



# Digital Filter Box

## Moku:Go User Manual

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With the Moku:Go Digital Filter Box, you can interactively design and generate different types of infinite impulse response filters with sampling rates of 61.035 kHz, 488.28 kHz and 3.9063 MHz. Select between low pass, high pass, band pass, and band stop filter shapes with up to eight fully configurable types including Butterworth, Chebyshev, and Elliptic.





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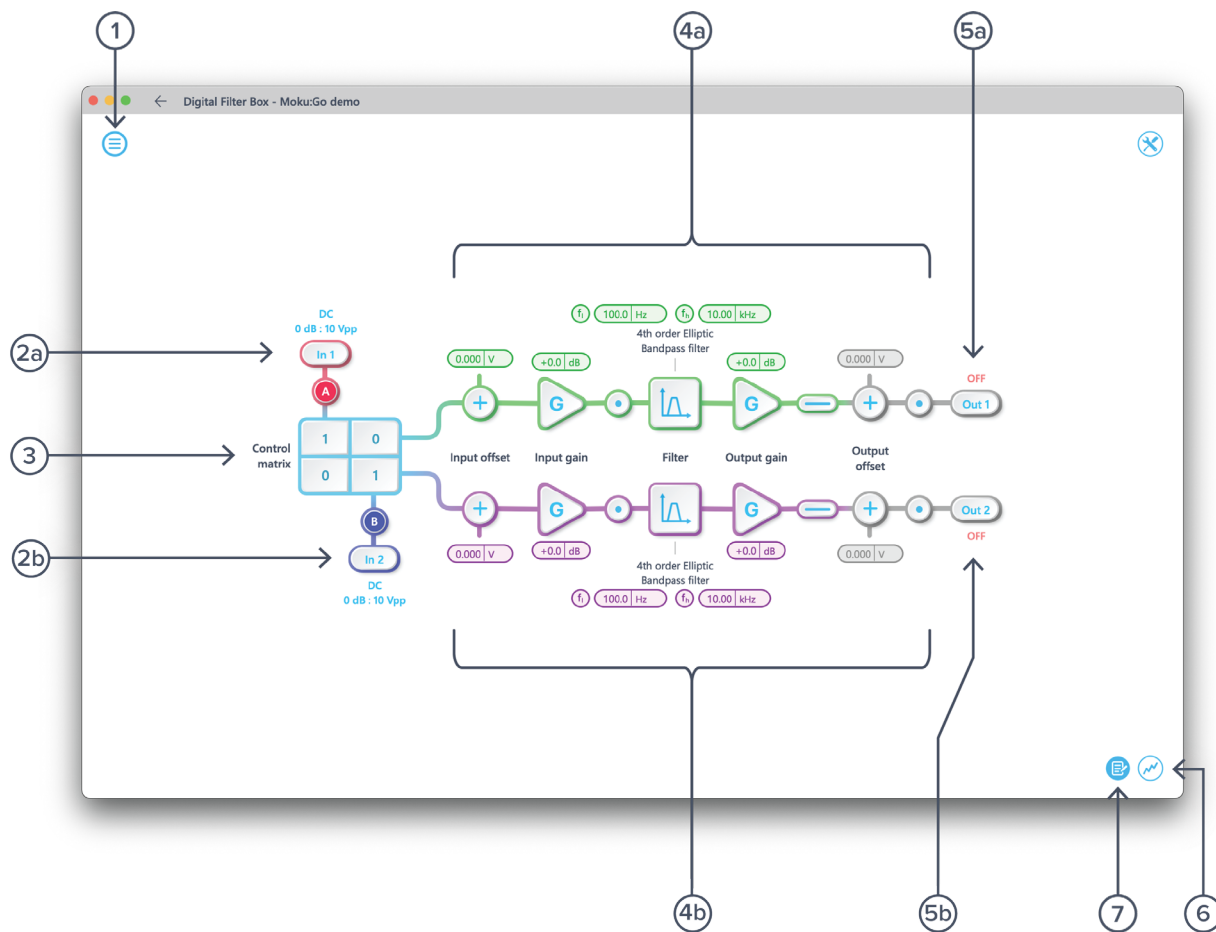


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# User interface



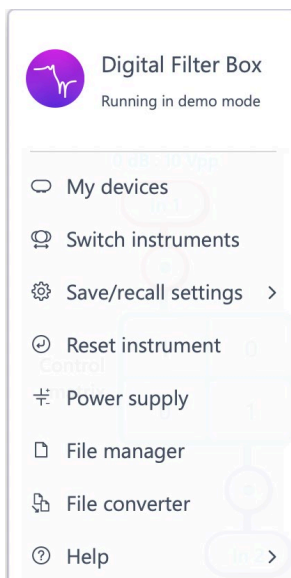
## ID Description

1	Main menu
2a	Input configuration for Channel 1
2b	Input configuration for Channel 2
3	Control matrix
4a	Configuration for filter 1
4b	Configuration for filter 2
5a	Output switch for Channel 1
5b	Output switch for Channel 2
6	Enable/disable the Oscilloscope view
7	Enable/disable the Data Logger view



