

Lab 4 Band Pass and Band Reject Filters

Introduction

During this lab you will design and build three filters. First you will build a broad-band band-pass filter by cascading the high-pass and low-pass filters you designed in Lab 3. Then you will design and test a high-Q band-pass filter and a band-reject, also called notch, filter.

As a result of performing this lab, the student will

- demonstrate the function of band-pass and band-reject filters, and
- calculate a filter's Q and roll-off rate, verifying the calculations with experimental data.

Prelab¹

During the prelab you will simulate the filter designs in MatLab, then test them with MicroSim.

NOTE: 10% of this lab's grade will be based on constructing the band-pass filter comprised of cascaded high-pass and low-pass active filters *before* you come to the lab session.

Prelab 4.1 MatLab Simulation

Prelab 4.1.1 Introduction to filtering using the system transfer function in Matlab.

In order to design band-pass and band-reject filters using MatLab, you must determine their respective transfer functions. From the transfer functions you will design the filters. The MatLab model will enable you to determine each filter's frequency and phase response. For this experiment you will design second order a Sallen-Key filter. The transfer function of the band-pass filter is

$$H(s) = \frac{V_o(s)}{V_i(s)} = \frac{s \cdot \left(\frac{W_c K}{Q}\right)}{s^2 + s \cdot (W_c / Q) + W_c^2}.$$

MatLab allows us to define a number of frequencies and corresponding magnitudes in order to design a digital filter that approximates the ideal analog filter.

The following MatLab code segment illustrates the solution:

```
f_c = 1000;           % define the center frequency of the filter
w_c = 2*pi*f_c;
```

¹ MatLab files are available at www.utdallas.edu/~gibbs/commlab/lab4.zip

```

Q = 1; % define the Quality of the filter
K = 4-sqrt(2)/Q; % K defines the gain of the filter.
BW = 2*pi*fc/Q; % center frequency and Q determine the 3-dB
bandwidth
num = [wc*K/sqrt(2) 0]; % define the numerator
den = [1 BW wc2]; % define the denominator in order of descending
powers of s

```

The elements of the vectors which define the numerator and denominator are the filter coefficients of the transfer function. The first element of the denominator is the coefficient of the s^2 term. The second element of the denominator is the coefficient of the s term.

To determine the frequency response for the filter system, generate an array of linearly spaced significant frequencies (in radians per/sec). This is the same function as *AC sweep* in MicroSim.

```
om = linspace(0, 2*pi*10000);
```

Data values greater than 100 can be generated by adding a the third term to the input argument of the *linspace* function. See MatLab Help for further information.

Next, compute the frequency response of the analog filter.

```

s = sqrt(-1)*om;
hs = polyval(num,s)./polyval(den,s);

```

For information concerning the use of *polyval*, see MatLab Help.

In order to compare results, a normalized plot is helpful. To see the normalized version of frequency response and phase response in MatLab, use the *freqz* and *freqs* functions.

Prelab 4.1.2 Design a band-pass filter

1. Design a band-pass filter using the system transfer function for the desired band-pass filter. Plot the frequency and phase response of the band-pass filter. The band-pass filter is defined by :

$$\begin{aligned}
f_c &= 1\text{kHz}, \\
\text{Quality factor, } Q, &\text{ is } 1 \\
\text{BW} &= w_c / Q
\end{aligned}$$

Modify the circuit by changing the value of Q . Use three different values in the range of 5 to 100. *In your report, discuss the impact of Q on the output waveform.* In order to more easily compare the plots, ensure that the graph axes are the same for all four plots (original, $Q = 1$, and three selected values).

