ENGR 210 Lab 9
Frequency Response of Active RC Filters

In class you studied some simple filters which used capacitors and resistors. However, these filters have several limitations. One that was mentioned in class is that the frequency roll-off of a passive filter does not occur very rapidly. Another which was not mentioned in class is that the frequency response depends upon the load that is attached to the filter—in general you don't want the frequency response to change. In this lab you will examine several types of filters that incorporate op amps. You will also use a type of band pass filter to remove noise from a signal.

A. BACKGROUND

1. Band Pass Filter with an Op Amp Buffer

You should have built and measured the performance a band pass filter that consisted of a high pass filter in series with a low pass filter, as shown in Figure 1, in the previous lab.. The frequency response for this filter is significantly different from a simple sum of the separate filter responses since the second circuit loads the first. One of the great applications of the operational amplifier is to use an op amp buffer amplifier to isolate two circuits so that the second is not loaded by the first.

In this lab you will examine a bandpass filter where the two filter sections are isolated by inserting an op amp buffer, as shown in Figure 2.

2. Active Filters

An active filter is a circuit that includes an op amp as well as having the characteristics of a filter. Recall the circuits for passive high pass and low pass filters. Their circuit diagrams are shown in Figure 3. Note that in each case a load resistor, R_L , has been added to the circuit to make it describe a more realistic situation (there will always be a load on the output of a filter circuit). The frequency characteristics of the filter are dependent upon the load resistor, which is hardly a desirable feature. In this lab you will study a variation of the low pass filter, namely, an active low pass filter as shown in Figure 4. Active filters include an op amp as an integral part of the circuit. The effect of the op amp is two-fold. First, it serves as the source of current for the load that follows the filter, thus eliminating the effect of the load resistance on the characteristics of the filter and, second, it permits adding positive gain to the filter.

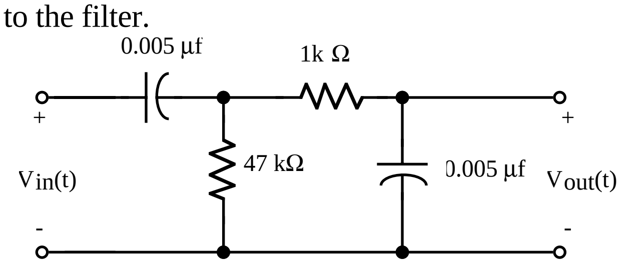


Figure 1. Band pass filter.

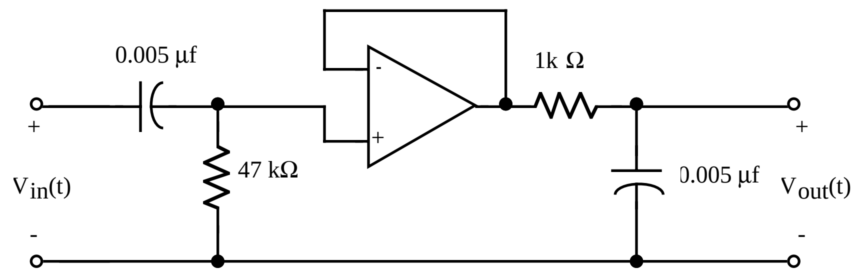
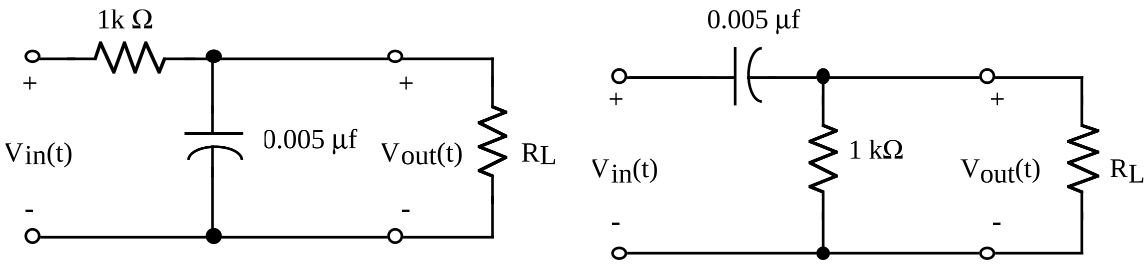


Figure 2. Band pass filter with op amp buffer.



