

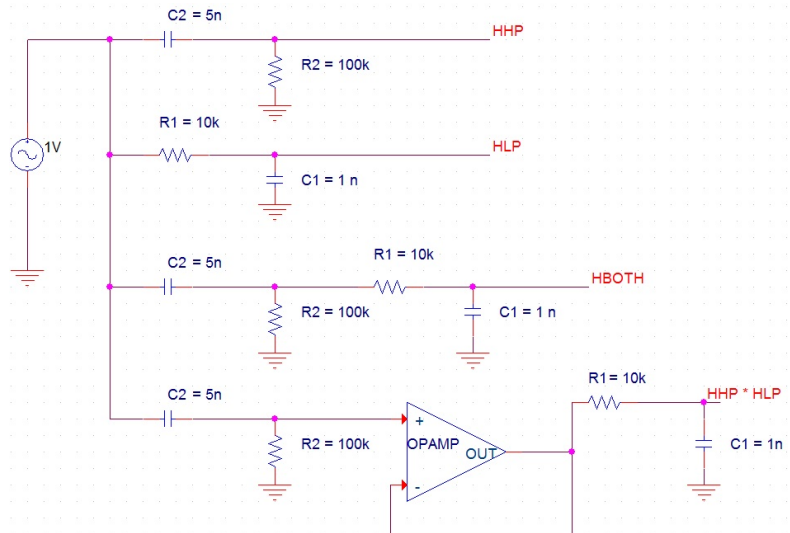
ECE35 Lab 5 RC Bandpass Filter

The objective of this lab is to simulate a few filters with MatLab, then construct and test those filters. The band-pass filter will be used to demonstrate how a circuit can hone in on a specific frequency and reject everything else. It will be composed of a high-pass and a low-pass cascaded together. A high-pass will block low frequencies and pass the higher frequency signals. The low-pass will block high frequencies and pass the lower frequency signals. The band-pass, in general, has the high-pass come first so large ambient noise does not get far into the system. We will design signal transmissions with -3dB frequencies of 300 Hz and 20 kHz, both of which we need within 10%.

We will design and test independent RC high-pass (HP) and low-pass (LP) filters, but we cannot connect them together directly without distorting their transfer functions. We will test the effect of a direct connection and measure the resulting transfer function. However we can connect them together if we provide an active buffer between the two filters. The buffer prevents any interaction between the circuits so their transfer functions simply multiply ideally.

Before the lab: Complete the analysis and design in section 1 below. Complete the simulation in section 2 below. Convince yourself that in the schematic below, there are 4 different circuits. Be prepared to show it to the TA on request.

1. Design and Analysis: The simple HP and LP filters shown to the right have been analyzed in class. The transfer functions are $H_{\text{HP}}(\omega) = j\omega RC / (1 + j\omega RC)$ and $H_{\text{LP}}(\omega) = 1 / (1 + j\omega RC)$. In either case the -3dB frequencies are $f_{-3\text{DB}} = 1 / (2\pi RC)$. These are 300 Hz for the HP and 20 kHz for the LP. To choose components you need to make some arbitrary choices. A good way is to consider the value of the resistors. For typical analog circuits, resistors shouldn't be too small because they will draw too much current, or too large because they will cause too much noise. A value of 10 k Ω is often a good compromise. Here we need a larger RC product for the HP so we'll use a 100 k Ω resistor there, and 10 k Ω for the LP.



(a) Calculate the capacitors needed using the $f_{-3\text{DB}}$ values for the respective filters. Plot the transfer functions for both circuits using the Matlab code on the web site and confirm that your choices are correct.

(b) Calculate the transfer function for the cascade of the band pass (hboth). The line of code you need to modify is commented out as:

```
%hboth = j*w*r2*c2./((1 + j*w*r2*c2).*(1 + j*w*r1*c1) + ???);
```

Modify the Matlab code by replacing `????` with the correct term and delete `%`. The entire code is now ready to plot. You will see in the plot that it falls significantly below the ideal product of “hp*hl”. Save your Mat-lab code on a USB drive and bring it to the lab because you will want to rerun it with the actual R and C values that you use in the lab.