2. Repeat step 1 with

$$\begin{aligned}
&\text{center frequency, } f_c = 22 \text{ kHz , and} \\
&\text{Initial Quality Factor, } Q = 5.
\end{aligned}$$

Prelab 4.1.3 Design a band-reject filter

- 1) Design a band-reject filter using the system transfer function for the desired band-reject filter. Plot the frequency and phase response of the band-reject filter. The band-reject filter is defined by:

$$f_c = 1\text{kHz, and}$$
$$\text{Quality Factor, } Q = 1.$$

Modify the circuit by changing the value of Q . As in 4.1.2 (1), use three different values. *In your report, discuss the impact of Q on the output waveform.* Again, ensure that the graph axes are the same for all four plots (original, $Q = 1$, and three selected values).

- 2) Repeat Prelab 4.2 step 1 with a center frequency of 120 Hz and Q equal to 50.

Prelab 4.2 Filter Design using MicroSim

Prelab 4.2.1 Band-Pass Filter Design and Simulation

The circuit diagram for a band-pass filter is given in Figure 1. A band-pass filter is characterized by its center frequency, ω_0 , and its Q .

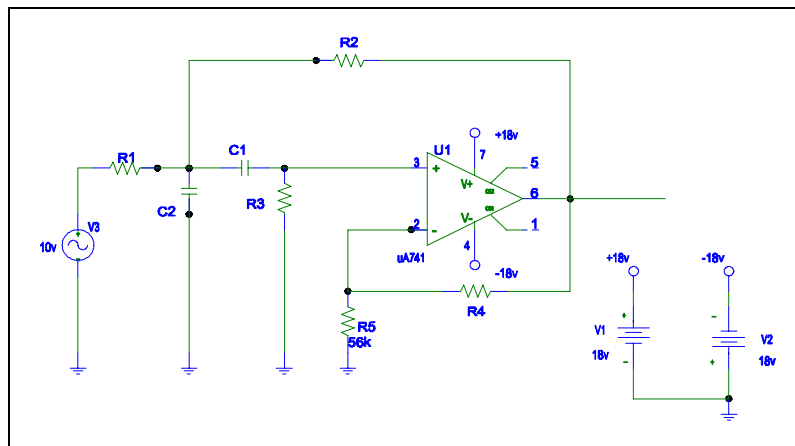


Figure 1. Band-Pass Filter

One typical band-pass filter design uses equal-valued capacitors and equal-valued resistors. This enables the design of the band-pass filter to be simplified:

$$R_1 = R_2 = R_3 = R, C_1 = C_2 = C.$$

The quality factor, Q , of this design is given by

$$Q = \frac{\sqrt{2}}{4-K}$$

1. Design a band-pass filter using the circuit in Figure 1 that meets the following requirements;

$$f_c = 22\text{kHz}$$

$$Q = 5$$

$$C_1 = C_2 = C = 0.022\mu\text{F}$$

2. Determine R_4 for a chosen K ($Q = 5$)
3. Calculate the values for the frequency dependent resistors, R_1 , R_2 , and R_3 .
4. Using MicroSim Schematic, build your circuit.
5. Plot the frequency and phase responses for the filter. The phase response can be determined by plotting $P(V(U1:OUT))$. The vertical axis displays degrees, and the horizontal axis displays frequency.
6. From the simulation, verify that Q is correct.

Prelab 4.2.2. Band Reject (Notch) Filter Design

Figure 2 shows a notch filter which is also known as a Twin-Tee band stop filter. In this circuit,

$$R = R_1 = R_2 = 2 * R_3, C = C_1 = C_2 = C_3 / 2.$$

1. Determine the transfer function of this circuit.
2. Design a band-reject filter to reject a signal at 120 Hz, using standard value capacitors and resistors. A good starting point would be with $C = 0.01$ microfarads.
3. Verify the design using MicroSim Schematic to determine the frequency and phase response for the circuit.

