FIR Filter Builder
Moku:Lab User Manual

With Moku:Lab's 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 244.1 kHz, or 232 coefficients at a sampling rate up to 15.63 MHz. Moku:Lab's iPad interface allows 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.

Table of Contents
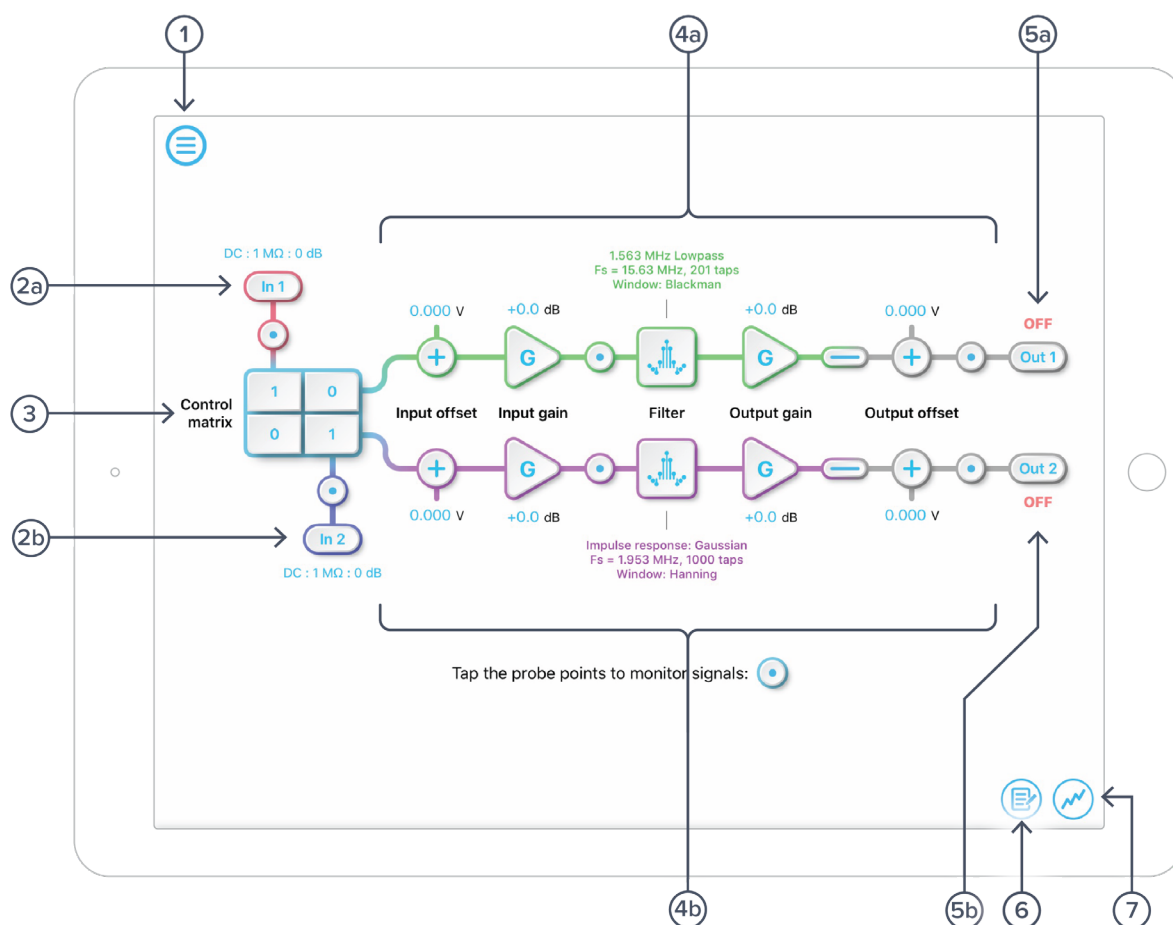
Ensure Moku:Lab is fully updated. For the latest information:

www.liquidinstruments.com

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 FIR filter 1
4b	Configuration for FIR filter 2
5a	Output switch for FIR filter 1
5b	Output switch for FIR filter 2
6	Enable the data logger
7	Enable the oscilloscope

Main Menu

The **main menu** can be accessed by pressing the ⊜ icon, allowing you to:

Select device or return to selection screen

Select instrument or return to selection screen

Save and load instrument settings

Reset the instrument to its default state (cannot be undone)

