Lab 3: Low Pass and High Pass Filters

Purpose

The purpose of this lab is to introduce you to Low Pass and High Pass Filters. As part of performing this lab you will

- Determine the amplitude and frequency response characteristics of Low and High Pass filters,
- Compare passive and active LPF and HPF filter configurations, and
- Compare theoretical models with actual filters.

Introduction

In this experiment you will design, build ¹, and test four filters. The configurations you will build are

- Passive Low-Pass Filter,
- Active Low-Pass Filter,
- Passive High-Pass Filter, and
- Active High-Pass Filter.

For each of the configurations you will

1. Design the filter for a specified cut-off frequency,
2. Model the filter in MatLab,
3. Simulate the design with PSpice ², and
4. Test the design in the Lab.

Steps 1, 2, and 3 are Prelab activities. Step 4 will be performed during the lab period.

In your report you will compare the theoretical and actual amplitude and phase plots for each of the four configurations.

If you are rusty on transfer functions or op amp usage you may want to review those subjects.

¹ UTD will supply integrated circuits, the student is expected to purchase resistors and capacitors. See Introduction to Communications System Labs, page 4.
² PSpice is available on the Communications Lab PCs. A free demo version may be obtained from MicroSim by calling (800) 245-3022. A limited number of copies are available for check out from Steve Gibbs, EC 4.216.
Prelab 3. LPF and HPF

Prelab 3.1 Introduction to Filtering.

1. Draw graphs showing the frequency responses of an ideal low-pass filter (LPF) and an ideal high-pass (HPF) filter.

2. Generate a signal in MatLab composed of two sine waves using the following parameters:
   a) \( f_1 = 2000 \text{ Hz} \)
   b) \( f_2 = 40000 \text{ Hz} \)
   c) \( 0 \leq t \leq 2 \text{ milliseconds} \)
   d) \( T_s = 5 \text{ microseconds} \)
   e) \( y(t) = \sin (2 \pi f_1 t) + 0.25 \cos (2 \pi f_2 t) \)

3. Plot the time domain and the frequency domain representations of the signal.

4. "Filter" the wave form by "zeroing out" the high frequency components of the FFT wave form:

   There are two ways in MatLab to "filter" a wave form. One technique is to "zero out" the higher frequency elements of the FFT. The other is to use the transfer function of a low pass filter. In the steps below you will zero out the high frequency elements of the FFT.

   a) \% create a new vector containing only the low
   b) \% frequency components of Y
   c) \( L = \text{length}(Y); \)
   d) \( \text{New}Y = \text{zeros}(L,1); \)
   e) \% define the number of data points to copy from the original file
   f) \( \text{New}Y(1:b)=Y(1:b); \)

   As an option, instead of replacing the values of higher frequency region with zeros, it is also feasible to replace the original values with very small values, such as 0.001, which represent out of band noise.

   Although at this point you are not actually filtering the signal, you are performing the same kind of function that a Low Pass Filter performs. The performance of this filtering method depends on the number of vector elements you replace with zeros in the high frequency components of the FFT.

5. After filtering in the frequency domain, reconstruct the signal using "ifft".

   In your report, compare the reconstructed signal with the original signal in the time domain.

6. Repeat this procedure for the lower frequency region of the FFT and observe the output.

   This method introduces the concept of filtering. This filtering is considered ideal filtering in terms of the performance of the filtering. However this filtering requires additional procedure for reconstruction of the signal. In the ‘real world’ the goal is to design filters that perform as well as this simulation.
7. Use Convolution to demonstrate filtering. (This will use the convolution technique you used in Lab 2.)
   a) Determine the impulse response of the filter.
   b) Convolve the impulse response of the filter with the signal that you are going to filter.

   Pre3_13.m simulates LPF filtering using this filtering method in MatLab. In your Lab Report, comment on the performance of the filter.

**Prelab 3.2 MicroSim Simulation**

1. Build the following passive low-pass filter in MicroSim and determine its transfer function and cut-off frequency:

   ![RC Low Pass Filter](image)

2. Build the following passive high-pass filter in MicroSim and determine its transfer function and cut-off frequency:

   ![RC High Pass Filter](image)

   **Figure 2. RC High Pass Filter**
3. Build the following active low-pass filter in MicroSim and determine its transfer function and cut-off frequency:

![Figure 3. Sallen-Key Equal Component Active Low Pass Filter]

4. Build the following active high-pass filter in MicroSim and determine its transfer function and cut-off frequency:

![Figure 4. Sallen-Key Equal Component Active High Pass Filter]
Lab Period – Low Pass and High Pass Filters

Parts required for this lab:

Resistors:
   Determined by circuit
Capacitors:
   Determined by circuit
Integrated circuits:
   2 – Op-amp uA741

Lab 3.1 Frequency response of a RC low pass filter

In this section you will determine the frequency response of an RC Low Pass Filter. Also, you will verify the filtering process by applying the sum of two sinusoids at the input and measuring the attenuation caused by the filter on the amplitudes of the two signals.

Hint: If you decide to print the graphs from LabVIEW during the lab period, you may want to zoom the display to improve the resolution of the plots before you print them.

