# StudentZone—December 2018 ADALM1000 SMU Training Topic 12: Band-Pass Filter

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After the introduction of the SMU ADALM1000 in our *Analog Dialogue* December 2017 article, we want to continue with the next of some small, basic measurements. You can find the previous ADALM1000 article here.



Figure 1. A schematic of the ADALM1000.

#### Objective

The objective of this lab activity is to: 1) Construct a band-pass filter by cascading a low-pass filter and a high-pass filter, and 2) Obtain the frequency response of the filter and learn how to use the Bode plotter software.

#### Background

A band-pass filter allows for a specific range of frequencies to pass, while blocking or attenuating lower and higher frequencies. It passes frequencies between the two cutoff frequencies while attenuating frequencies outside the cutoff frequencies.

One typical application of a band-pass filter is in audio signal processing, where a specific range of frequencies of sound are desired while attenuating the rest. Another application is in the selection of a specific signal from a range of signals in communication systems.

A band-pass filter may be constructed by cascading a high-pass RL filter with a roll-off frequency  $f_{\rm L}$  and a low-pass RC filter with a roll-off frequency  $f_{\rm H}$ , such that:

$$f_L < f_H$$

The lower cutoff frequency is given as:

$$f_L = \frac{R}{(2 \pi L)} \tag{2}$$

The higher cutoff frequency is given as:

$$f_H = \frac{1}{(2 \pi RC)} \tag{3}$$

The bandwidth of frequencies passed is given by:

$$BW = f_L < f_H \tag{4}$$

All the frequencies below  $f_{\rm L}$  and above  $f_{\rm H}$  are attenuated and the frequencies between are passed by the filter.



Figure 2. Band-pass filter circuit.

From the previous lab on parallel LC resonance, we can also use the formula for the LC resonance to calculate the center frequency of the band-pass filter. The resonant frequency  $\omega_{\scriptscriptstyle 0}$  is given by:

$$\omega_o = \frac{1}{\sqrt{LC}} \tag{5}$$

or

(1)

$$f_o = \frac{1}{(2 \pi \sqrt{LC})} \tag{6}$$

#### **Frequency Response**

To show how a circuit responds to a range of frequencies, a plot of the magnitude (amplitude) of the output voltage of the filter as a function of the frequency can be drawn. It is generally used to characterize the range of frequencies in which the filter is designed to operate within. Figure 3 shows a typical frequency response of a band-pass filter.







Figure 4. Band-pass filter connections.

#### Materials:

- ADALM1000 hardware module
- Resistors (1.0 kΩ)
- Capacitors (0.047 µF)
- Inductors (20 mH)

#### Procedure

► 1. Set up the filter circuit as shown in Figure 2 on your solderless breadboard, with the component values R1 = 1 k $\Omega$ , C1 = 0.047 µF, L1 = 20 mH.



Figure 5. Band-pass filter breadboard connection.

- 2. Set the Channel A AWG Min value to 0.5 and Max value to 4.5 V to apply a 4 V p-p sine wave centered on 2.5 V as the input voltage to the circuit. From the AWG A Mode drop-down menu, select SVMI mode. From the AWG A Shape dropdown menu, select Sine. From the AWG B Mode dropdown menu, select Hi-Z mode.
- 3. From the ALICE Curves drop-down menu, select CA-V and CB-V for display. From the Trigger drop-down menu, select CA-V and Auto Level. Set the Hold Off to 2 msec. Adjust the time base until you have approximately two cycles of the sine wave on the display grid. From the Meas CA dropdown menu, select P-P under CA-V and do the same for CB. Also, from the Meas CA menu, select A-B Phase.
- 4. Start with a low frequency—we'll use 100 Hz for our example—and measure the output voltage CB-V peak to peak from the scope screen. It should be much lower than the Channel A output. Increase the frequency of Channel A in small increments until the peak-to-peak voltage of Channel B is roughly 0.7 times the peak-to-peak voltage of Channel A. Compute 70% of V p-p and obtain the frequency at which this happens on the oscilloscope. This gives the cutoff (roll-off) frequency for the constructed high-pass RL section of the filter.
- 5. Continue increasing the frequency of Channel A until the peak-to-peak voltage of Channel B falls back to roughly 0.7 times the peak-to-peak voltage of Channel A. Compute the frequency at which this happens on the oscilloscope. This gives the cutoff (roll-off) frequency for the constructed low-pass RC section of the filter. Note that this 70% amplitude point occurs twice on the band-pass filter: at the lower cutoff and upper cutoff frequencies.