Manage your files

Enable or disable external 10 MHz reference clock

Switch between light and dark user interface modes

Notify the Liquid Instruments development team of an issue

Get help on how to use various instrument features

Launch the liquidinstruments.com website

Input Configuration

The **input configuration** can be accessed by tapping the In 1 or In 2 icon, allowing you to adjust the coupling, impedance, and input range for each input channel.
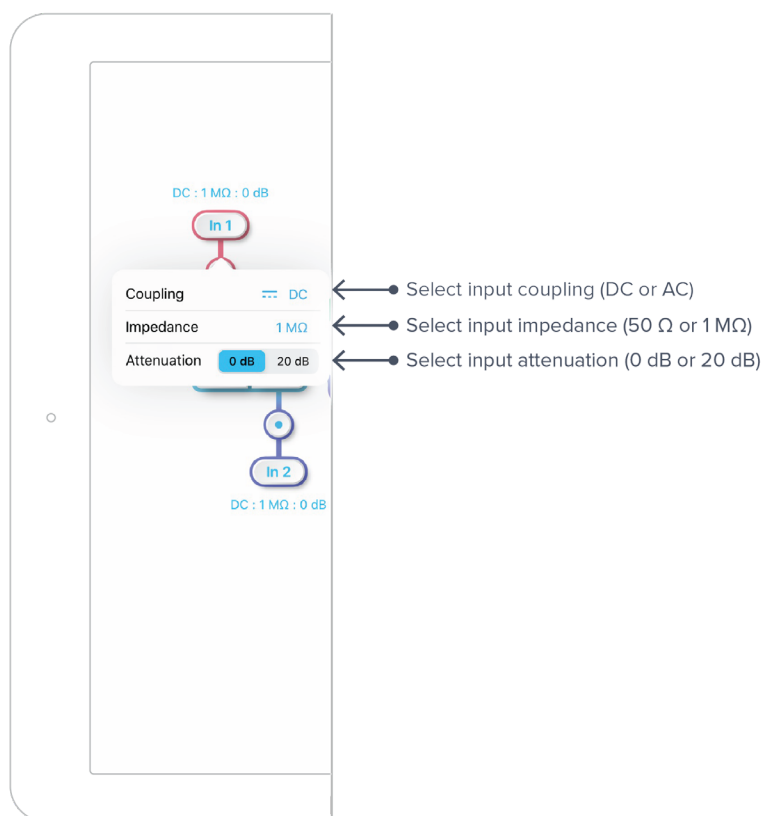
Details about the probe points can be found in the Probe Points section.

Control Matrix

The **control matrix** combines, rescales, and redistributes the input signals to the two independent FIR 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 $\begin{bmatrix} 1 & 1 \\ 0 & 2 \end{bmatrix}$ adds Input 1 and Input 2 and routes to the top *Path1* (FIR Filter 1); multiples 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. Tap the element to adjust the value.
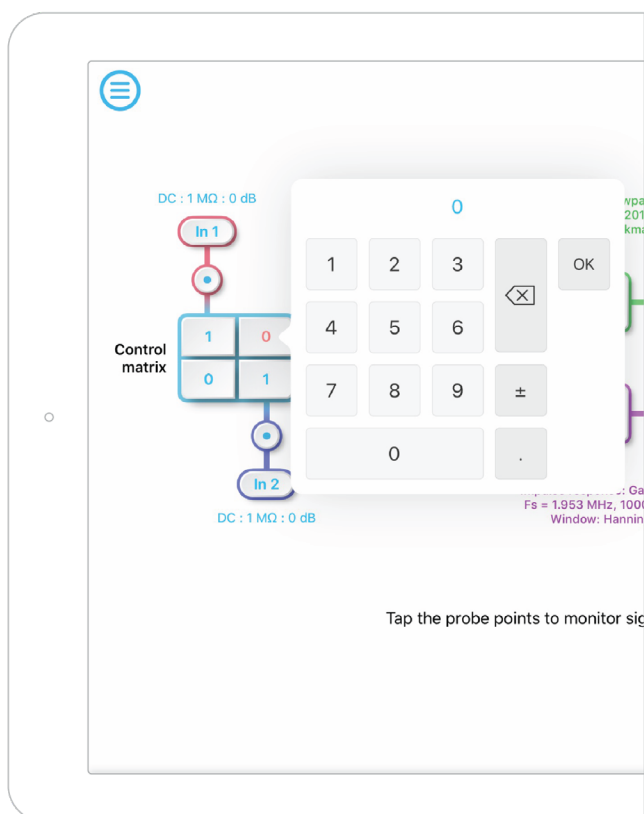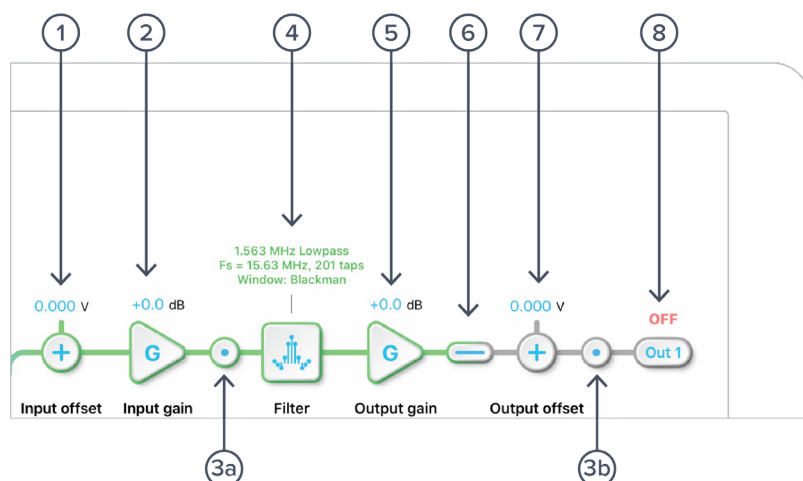

