# 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) Labivew Software
7) Data Acquisition Board
8) Resistors
9) Capacitors
10) 2 operational amplifiers (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 narrower 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.

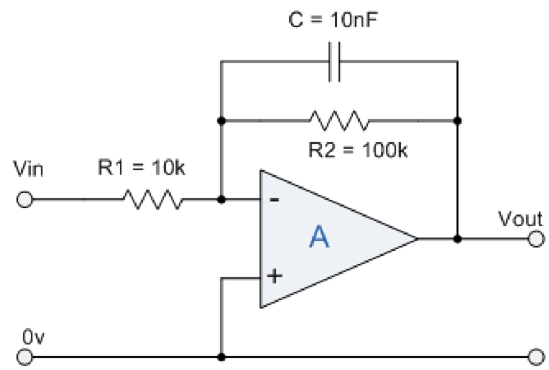
A = Gain of filter → $-\frac{R2}{R1}$

F = frequency of input signal in Hertz

FL = cut off frequency in Hertz → $f_c = \frac{1}{2\pi R_2 C}$

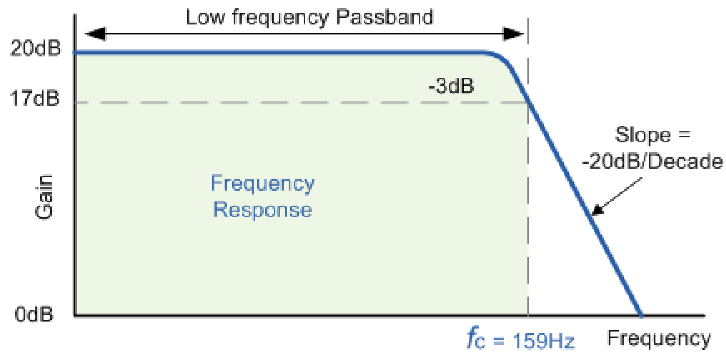
**Example**

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 R1 = 10k, R2 = 100k, and C = 10nF. 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

$$Gain = 20\log(A)$$



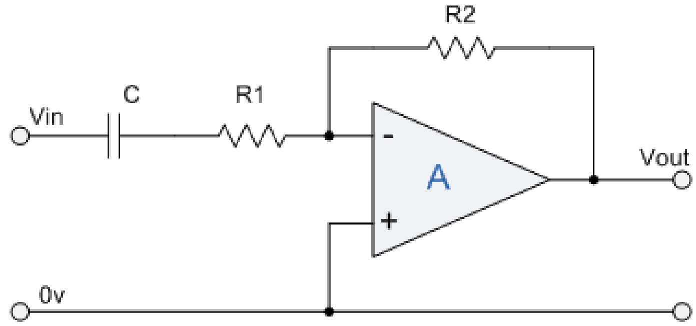

**Active High Pass Filters**

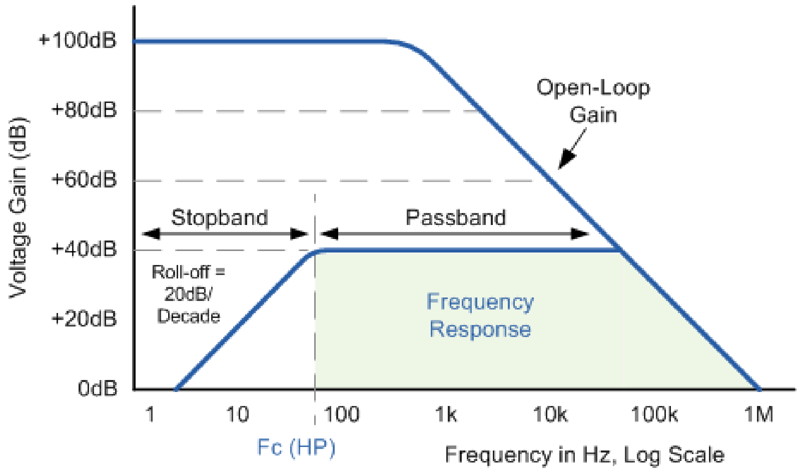
A 1st-Order (single-pole) **Active High Pass Filter** as its name implies, attenuates low frequencies and passes high frequency signals. It consists simply of a passive filter section followed by an inverting operational amplifier. The passband starts from the -3dB cut-off frequency and continues up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

A = Gain of filter → $-\frac{R2}{R1}$

F = frequency of input signal in Hertz

FH = cut off frequency in Hertz → $f_c = \dfrac{1}{2\pi R_1 C}$

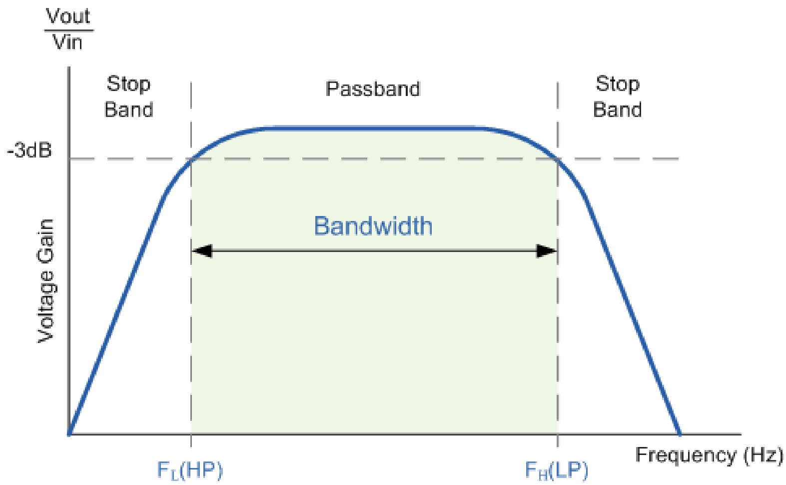



<u>**Active Band Pass Filter**</u>

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" (ƒL) and "higher frequency" (ƒH) 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** (*ƒ*r) at its "centre frequency", *ƒ*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:

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

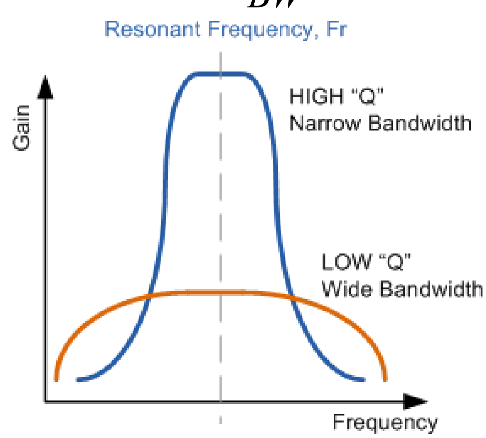
Where Fr is the resonant frequency, FL is low cut off frequency, and FH is the high cut off frequency.

The example given results in $F_R = \sqrt{200x600} = 346Hz$

**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: 346Hz / 400Hz = **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 (ƒr) 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 **Xi**, (ξ) where:

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

## LABORATORY PROCEDURE:

### Low Pass Filter

1. Design a low pass filter using the resistor and capacitor values calculated and tested for your prelab onto your breadboard.

2. Connect your lowpass filter on your breadboard and show the TA your breadboard before moving on to testing it.

3. Use the function generator to produce a sin wave with an amplitude of 1 volt peak to peak and a frequency within your designed passband.

4. Input the function generator signal into your low pass filter input.

5. Connect the output of your low pass filter to the A input of the oscilloscope and the output of the function generator to the B input.

6. Connect the DC power to the circuit.

7. Press auto set on the oscilloscope and show that the signal should be amplified according to your specifications. What is the maximum gain you have achieved and at what frequency?

   Max Gain (pass band):________, Frequency: __________,

8. Next, begin to adjust the frequency of the function generator until the amplitude decreases by 3 db. What frequency does this occur at?

   Cut off frequency (low pass):________,

9. Continue adjusting the frequency until the filter provides practically no gain to the signal. At what frequency does this occur?

   Gain:________, Frequency: __________,

### High Pass Filter

10. Repeat steps 1-9 for the high pass filter.

    Max Gain (pass band):________, Frequency: __________,

    Cut off frequency (high pass):________,

Gain:________, Frequency: __________,

**Band Pass Filter**

11. The bandpass filter should be constructed by cascading the low pass filter with the high pass filter. Based on the values calculated above, what will be the Bandwidth, Q factor, and damping factor. Show your values to the TA before proceeding.

12. Bandwidth:____________

13. Q factor:_______________

14. Damping Factor:________

15. Demonstrate your circuit to the TA

**LabVIEW Setup**

16. Attach the output of the instrumentation amplifier to the input of your cascaded bandpass filter. (low pass output connected to the high pass input)

17. Connect the output of the band pass filter to Ai0 of the Elvis Board. Connect the ground of the filter to the Aground of the Elvis Board.

18. Connect the output of the instrumentation amplifier to Ai1 of the Elvis Board.

19. Open Labview and open a new blank project. It should be familiar (based on previous labs) how to insert a DAQ vi on the block diagram. Insert a DAQ and evaluate the signal with a sampling frequency of 500 Hz.

20. Connect a Frequency analysis vi to the output of the DAQ.

21. On the Control screen, place 3 graphs. Split the signal coming from the DAQ vi with a signal splitter. Place a graph on each one. One will display the signal from the instrumentation amplifier and the other from the output of the bandpass filter.

22. Next, connect the frequency analysis vi to the output of the signal splitter for the bandpass filter output.

23. Place a while loop around all the vi's on the block diagram. This completes the LabVIEW setup. Run it to confirm its operation.

**ECG Signal Acquisition**

24. Set the function generator to create an ECG signal of 20mV and 80Hz.

25. Connect the function generator to the instrumentation amplifier. Connect the positive lead of function generator the v1, and negative lead to v2 of the instrumentation amplifier.

26. Turn on the DC power to the breadboard and press run on the Labview vi.

27. Show the TA the following output graphs.

    Original ECG coming from instrumentation amplifier

    ECG coming from bandpass filter output.

    ECG frequency response coming from bandpass filter output.

28. Remove the ECG electrode connectors from the isolation amplifier.

29. Attach the ECG electrode patches to the patient according to Lab 6. The positive electrode connects to v1, the negative electrode connects to v2 and the gnd electrode connects to agnd of your instrumentation amplifier.

30. Ask TA for check off

**Wrap Up**

1. Once the TA has checked off your circuit, clean up your lab bench and put all wire trimmings in the trash.
2. Return your breadboards to the TA
3. Turn in your Grading Sheet to the TA.