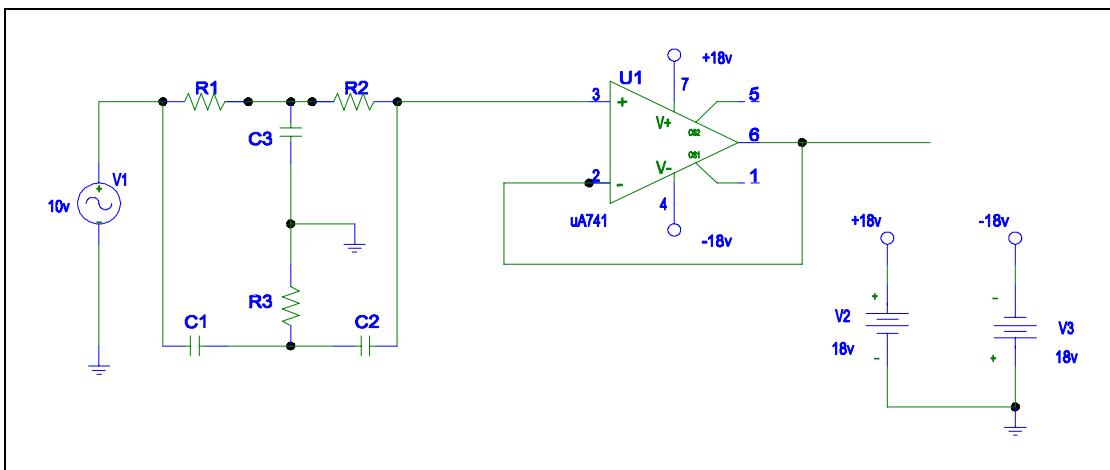


Figure 2. Twin-Tee Notch Filter

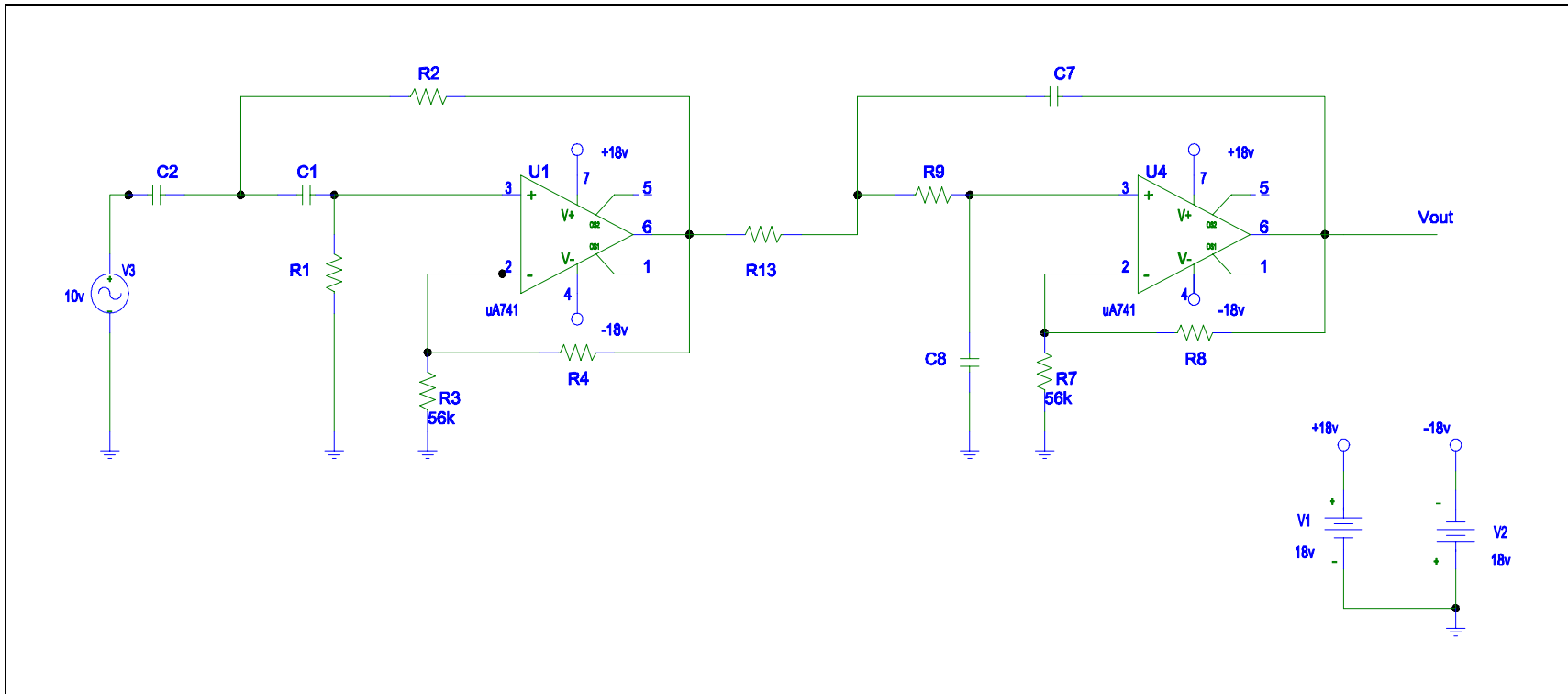


Figure 3. Band Pass Filter from Cascaded Low Pass and High Pass Filters

Prelab 4.3 Band-Pass Filter Using Cascaded Low-Pass and High-Pass filters

A band-pass filter can be created by cascading a low-pass filter and a high pass filter as shown in Figure 3.

1. Modify the circuits you designed in Lab 3 so that the high pass filter has a cut-off frequency of 1 kHz and the low pass filter has a cut-off frequency of 10 kHz. Design each filter for a gain of 4 dB.
2. Verify your design using MicroSim Schematic.
3. Build the circuit shown in Figure 3 before coming to your lab session this week.

NOTE: 10% of this lab's grade will be based on constructing this band-pass filter *before* you come to the lab session.

Lab 4 Frequency Response Of Active Filters

Parts Required for Lab 4

Resistors:

Determined by circuit

Capacitors:

Determined by circuit

Integrated circuits:

2 – Op-amp uA741

Once you have built the active filters meeting the given specifications, you can prove their performance by obtaining the frequency response. For each filter, connect the function generator and *channel 2 of the oscilloscope to the input of the circuit and channel 1 to the output*. Make sure that both channels are configured for 10X probes.

Lab 4.1. Test the Band-Pass Filter Designed from the Cascaded HPF-LPF.

