



FIR Filter Builder

Moku:Pro User Manual

With the Moku:Pro FIR Filter Builder, you can design and implement lowpass, highpass, bandpass, and bandstop finite impulse response (FIR) filters with up to 14,819 coefficients at a sampling rate of 305.2 kHz, or 232 coefficients at a sampling rate up to 39.06 MHz. Moku:Pro Windows, macOS and iPad interfaces allow you to fine tune your filter's response in the frequency and time domains to suit your specific application. Select between four frequency response shapes, five common impulse responses, and up to eight window functions.





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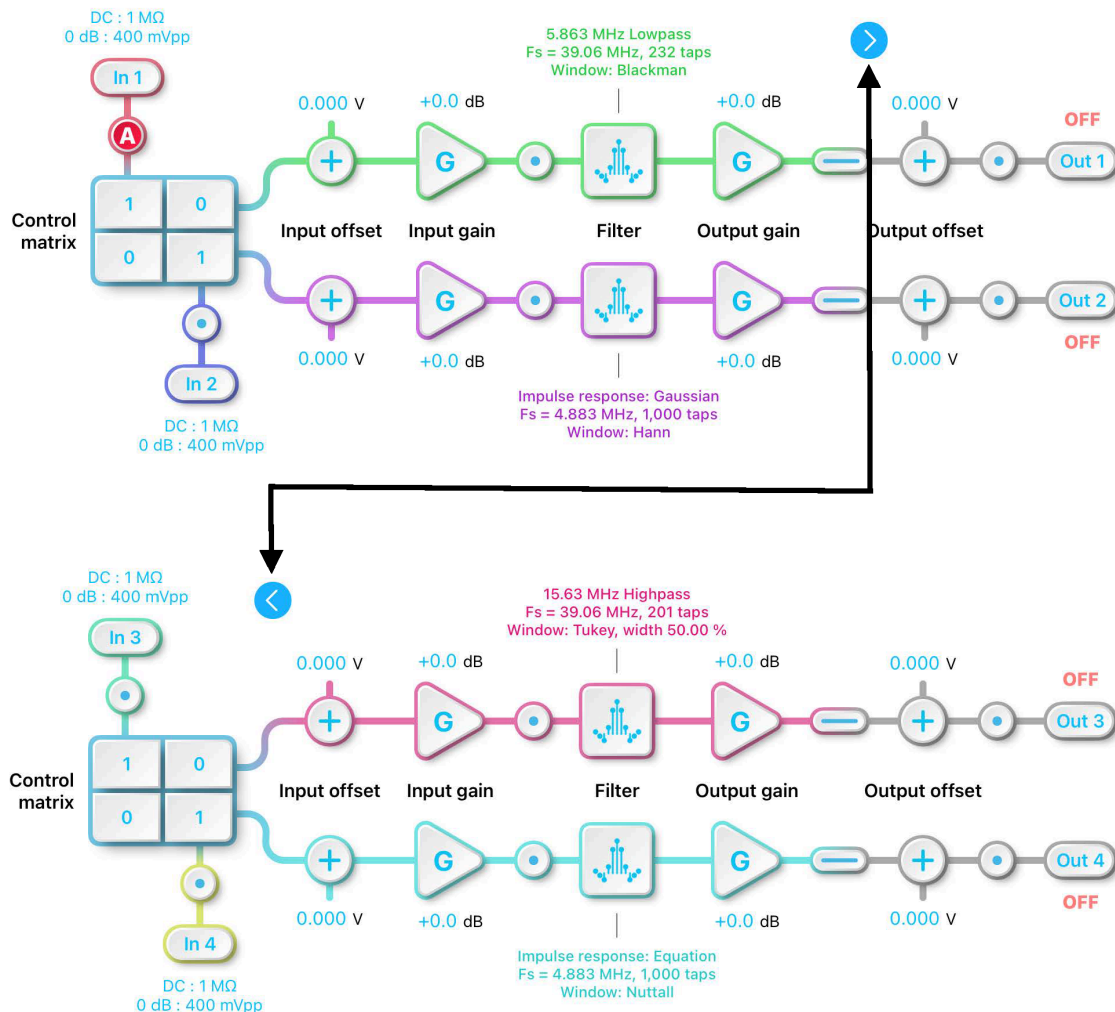
Ensure Moku:Pro is fully updated. For the latest information, visit:

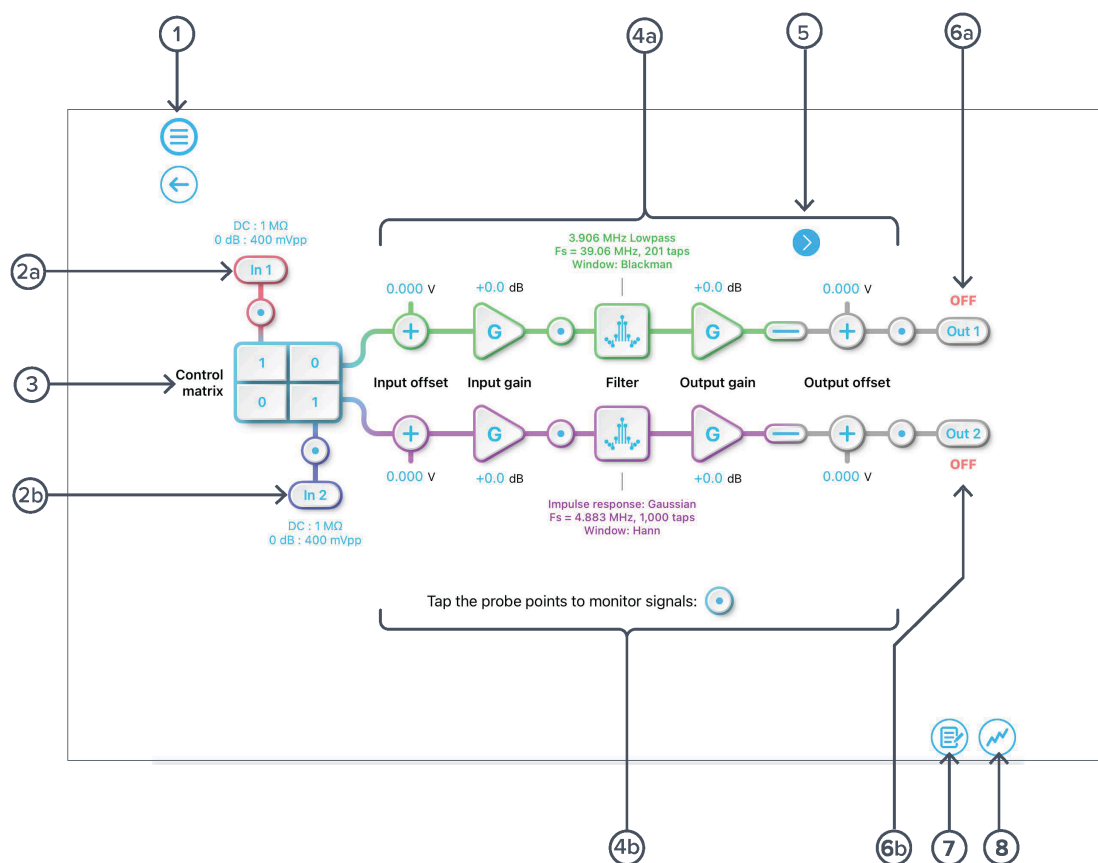
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User interface

Moku:Pro is equipped with four inputs, four outputs, and four filter controllers. Two control matrices are used to 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 like MIMO group 1.





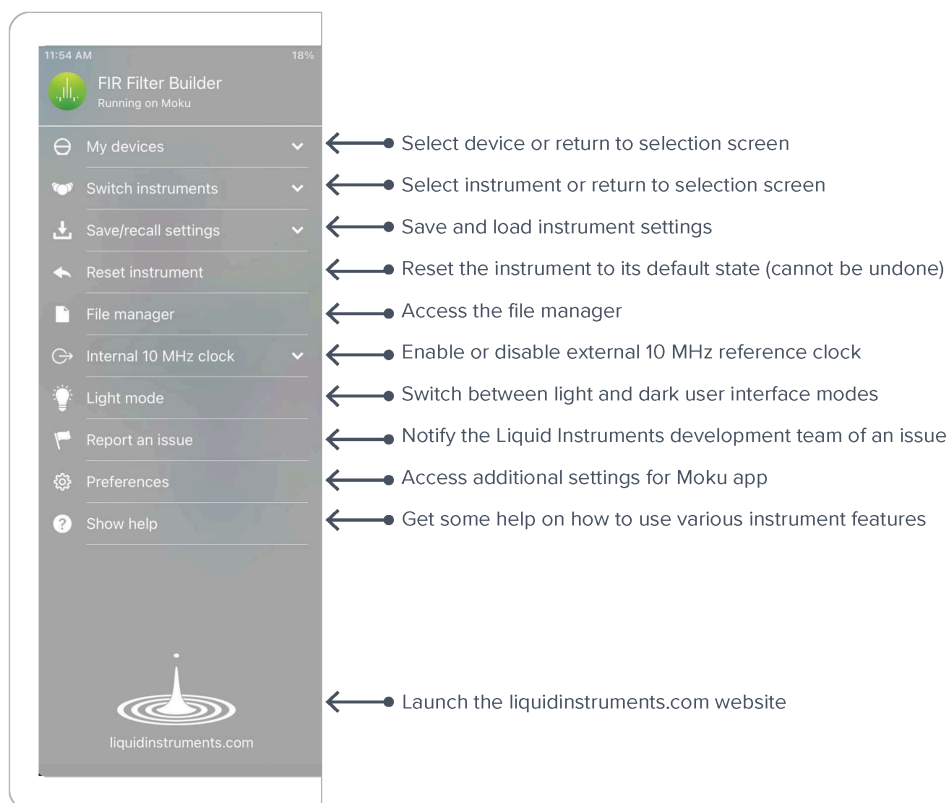
ID Description

1	Main menu
2a	Input configuration for Channel 1
2b	Input configuration for Channel 2
3	Control matrix
4a	Configuration for FIR filter 1
4b	Configuration for FIR filter 2
5	Switch to channels 3 and 4
6a	Output switch for FIR filter 1
6b	Output switch for FIR filter 2
7	Enable the data logger
8	Enable the oscilloscope



Main menu

The **main menu** can be accessed by clicking the  icon in the top-left corner allowing you to:

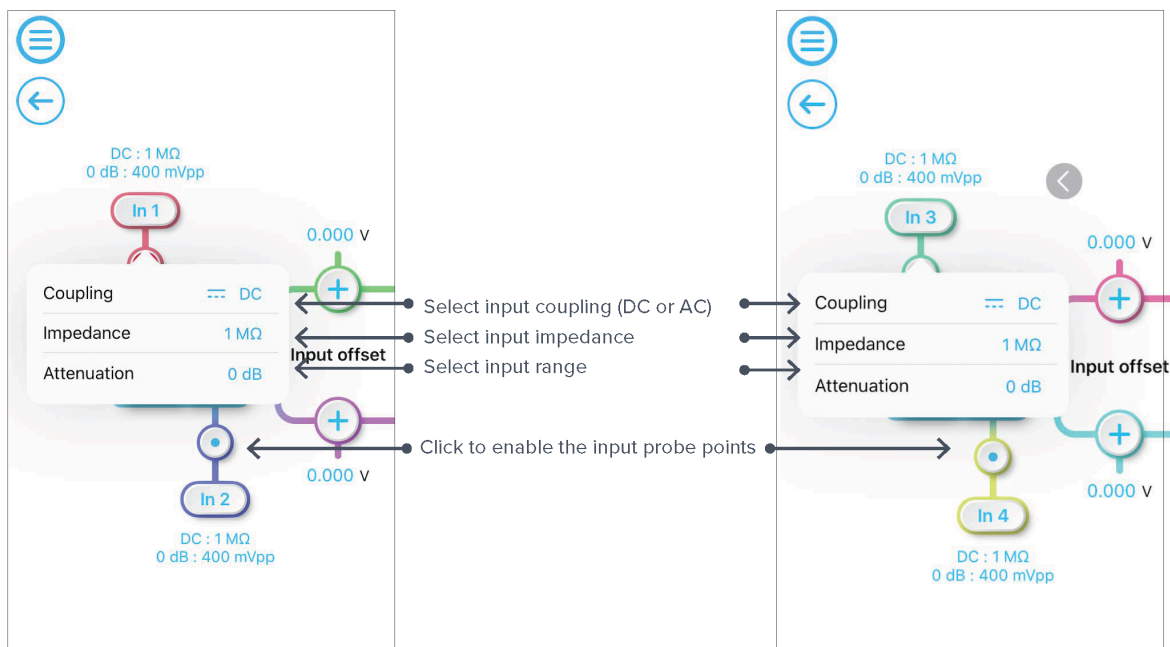


Detailed information about the file manager and file converter can be found at the end of this user manual.



Input configuration

The **input configuration** can be accessed by clicking the **In 1**, **In 2**, **In 3** or **In 4** icon, allowing you to adjust the coupling, input impedance, and input 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 signals to the two independent FIR filters. There is a control matrix for input 1 and input 2; a second control matrix for input 3 and input 4. 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

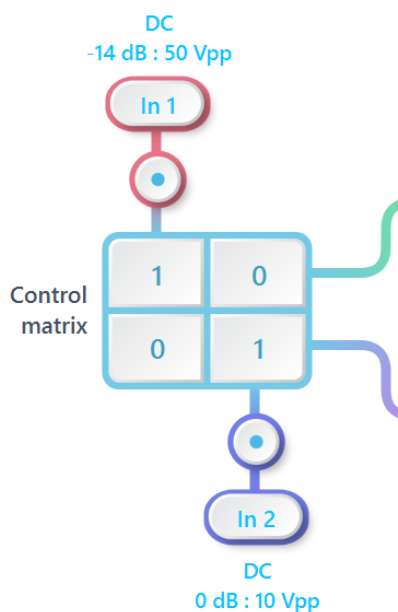
$$Path1 = a \times In1 + b \times In2$$

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

and similarly, for path 3 and path 4.

For example, a control matrix of $\begin{bmatrix} 1 & 1 \\ 0 & 2 \end{bmatrix}$ adds **Input 1** and **Input 2** and routes to the top *Path1* (FIR Filter 1), multiplies **Input 2** by a factor of two, and then routes it to the bottom *Path2* (FIR 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. Adjust the value by clicking on the element.



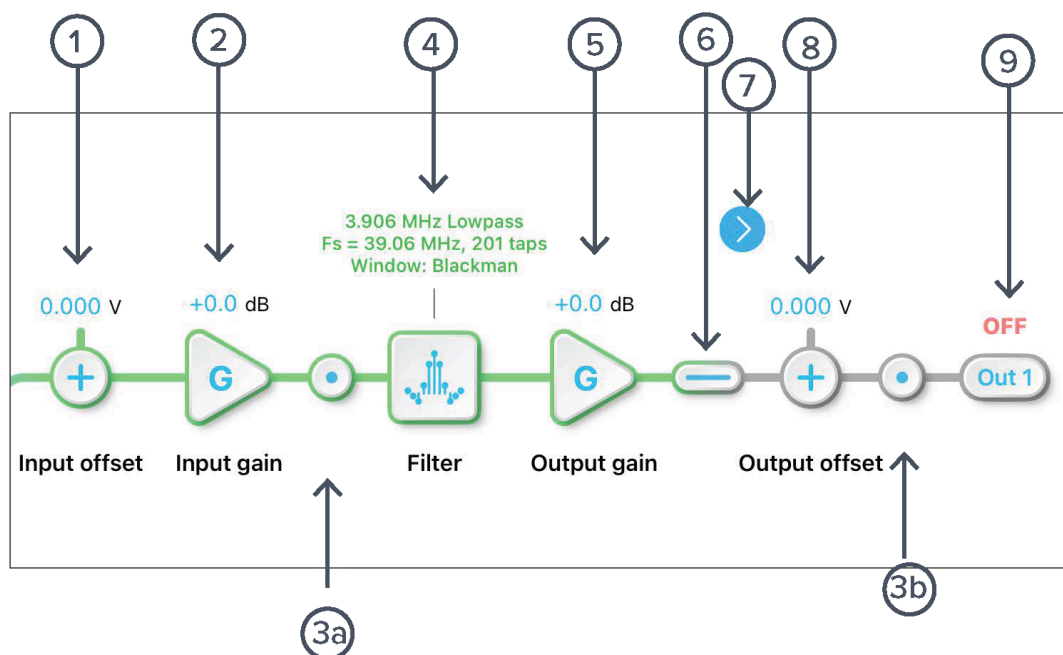




FIR filter

The four independent, real-time configurable digital FIR 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 similar.

User interface



ID	Parameter	Description
1	Input offset	Click to adjust the input offset (-1.0 to +1.0 V)
2	Input gain	Click to adjust the input gain (-40 to +40 dB)
3a	Pre-filter probe	Click to enable/disable the pre-filter probe point. See Probe Points section for details.
3b	Output probe	Click to enable/disable the output probe point. See Probe Points section for details.
4	FIR filter	Click to open view and configure the FIR filter builder
5	Output gain	Click to adjust the input gain (-40 to +40 dB)
6	Output switch	Click to zero the filter output
7	Scroll right	Click to scroll to channels 3 and 4
8	Output offset	Click to adjust the input offset (-1.0 to +1.0 V)
9	DAC switch	Click to enable/disable the Moku DAC output



FIR Filter Builder

Builder interface



Click the  icon to open the full FIR Filter Builder view.



