

Lab 8: Active Filters for Instrumentation Amplifier

INTRODUCTION:

In Lab 6, a simple instrumentation amplifier was implemented and tested. Lab 7 expanded upon the instrumentation amplifier by improving circuit performance and by building a LabVIEW user interface. This lab will complete the design of your biomedical instrument by introducing a filter into the circuit.

REQUIRED PARTS AND MATERIALS:

Materials Needed

- 1) Instrumentation amplifier from Lab 7
- 2) Results from Prelab
- 3) Oscilloscope
- 4) Function Generator
- 5) DC Power Supply
- 6) Labview Software
- 7) Data Acquisition Board
- 8) Resistors
- 9) Capacitors
- 10) Dual operational amplifier (UA747)

PRELAB:

1. Print the Prelab and Lab8 Grading Sheets. Answer all of the questions in the Prelab Grading Sheet and bring the Lab8 Grading Sheet with you when you come to lab. ***The Prelab Grading Sheet must be turned in to the TA before beginning your lab assignment.***
2. Read the LABORATORY PROCEDURE before coming to lab. Note: you are not required to print the lab procedure; you can view it on the PC at your lab bench.
3. For further reading consult class notes, text book and see
Low Pass Filters http://www.electronics-tutorials.ws/filter/filter_2.html
High Pass Filters http://www.electronics-tutorials.ws/filter/filter_3.html

BACKGROUND:

Active Filters

As their name implies, **Active Filters** contain active components such as operational amplifiers or transistors within their design. They draw their power from an external power source and use it to boost or amplify the output signal. Operational amplifiers can also be used to shape or alter the frequency response of the circuit by producing a more selective output response by making the output bandwidth of the filter more narrow or even wider.

Active filters generally use Operational Amplifiers within their design. An Op-amp has a high Input impedance, a Low Output impedance and a Voltage Gain resulting from the resistor combination within its feedback loop. Active filters produce good performance characteristics, very good accuracy with a steep roll-off and low noise when used with careful circuit design.

Active Low Pass Filter.

This 1st-Order low pass type filter, consists simply of a passive RC filter connected to the input of an inverting operational amplifier. The frequency response of the circuit will be the same as that of the passive RC filter, except that the amplitude of the output signal is increased by the passband voltage

gain of the amplifier. For a low pass filter, the passband starts from 0Hz or DC and continues up to the specified cut-off point at -3dB. Signals beyond the cut off frequency are attenuated.

$$A = \text{Gain of filter} \rightarrow \frac{R_2}{R_1}$$

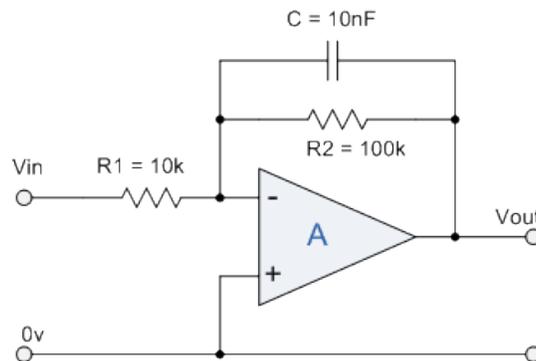
$$F = \text{frequency of input signal in Hertz}$$

$$f_c = \frac{1}{2\pi R_2 C}$$

$$\text{FL} = \text{cut off frequency in Hertz} \rightarrow$$

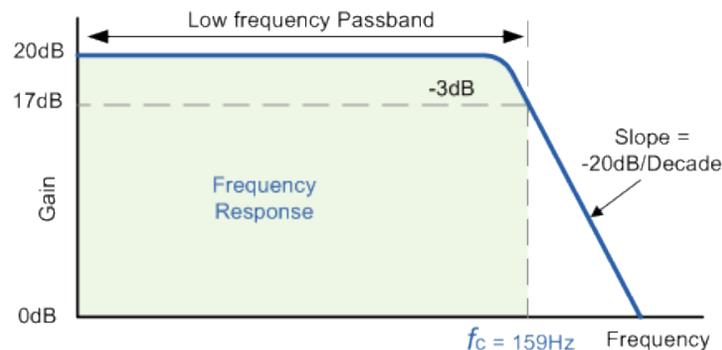
Example

Design a Low Pass filter circuit that has a gain of 10 at low frequencies and a corner frequency of 159Hz. Solve for C using the equation for the cutoff frequency. The result is a $R_1 = 10\text{k}$, $R_2 = 100\text{k}$, and $C = 10\text{nF}$. The following diagram is the simplest form of an inverting low pass filter.