FIR Filter

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

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).
3a	Pre-filter probe	Tap to enable/disable the pre-filter probe point. See <u>Probe Points</u> section for details.
3b	Output probe	Tap to enable/disable the output probe point. See <u>Probe Points</u> section for details.
4	FIR filter	Tap to open view and configure the FIR filter builder.
5	Output gain	Tap to adjust the input gain (-40 to 40 dB).
7	Output switch	Tap to zero the filter output.
7	Output offset	Tap to adjust the input offset (-2 to +2 V).
8	DAC switch	Tap to enable/disable Moku:Lab's DAC output.

FIR Filter Builder

Builder Interface

Tap the [icon] icon to open the full **FIR Filter Builder** view.
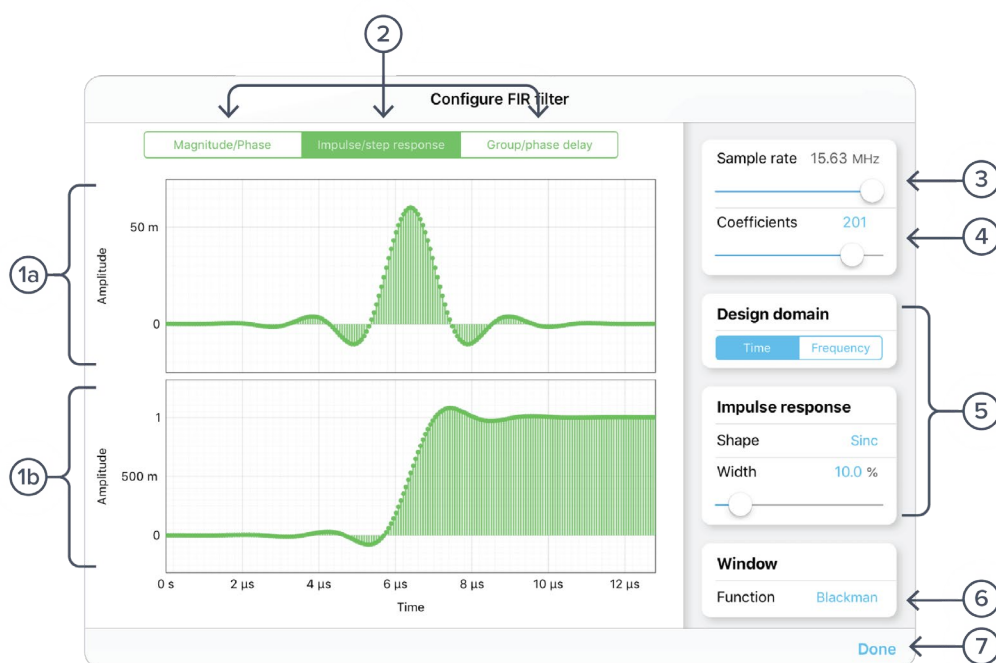
| ID	Parameter	Description
1a	Plot 1	Impulse response plot.
1b	Plot 2	Step reponse plot.
2	Plot set selection	Tap to select the set of plots to display in the plot area.
3	Sampling rate	Adjust the sampling rate for the input. Slide between 122.1 kHz and 15.63 MHz.
4	Number of coefficients	Tap the number to enter or slide the slider to adjust the number of coefficients.
5	Filter design	Configure the parameters for the FIR filter. Detailed information can be found in a later section.
6	Window function	Tap to select the window function.
7	Save & close	Tap to save and close the filter builder view.

Filter Characteristic Graphs

A set of two real-time filter characteristic plots can be shown at a time in the FIR filter builder. Tap the **plot set selection** buttons ② to select between **Magnitude/Phase**, **Impulse/step response**, and **Group/phase delay** plot sets.