## Frequency Response Plots with the ALICE Bode Plotter

The ALICE Desktop software can display Bode plots, which are graphs of the magnitude and the phase vs. the frequency of a given network. The procedure is as follows:

Use the band-pass circuit in Figure 2. By having R1 = 1.0 k $\Omega$ , C1 = 0.047  $\mu$ F, and L1 = 20 mH, we can sweep the input frequency from 500 Hz to 12,000 Hz and plot the signal amplitude of both Channel A and B and the relative phase angle between Channel B and A.

With the circuit connected to the ALM1000, as in Figure 2, start the ALICE Desktop software. Open the Bode plotter.

Under the **Mode** dropdown menu, select **Peak Hold** mode. Under the **FFT** window menu, select **Flat Top Window**. Click the **+ Samples** button until 4096 samples are selected. Under the **Curves** menu, select **CA-dBV**, **CB-dBV**, and **Phase B-A**.

Under the Options dropdown menu, click on Cut-DC.

Set the AWG Channel A Min value to 1.086 and the Max value to 3.914. This will be a 1 V rms (0 dBV) amplitude centered on the 2.5 V middle of the analog input range. Set the AWG A mode to SVMI and Shape to Sine. Set AWG Channel B to Hi-Z mode. Be sure the Sync AWG check box is selected.

Use the **Start Frequency** button to set the frequency sweep to start at 500 Hz and use the **Stop Frequency** button to the sweep to stop at 12,000 Hz. Select CHA as the channel to sweep. Also use the **Sweep Steps** button to enter the number of frequency steps, using 700 as the number.

You should now be able to press the green **Run** button and run the frequency sweep. After the sweep is completed (this could take several minutes for 700 points), you should see something like the screenshot in Figure 6. You may want to use the **LVL** and **dB/div** buttons to optimize the plots to best fit the screen grid.

Record the results and save the Bode plot using a screen capture tool and include it in your lab report.



Figure 6. Bode analyzer settings.

To better understand the frequency characteristics of this parallel LC filter plot the low-pass frequency response with just the capacitor (that is, remove the inductor). Make the same frequency sweep and take a snapshot of the gain (CB-db – CA-dB) and relative phase (CA – CB). Now plot the high-pass frequency response with just the inductor (that is, put the inductor back and remove the capacitor). The Bode plot in Figure 7 shows these results. Note that the frequency where the low-pass and high-pass gain is the same and the relative phase sums to zero (at about +70° and  $-70^{\circ}$ ) is at the resonant frequency.



Figure 7. Low- and high-pass response.

#### Questions

1. Compute the cutoff frequencies for each band-pass filter constructed using the formula in Equation 1 and Equation 2. Compare these theoretical values to the ones obtained from the experiment and provide suitable explanation for any differences.

#### Notes

As in all the ALM labs, we use the following terminology when referring to the connections to the ALM1000 connector and configuring the hardware. The green shaded rectangles indicate connections to the ADALM1000 analog I/O connector. The analog I/O channel pins are referred to as CA and CB. When configured to force voltage/measure current, -V is added (as in CA-V) or when configured to force current/measure voltage, -I is added (as in CA-I). When a channel is configured in the high impedance mode to only measure voltage, -H is added (as in CA-H).

Scope traces are similarly referred to by channel and voltage/current, such as CA-V and CB-V for the voltage waveforms, and CA-I and CB-I for the current waveforms.

We are using the ALICE Rev 1.1 software for those examples here.

File: alice-desktop-1.1-setup.zip. Please download here.

The ALICE Desktop software provides the following functions:

- A 2-channel oscilloscope for time domain display and analysis of voltage and current waveforms.
- The 2-channel arbitrary waveform generator (AWG) controls.
- The X and Y display for plotting captured voltage and current vs. voltage and current data, as well as voltage waveform histograms.
- The 2-channel spectrum analyzer for frequency domain display and analysis of voltage waveforms.
- The Bode plotter and network analyzer with built-in sweep generator.
- An impedance analyzer for analyzing complex RLC networks and as an RLC meter and vector voltmeter.
- A dc ohmmeter measures unknown resistance with respect to known external resistor or known internal 50 Ω.
- Board self-calibration using the AD584 precision 2.5 V reference from the ADALP2000 analog parts kit.
- ALICE M1K voltmeter.
- ALICE M1K meter source.
- ALICE M1K desktop tool.

For more information, please look here.

Note: You need to have the ADALM1000 connected to your PC to use the software.



Channels A, B Voltage/Current Range and Position Controls Figure 8. ALICE desktop 1.1 menu.

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Also by this Author: ADALM1000 SMU Training Topic 11: Frequency

**Compensated Voltage** 

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Dividers StudentZone— November 2018

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Also by this Author: ADALM1000 SMU Training Topic 11: Frequency Compensated Voltage Dividers

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