Digital Filter Box

Moku:Pro User Manual

With the Moku:Pro Digital Filter Box, you can interactively design and generate different types of infinite impulse response filters with sampling rates of 305.18 kHz, 4.8828 MHz and 39.063 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.

LIQUID INSTRUMENTS

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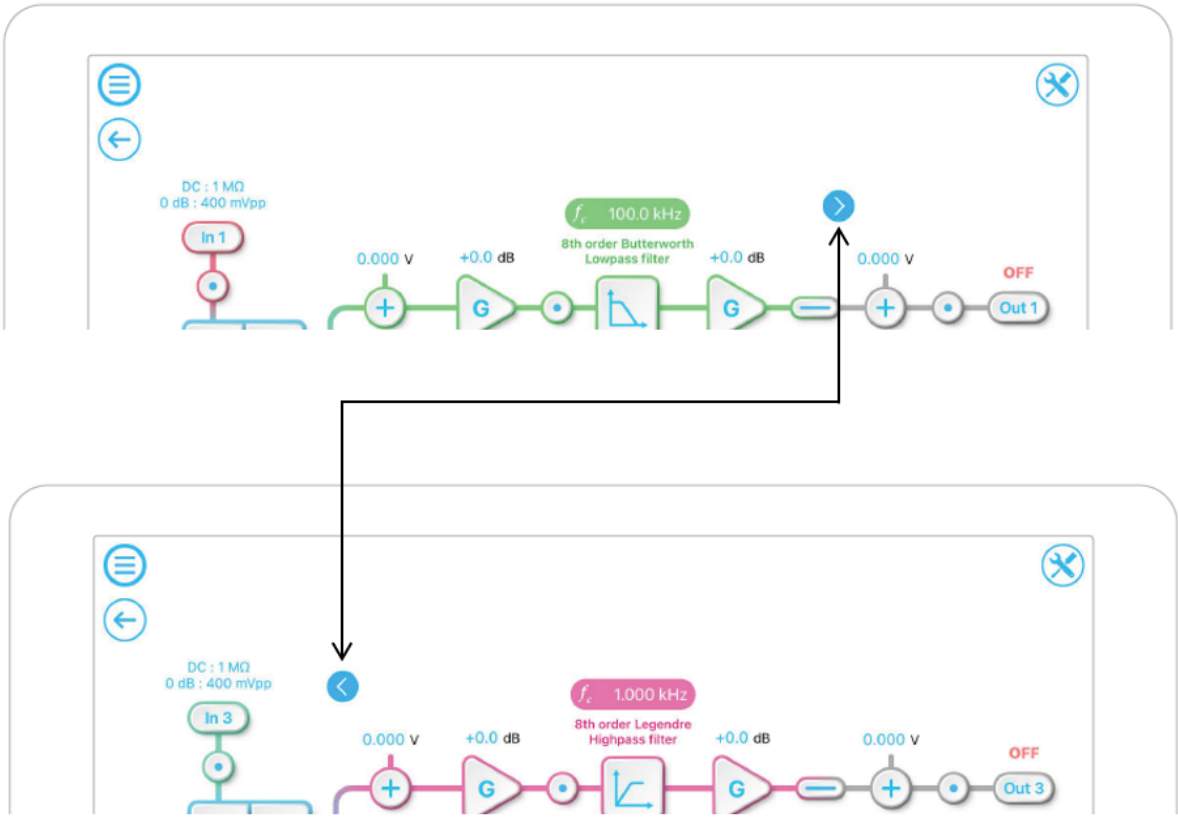
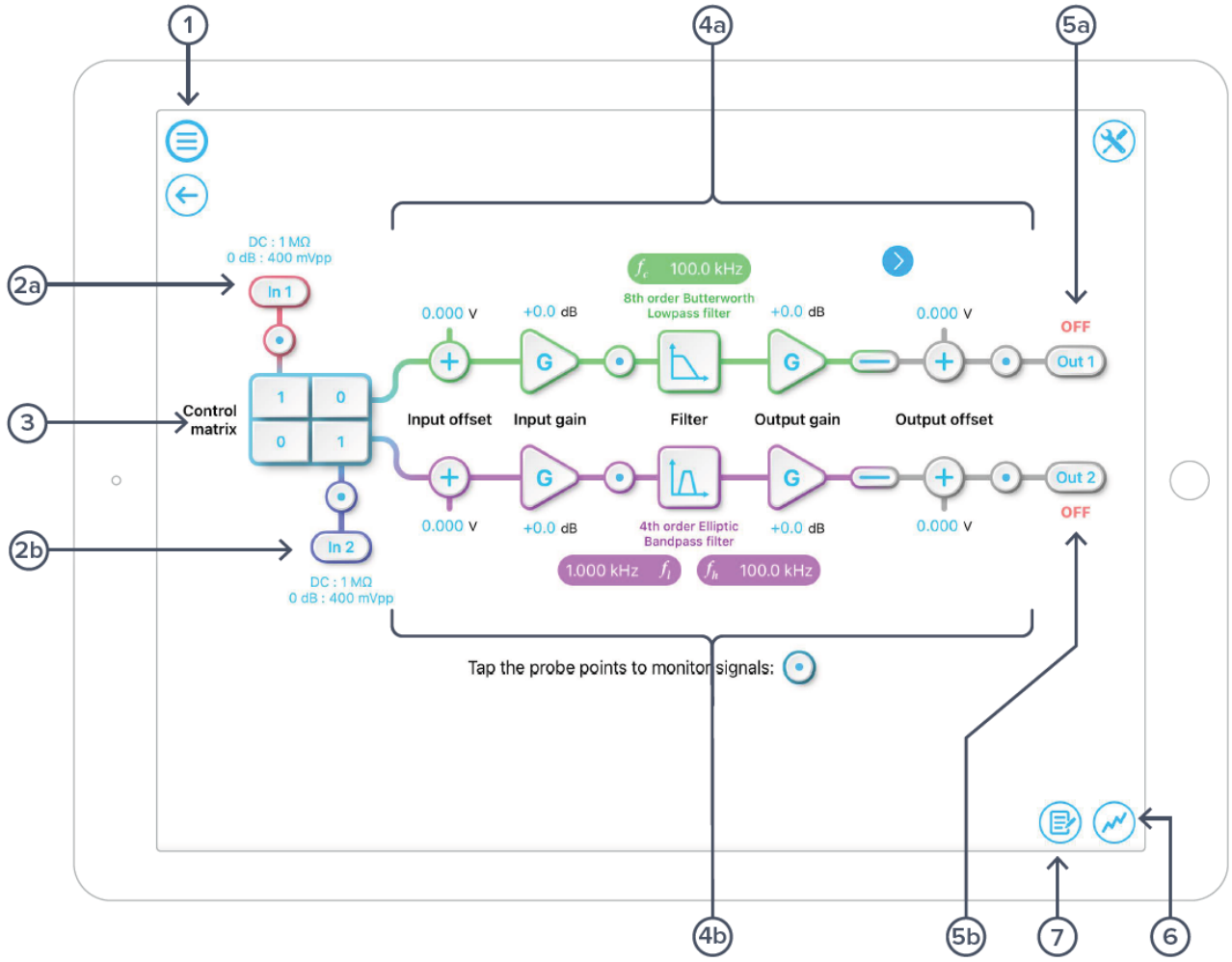
Ensure Moku:Pro is fully updated. For the latest information:

liquidinstruments.com

User interface

Moku:Pro is equipped with four inputs, four outputs, and four filter controllers. Two control matrices create two multiple-input and multiple-output (MIMO) controllers for filters 1 / 2, and filters 3 / 4. You can tap the or icons to switch between MIMO group 1 and 2. MIMO group 1 (inputs 1 and 2, filters 1 and 2, outputs 1 and 2) is used throughout this manual. The settings for MIMO group 2 are similar to MIMO group 1.

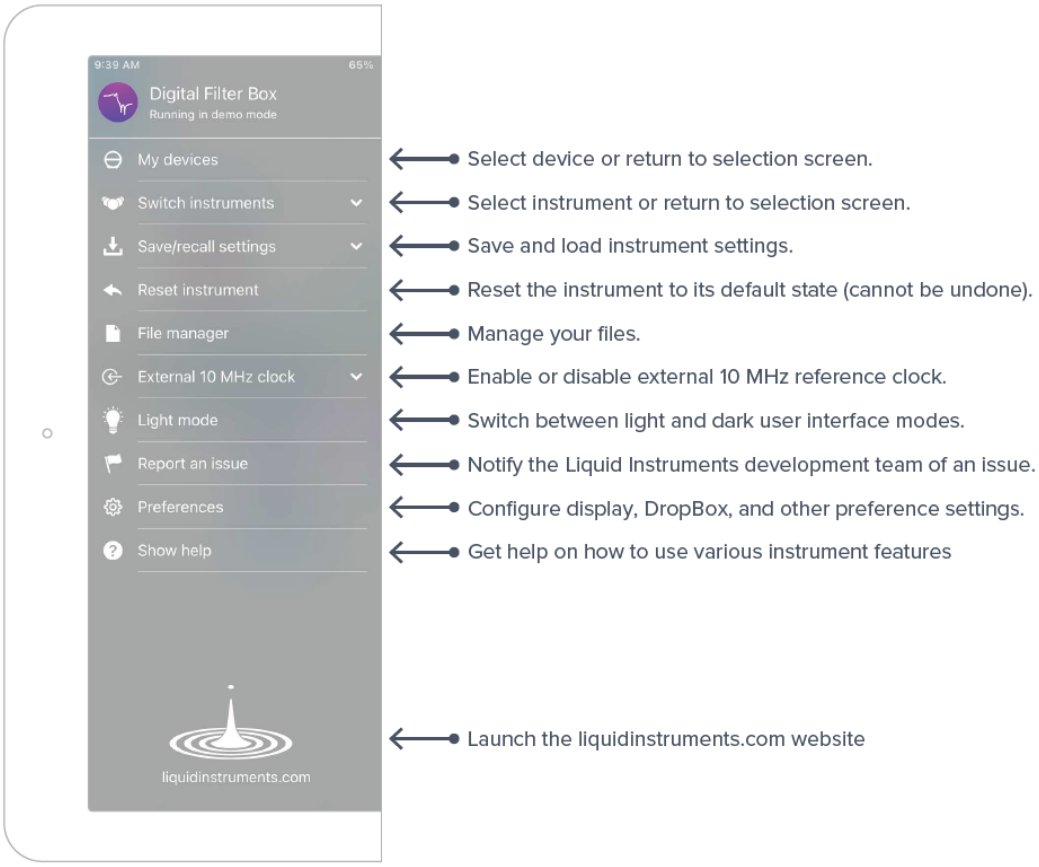




ID	Description
1	Main menu
2a	Input configuration for Channel 1.
2b	Input configuration for Channel 2.
3	Control matrix.
4a	Configuration for filter 1.
4b	Configuration for filter 2.
5a	Output switch for Channel 1.
5b	Output switch for Channel 2.
6	Enable/disable the Oscilloscope view.
7	Enable/disable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

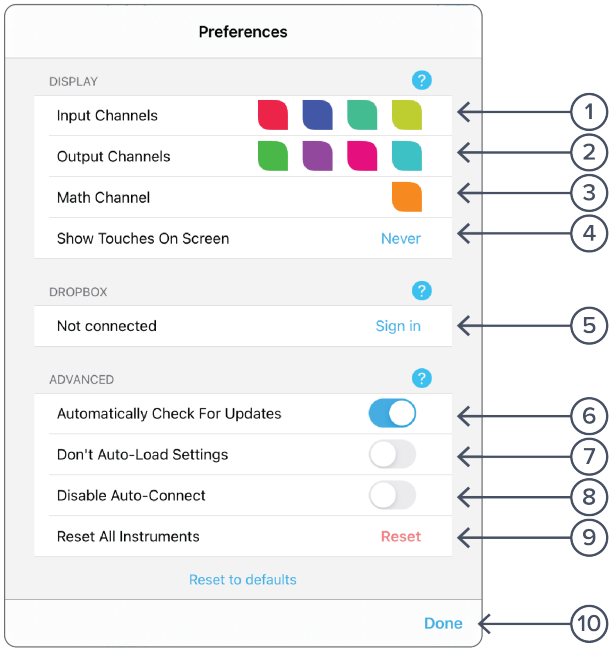
Main menu

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



Preferences

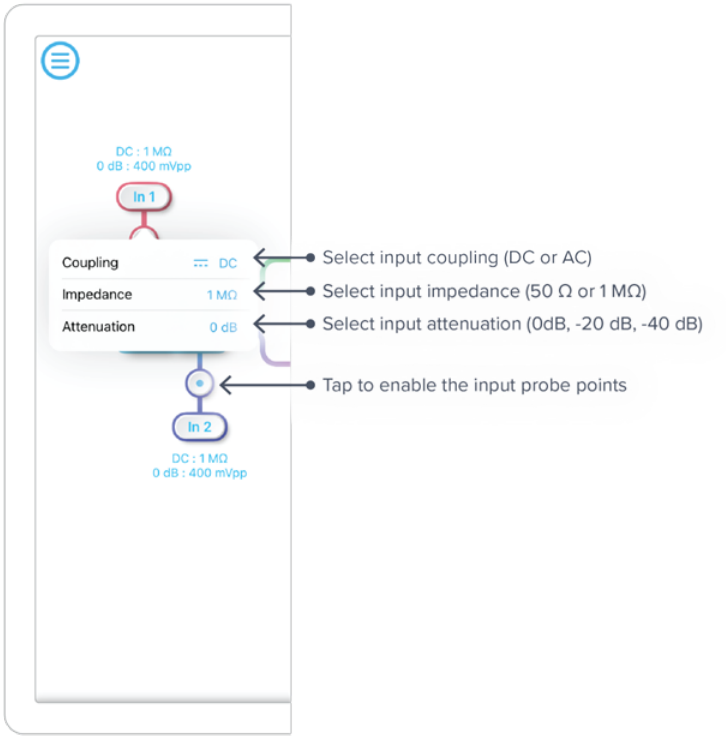
The preferences pane can be accessed via the main menu. Here, you can reassign the color representations for each channel, connect to Dropbox, and more. Throughout the manual, the default colors (shown in the figure below) correspond to instrument features.



ID	Description
1	Tap to change the color associated with input channels.
2	Tap to change the color associated with output channels.
3	Tap to change the color associated with math channel.
4	Indicate touch points on the screen with circles. This can be useful for demonstrations.
5	Change the currently linked Dropbox account to which data can be uploaded.
6	Notify when a new version of the app is available.
7	Moku:Pro automatically saves instrument settings when exiting the app, and restores them again at launch. When disabled, all settings will be reset to defaults on launch.
8	Moku:Pro can remember the last used instrument and automatically reconnect to it at launch. When disabled, you will need to manually connect every time.
9	Reset all instruments to their default state.
10	Save and apply settings.

