

# EXPERIMENT NUMBER 8

## Introduction to Active Filters

### Preface:

- **NO Preliminary** for this lab
- Laboratory hardware exercises are to be done in groups
- The **Lab Report** is the **Lab Notebook**, and it can be written by any one member of the group
- The student-group **MUST** have the data and answers acquired during the lab and entered in the **Lab Notebook** verified by the TA before they leave the class
- Failure to show the **Lab Notebook** to the TA, will result in no score for **Lab Report** for the entire group
- **Tech Memo** to be done in Word Doc according to the format uploaded on CANVAS and submitted by individual students at the **beginning of the next class**
- Review the guidelines for plagiarism to be aware of acceptable laboratory and classroom practices.

Filters are fundamental to many circuit designs and they exist for analog and digital applications. Applications include noise reduction in communication systems, band-limiting of signals before sampling them, conversion of sampled signals into continuous-time signals, signal demodulation, improving the sound quality of audio system components such as loudspeakers and receivers, and many others.

### Objectives:

- To learn how to create filter circuit models in PSpice
- To learn how to simulate circuit models using AC Sweep Analysis
- To learn how to construct active low-pass, high-pass and band-pass filter circuits
- To determine the frequency responses of active low-pass, high-pass and band-pass filters

### References:

- PSpice experiments in EE 152 and PSpice Tutorials (See departmental website)
- EE 151 and EE 153 text: Cunningham and Stuller, *Circuit Analysis*, 2nd Ed. (Houghton Mifflin Company, Boston, 1995).
- Neamen, Donald A., *Electronic Circuit Analysis and Design*, 2nd ed., (McGraw-Hill, New York, New York, 2001), Chap 15.

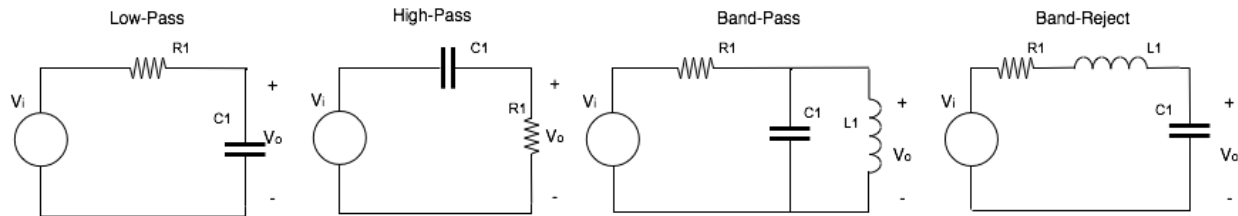
### Background:

Filters are used in circuits to block undesired frequencies and there are two main types: (1) active and (2) passive. The most common filters are low-pass, high-pass, band-pass and band-reject. Each filter has a specific cut-off frequency that is determined by resistor and capacitor values in the circuit. The cut-off frequency is determined by equation 1. The cut-off frequency is often referred to as the 3dB cut-off and is when the output has an amplitude of  $1/\sqrt{2}$  or 0.707 times the maximum input.

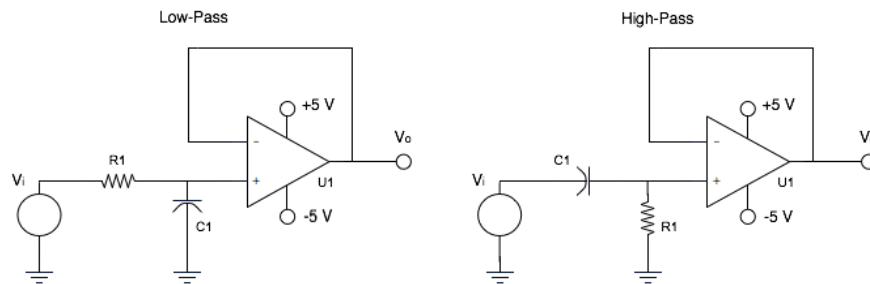
$$F_c = \frac{1}{2\pi RC} \quad (1)$$

Consider the low-pass filter, all frequencies below the cut-off are passed at maximum value and slowly begin to decline as the cut-off frequency is approached. At the cut-off frequency, the output ideally has an amplitude of  $1/\sqrt{2}$  or 0.707 times the maximum input. After the cut-off frequency the output continues to decline with the same slope as before until reaching zero. The opposite can be said for the high-pass filter; low frequencies are blocked until the cut-off frequency is reached. The band-pass filter does exactly what its name implies, frequencies within a specified bandwidth are passed and all others are rejected. The band-reject filter works in an opposite manner from the band-pass filter and is sometimes referred to as a notch filter.