Use the following formula to evaluate the gain of the filter in decibels where

$$\text{Gain} = 20 \log(A)$$



Active High Pass Filters

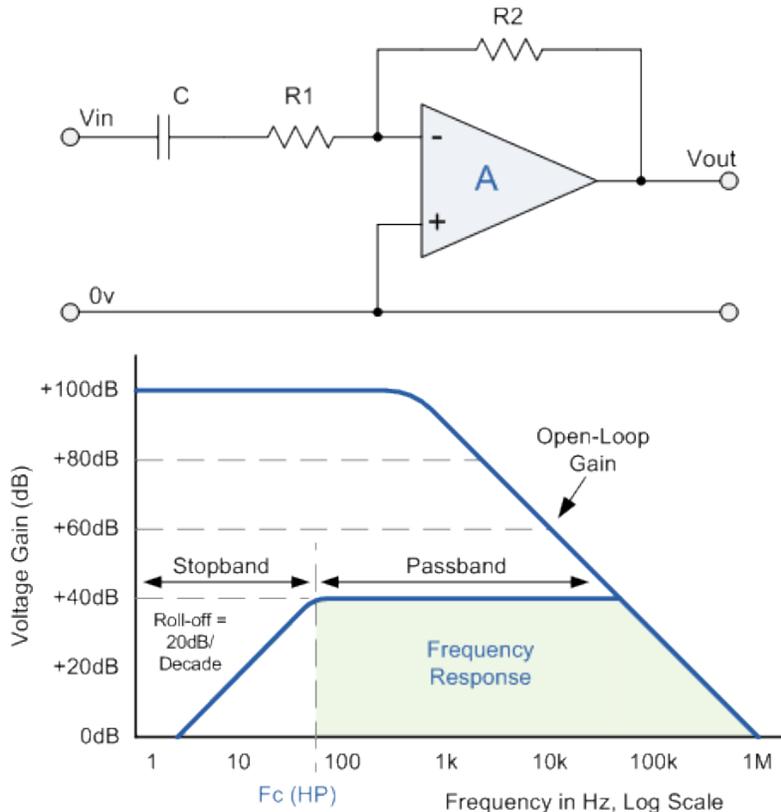
A 1st-Order (single-pole) **Active High Pass Filter** as its name implies, attenuates low frequencies and passes high frequency signals. It consists simply of a passive filter section followed by an inverting operational amplifier. The passband starts from the -3dB cut-off frequency and continues up to infinity or the maximum open loop gain for an active filter.

$$A = \text{Gain of filter} \rightarrow \frac{R_2}{R_1}$$

F = frequency of input signal in Hertz

$$f_c = \frac{1}{2\pi R_1 C}$$

FH = cut off frequency in Hertz →

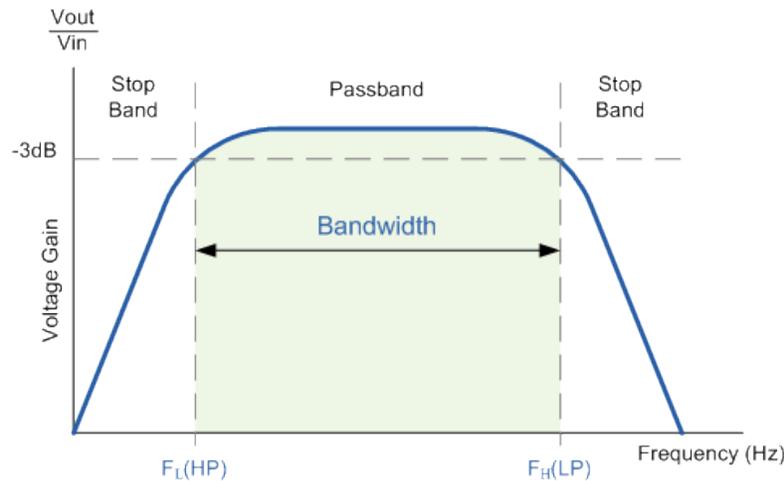


Active Band Pass Filter

For a low pass filter, the passband starts from 0Hz or DC and continues up to the specified cut-off point at -3dB. Equally, for a high pass filter the passband starts from the -3dB cut-off frequency and continues up to infinity or the maximum open loop gain for an active filter.