# Main menu

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



Options	Shortcuts	Description
<b>My devices</b>		Search for Moku devices.
<b>Switch instruments</b>		Switch instruments on this Moku:Go.
<b>Save/recall settings:</b>		
• <b>Save instrument state</b>	Ctrl+S	Save the current instrument settings.
• <b>Load instrument state</b>	Ctrl+O	Load last saved instrument settings.
• <b>Show current state</b>		Show the current instrument settings.
<b>Reset instrument</b>	Ctrl+R	Reset the instrument to its default state.
<b>Power Supply</b>		Access Power Supply control window.*
<b>File manager</b>		Open file manager tool.**
<b>File converter</b>		Open file converter tool.**
<b>Help</b>		
• <b>Liquid Instruments website</b>		Access Liquid Instruments website.
• <b>Shortcuts list</b>	Ctrl+H	Show Moku:Go app shortcuts list.
• <b>Manual</b>	F1	Access instrument manual.
• <b>Report an issue</b>		Report bug to Liquid Instruments.
• <b>About</b>		Show app version, check for updates, or show license information.

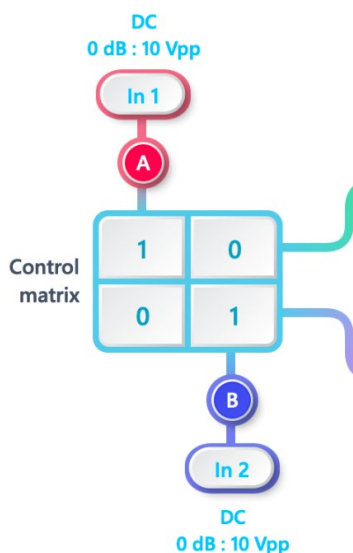
\*Power Supply is available on Moku:Go M1 and M2 models. Detailed information about Power Supply can be found in the Moku:Go Power Supply section toward the end of this user manual.

\*\*Detailed information about the file manager and file converter can be found toward the end of this user manual.



# Input configuration

The **input configuration** can be accessed by clicking the **In 1** or **In 2** icon, allowing you to adjust the coupling and input attenuation (and therefore voltage range) for each input channel.



Details about the probe points can be found in the [Probe Points](#) section.

## Control matrix

The **control matrix** combines, rescales, and redistributes the input signal to the two independent filters. The output vector is the product of the control matrix multiplied by the input vector.

$$\begin{bmatrix} Path1 \\ Path2 \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \times \begin{bmatrix} In1 \\ In2 \end{bmatrix}$$