2. Testing: Setup the HP and LP filters on the breadboard separately. There are lots of 10 k Ω resistors and 100 k Ω resistors, but you will have some trouble finding the right capacitors. Get the capacitors within 20% of the desired values by putting two capacitors in parallel if necessary. It shouldn't be necessary to use more than two in parallel. Measure the combined capacitance to confirm that you have not made a mistake. Calculate the actual -3dB frequencies from the actual component values. Rerun your Matlab calculations with the actual values and make a hard copy of the transfer functions of “hp*hl” and “hboth”. You can plot your measurements on this hard copy. Print out a hard copy showing two traces: the product of the “hp*hl” and “hboth”.

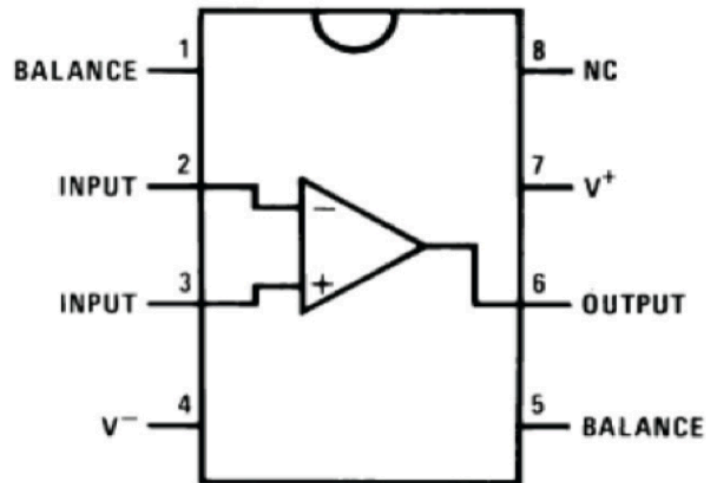
First check that the HP and LP are working separately. Measure the output voltage with the O-scope as you change the frequency of the signal generator through the -3dB frequency. Then connect the two directly together and measure the transfer function of HBOTH, carefully. Use the frequencies corresponding to the grid on the Matlab hard copy and plot on your actual transfer function. Mark the measurements clearly with a symbol like O, X or +. The measurements should be very close to the simulation.

Now insert a buffer between the HP and LP filters. Make the buffer using a LF411 Op-amp. The supply terminals, pin 4 and pin 7 must be connected to $\pm 15\text{ V}$. The *balance* terminals and pin 8 can be left “floating”, i.e. not connected. Then measure the transfer function of the buffered combination (HHP*HLP) carefully, as you did the band pass, and plot on your Matlab hard copy using a different symbol. Again you should have good agreement between measurements and theory. Ask a TA to review your measurements and sign your hard copy.

Discuss in your lab report:

- 1) What are the functions of a low-pass, high-pass, band-pass, and buffer-pass?
- 2) Explain how the Matlab simulation was used in this lab, and how it relevant to your actual experiment.
- 3) Why can you not simply multiply the expression of the low-pass with the high-pass, to obtain the band-pass equation?
- 4) Why is the expression for the buffer-pass, a simple multiplication of the low-pass and high-pass filter?
- 5) Why is the max transfer function of the buffer-pass filter larger than the band-pass filter? Explain the difference and similarities of a band-pass filter and buffer-pass filter

Dual-In-Line Package



LF 411 Op-amp

3. Application (Optional for Lab): The purpose of the bandpass filter is improving the performance of your optical data link. If you have time, connect the output of your photo detector circuit to the input of the bandpass filter. Drive the LED with a sine wave between 300 Hz and 20 kHz and observe both the output of the photo detector directly, and the output of the bandpass filter. The filter output should be noticeably cleaner. Set the generator to the middle of the band, say 3 kHz, and put both the input of the filter and its output on the two scope traces. You should see that the output is less sensitive to ambient light, and also that the high frequency “fuzz” on the scope trace is greatly reduced. To get a good measure of the Op-amp noise you will have to reduce the signal level to about 1 v peak to peak and increase the scope sensitivity. You may also have to put the channel connected to the input on “AC coupling” so it doesn’t go off scale. Make a hard copy. Ask a TA to witness your results and sign the hard copy.