1. Build the circuit shown in Figure 1. Manually determine its cut-off frequency. Recall that voltage at the cut-off frequency is 0.707 (-3 dB) times the input voltage to the filter. Connect channel 2 of the oscilloscope to the input and channel 1 to the output.

2. Use RESPONSE.VI to obtain the frequency response of this filter. Enter the parameters for the sweep. Use Lowfreq = 100 Hz, Upperfreq = 100000 Hz, Amplitude = 10 V, points/decade = 10. Note the GPIB address of the signal generator that you are using. Select an appropriate filename to save the data in the "Data file" box. Remember to use a different filename each time that you run the VI.

3. Notice that the frequency axis in the graph has a logarithmic scale. Report the cut-off frequency by finding the -3 dB point (i.e. the point which is 3 dB below the maximum amplitude). Also, find the amplitudes at $f_1 = 10$ kHz and $f_2 = 100$ kHz.

   Cut-off frequency ($f_c$) =
   Amplitude at $f_1$ ($m_1$) =
   Amplitude at $f_2$ ($m_2$) =

4. From the last two coordinates, estimate the slope of the magnitude response. Determine the phase shift at the cut-off frequency. Derive a function to determine the phase shift of this circuit and calculate the phase shift at the theoretical cut-off frequency. Compare it with the measured value.

   Slope (dB/decade) =
   Phase shift at cut-off frequency =
   Theoretical =
   Measured =
**Hint:** To make the measurements easier, zoom in on the graph by changing the lower and upper values shown for each axis. Select by clicking on the parameter to be changed and enter the new value.

1. Disconnect the signal generator from the circuit. Connect the ground clips of the two signal generators to the circuit ground, and the red test leads to the circuit’s input. Set both signal generators to produce 10 Vpp sine waves. Set one of the function generators to produce a 10 kHz sine wave, and the other function generator to 100 kHz. Connect channel 1 of the oscilloscope to the same point as the red clips. Connect oscilloscope channel 2 to ground.

![Diagram of Function Generator Connection for LPF and HPF Filters](image)

2. Using WAVEFFT.VI, obtain the frequency spectrum of the input signal. Enter $t_s = 8E-3$ as the **time span** in the control panel of the VI. Measure the amplitude of the main peaks of the spectrum.

   Amplitude at $f_1 (p_i) =$ __________

   Amplitude at $f_2 (p_i)$ = __________

3. Apply the signal to the circuit by connecting the leads as shown in Figure 5. Move the channel 1 probe to the output of the RC Low Pass Filter. Run WAVEFFT.VI using the same time span, remember to save the data with a different filename. Measure the amplitude of the main peaks in the displayed spectrum.

   Amplitude at $f_1 (p_o) =$ __________

   Amplitude at $f_2 (p_o)$ = __________

4. What is the relationship between $m_1$, $p_i$ and $p_o$? Verify your conclusion with $m_2$, $p_i$ and $p_o$.

**Lab 3.2 Frequency response of an RC High Pass Filter**

1. Construct an RC High Pass Filter as shown in Figure 2.

2. Repeat the procedure described in LAB 3.1 to analyze the frequency response of the RC High Pass Filter. Use $f_1$=100 Hz, $f_2$ =1000 Hz, and $t_s = 0.5$ (i.e. 500E-3).
**Lab 3.3 Frequency response of an active low-pass active**

1. Construct the active Low Pass Filter shown in Figure 3 using the following parameters:

   **Equipment Settings:**
   - \( V_{CC} \) 18 V (power supply voltages)
   - \( V_{SS} \) -18 V
   - \( f_1 \) 3,000 Hz
   - \( f_2 \) 30,000 Hz
   - Amplitude 5 V \( V_{pp} \)

   **LabVIEW Settings:**
   - Lowfreq 100 Hz
   - Upperfreq 30 kHz
   - points/decade 10
   - \( ts \) 20E-3

2. Analyze the response of the filter by following the steps of Lab 3.1.

**Lab 3.4 Frequency response of a high-pass active filter.**

1. Construct the active High Pass Filter shown in Figure 4 using the following parameters:

   **Equipment Settings:**
   - \( V_{CC} \) 18 V
   - \( V_{SS} \) -18 V
   - \( f_1 \) 50 Hz
   - \( f_2 \) 500 Hz
   - Amplitude 5 V \( V_{pp} \)

   **LabVIEW Settings:**
   - Lowfreq 50 Hz
   - Upperfreq 50 kHz
   - points/decade 10
   - \( ts \) 20E-3

2. Analyze the response of the filter by following the steps of Lab 3.1.

**Do not disassemble the active filters, they will be used in the Lab 4.**

**Lab Report**

During this Lab you modeled and built several different low pass and high pass filters. In your report,

- Compare the frequency and phase responses of all the Low Pass Filters.
- Compare the frequency and phase responses of all the High Pass Filters.
- Explain any discrepancies you noted between the models and the actual circuits.
- Note any deviations you made from the assigned procedure.
- The filters designed in this lab were limited to first or second order filters. Design a 4\(^{th}\) order LPF with a cutoff frequency of 3500 Hz. With your design, specify the transfer function and the formula to determine the cutoff frequency.