where

$$Path1 = a \times In1 + b \times In2$$

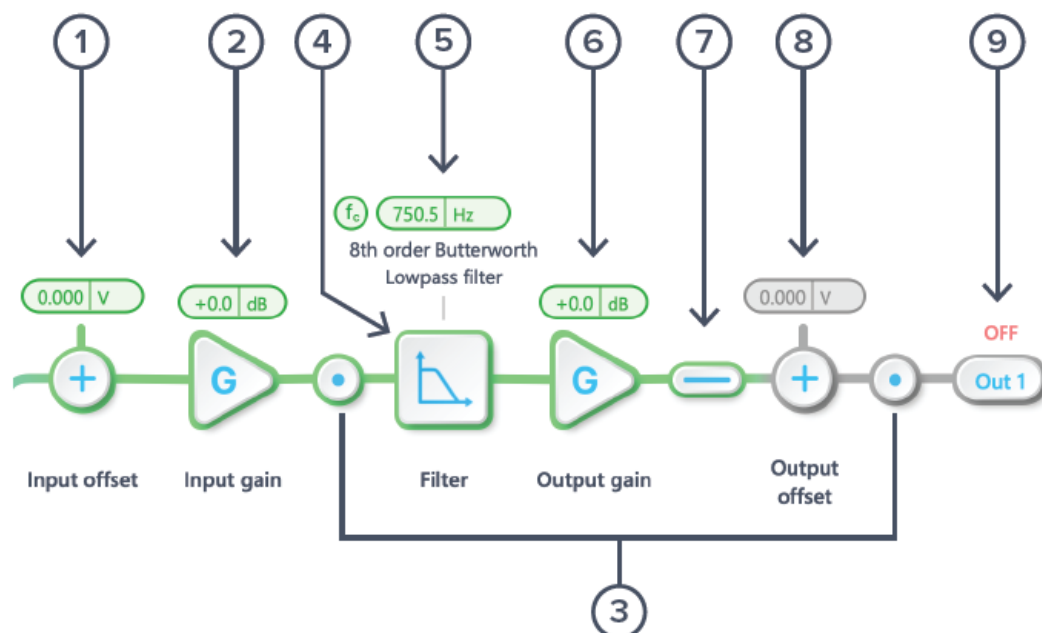
$$Path2 = c \times In1 + d \times In2$$

For example, a control matrix of  $\begin{bmatrix} 1 & 1 \\ 0 & 2 \end{bmatrix}$  equally combines the **Input 1** and **Input 2** to the top **Path1** (filter 1), multiplies **Input 2** by a factor of two, and then sends it to the bottom **Path2** (filter 2).

The value of each element in the control matrix can be set between -20 to +20 with 0.1 increments when the absolute value is less than 10, or 1 increment when the absolute value is between 10 and 20. Click the element to adjust the value.



## Digital filters



The two independent, real-time configurable digital IIR filter paths follow the control matrix in the block diagram, represented in green and purple for filters 1 and 2, respectively.

## User interface

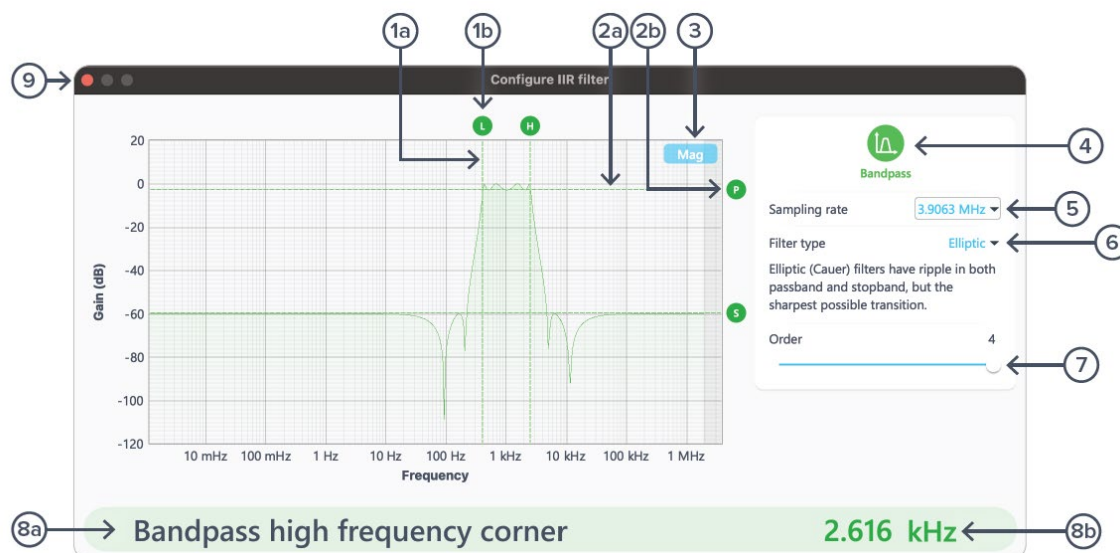
ID	Parameter	Description
1	Input offset	Click to adjust the input offset (-2.5 to +2.5 V).
2	Input gain	Click to adjust the input gain (-40 to 40 dB).
3	Probe points	Click to enable/disable the probe points. See <a href="#">Probe Points</a> section for details.
4	Digital filter	Click to view and configure the digital filter builder.
5	Quick filter control	Click or slide to quickly adjust the filter settings.
6	Output gain	Click to adjust the output gain (-40 to 40 dB).
7	Output switch	Click to zero the filter output.
8	Output offset	Click to adjust the output offset (-2.5 to +2.5 V).
9	DAC switch	Click to enable/disable the Moku:Go DAC output.



## Configure IIR filter characteristics

### Detailed filter interface

Click the  icon to open the full filter view.



ID	Parameter	Description
1a	Frequency (horizontal) cursor	Cursor for corner frequency.
1b	Cursor reading	Reading for frequency cursor. Drag to adjust the corner frequency. Click to select and manually enter the corner frequency in 8b.
2a	Gain (vertical) cursor	Cursor for ripple/gain/attenuation level.
2b	Cursor handle	Short name and handle for gain cursor. Drag to adjust the gain/ripple level. Click to select and manually enter passband ripple in 8b.
3	Display toggle	Toggle between magnitude and phase response curve.
4	Filter shape selection	Click to select between low pass, high pass, band pass, band stop, and custom filters.
5	Sampling rate	Click to select between 3.9063 MHz, 488.28 kHz, or 61.035 kHz.
6	Filter type selection	Click to select between Butterworth, Chebyshev I/II, Elliptic, Bessel, Gaussian, Cascaded or Legendre filters. When selected, a short description of the filter type will be given below.
7	Filter order	Slide to adjust filter orders.
8a	Active configurable parameter	Name of the active configurable parameter.
8b	Parameter value	Click to manually enter the active configurable parameter value.
9	Save and close	Click to save and close the filter builder.