1. Connect the power supply, function generator, and oscilloscope to the cascaded HPF-LPF you built in the Prelab.
2. Open RESPONSE.VI and enter the following parameters: *Lowfreq* = 100 Hz, *Upperfreq* = 100 kHz, *points/dec* = 10, *Amplitude* = 3 V_{pp}. Make sure to enter the correct GPIB address for the function generator you are using.
3. Depending on the source voltage (e.g., ± 15 V) and the gain of the filter, you may observe some clipping in the output waveform as the sweep is made. If this occurs, reduce the *Amplitude* voltage in the VI to an appropriate level.
4. Obtain the frequency response of the band pass filter.
5. Determine the frequency at which the maximum amplitude of the frequency response occurs and compare it with the theoretical value. Find the two -3 dB frequencies, i.e.,

the points whose amplitude are 3 dB below the maximum amplitude. Determine the bandwidth and Q factor of the filter.

6. Apply a sum of two sinusoids of equal amplitude with frequencies f_1 and f_2 at the filter input (as in Lab 3). Set the function generator output amplitudes as high as possible without causing the filter to introduce clipping or other distortion. Using $f_1 = 100$ Hz and $f_2 = 3$ kHz, obtain the input and output spectra by using the WAVEFFT.VI.
7. Perform step 6 again with $f_1 = 8$ kHz and $f_2 = 15$ kHz.
8. Using WAVEFFT.VI, obtain the frequency spectrum of the *input* signal. Enter $ts = 8E-3$ as the *time span* in the control panel of the VI. Measure the amplitude of the main peaks of the spectrum.