However, the **Active Band Pass Filter** is slightly different in that it will only pass frequencies or signals within a certain "Band" or range of frequencies that are set between two cut-off or corner points labeled "lower frequency" (f_L) and "higher frequency" (f_H) while attenuating any signals outside of these two points.

A simple **Active Band Pass Filter** can be easily made by cascading together a single *Low Pass Filter* with a single *High Pass Filter*. This will be the chosen method for this lab exercise. The cut-off or corner frequency of the low pass filter (LPF) is higher than the cut-off frequency of the high pass filter (HPF) and the difference between the frequencies at the -3dB point will determine the "Bandwidth" of the filter while attenuating any signals outside of these points. The Bandwidth of the circuit is the difference between the upper and lower -3dB points. For example, if the -3dB cut-off points are at 200Hz and 600Hz then the bandwidth of the filter would be given as: **Bandwidth (BW) = 600 - 200 = 400Hz.**



Resonant Frequency

The actual shape of the frequency response curve for a band pass filter will depend upon the characteristics of the filter circuit with the curve above being defined as an "ideal" band pass response. An active band pass filter is a **2nd Order** type filter because it has "two" reactive components (two capacitors) within its circuit design and will have a peak response or **Resonant Frequency** (f_r) at its "centre frequency", f_c . The centre frequency is generally calculated as being the geometric mean of the two -3dB frequencies between the upper and the lower cut-off points with the resonant frequency (point of oscillation) being given as:

$$F_R = \sqrt{F_L \times F_H}$$

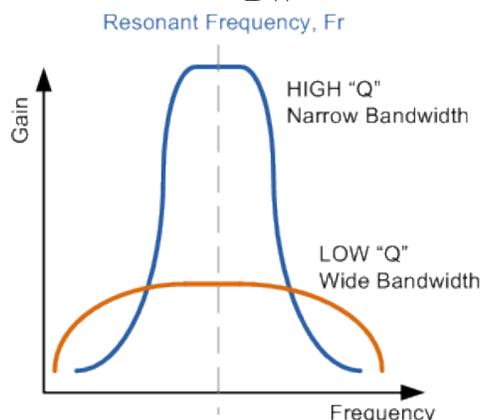
Where F_R is the resonant frequency, F_L is low cut off frequency, and F_H is the high cut off frequency.

The example given results in $F_R = \sqrt{200 \times 600} = 346\text{Hz}$

The "Q" or Quality Factor

In a **Band Pass Filter** circuit, the overall width of the actual passband between the upper and lower -3dB corner points of the filter determines the **Quality Factor** or **Q-point** of the circuit. This **Q Factor** is a measure of how "Selective" or "Un-selective" the band pass filter is towards a given spread of frequencies. The lower the value of the Q factor the wider is the bandwidth of the filter and consequently the higher the Q factor the narrower and more "selective" is the filter. The Q factor is calculated from the resonant frequency and bandwidth of the filter.

$$Q = \frac{F_r}{BW}$$



Then for our simple example above the quality factor "**Q**" of the band pass filter is given as:
 $346\text{Hz} / 400\text{Hz} = \mathbf{0.865}$.

As the quality factor of a band pass filter (Second-order System) relates to the "sharpness" of the filters response around its centre resonant frequency (f_r) it can also be thought of as the **Damping Factor** or **Damping Coefficient** because the more damping the filter has the flatter is its response and likewise, the less damping the filter has the sharper is its response. The damping ratio is given the Greek symbol of ξ , (ξ) where:

$$\xi = \frac{2}{Q}$$

LABORATORY PROCEDURE:

Exercise 1

Low Pass Filter

1. Using the UA747 dual opamp, construct on your breadboard a low pass filter using the resistor and capacitor values calculated and simulated in the prelab. You may have to adjust component values based on the values that are available in real resistors and capacitors. Double-check your gain and cutoff frequency calculations for the new R and C values. Connect the power pins of the UA747 chip to the circuit breadboard power supply rails.
2. Ask the TA to check your breadboard design before moving on to testing.
3. Setup a DC power supply to provide 0 to 10V supply to your circuit breadboard. For analog ground, use the **agnd** output of the instrumentation amplifier.
4. Setup the function generator to produce a sin wave with an amplitude of 1 volt peak to peak and a frequency within your designed passband, say 50Hz.
5. Connect the positive function generator output to the input of your low pass filter and to one input on the oscilloscope. Connect the negative terminal of function generator to analog ground (5V). Do not connect the negative terminal of the function generator to the oscilloscope; the scope's negative terminal is at 0V (earth ground).
6. Connect the output of your low pass filter to the oscilloscope. Double check all connections.
7. Press auto set on the oscilloscope and observe if the signal output signal is amplified according to your gain specifications. On the grading sheet, record the output peak to peak, the calculated gain you have achieved, and the tested input frequency.
8. Calculate and record the output voltage that would represent -3dB drop in gain (drop to $\frac{1}{2}$ of the output voltage). Start slowly increasing the frequency of the function generator until the output amplitude falls to the -3dB point. Record the measured -3dB frequency.
9. Continue increasing the frequency until the filter reaches unity gain, where the output amplitude should match the input signal amplitude. Record this frequency as the *unity gain bandwidth*.

High Pass Filter

10. Without disconnecting your low pass filter, use the second opamp on the UA747 to repeat steps 1-9 for the high pass filter. The only difference is, in steps 8 and 9 you will have to decrease frequency of the function generator to find the high pass cutoff frequency.

Band Pass Filter

11. Constructed the bandpass filter by cascading the low pass filter output into the input of the high pass filter. Quickly test the cascaded filter is working correctly by inputting a 1V sine wave and varying the frequency to record the passband gain, low pass (upper) cutoff frequency, and high pass (lower) cutoff frequency. Use the values to calculate the bandwidth, Q factor, and damping factor. Ask the TA to check off exercise 1 before proceeding.

Exercise 2LabVIEW Setup

1. Attach the output of the Lab 6 instrumentation amplifier to the input of your cascaded bandpass filter and to Ai1 of the Elvis Board.
2. Connect the output of the bandpass filter to Ai0 of the Elvis Board. Connect the ground of the amplifier/filter circuit breadboard to Aground of the Elvis Board.
3. Open LabVIEW and open a new blank project. Insert a DAQ vi on the block diagram and configure it to evaluate signals with a sampling frequency of 5,000 Hz.
4. On the Control screen, place 2 graphs. Split the signal coming from the DAQ vi with a signal splitter vi and place a graph on each of these signals. One graph should display the signal from the instrumentation amplifier and the other should display the output of the bandpass filter.
5. Place a *while* loop around all the vi's on the block diagram. Run your LabVIEW setup to confirm operation.
6. Setup the function generator to create a simulated ECG signal of ~30-40mV and 10Hz.
7. Connect the function generator to the instrumentation amplifier by connecting the positive lead to **v2** on your amplifier and the negative lead to **v1**. Also, connect **v1** to **agnd** so the amplifier and function generator have the correct DC reference.
8. Turn on the DC power supply to the breadboard and press run on the LabVIEW vi.
9. Show the TA the following output graphs and ask him to check off exercise 2, step 9.
 - Output of instrumentation amplifier (amplified version of ECG input)
 - Output of bandpass filter (filtered version of amplified ECG input)

ECG Signal Acquisition

10. Remove the ECG electrode connectors from the isolation amplifier.
11. Select a student on your team to be the patient. Attach the ECG electrode patches to the patient (see Lab 4 if you need instructions). It is recommended you attach electrodes to your chest instead of your wrists to get good ECG signals. Connect the positive electrode to instrument amp input **v2** and the negative electrode to **v1**. Connect the **gnd** electrode connects to **agnd** of your instrumentation amplifier. Show the output graphs as described in step 27.
12. Run your LabVIEW vi and observe the following output graphs. You have now replaced an expensive commercial bioamplifier with a simple circuit and LabVIEW interface that you built yourself in Labs 6-8! Give your partner a pat on the back. Show your plots to the TA and ask him to check off exercise 2, step 12.
 - Output of instrumentation amplifier (amplified version of ECG input)
 - Output of bandpass filter (filtered version of amplified ECG input)

Wrap Up

1. Once the TA has checked off your circuit, clean up your lab bench and return everything to its proper place.
2. Return your breadboards to the TA
3. Turn in your Grading Sheet to the TA.