Input configuration

Access the **input configuration** by tapping the In 1 or In 2 icon, allowing you to adjust the coupling and input attenuation (and therefore voltage range) for each input channel.



Find details about the probe points 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.

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

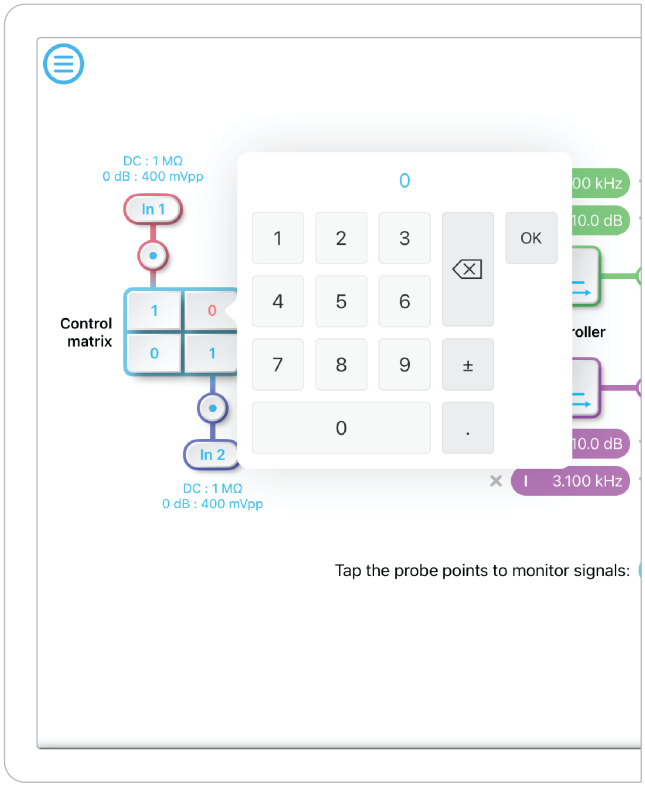
where

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

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

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), multiples Input 2 by a factor of two, and then sends it to the bottom *Path2* (filter 2).

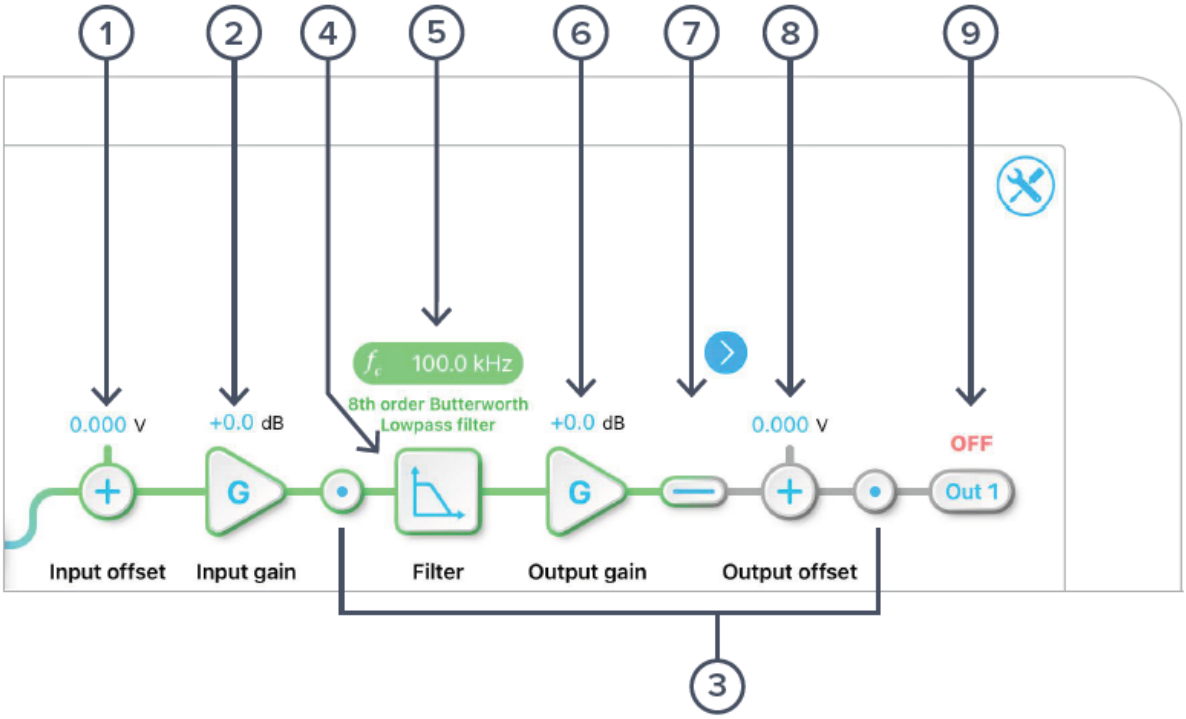
The value of each element in the control matrix can be set between -20 to +20 with 0.1 increments when the absolute value is less than 10, or 1 increment when the absolute value is between 10 and 20. Tap the element to adjust the value.



Digital filters

The four independent, real-time configurable digital IIR filter paths follow the control matrix in the block diagram for filter 1 and filter 2, respectively. The settings for filter 3 and filter 4 are the same.