Passive filters, as shown in Figure 1, contain only passive elements such as, resistors, capacitors and inductors and generally provide a maximum gain of 1. Furthermore, when an impedance is added in series or in parallel to the load, the output amplitude is directly affected and the filter must be redesigned. This is referred to as a loading effect, which may change the low and/or high cutoff frequencies. The only passive filter that can amplify its output is the RLC resonant filter. To avoid redesigning the filter for each application, active filters are used. An active filter simply implies that an active device is used in the circuit, such as an op-amp as shown in Figure 2. Active filters allow for a gain greater than 1 and the loading effect is minimal, meaning that the output response is essentially independent of the load driven by the filter.



**Figure 1: Passive filter circuits**



**Figure 2: Active filter circuits**

Band-pass and band-reject filters have two cut-off frequencies, which can be used to calculate the filters' bandwidth. The bandwidth (BWD) is just the high cut-off frequency ( $f_{HC}$ ) minus the low cut-off frequency ( $f_{LC}$ ), as shown in equation 2. The high and low cut-off frequencies are calculated from RC pairs within the circuit. Active band filters also have a predictable point where the output will be at its maximum within the bandwidth. The maximum output occurs at the center frequency ( $f_0$ ). The center frequency calculation is shown in equation 3.

$$BWD = f_{HC} - f_{LC} \quad (2)$$

$$f_o = \sqrt{f_{LC} f_{HC}} \quad (3)$$

As a reminder the pin out diagram of the op-amp is provided in Figure 3. The input terminals of the OpAmp are pin 3 - (+) or non-inverting, and pin 2 - (-) or inverting. A positive voltage up to 15V should be applied to the (+) terminal and negative voltage down to -15V should be applied to the (-) terminal. Pin 6 is the output of the op-amp. The unmarked pins are not used in this experiment. Pins 1 and 5 are for the offset null and pin 8 is not connected.

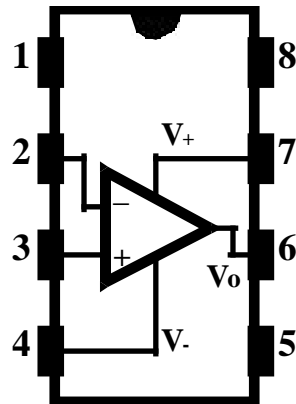


Figure 3: Op-amp pin out diagram

### Equipment:

- OpAmp LM741 Chip
- DC Power Supply
- DMM
- Resistors (470  $\Omega$ , 22 k $\Omega$ , and 33 k $\Omega$ )
- Capacitors (.0047  $\mu$ F and 0.01  $\mu$ F)
- Breadboard
- Oscilloscope
- Function Generator

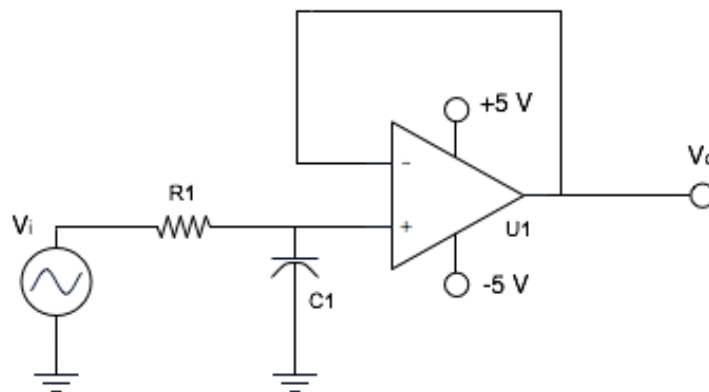


Figure 4: Filter 1

## Experimental Procedure:

(Record specifics in the Laboratory Notebook.)