## Filter shapes

The shape of the filter can be selected by clicking the ④ button (page 9). There are four pre-defined filter shapes and a fully customizable filter option.



## Sampling rates

Users can select between 3.9063 MHz, 488.28 kHz, or 61.035 kHz of output sampling rate based on the desired corner frequencies. The following table summarizes the lower and upper bounds for each shape of pre-defined filters with different sampling rates:

Shape	Sampling Rate	Minimum corner frequency	Maximum corner frequency
Lowpass	61.035 kHz	11.73 mHz	27.47 kHz
	488.28 kHz	93.81 mHz	219.7 kHz
	3.9063 MHz	750.5 mHz	1.758 MHz
Highpass	61.035 kHz	144.7 mHz	27.47 kHz
	488.28 kHz	1.158 Hz	219.7 kHz
	3.9063 MHz	9.263 Hz	1.758 MHz
Bandpass	61.035 kHz	610.4 mHz	27.47 kHz
	488.28 kHz	4.883 Hz	219.7 kHz
	3.9063 MHz	39.06 Hz	1.758 MHz
Bandstop	61.035 kHz	11.73 mHz	27.47 kHz
	488.28 kHz	93.81 mHz	219.7 kHz
	3.9063 MHz	750.5 mHz	1.758 MHz



## Filter types

The type of filter can be selected by pressing the ⑥ button (on Page 9). There are seven pre-defined filter types with user-selectable filter orders from 2 up to 8, depending on the filter shapes.

Filter types	Description
<b>Butterworth</b>	Butterworth filters have a maximally flat passband and a monotonic frequency response.
<b>Chebyshev I</b>	Chebyshev I filters have ripple in the passband but a sharper transition than Butterworth filters.
<b>Chebyshev II</b>	Chebyshev II filters have ripple in the stopband but a sharper transition than Butterworth filters.
<b>Elliptic</b>	Elliptic (Cauer) filters have ripple in both passband and stopband, but the sharpest possible transition.
<b>Cascaded</b>	Cascaded first-order filters have zero overshoot in the time domain.
<b>Bessel</b>	Bessel filters have a maximally flat group and phase delay in the passband, thus preserving the wave shape of passed signals.
<b>Gaussian</b>	Gaussian filters have the minimum possible group delay, and a step response with no overshoot and minimum rise and fall time.
<b>Legendre</b>	Legendre (Optimum L) filters have the sharpest possible transition while maintaining a monotonic frequency response.

## Filter orders

For single sided filters, the order of the filter can be set to 2, 4, 6, or 8. For double sided filters, the order of the filter can be 2 or 4.

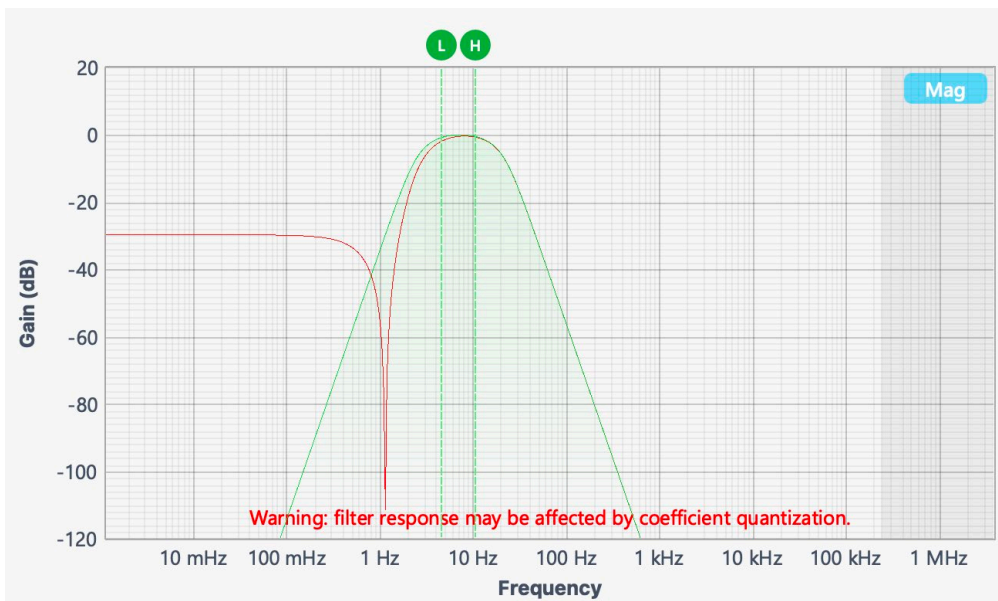
## Ripples

Chebyshev I, II, and Elliptic filters have ripples on either passband, stopband, or both. The following table summarize the adjustable range for the passband and stopband ripples for these filter types.