User interface

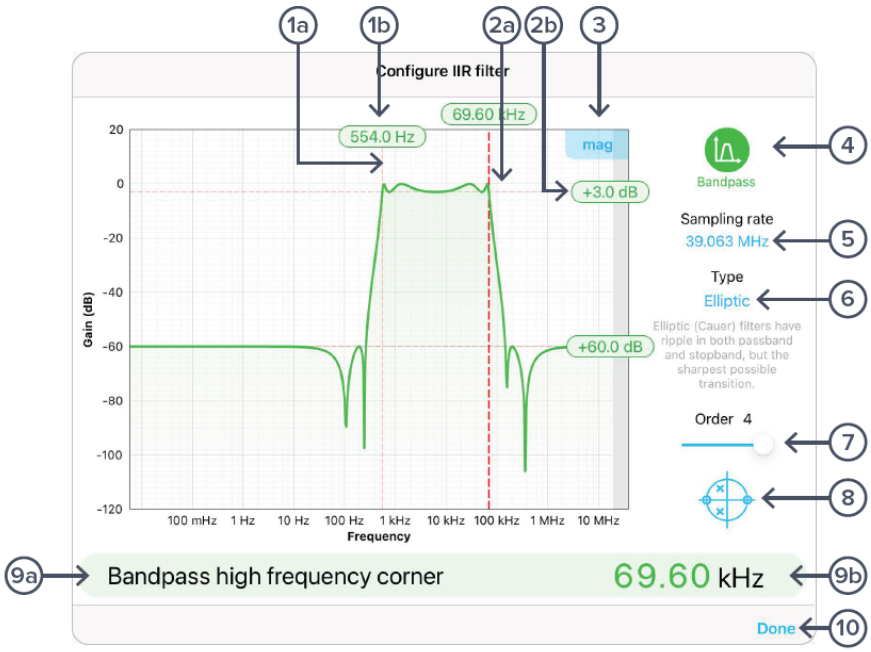


ID	Parameter	Description
1	Input offset	Tap to adjust the input offset (-1 to +1 V).
2	Input gain	Tap to adjust the input gain (-40 to 40 dB).
3	Probe points	Tap to enable/disable the probe points. See the Probe Points section for details.
4	Digital filter	Tap to view and configure the digital filter builder.
5	Quick filter control	Tap or slide to quickly adjust the filter settings.
6	Output gain	Tap to adjust the output gain (-40 to 40 dB).
7	Output switch	Tap to zero the filter output.
8	Output offset	Tap to adjust the output offset (-1 to +1 V).
9	DAC switch	Tap to disable the Moku:Pro DAC output or enable the output with 0 dB or 14 dB gain settings.

Configure IIR filter characteristics

Detailed filter interface

Tap the  icon to open the full filter view.



ID	Parameter	Description
1a	Frequency (horizontal) cursor	Cursor for corner frequency.
1b	Cursor reading	Drag to adjust the corner frequency. Tap to select and manually enter the corner frequency in 9b.
2a	Gain (vertical) cursor	Cursor for ripple/gain/attenuation level.
2b	Cursor reading	Drag to adjust the gain/ripple level. Tap to select and manually enter passband ripple in 9b.
3	Display toggle	Toggle between magnitude and phase response.
4	Filter shape selection	Tap to select between low pass, high pass, band pass, band stop, and custom filters.
5	Sampling rate	Tap to select between 305.28 kHz, 4.8828 MHz, or 39.063 MHz.
6	Filter type selection	Tap to select between filter types. See the Filter types section on page 12 for more information.
7	Filter order	Slide to adjust filter orders.
8	Pole/zero plot	Tap to view the poles and zeroes in the s-plane.
9a	Active configurable parameter	Name of the active configurable parameter.
9b	Parameter value	Tap to enter the active parameter value.
10	Save and close	Tap to save and close the filter builder.

Filter shapes

Select the shape of the filter by taping the ④ button (page 9). There are four pre-defined filter shapes and a fully customizable filter option.

Sampling rates

Users can select between 39.063 MHz, 4.8828 MHz, or 305.28 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	305.28 kHz	58.63 mHz	137.3 kHz
	4.8828 MHz	938.1 mHz	2.197 MHz
	39.063 MHz	7.505 Hz	17.58 MHz
Highpass	305.28 kHz	723.7 mHz	137.3 kHz
	4.8828 MHz	11.58 Hz	2.197 MHz
	39.063 MHz	92.63 Hz	17.58 MHz
Bandpass	305.28 kHz	3.052 Hz	137.3 kHz
	4.8828 MHz	48.83 Hz	2.197 MHz
	39.063 MHz	390.6 Hz	17.58 MHz
Bandstop	305.28 kHz	58.63 mHz	137.3 kHz
	4.8828 MHz	938.1 mHz	2.197 MHz
	39.063 MHz	7.505 Hz	17.58 MHz