(a) Low pass filter (b) High pass filter

Figure 3. Passive filters.

Note that in the circuit of Figure 4 there is a capacitor in the feedback loop. This circuit will behave similar to the low pass filter of Figure 3, but with a different cutoff frequency. (Note that the component values in the circuit of Figure 4 are not the same as those in Figure 3.) This is primarily because of non-ideal characteristics of the 741 op amp.

The filter circuits of Figure 3 and Figure 4 are called ***first order filters*** and they have similar abilities to reject frequencies past the cutoff frequency, i.e., their frequency response rolls off at the same rate. There will be occasions when you would like to have better frequency rejection than is provided by a first order filter. (Perhaps the signal that you are interested in is corrupted by lots of noise.) A filter such as that shown in Figure 5 can provide this increased attenuation of the high frequencies. Note that this filter includes a capacitor in the input network as well as in the feedback network. Such a filter is called a ***second order filter***.

3. Active Notch Filter

As you will quickly learn - probably the first time that you are required to use a sensor to obtain information from a system - a common problem that one encounters is the presence of 60 Hz "hum" on the output of the sensor. (You have probably already experienced this problem on your AM car radio when driving under a high voltage transmission line.) The origin of the hum is the 60 Hz power lines that supply all electrical power in the U. S. An example of the problem is shown in Figure 6. In Figure 6(a), a 120 mV, 5 Hz signal with 150 mV of hum superimposed is shown. In Figure 6(b) the hum has been removed with little attenuation of the desired signal.

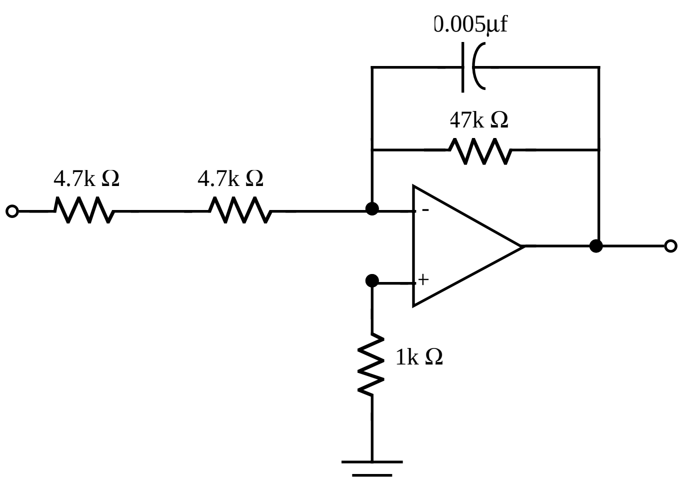


Figure 4. Active low pass filter.

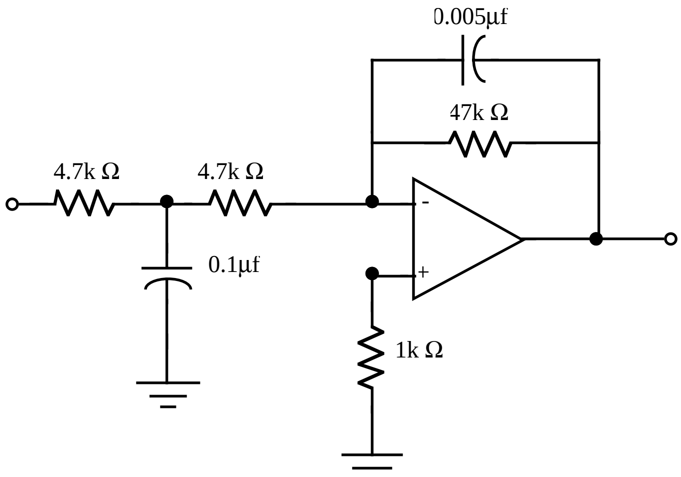


Figure 5. Second order low pass filter.