1. Build the circuit in Figure 4 from the preliminary on a breadboard. Use the same component values of  $R=22k\Omega$  and  $C=0.0047\mu F$ . Use a power supply to power the op-amp with +5 and -5 volts and connect a function generator as the circuit input. **\*\*\*Do not use the same ground connect for  $V_i$  and the op-amp, your readings will be incorrect.** Set the function generator to 2  $V_{pk-pk}$  sine wave starting at a frequency of 1Hz. Use the oscilloscope to observe the output of the circuit and the voltage output of the function generator (use a "T" connector at the function generator output). Record the initial peak-to-peak output of the circuit ( $V_{pk-pk}$ ).

*Q1: What is the initial output value of the circuit?*

Vary the frequency of the function generator and fill in the values for Filter 1 in Table 1.

**Table 1: Experimental frequency response values**

F (Hz)	Filter 1 $V_{pk-pk}$	Filter 2 $V_{pk-pk}$
100		
300		
500		
700		
900		
1k		
1.1k		
1.2k		
1.3k		
1.4k		
1.5k		
2k		
5k		
10k		
15k		
20k		
30k		
40k		
50k		

*Q2: What is the experimental cut-off frequency and how does it compare to the theoretical value?*

*Q3: Calculate the percent difference between the theoretical and experimental cut-off frequencies?*

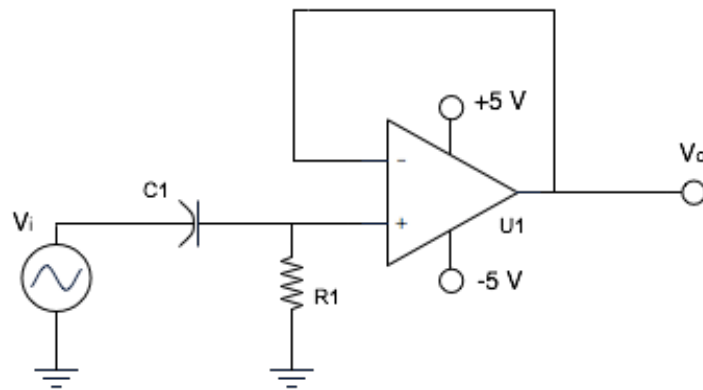


Figure 5: Filter 2

- Build the circuit in Figure 5 from the preliminary on a breadboard. Use the same component values of  $R=22k\Omega$  and  $C=.0047\mu F$ . Use a power supply to power the op-amp with +5 and -5 volts and connect a function generator as the circuit input. **\*\*\*Do not use the same ground connect for  $V_i$  and the op-amp, your readings will be incorrect.** Set the function generator to 2  $V_{pk-pk}$  sine wave starting at a frequency of 1Hz. Use the oscilloscope to observe the output of the circuit and the voltage output of the function generator (use a “T” connector at the function generator output). Record the initial peak-to-peak output of the circuit ( $V_{pk-pk}$ ).

*Q4: What is the initial output value of the circuit?*

Vary the frequency of the function generator and fill in the values for Filter 2 in Table 1.

*Q5: What is the experimental cut-off frequency and how does it compare to the theoretical value?*

*Q6: Calculate the percent difference between the theoretical and experimental cut-off frequencies?*

## Technical Memorandum:

- Memorandum discussion:
  - Discuss your observations for Filter 1. What type of filter is Filter 1? Was the initial output value as you expected? Explain. (Q1) Construct a graph with the values collected in Table 1 for Filter 1 and compare that graph with the simulation results from the preliminary. Was the cut-off frequency similar? (Q2) Was the slope of the curve similar? Explain any discrepancies. (Q3)
  - Discuss your observations for Filter 2. What type of filter is Filter 2? Was the initial output value as you expected? Explain. (Q4) Construct a graph with the values collected in Table 1 for Filter 1 and compare that graph with the simulation results from the preliminary. Was the cut-off frequency similar? (Q5) Was the slope of the curve similar? Explain any discrepancies. (Q6)
- Appendix 1: Plot the output voltage curve vs. frequency for Filter 1. Specify the cut-off frequency on the plot (Q2).
- Appendix 2: Plot the output voltage curve vs. frequency for Filter 2. Specify the cut-off frequency on the plot (Q5).