ID	Parameter	Description
1a	Plot 1	Impulse, magnitude, or group delay plot.
1b	Plot 2	Step, phase, or phase delay plot.
2	Plot set selection	Click to select the set of plots to display in the plot area.
3	Sampling rate	Adjust the sampling rate for the input. Slide between 305.2 kHz and 39.06 MHz or use the scroll wheel to adjust.
4	Number of coefficients	Click the number to enter or slide the slider to adjust the number of coefficients or use the scroll wheel to adjust.
5	Filter design	Configure the parameters for the FIR filter. Find detailed information in a later section.
6	Window function	Click to select the window function.

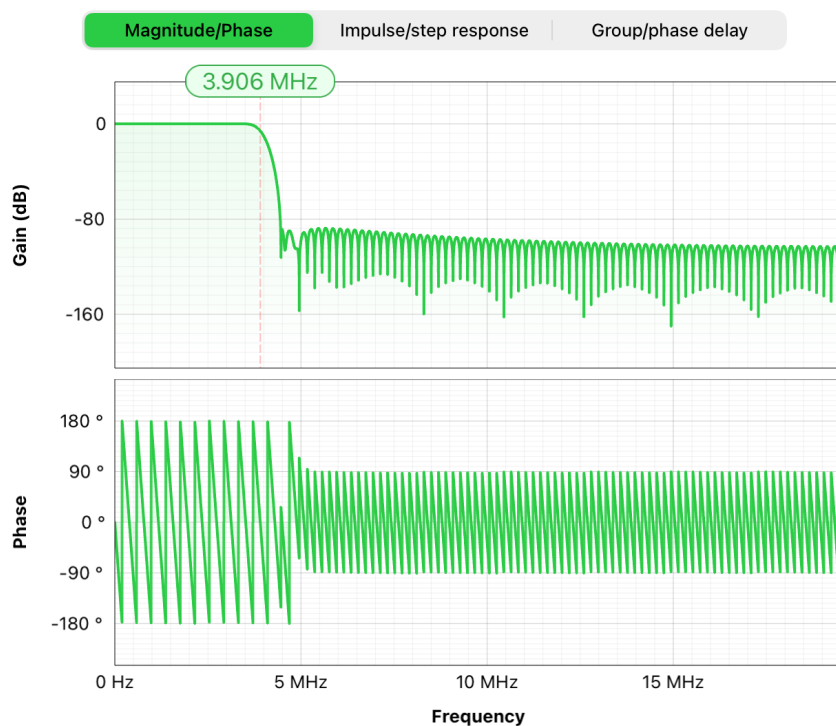


Filter characteristic graphs

A set of two real-time filter characteristic plots can be shown at a time in the FIR filter builder. Click the **plot set selection** buttons to select between **Magnitude/phase**, **Impulse/step response**, and **Group/phase delay** plot sets. Click and drag the cut-off frequency tab in the **Magnitude/phase** to adjust the corner frequency in real-time.

	Magnitude/phase		Impulse/step response		Group/phase delay	
	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
X - axis	Frequency		Time		Frequency	
Y - axis	Gain	Phase	Amplitude		Group/phase delay	

Magnitude/phase plot set:

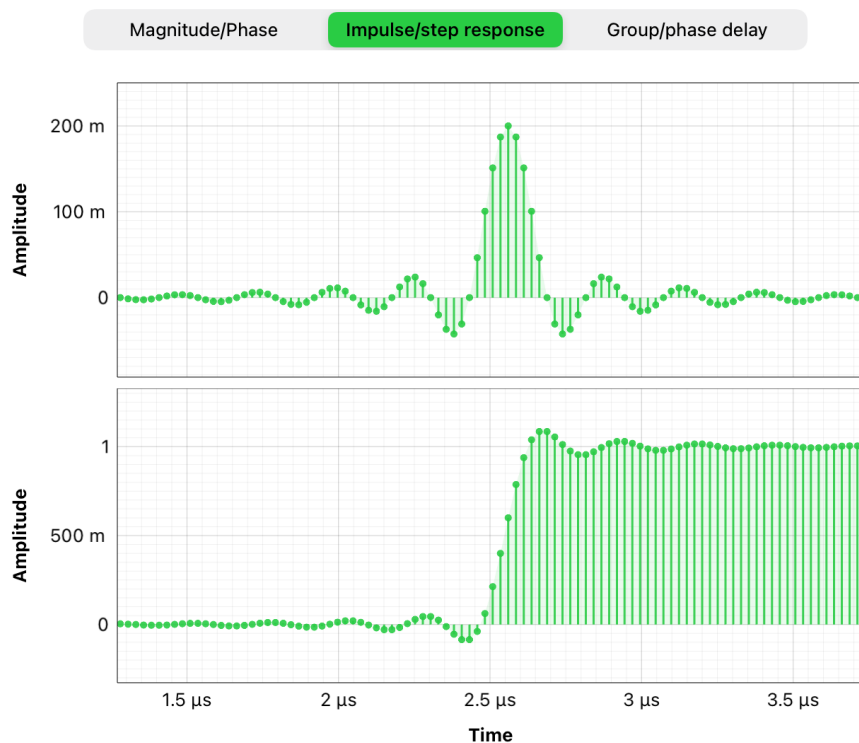


The control panel on the right side of the interface includes the following settings:

- Sample rate:** 39.06 MHz (with a slider)
- Coefficients:** 201 (with a slider)
- Design domain:** Time (selected), Frequency
- Frequency response:** Shape: Lowpass
- Window:** Function: Blackman



Impulse/step response plot set:



Sample rate 39.06 MHz

Coefficients 201

Design domain

Time | **Frequency**

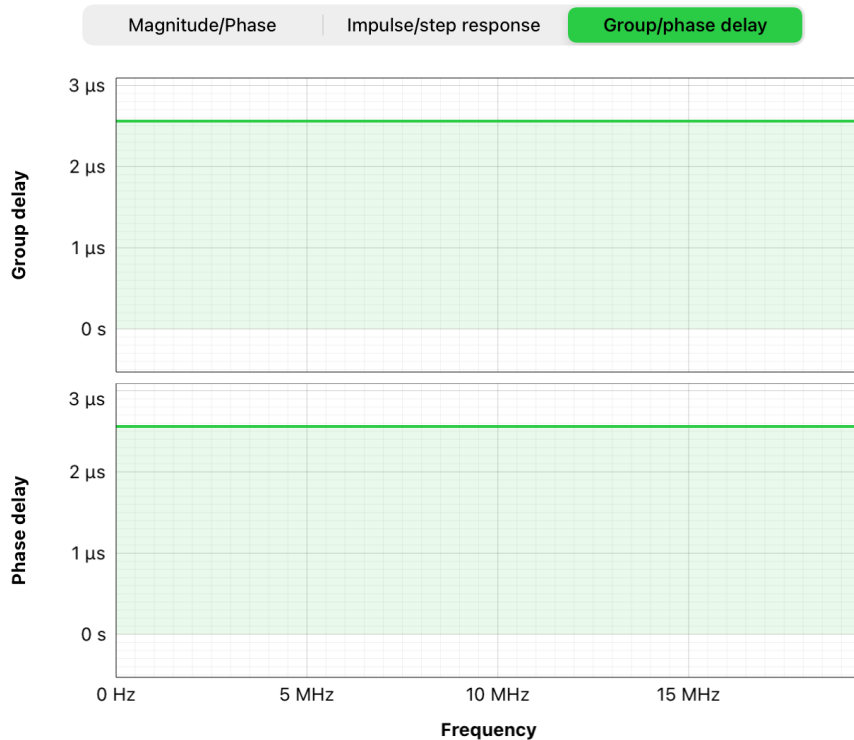
Frequency response

Shape Lowpass

Window

Function Blackman

Group/phase delay plot sets:



Sample rate 39.06 MHz

Coefficients 201

Design domain

Time | **Frequency**

Frequency response

Shape Lowpass

Window

Function Blackman



Sampling rate and coefficient count

The maximum number of coefficients depends on the chosen sampling rate. See available sampling rates with their corresponding maximum numbers of coefficients in the table below.

Sampling rate	Maximum number of coefficients
305.2 kHz	14,819
610.4 kHz	14,819
1.221 MHz	7,424
2.441 MHz	3,712
4.883 MHz	1,856
9.766 MHz	928
19.53 MHz	464
39.06 MHz	232



Design domain

Design the FIR filter in either the time or frequency domain. If designing in the **time domain**, you set the impulse response function. Several predefined functions are available. Enter an equation with the **equation editor**, or load your own set of coefficients with the **custom impulse response** option. If you design in the **frequency domain**, you choose from lowpass, highpass, bandpass, and bandstop filter shapes and set the cut-off frequencies.

Time domain designer



ID	Parameter	Description
1	Impulse shape	Click to select the shape of the impulse response.
2	Impulse width	Click the number to enter or slide the slider to adjust the impulse width.