The hum in Figure 6(a) has been removed by a "notch" filter. A notch filter is a circuit having a very high attenuation for a selected frequency and very little attenuation for other frequencies. There are many types of notch filters and they are typically named after their inventor. One such filter, called a Wein bridge circuit, is shown in Figure 7. You will study the Wien Bridge circuit in this lab. You may wish to determine the transfer characteristic of this circuit to test your understanding of phasor analysis, although this is not required.

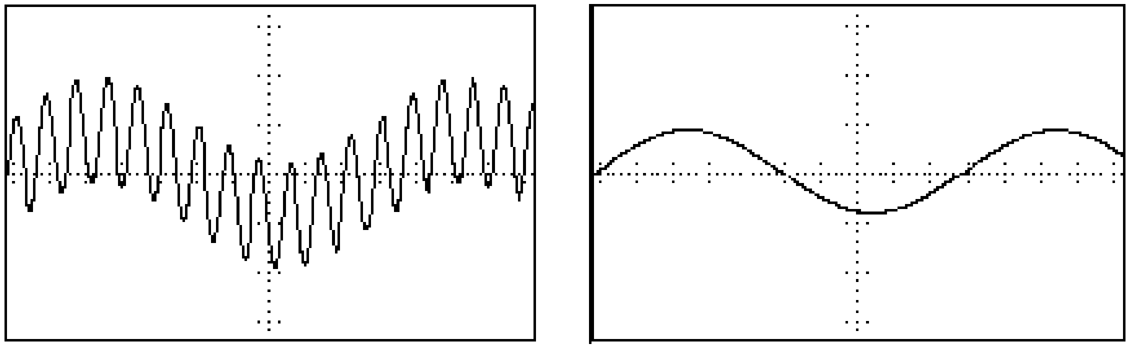
B. LAB PREPARATION

- Find an expression for the transfer function, $H(j\omega)$, for the band pass filter shown in Figure 2. From this result, find expressions for the magnitude and angle of $H(j\omega)$.
- Find an expression for the transfer function, $H(j\omega)$, for the circuit in Figure 4. From this result, find expressions for the magnitude and angle of $H(jw)$.
- Record these transfer functions in Data Table 1

C. LAB INSTRUCTIONS

PART 1: Buffered band pass filter.

1. Build the circuit shown in Figure 2. Use a 741 op amp and **be sure to connect the power supply**. Use ±15V for $\pm V_{CC}$. You should check the operational status of the 741 before using it. (The pinout diagram for the 741 is shown in Figure 8.)
2. Set up CH1 of the oscilloscope for AC coupling and a x10 probe. Set the probe itself to x10 if it has a switch. Connect the CH1 probe to the output of your circuit. Connect the output of the Waveform Generator to CH2 using a BNC Tee and a BNC cable. Set the Waveform Generator output impedance to HIGH Z.
3. Connect the Waveform Generator to the input of your circuit using a BNC to banana adapter, banana leads, and clips. Set the generator output to produce a 200 Hz sinusoidal , 5 V_{PP} output.
4. Measure and record $V_{in,PP}$, $V_{out,PP}$, the period of the input signal that you are using, and the time shift between the output and input at the frequencies listed in Data Table 2. Record your measured data there.



(a) Signal with 150 mV hum (b) Signal with hum removed

Figure 6. Example of effect of 60 Hz hum on 120 mV, 5 Hz signal.