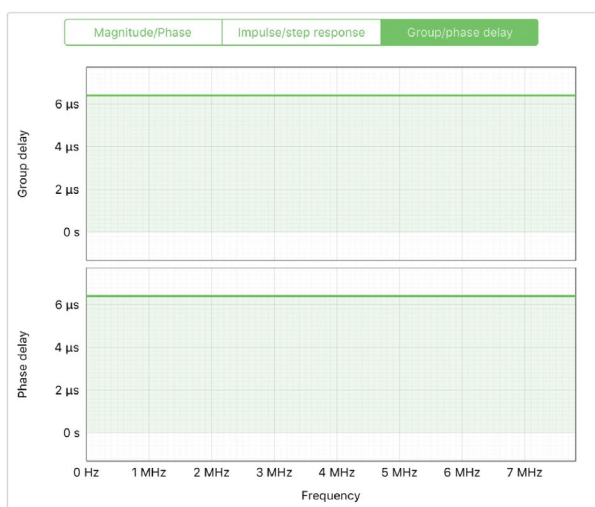|	Magnitude/Phase		Impulse/step response		Group/phase delay	
	Plot 1	**Plot 2**	**Plot 1**	**Plot 2**	**Plot 1**	**Plot 2**
X - axis	Frequency (MHz)		Time (µs)		Frequency (MHz)	
Y - axis	Gain (dB)	Phase (°)	Amplitude (V)		Group/phase Delay (µs)	

Magnitude/Phase plot set:
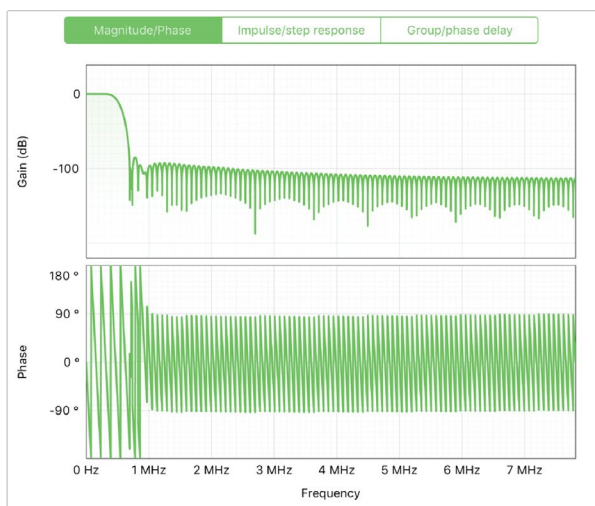
Impulse/step reponse plot set:
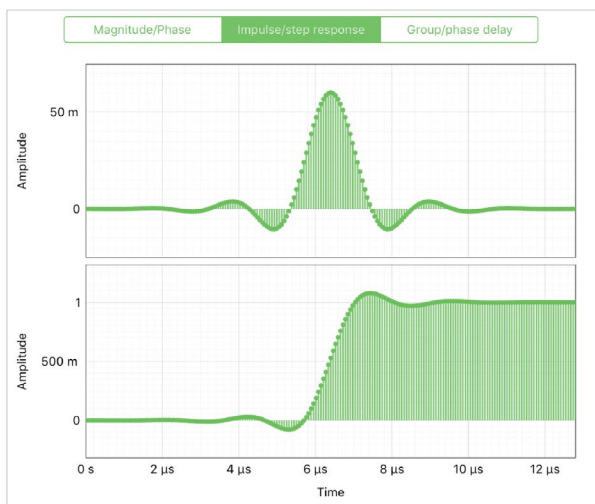
Group/phase delay plot sets:

Sampling Rate/Coefficients

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

Sampling rate	Maximum number of coefficients
122.1 kHz	14,819
244.1 kHz	14,819
488.3 kHz	7,424
976.6 kHz	3,712
1.953 MHz	1,856
3.906 MHz	928
7.813 MHz	464
15.63 MHz	232

Design Domain

The FIR filter can be designed in either time or frequency domain. In **time domain designer**, an impulse response function builder is accessible. Several predefined functions are available. Users can also enter an equation with the **equation editor** or load their own set of coefficients with the **custom impulse response** option. In **frequency domain designer**, a frequency response builder is accessible. Lowpass, highpass, bandpass, and bandstop filters are available with adjustable cut-off frequencies.