Filter types

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

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

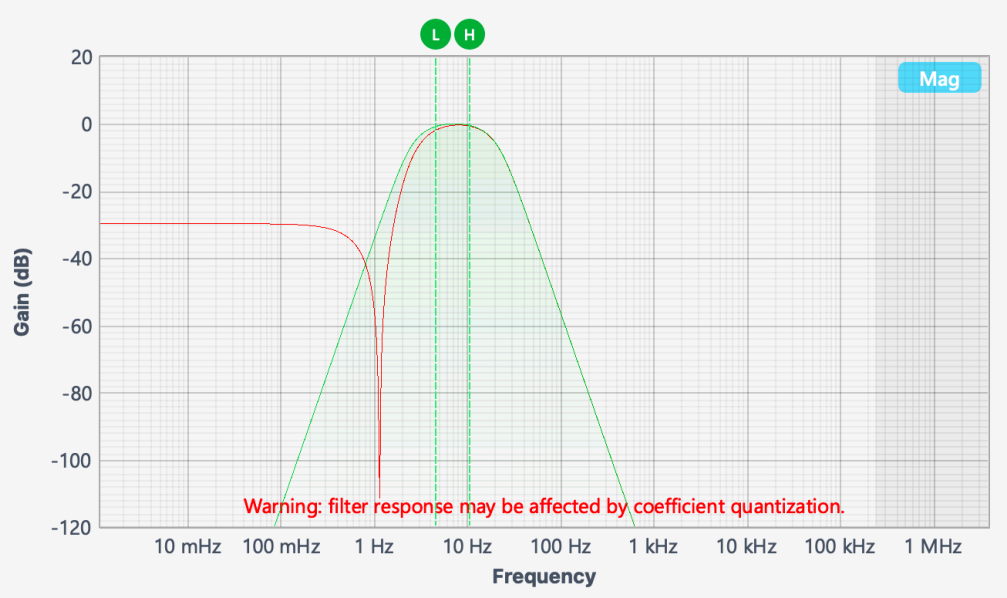
Ripples

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 attenuation
Chebyshev I	0.1 dB to 10.0 dB with 0.1 dB increment	N/A.
Chebyshev II	N/A	10.0 dB to 100.0 dB with 1 dB increment.
Elliptic	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, a custom filter type allows for their filter coefficients to be uploaded from the clipboard or a local file. Tap the icon to see explanation of the coefficients and file format.

Sampling rate
39.063 MHz

Load coefficients

Custom filter details

The Moku:Pro Digital Filter Box implements infinite impulse response (IIR) filters using 4 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:

g (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
⋮	s	b_0	b_1	b_2	a_1	a_2

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 configuration

Switches can be used to connect or disconnect the output signal. When a switch is in the open state, the output signal will be the Output offset voltage.