Filter types	Passband ripple	Stopband ripple
<b>Chebyshev I</b>	0.1 dB to 10.0 dB with 0.1 dB increment	N/A.
<b>Chebyshev II</b>	N/A	10.0 dB to 100.0 dB with 1 dB increment.
<b>Elliptic</b>	0.1 dB to 10.0 dB with 0.1 dB increment	10.0 dB to 100.0 dB with 1 dB increment.

## Coefficient quantization

Due to the limited precision with which a coefficient can be digitally represented, quantization error is pronounced at certain IIR filter settings. A red coefficient quantization warning may appear on the bottom of the response plot with a red trace in the transfer function showing the closest achievable filter response to the ideal value in green.



### Custom filter


Additionally, you can upload filter coefficients for a custom filter type from the clipboard or a local file. Click the  icon to see explanation of the coefficients and file format.

Custom

Sampling rate

Load from clipboard

Load from file





## Custom filter details

The Moku:Go Digital Filter Box implements infinite impulse response (IIR) filters using four cascaded Direct Form I second-order stages with a final output gain stage. The total transfer function can be written:

$$H(z) = g \prod_{k=1}^4 s_k \frac{b_{0k} + b_{1k}z^{-1} + b_{2k}z^{-2}}{1 + a_{1k}z^{-1} + a_{2k}z^{-2}}$$

To specify a filter, you must supply a text file containing the filter coefficients. The file should have six coefficients per line, with each line representing a single stage. If output scaling is required, this should be given on the first line:

<i>g</i> (optional)	7.8357416974,					
Stage 1	1.0000000000,	0.0044157497,	0.0088314994,	0.0044157497,	-1.6692917152,	0.9692269375
Stage 2	1.0000000000,	0.0472217267,	0.0944434535,	0.0472217267,	-1.8988580275,	0.9341904809
Stage 3	1.0000000000,	0.0375275838,	0.0750551677,	0.0375275838,	-1.9259771042,	0.9311308010
⋮	<i>s</i>	<i>b</i> <sub>0</sub>	<i>b</i> <sub>1</sub>	<i>b</i> <sub>2</sub>	<i>a</i> <sub>1</sub>	<i>a</i> <sub>2</sub>

Each coefficient must be in the range [-4.0,+4.0). Internally, these are represented as signed 48-bit fixed-point numbers, with 45 fractional bits. The output scaling can be up to 8,000,000. Filter coefficients can be computed using signal processing toolboxes in e.g. MATLAB or SciPy.

Some coefficients may result in overflow or underflow, which degrade filter performance. Check filter responses prior to use.

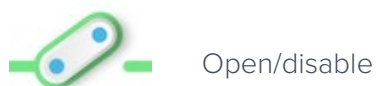


## Output switches

Connect or disconnect the output signal using switches. When a switch is in the open state, the output signal will be the output offset voltage.