Time Domain Designer
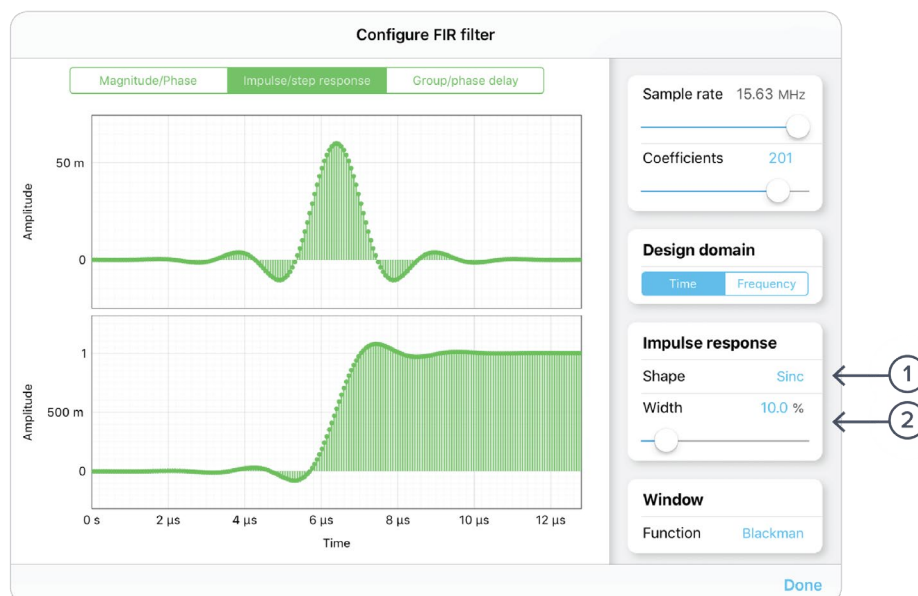
| ID	Parameter	Description
1	Impulse shape	Tap to select the shape of the impulse response.
2	Impulse width	Tap the number to enter or slide the slider to adjust the impulse width.

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	Tap the equation to open the equation editor. Details about the equation editor can be found in the in the **Equation Editor** section.
Custom	Details about the custom impulse response can be found in **Custom Impulse Response** section

Coefficient Quantization

Due to the limit of digitization depth, the quantization error is pronounced at 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.
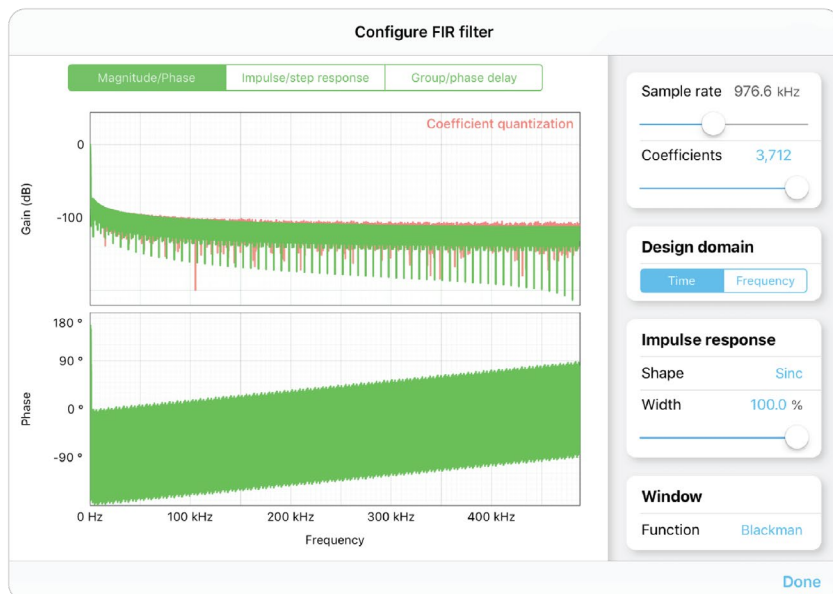
Equation Editor

