ELE344, Electronics II Laboratory

LAB 9

Operational Amplifiers I: RC Active Filters

Objective:

Filters are ubiquitous building blocks in communication systems. Filters are predominantly applied for (signal) band limitation to maximize channel capacity and band selection.

Interconnecting operational amplifiers with resistors and capacitors (→ RC active circuits) can yield effective solutions for audio range filters. This lab introduces a simple 2nd order circuit, the *Sedra-Espinoza* band-pass filter. This robust filter architecture allows for orthogonal tuning of center frequency and selectivity (Q-factor).

Second-order Bandpass Filters:

A second-order bandpass filter has the following (Laplace domain) transfer function:

$$T_{BP2}(s) = G_0 \frac{2\sigma_p s}{\omega_p^{\;2} + 2\sigma_p s + s^2}$$

where G_0 and ω_p describe the filter mid-band gain and pole frequency (in radians), respectively. The linear coefficient $2\sigma_p$ in the above expressions is nothing else but the 3 dB bandwidth of the filter. Another quantity frequently used to describe the filter selectivity is the quality factor Q_p defined as the ratio of center frequency to bandwidth, i.e., $Q_p = \omega_p / 2\sigma_p$.

Tasks:

1. Consider the bandpass circuit in figure 2 and derive an expression of its transfer function under the assumption that the 2 opamps are **ideal**. Specifically, find expressions for $\boldsymbol{\omega_p}$, $\boldsymbol{2\sigma_p}$ and $\boldsymbol{Q_p}$. Hint: If the opamps are ideal, it can readily be shown (can you?) that $V_1 = V_3 = V_4 = V_{out}/k$. This leaves only 2 unknown voltages, V_2 and V_{out}. **Pre-lab assignment**.
2. Assume that $\mathbf{C_1 = C_2 = 100nF}$. Find values for $\mathbf{R_1}$, $\mathbf{R_2}$, $\mathbf{R_3}$ and **k** such that the filter has a center frequency f_p of **1.4 kHz**, a gain $\mathbf{G_0}$ of **4.9** and a quality factor $\mathbf{Q_p}$ of **9**. **Pre-lab assignment**.
3. Figure 1 depicts a macro-model for a typical opamp. The corresponding netlist is available on the ele344 web site. Use PSpice to verify the proper functionality of this model, i.e., determine the opamp **gain**, **bandwidth** and **saturation voltage** through simulations.
4. Simulate your filter circuit with PSpice and verify its performance, i.e., mid-band gain, center frequency and selectivity. To do so, it is strongly suggested you use a **netlist** and include the opamp macro-model as a sub-circuit. The latter is available on the ele344 web page.

5. Realize your bandpass filter on the Protoboard and measure its performance parameters with the help of the sine generator and the scope. Use a single **LF353** chip for the 2 opamps and supply it with +/-10V. To record the frequency response, fix the swing of the sinusoidal source to **1 V**, vary the input frequency **logarithmically** from **140 Hz** to **14 kHz** in **20 steps** and record the resulting output swing.
6. Find the exact center frequency of your filter by considering the **phase difference** between input and output on the scope. Note that the phase difference approaches zero at the center frequency. Now apply a square wave of exactly 1/3 of your center frequency with a step size of 2 V, i.e. -1V to +1 V. Compare input and output. Can you explain the observation?
7. Repeat task 6 for an input frequency of 1/5 the filter center frequency and explain the picture on your scope (input versus output).
8. Repeat task 6 for a triangular input signal of 1 V swing positioned at exactly 1/3 the filter center frequency. Did you expect this result?

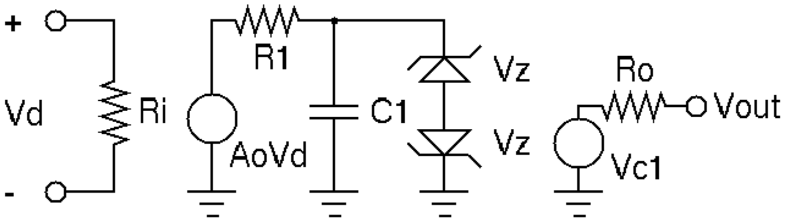

Figure 1: Opamp macro-model mimicking finite gain, bandwidth, input and output resistance and voltage saturation.

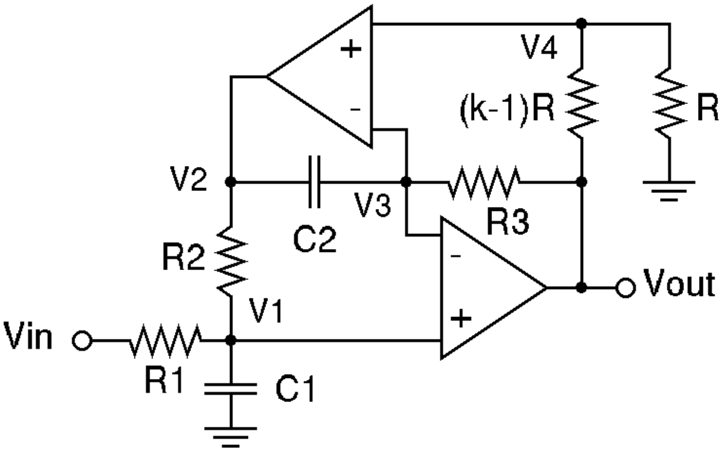

Figure 2: High-Q Second-order bandpass filter (Sedra-Espinoza topology).