Closed/enable



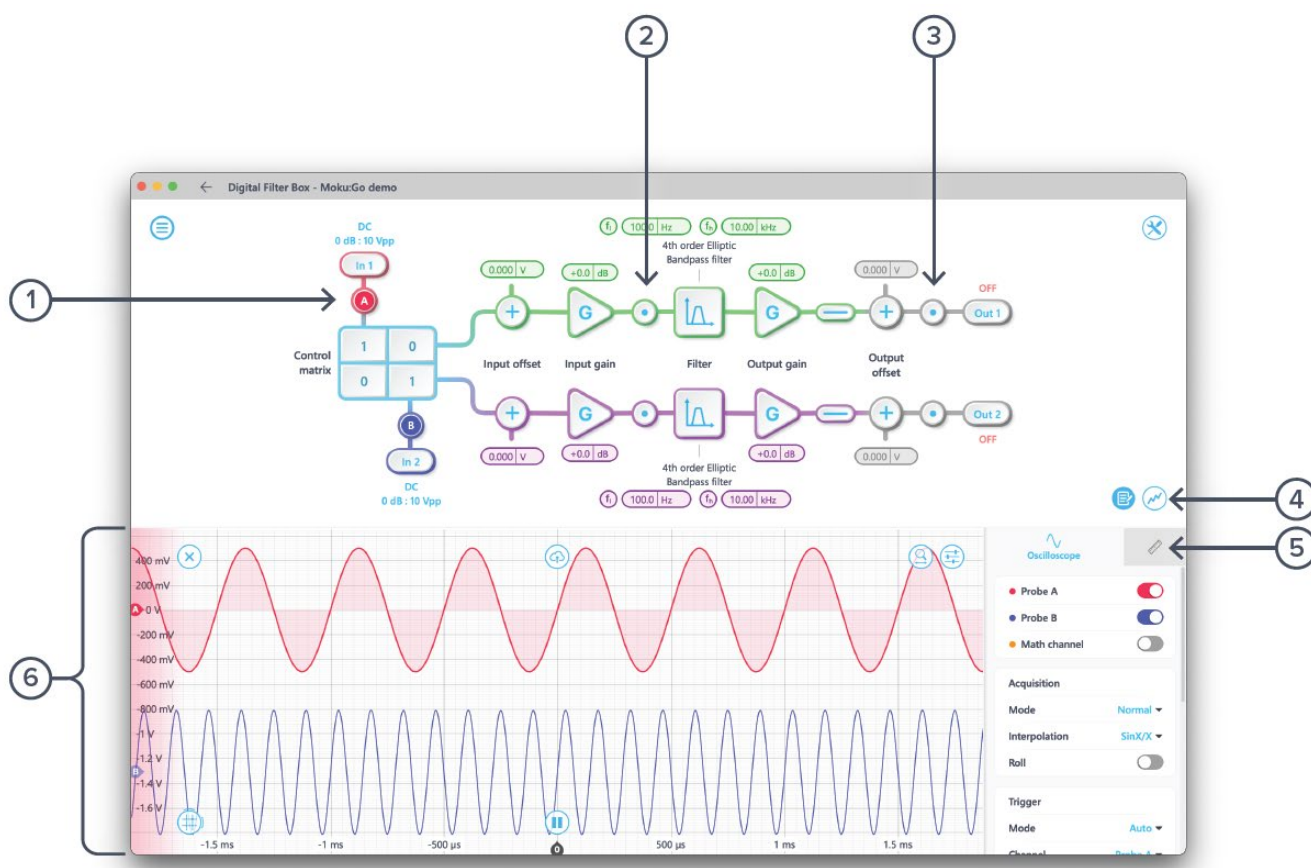
Open/disable



# Probe points

The Moku:Go Digital Filter Box has an integrated oscilloscope that can be used to probe the signal at the input, pre-filter, and output stages. Add the probe points by clicking the  icon.