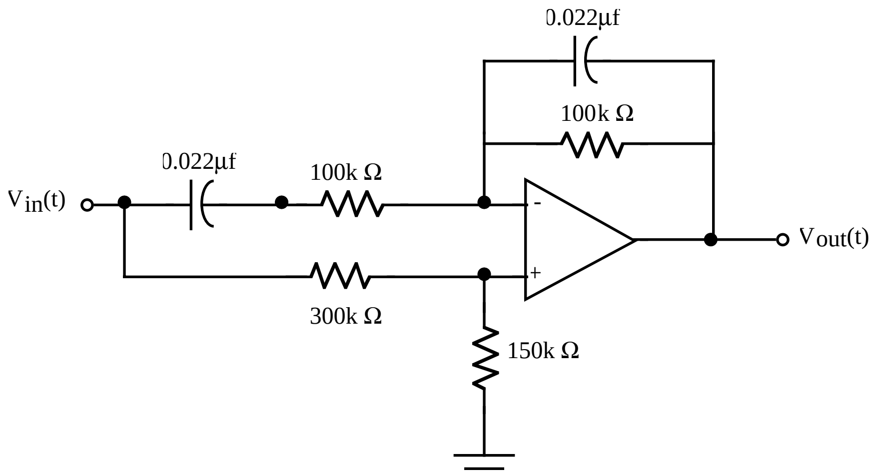


Figure 7. Wein Bridge notch filter.

Part 2: Active low pass filter.

1. Build the active first order low pass filter circuit shown in Figure 4. Keep the power supply output turned off while assembling the circuit. After completing a set of measurements on this circuit you will be adding a capacitor between the two 4.7kΩ resistors as shown in Figure 5, so be sure to leave adequate space.
2. Connect the oscilloscope to the input and output of the Waveform Generator as in Part 1. Connect the Waveform Generator to the circuit input and set the generator to produce a 10 Hz, 2 V_{PP} output.
3. Measure $V_{in,PP}$, $V_{out,PP}$, the period of the input signal that you are using, and the time shift between the output and input at the frequencies listed in Data Table 3. Record your data in Data Table 3.
4. Connect a 0.1 µF capacitor into the circuit as shown in Figure 5 and repeat Steps (2) and (3) above, recording your data in Data Table 4.

Part 3: 60 Hz Notch Filter

1. Build the circuit shown in Figure 7.
2. Connect the oscilloscope and Waveform Generator as before. Set the Waveform Generator to produce a 1 Hz, 5 V_{PP} output.
3. **Slowly** scan the output frequency of the function generator while monitoring the output of the circuit on the oscilloscope (CH2). Determine the notch frequency of your filter. (60 Hz is the nominal frequency, but it is unlikely that your circuit will have its minimum output at exactly 60 Hz. Mine was at ≈ 49 Hz!)
4. Measure $V_{in,PP}$ and $V_{out,PP}$ at the frequencies listed in Data Table 5. You should modify the listed frequencies in the 40 Hz to 600 Hz range to get a good plot of the notch that your filter provides. Record your measurements in Data Table 5.

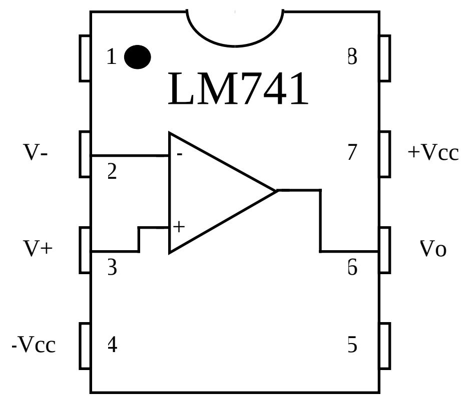


Figure 8. Pinout for 741 op amp.

DATA AND REPORT SHEETS FOR LAB 9

Student Name (Print): ___________________ Student ID: ________________________

Student Signature: ______________________ Date: _____________________________

Student Name (Print): ___________________ Student ID: ________________________

Student Signature: ______________________ Date: _____________________________

Lab Group: ___________________

Data Table 1. Derived Transfer Functions

	$\lvert H(j\omega)\rvert$	$\angle H(j\omega)$
Band pass filter with op amp buffer (Figure 2.)		
Active low pass filter (Figure 4.)		