Amplitude at f_1 (pi_1) = _____

Amplitude at f_2 (pi_2) = _____

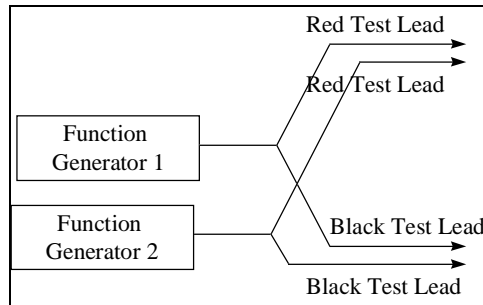


Figure 4. Function Generator Connection for LPF and HPF Filters

9. Apply the signal to the circuit by connecting the leads as shown in Figure 4. Move the channel 1 probe to the output of the filter. Run WAVEFFT.VI using the same time span, saving the data with a different filename. Measure the amplitude of the main peaks in the displayed spectrum.

Amplitude at f_1 (po_1) = _____

Amplitude at f_2 (po_2) = _____

10. What is the relationship between pi_1 and po_1 ? Verify your conclusion with pi_2 and po_2 .

Lab 4.2. Build and Test an Active Band-Pass Filter.

1. Build the circuit shown in Figure 1, with a center frequency, f_c , of 22 kHz.
2. Open RESPONSE.VI and enter the following parameters: *Lowfreq* = 100 Hz, *Upperfreq* = 100 kHz, *points/dec* = 10, *Amplitude* = 3 Vpp. Make sure to enter the correct GPIB address for the function generator you are using. Obtain the frequency response.

Depending on the source voltage (e.g., ± 15 V) and the gain of the filter, you may observe some clipping in the output waveform as the sweep is made. If this occurs, reduce the *Amplitude* voltage in the VI to an appropriate level.

- 3 Determine the frequency at which the maximum amplitude of the frequency response occurs and compare it with the theoretical value. Find the two -3 dB frequencies, i.e., the points whose amplitude are 3 dB below the maximum amplitude. Determine the bandwidth and the Q factor of the filter.
- 4 Apply a sum of two sinusoids of the same amplitude with frequencies f_1 and f_2 at the filter input. Set the function generator output amplitudes as high as possible without causing the filter to introduce clipping or other distortion. Using $f_1 = 22$ kHz and $f_2 = 50$ kHz, obtain the input and output spectra by using the WAVEFFT.VI.

Lab 4.3. Build and Test a Notch filter.

1. Determine the frequency response of the notch filter by sweeping the signal from 10 Hz to 1000 Hz. If clipping or distortion occurs, adjust the input signal amplitude to correct for the problem.
2. Determine the frequency of the lowest amplitude and compare it with the theoretical value. Find the two points whose amplitude is 3 dB above the minimum amplitude of the frequency response. From this data determine the bandwidth and the Q factor of the filter.
- 1 Apply a sum of two sinusoids of the same amplitude with frequencies f_1 and f_2 at the filter input. Set the function generator output amplitudes as high as possible without causing the filter to introduce clipping or other distortion. Using $f_1 = 120$ Hz and $f_2 = 500$ Hz, obtain the input and output spectra by using the WAVEFFT.VI.

Lab Report

During this Lab you modeled and built several different band-pass and band-reject filters. In your report,

1. Compare the frequency and phase responses of the theoretical versus actual cascaded band-pass filters.
2. Compare the frequency and phase responses of the theoretical filters (MatLab and MicroSim) versus the actual High-Q band-pass filters.
3. Compare the frequency and phase responses of the theoretical (MatLab and MicroSim) and actual notch filters.
4. Explain any discrepancies you noted between the models and the actual circuits.
5. Include in your report a design, including component values, for a filter which could be used in a telephone system. The purpose of the filter is to remove all high and low frequency components, and to allow only the range of frequencies between 300 Hz and 3500 Hz to pass.
6. Note any deviations you made from the assigned procedure.