## Oscilloscope

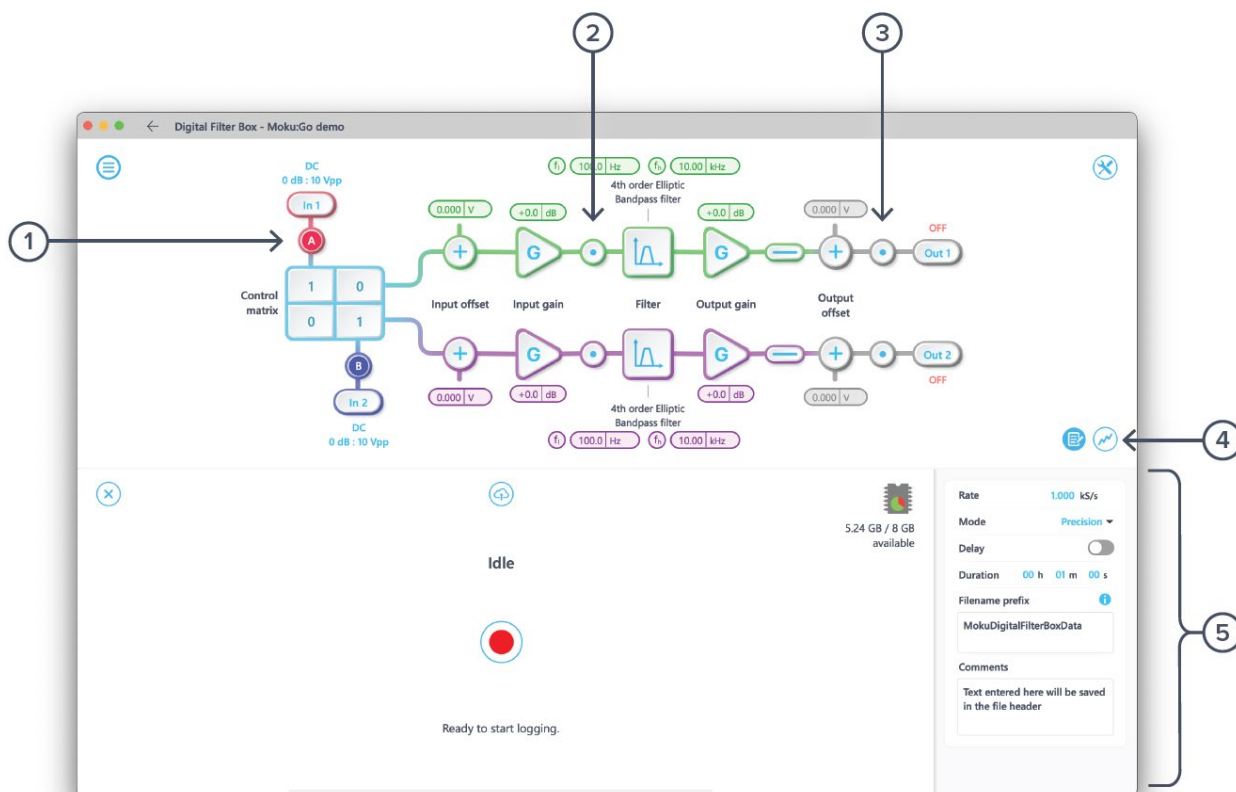


ID	Parameter	Description
1	Input probe point	Click to place the probe point at the input.
2	Pre-filter probe point	Click to place the probe after the input gain.
3	Output probe point	Click to place the probe at the output.
4	Oscilloscope/Data Logger toggle	Toggle between the built-in Oscilloscope or Data Logger.
5	Measurement*	Measurement function for the built-in oscilloscope.
6	Oscilloscope*	Signal display area for the oscilloscope.

\*Detailed instructions for the oscilloscope instrument can be found in the Moku:Go Oscilloscope manual.



# Data Logger



ID	Parameter	Description
1	Input probe point	Click to place the probe point at the input.
2	Pre-Filter probe point	Click to place the probe before the filter.
3	Output probe point	Click to place the probe at the output.
4	Oscilloscope/Data Logger toggle	Toggle between the built-in Oscilloscope or Data Logger.
5	Data Logger	Refer to the <b>Moku:Go Data Logger</b> manual for the details.

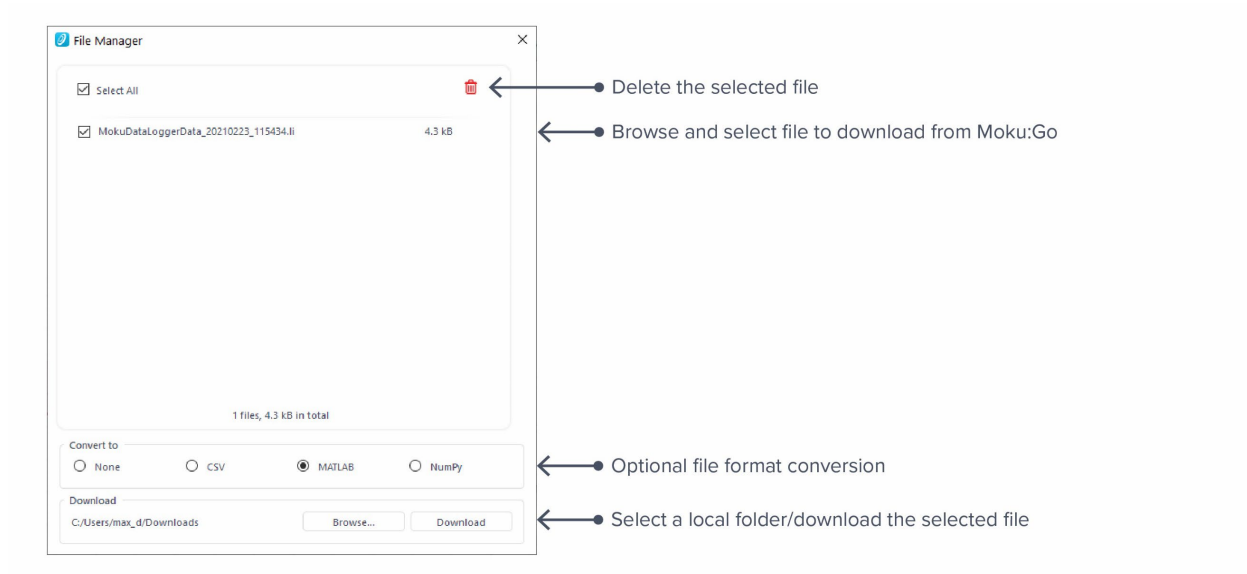
The Embedded Data Logger can stream over a network or save data on the Moku. For details, refer to the Data Logger user manual. More streaming information is in our API documents at [apis.liquidinstruments.com](https://apis.liquidinstruments.com)



## Additional tools

The Moku:Go app has two built-in file management tools: File Manager and File Converter. The File Manager allows users to download the saved data from Moku:Go to a local computer, with optional file format conversion. The file converter converts the Moku:Go binary (.li) format on the local computer to either .csv, .mat, or .npy format.