NOTE: Be sure to attach your calculations

Data Table 2. Buffered Band Pass Filter Characteristics

Frequency	V_{in}	V_{out}	$20\log_{10}\lvert H(j\omega)\rvert$	Period	t1-t2	$\Delta\phi$ (deg)
100 Hz						
200						
300						
500						
1 kHz						
2						
4						
10						
20						
40						
70						

Data Table 3. First Order Low Pass Filter Characteristics

Frequency	V_{in}	V_{out}	$20\log_{10}\|H(j\omega)\|$	Period	t1-t2	$\Delta\phi$ (deg)
30 Hz						
100						
200						
500						
1.5 kHz						
5						
10						
50						

Data Table 4. Second Order Active Low Pass Filter Characteristics

Frequency	V_{in}	V_{out}	$20\log_{10}\|H(j\omega)\|$	Period	t1-t2	$\Delta\phi$ (deg)
30 Hz						
100						
200						
500						
1.5 kHz						
5						
10						
50						

Data Table 5. Notch Filter Characteristics

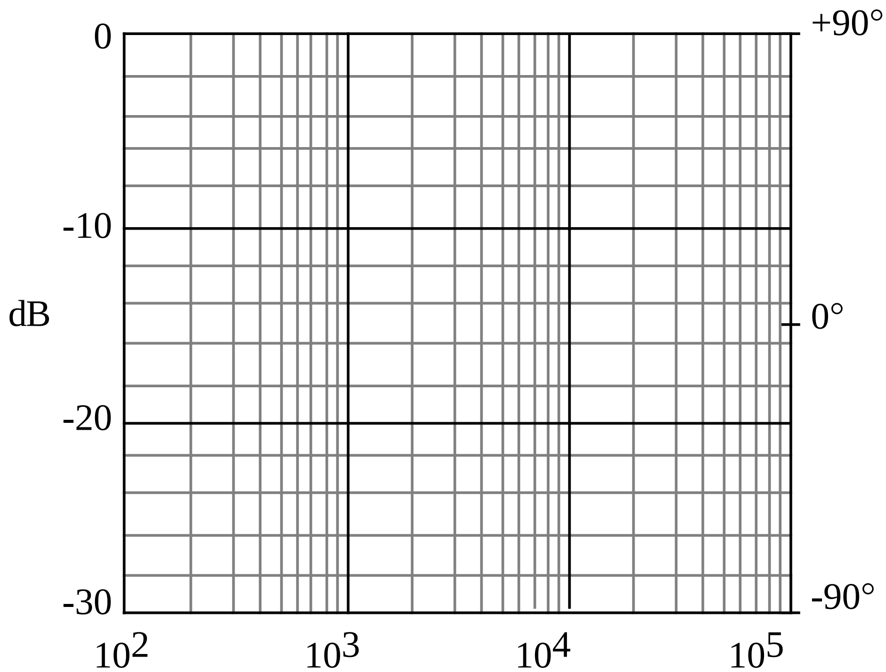
Frequency	V_{in}	V_{out}	$20\log_{10}\lvert H(j\omega)\rvert$
10 Hz			
25			
35			
40			
45			
55			
60			
70			
80			
100			
150			

Questions:

1. For the buffered and op-amp buffered bandpass filters, plot both $20\log_{10}|H(j\omega)|$ and $\Delta\phi(j\omega)$ as functions of $\log_{10}\omega$. You can use the graph below for this. Determine the cutoff[*] frequencies from your plot and compare them with calculated values from the equations that you obtained in Data Table 1.

   ω_{LO} (calculated) = ___________ ω_{LO} (measured) = ___________
   ω_{HI} (calculated) = ___________ ω_{HI} (measured) = ___________

   Discuss the differences between your calculated and measured cutoff frequencies.



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[*] NOTE: Remember from class that this is the frequency at which the magnitude of the frequency response drops to 0.707 of its maximum value. A low-pass or high pass filter has one cutoff frequency. A notch or bandpass filter has two cutoff frequencies. Break frequency is another term for cutoff frequency.

2. Plot your data for $\log_{10}|H(j\omega)|$ and $\Delta\phi\ (j\omega)$ for the first and second order active low pass filters as functions of $\log_{10}\omega$. Use the graph provided below for this. Draw best fit asymptotic (straight line) approximations for each of the two gain curves. This simply means that you should use a straight edge and draw a good fit to the passband and stop band parts of your frequency response curve. From your plots determine the cutoff frequencies and the slopes (this is also called the roll-off) for the two curves. Note the we are not interested in any slight slope in the passband; we are only interested in the slope in the stop band.