- 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 by pressing the 🕐 icon.
- The validity of the entered equation is indicated by the ✅ and ❌ icons that appear to the right of the equation box.
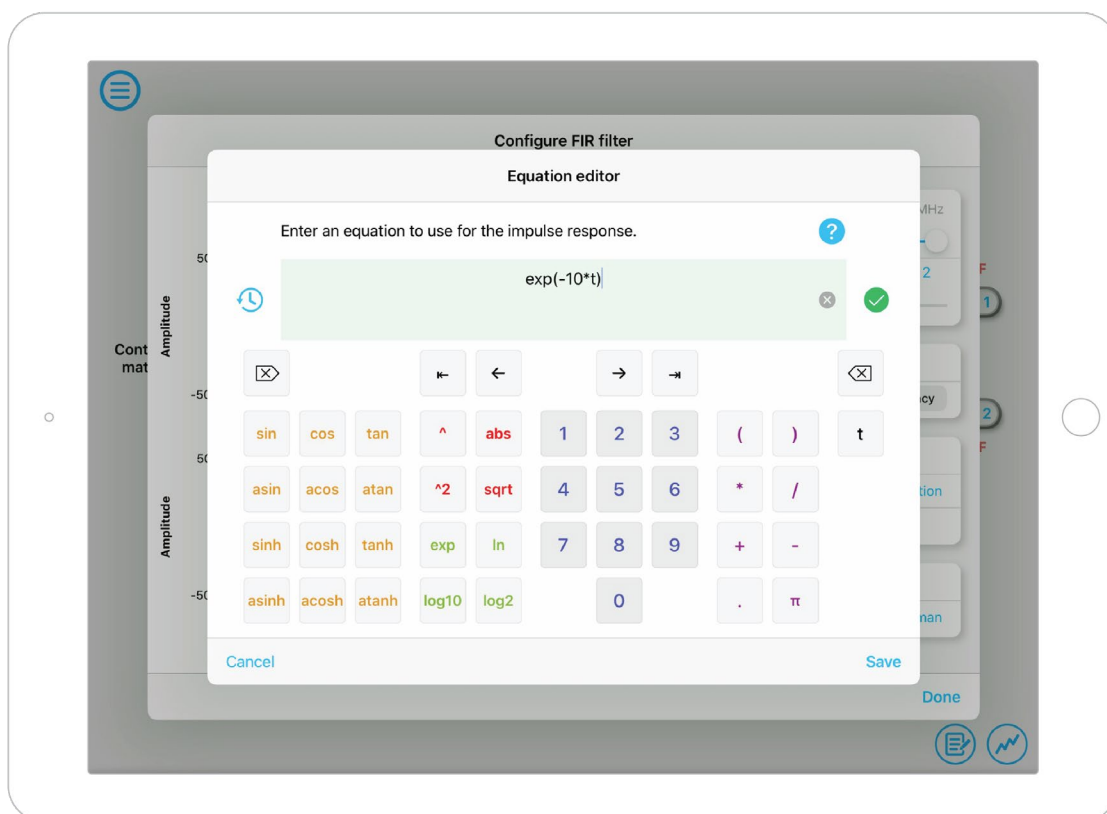
Custom Impulse Response