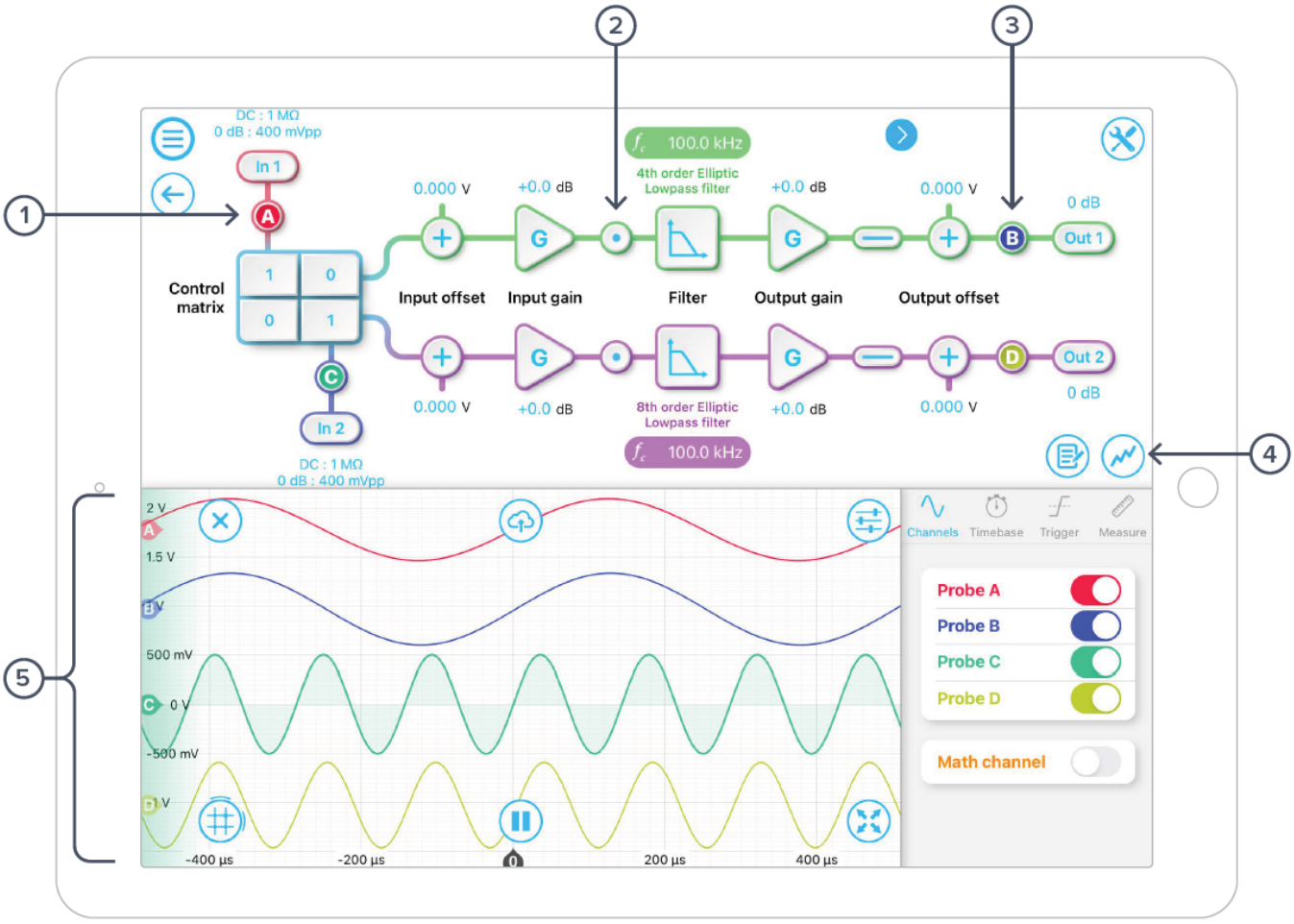
Closed/enable

Open/disable

Probe points

The Moku:Pro 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 tapping the icon.

