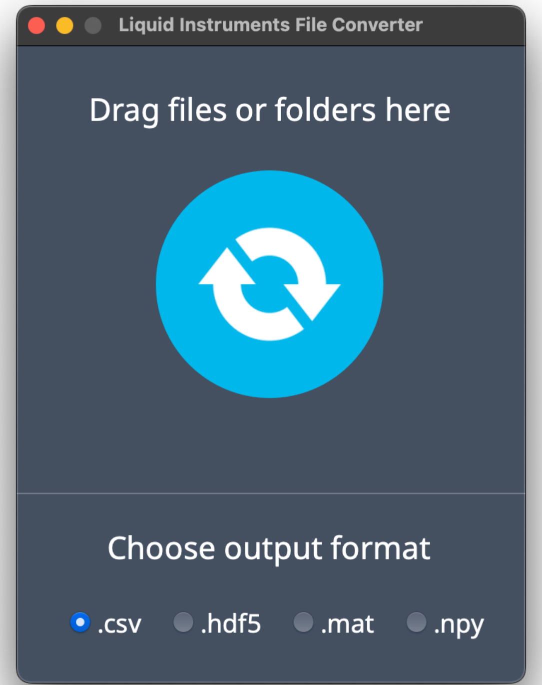


Figure 32: File Converter user interface.

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.

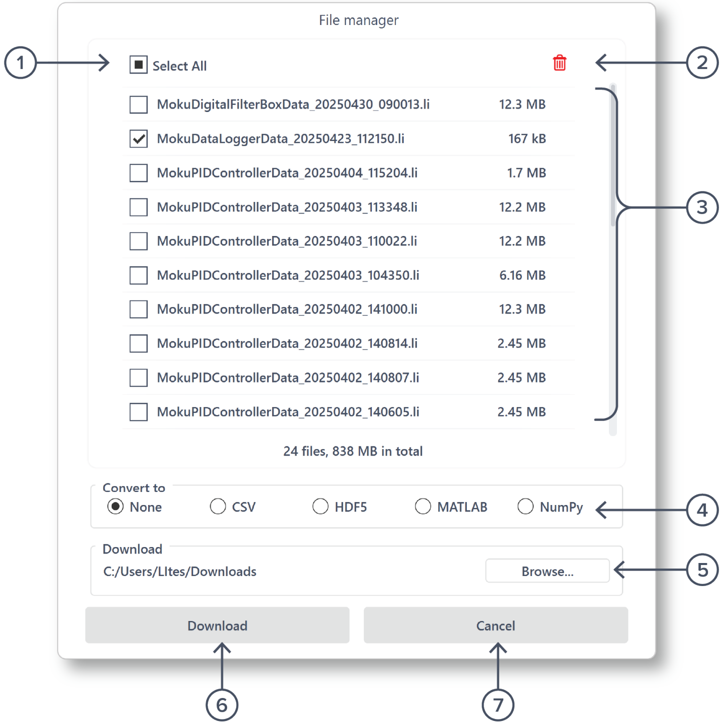


Figure 54. File exporting User Interface and settings.

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.

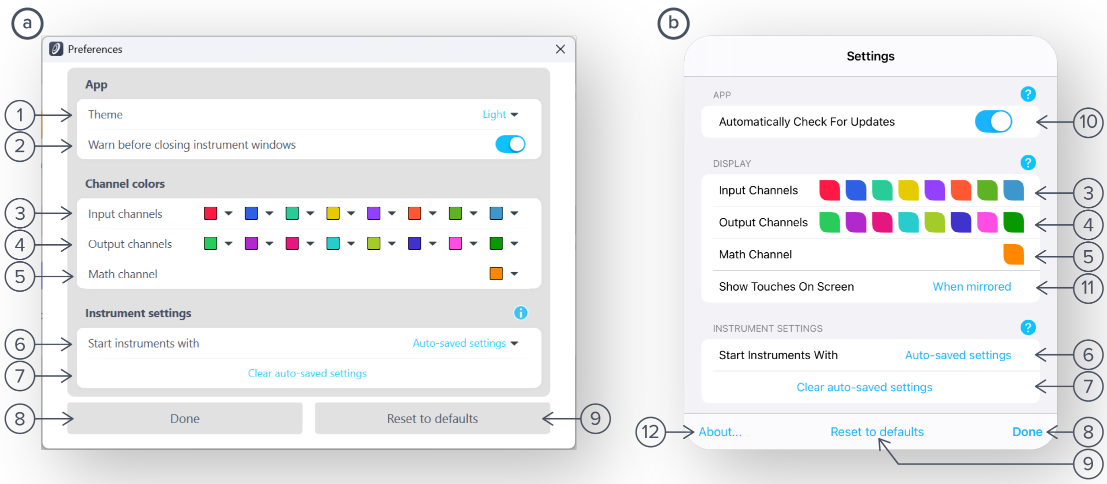


Figure 55. Preferences and settings for the Desktop (a) and for the iPad (b) App.

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.

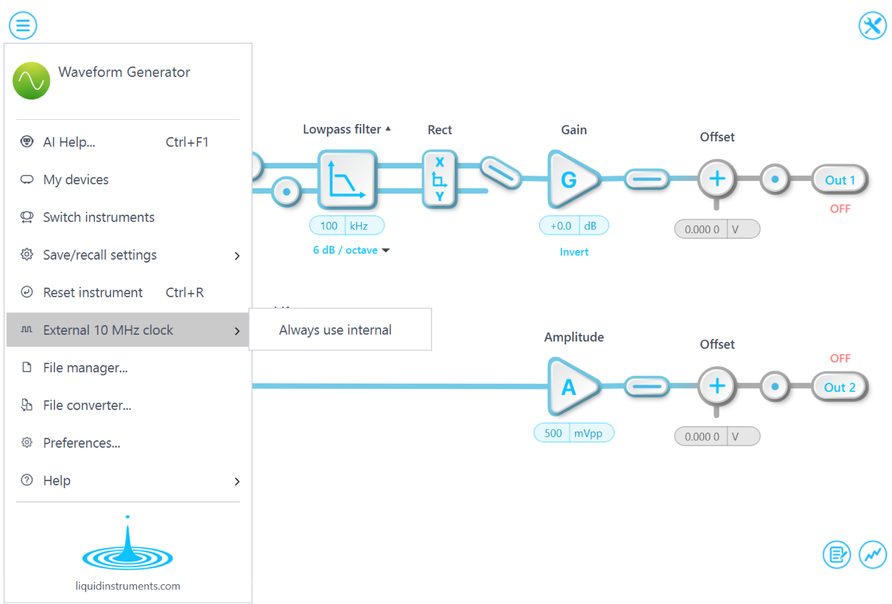


Figure 56. Moku main menu with "Always use internal" reference disabled and using an external reference.

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 57, 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 57. 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).