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 on Moku:Lab's SD card or iPad storage. The file can contain up to 14,819 coefficients separated by commas or new lines. The coefficients also can be loaded from the iPad clipboard. 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.
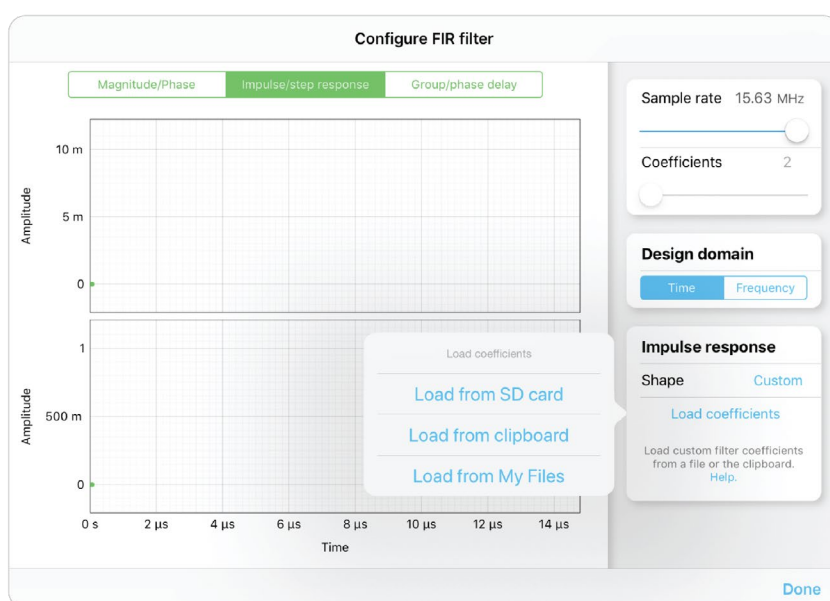
Frequency Domain Designer
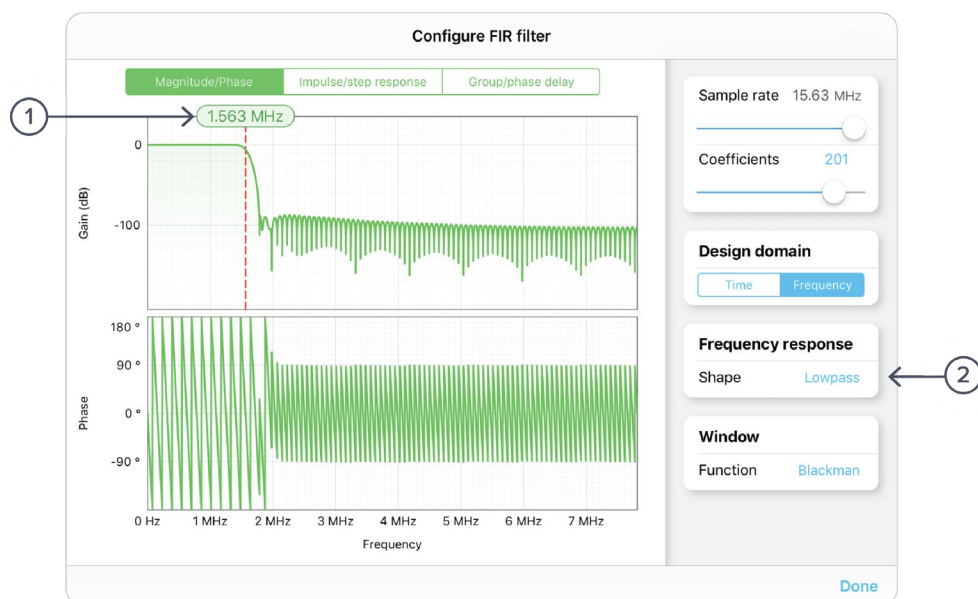
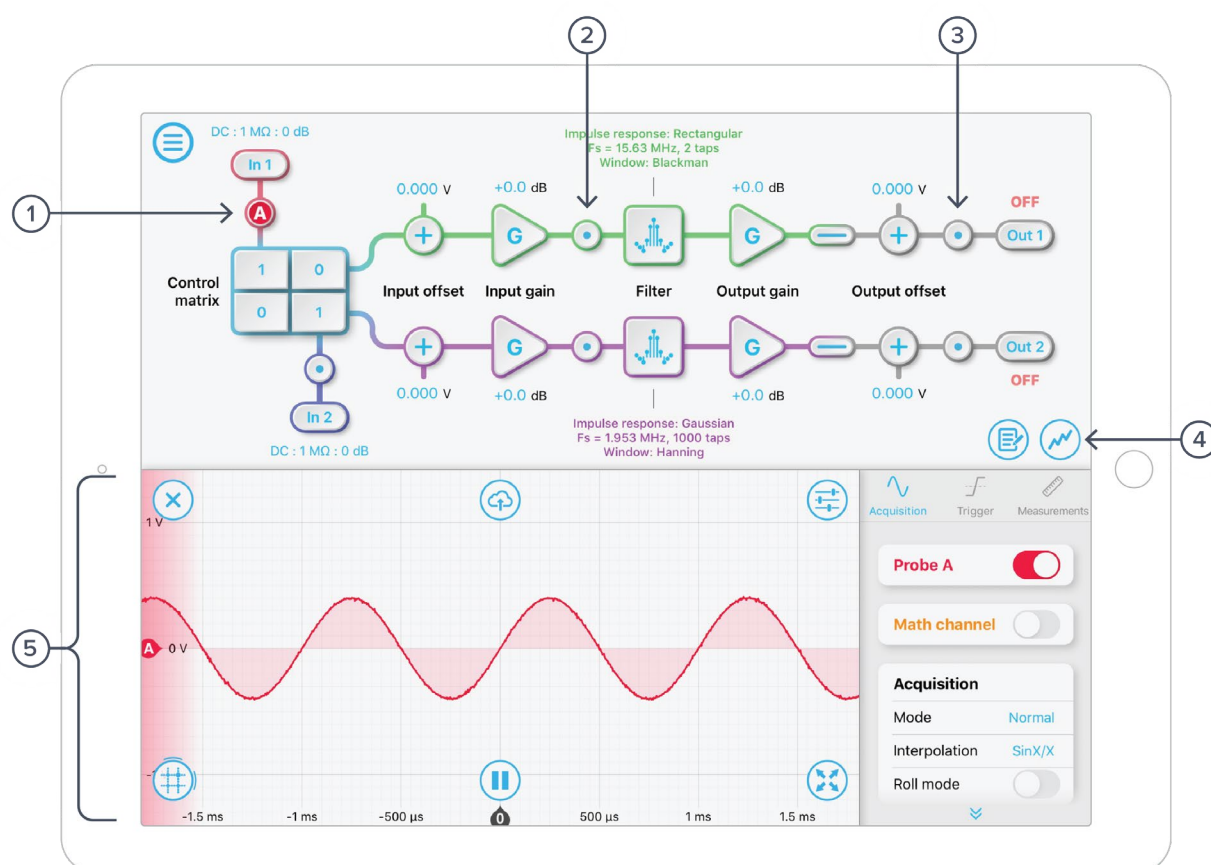| ID	Parameter	Description
1	Cut-off cursor	Tap to enter a specific number or hold to slide in the frequency axis.
2	Impulse width	Tap to select the filter shape.