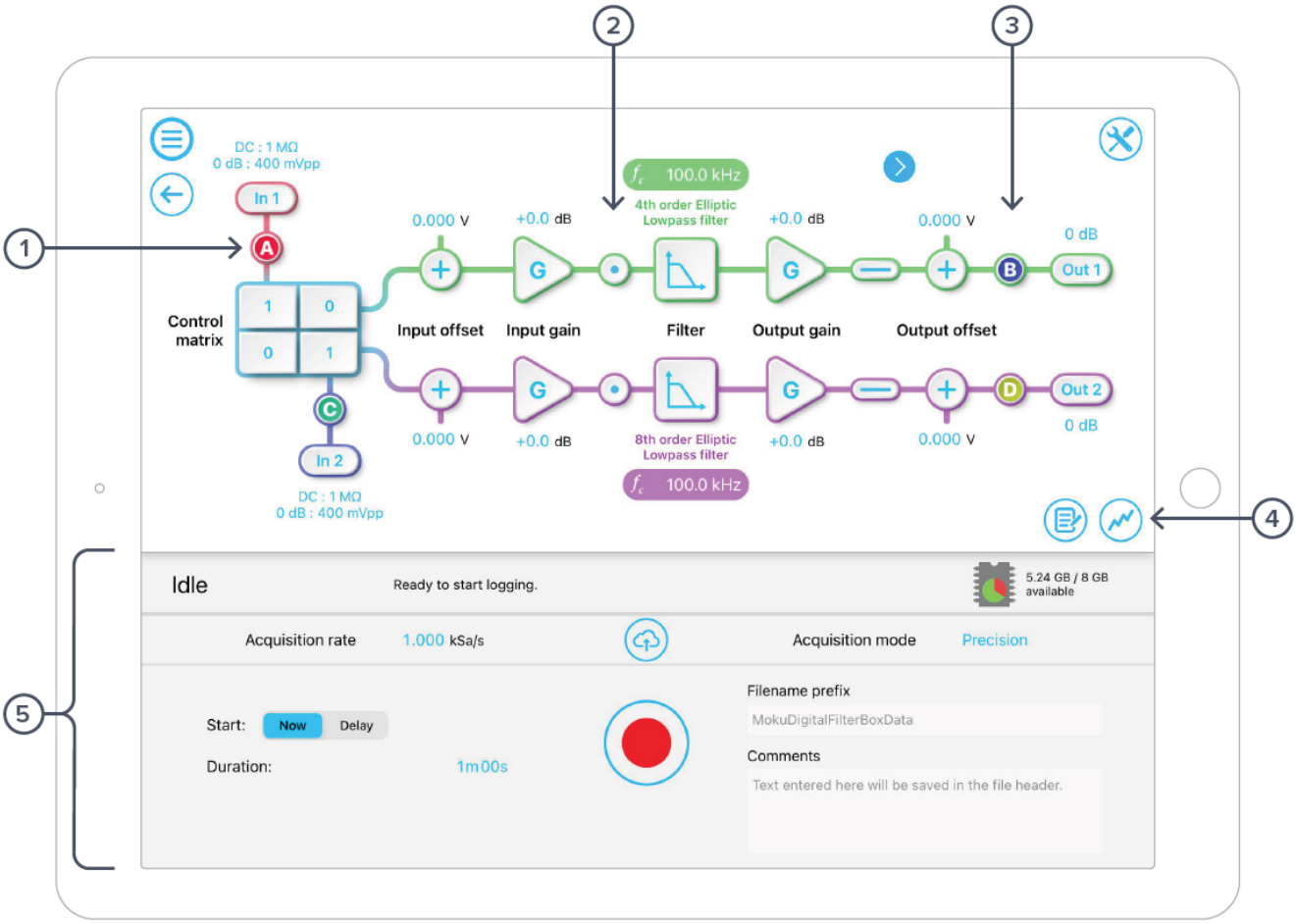
Oscilloscope



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

*Find detailed instructions for the Oscilloscope instrument in the Moku:Pro Oscilloscope manual.