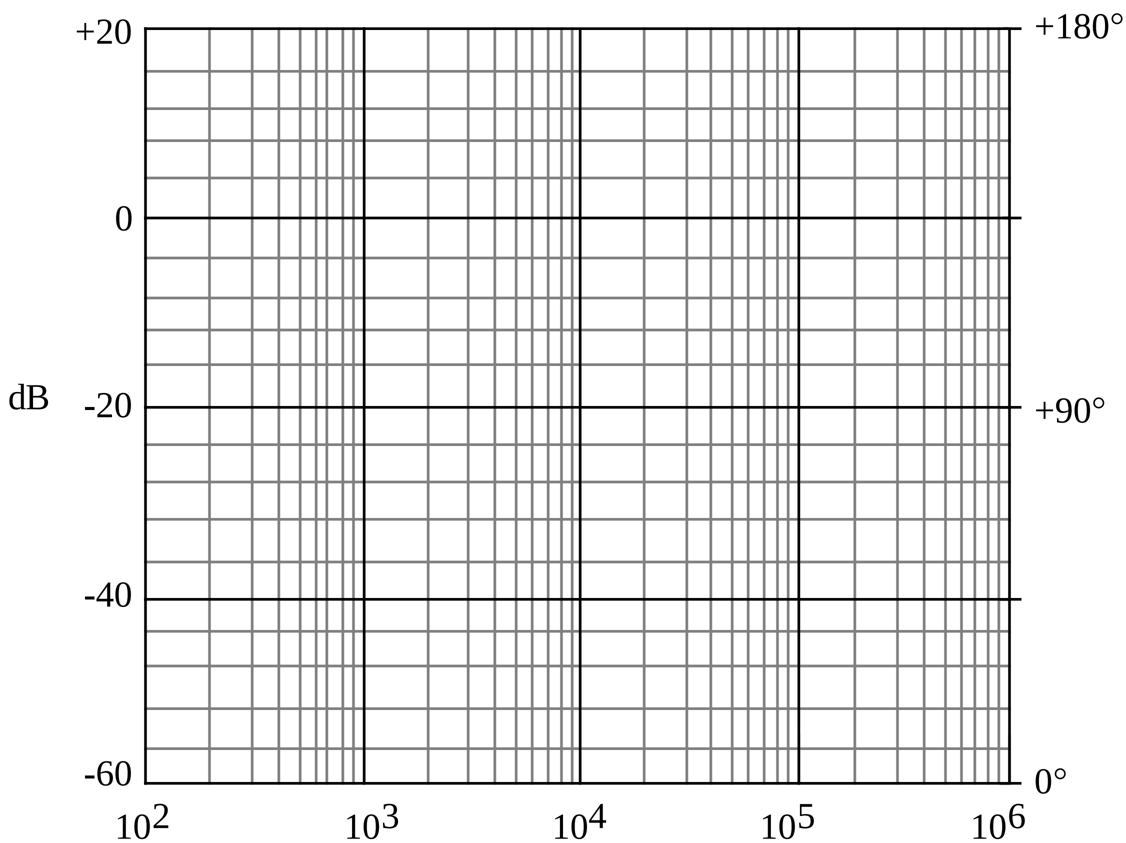
1st order low-pass:

ω_{cutoff} = ___________ slope = ___________ dB/decade

2nd order low-pass:

ω_{cutoff} = ___________ slope = ___________ dB/decade

Discuss the differences between the performance of the two filters.



3. Plot $20\log_{10}|j\omega)|$ as a function of $\log_{10}\omega$ for the notch filter. Use the graph provided below for this.

What are the notch frequency and the maximum attenuation that you obtained with your circuit? The maximum attenuation would be the ratio of the output to input voltage computed at the notch frequency. Note that this should be computed in decibels.

f_{notch} = __________Hz   Max attenuation = __________dB