List of available shapes:

Shape	Note
Lowpass	Single adjustable cursor.
Highpass	Single adjustable cursor.
Bandpass	Two adjustable cursors.
Bandstop	Two adjustable cursors.

Probe Points

Moku:Lab's FIR Filter Builder has an integrated oscilloscope and data logger that can be used to probe the signal at the input, pre-FIR filter, and output stages. The probe points can be added by tapping the ⊙ icon.
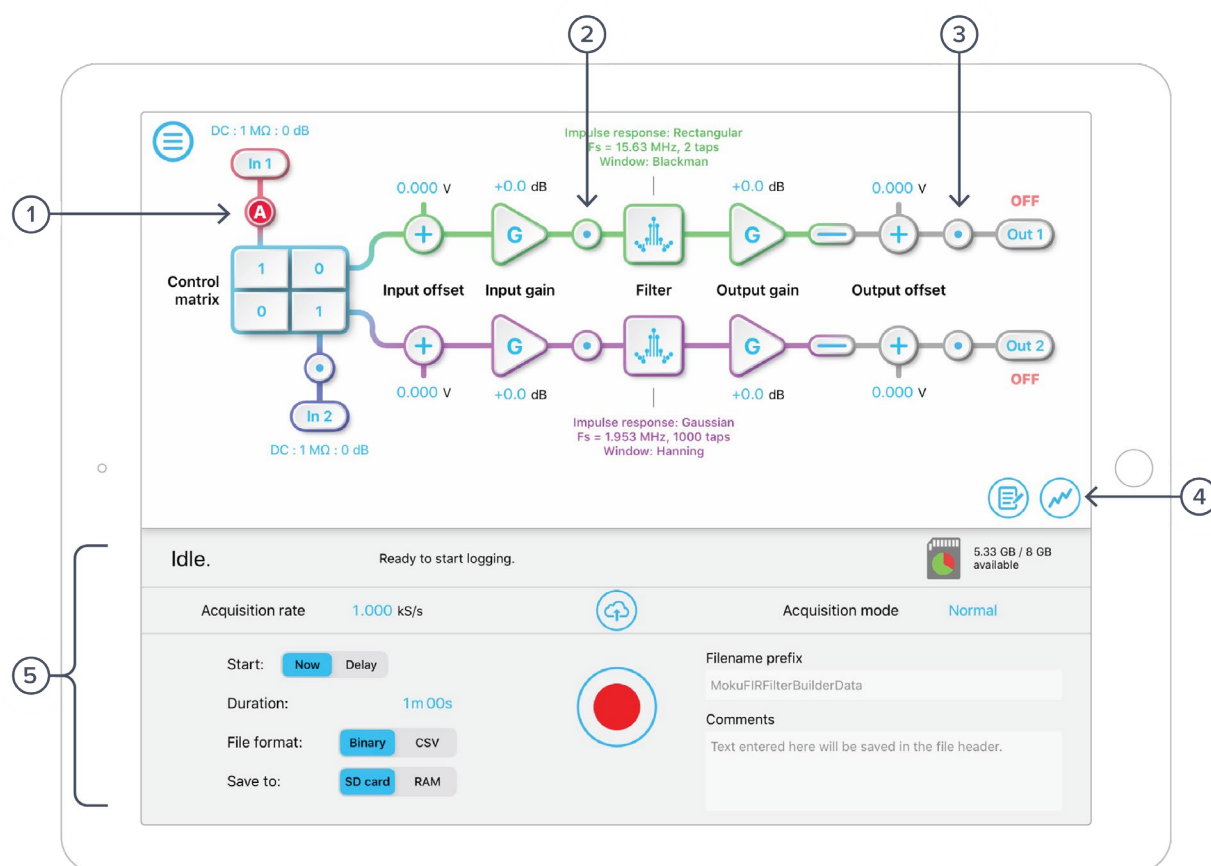
Oscilloscope

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

Data Logger

ID	Parameter	Description
1	Input probe point	Tap to place the probe point at input.
2	Pre-FIR probe point	Tap to place the probe before the FIR filter.
3	Output probe point	Tap 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:Lab's Data Logger** manual for the details.

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