### File Manager

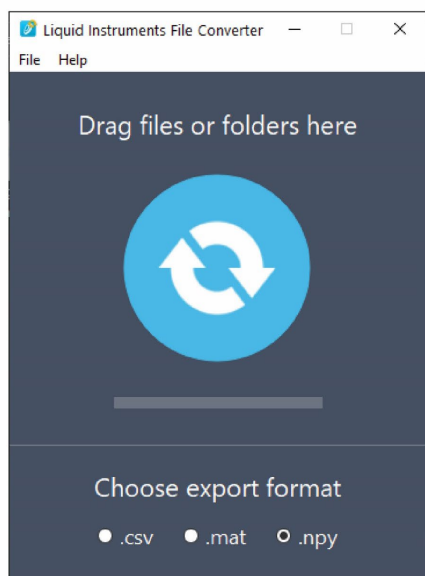


Once a file is transferred to the local computer, a  icon shows up next to the file.





## File Converter



← Drag .li file here to convert

← Select output format

The converted file is saved in the same folder as the original file.

Liquid Instruments File Converter has the following menu options:

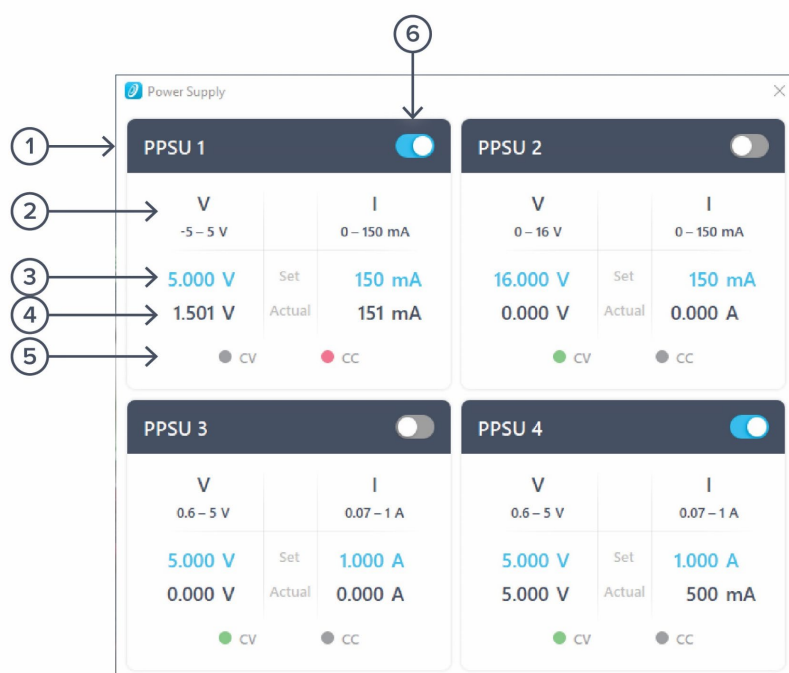
Options	Shortcut	Description
<b>File</b>		
• <b>Open file</b>	Ctrl+O	Select a .li file to convert
• <b>Open folder</b>	Ctrl+Shift+O	Select a folder to convert
• <b>Exit</b>		Close the file converter window
<b>Help</b>		
• <b>Liquid Instruments website</b>		Access Liquid Instruments website
• <b>Report an issue</b>		Report bug to Liquid Instruments
• <b>About</b>		Show app version, check update, or license information



# Power Supply

The Moku:Go Power Supply is available on M1 and M2 models. M1 features a 2-channel Power Supply, while M2 features a 4-channel Power Supply. Access the Power Supply control window in all instruments under the main menu.

The Power Supply operates in two modes: **constant voltage (CV)** or **constant current (CC)** mode. For each channel, the user can set a current and voltage limit for the output. Once a load is connected, the Power Supply operates either at the set current or set voltage, whichever comes first. If the Power Supply is voltage limited, it operates in the CV mode. If the Power Supply is current limited, it operates in the CC mode.



ID	Function	Description
1	Channel name	Identifies the Power Supply being controlled
2	Channel range	Indicates the voltage/current range of the channel
3	Set value	Click the blue numbers to set the voltage and current limit
4	Readback numbers	Voltage and current readback from the Power Supply, the actual voltage and current being supplied to the external load
5	Mode indicator	Indicates if the Power Supply is in CV (green) or CC (red) mode
6	On/Off toggle	Click to turn the Power Supply on and off



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