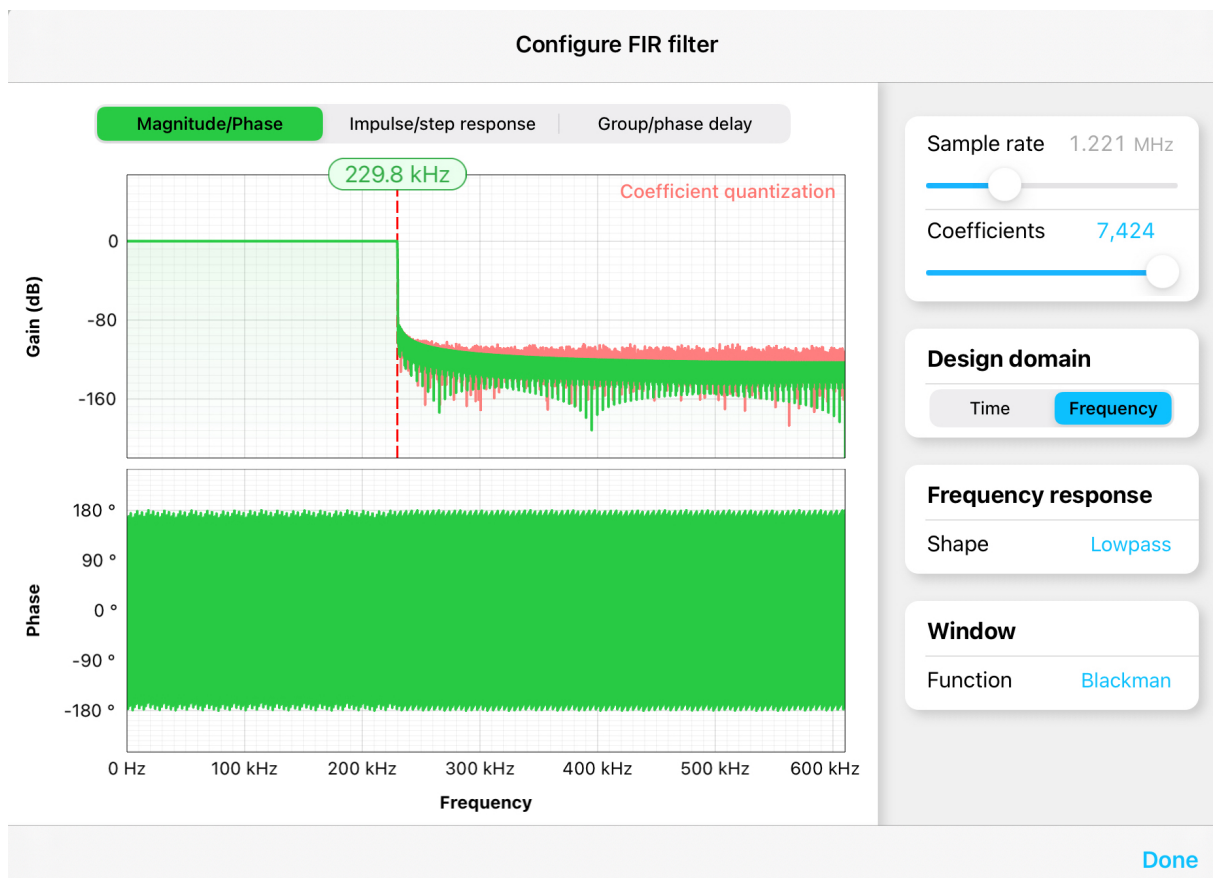
List of available shapes

Shape	Note
Rectangular	
Sinc	Width adjustable from 0.1% to 100%.
Triangular	
Gaussian	Width adjustable from 0.1% to 100%.
Equation	Click the equation to open the equation editor. Find details of the equation editor in the Equation Editor section.
Custom	Find details of the custom impulse response in Custom Impulse Response section.






Coefficient quantization

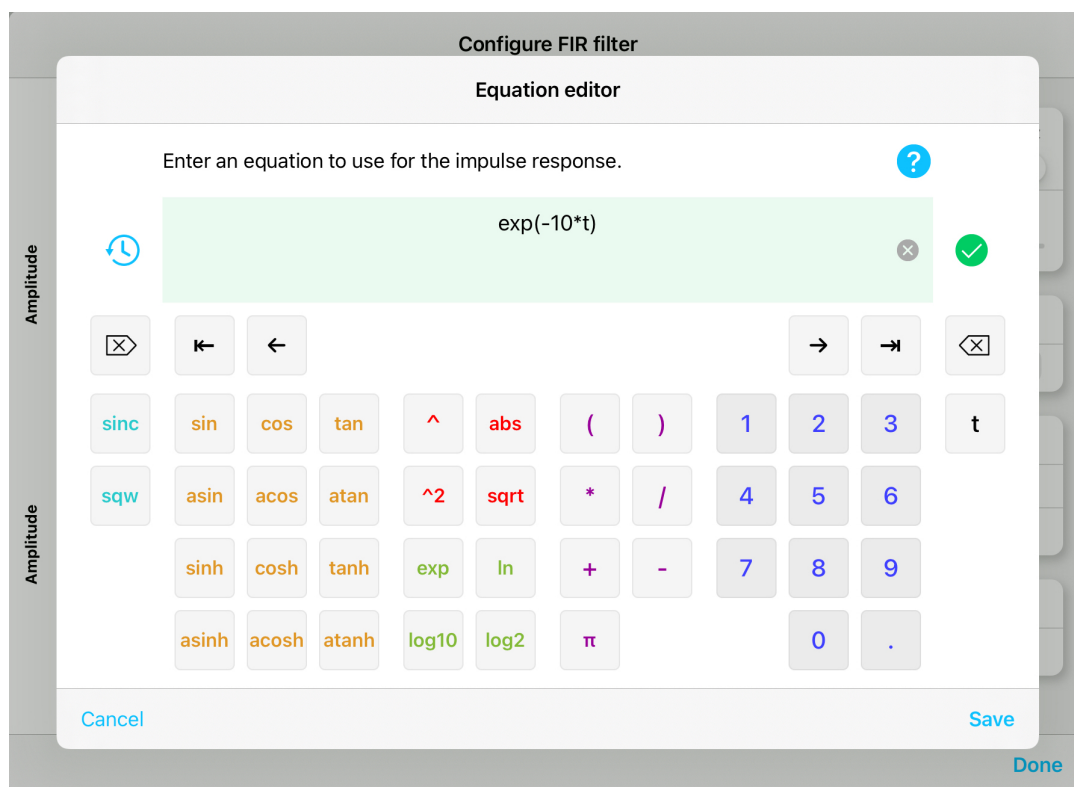
The coefficients used to define the filter have a finite bit depth, leading to a possible quantization error. This error is more pronounced for certain FIR filter settings. A red coefficient quantization warning may appear on the top-right corner of the plot, and the actual response curve will be plotted in red.





Equation editor

- The equation editor allows you to define arbitrary mathematical functions for the impulse response.
- Select from a range of common mathematical expressions including trigonometric, quadratic, exponential, and logarithmic functions.
- The variable **t** represents time in the range from 0 to 1 periods of the total waveform.
- Access recently entered equations 
- The validity of the entered equation is indicated by the green  tick or red cross  icons that appear to the right of the equation box.





Custom impulse response

The output of the FIR filter is a weighted sum of the most recent input values:

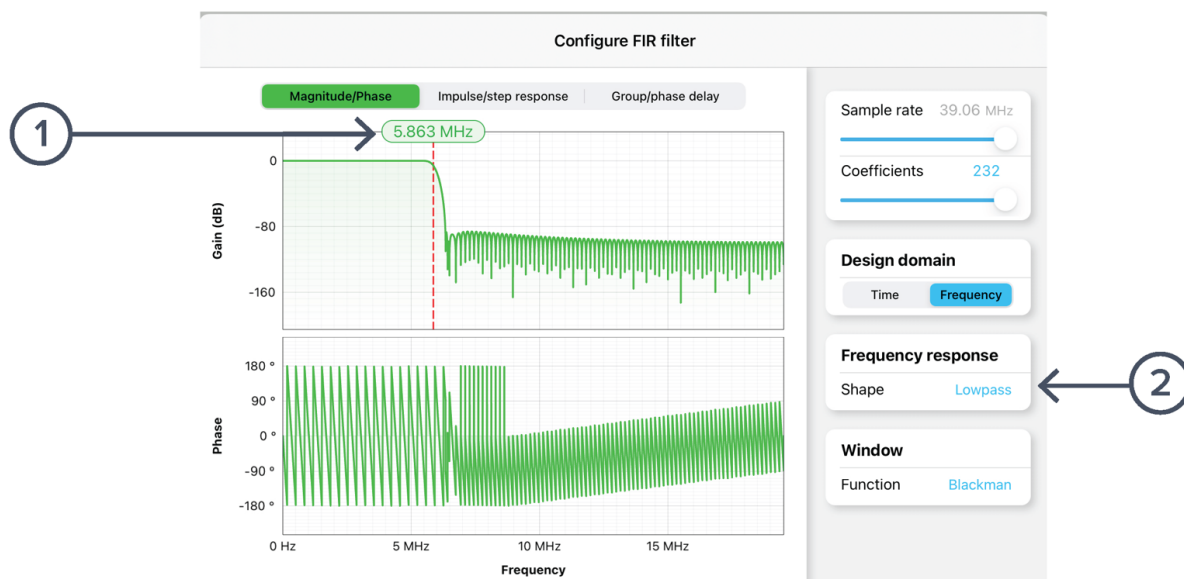
$$y[n] = \sum_{i=0}^{N-1} c_i x[n - 1]$$

To specify a custom filter, you must supply a text file containing the filter coefficients from your computer that is connected to Moku:Pro. The file can contain up to 14,819 coefficients separated by commas or new lines. Each coefficient must be in the range of [-1.0, +1.0]. Internally, these are represented as signed 25-bit fixed-point numbers, with 24 fractional bits. Filter coefficients can be computed using signal processing toolboxes in MATLAB, SciPy, etc.

Some coefficients may result in overflow or underflow, which degrade filter performance. Filter responses should be checked prior to use.



Frequency domain designer



ID Parameter

Description

- | ID | Parameter | Description |
|----|----------------|--|
| 1 | Cut-off cursor | Click and hold to slide in the frequency axis. |
| 2 | Impulse width | Click to select the filter shape. |

List of available shapes:


Shape

Note

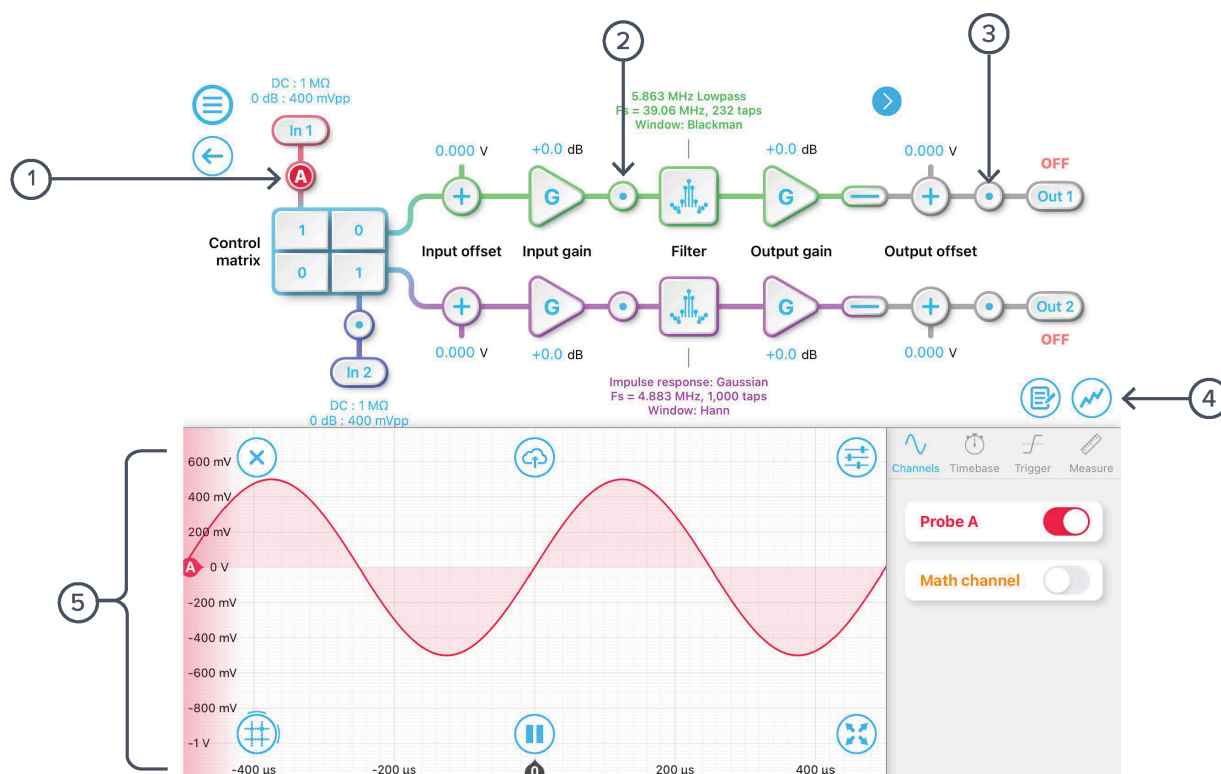
- | Shape | Note |
|----------|--------------------------|
| Lowpass | Single adjustable cursor |
| Highpass | Single adjustable cursor |
| Bandpass | Two adjustable cursors |
| Bandstop | Two adjustable cursors |



Probe points

The Moku:Pro FIR Filter Builder has an integrated oscilloscope and data logger that can be used to probe the signal at the input, immediately before the FIR filter, and at the output. Add the probe points by clicking the  icon.