Data Logger



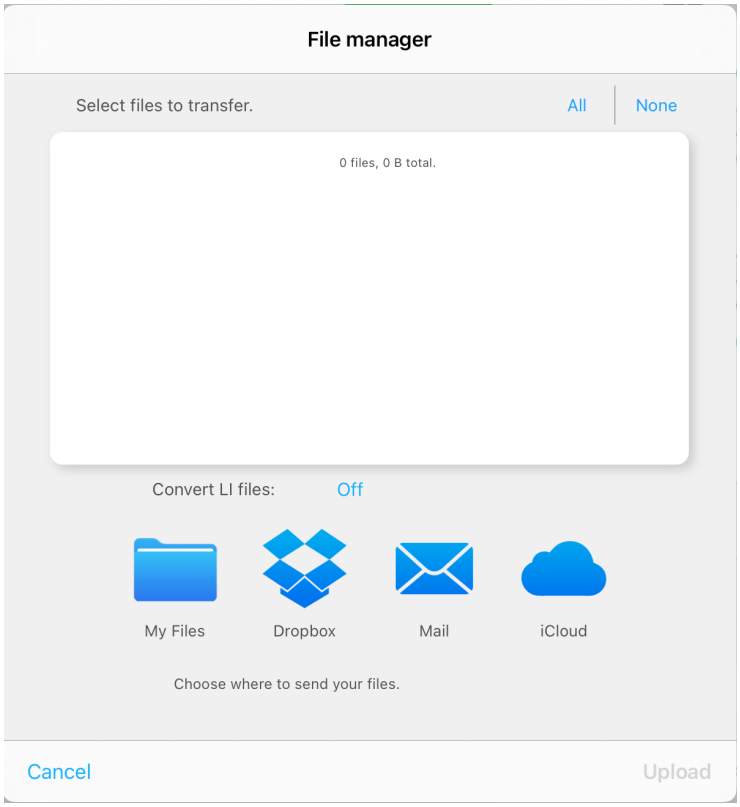
ID	Parameter	Description
1	Input probe point	Tap to place the probe point at the input.
2	Pre-filter probe point	Tap to place the probe before the filter.
3	Output probe point	Tap to place the probe at the output.
4	Oscilloscope/Data Logger toggle	Toggle between the integrated Oscilloscope or Data Logger.
5	Data Logger	Refer to the Moku:Pro Data Logger 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 documentation at http://apis.liquidinstruments.com/

Additional tools

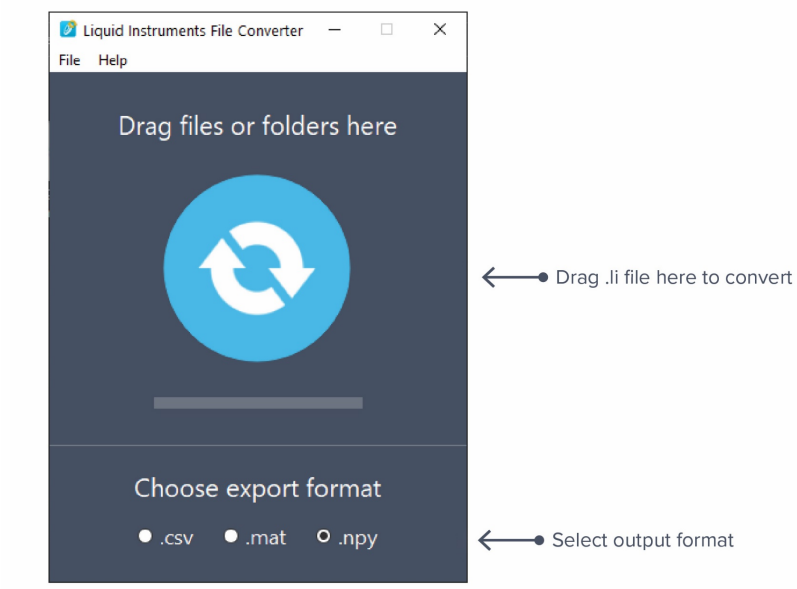
The Moku:Pro app has two built-in file management tools: File Manager and File Converter. The File Manager allows users to download the saved data from Moku:Pro to a local computer, with optional file format conversion. The File Converter converts the Moku:Pro binary (.li) format on the local computer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



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
File		
• **Open file**	Ctrl/Cmd+O	Select a .li file to convert.
• **Open folder**	Ctrl/Cmd+Shift+O	Select a folder to convert.
• **Exit**		Close the file converter window.
Help		
• **Liquid Instruments website**		Access the Liquid Instruments website.
• **Report an issue**		Report a bug to Liquid Instruments.
• **About**		Show app version or license information.

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