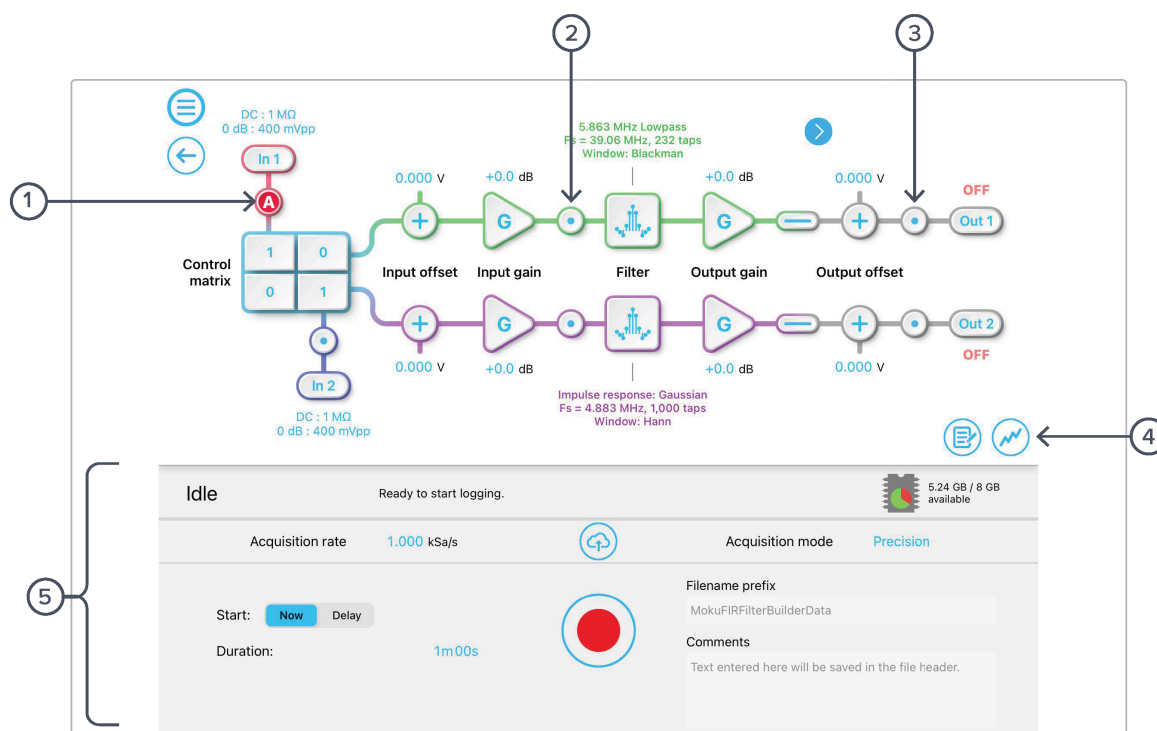
Oscilloscope



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



Data Logger



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

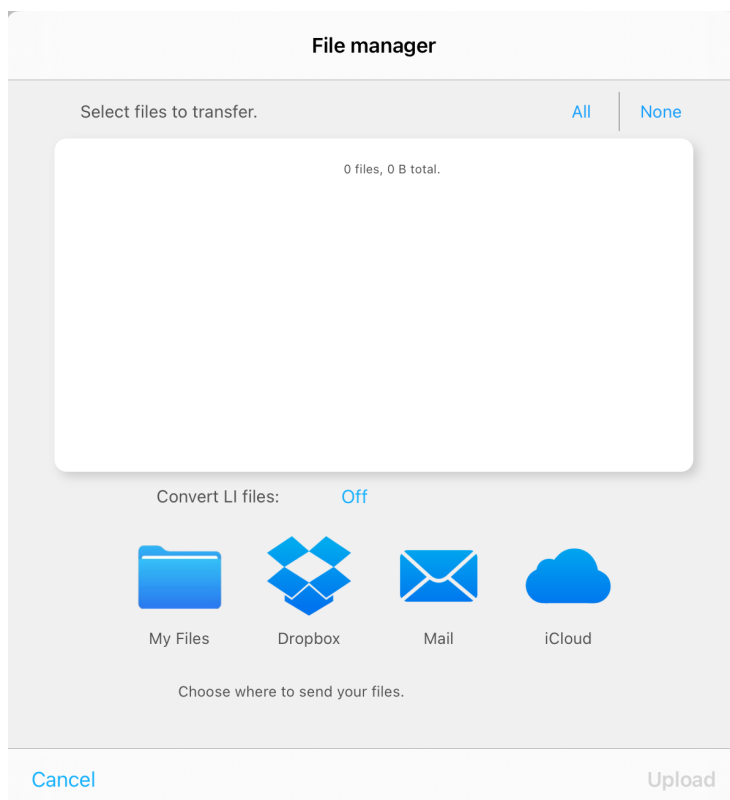
The embedded Data Logger can stream over a network, or save data on the Moku. For details, refer to the Data Logger user manual. More streaming information is in our API documentation at <http://apis.liquidinstruments.com/>



Additional tools

The Moku:Pro desktop 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.

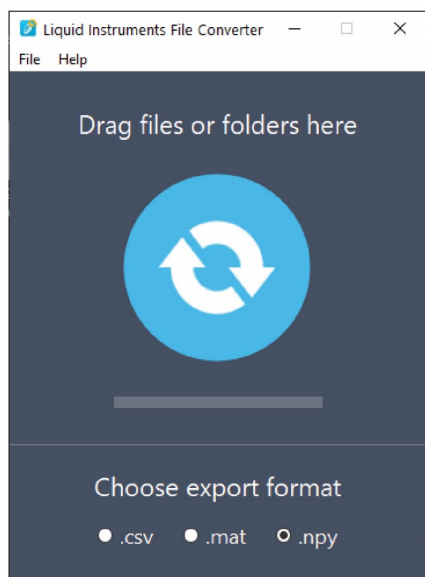
File Manager



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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