UNIVERSITY OF UTAH
ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

ECE 3110 LABORATORY EXPERIMENT NO. 3

# FEEDBACK AMPLIFIER

## Objective

This experiment will (1) demonstrate the effect of negative feedback on amplifier performance, and (2) demonstrate several methods of frequency compensation.

This experiment has two parts. Part 1 is the construction and characterization of an amplifier whose poles are accurately set by discrete resistors and capacitors. In Part 2, we will close the feedback loop and measure the effect on the amplifier.

In a "practical" amplifier, the high-frequency poles and zeros are primarily due to internal capacitances of the transistors. These poles occur at frequencies too high for the type of breadboard construction used in this laboratory. The long wires result in stray capacitances comparable to the transistor internal capacitances. This makes the amplifier high-frequency characteristics more dependent on the breadboard layout than on the transistor parameters.

To avoid this problem, the "high-frequency" poles of the amplifier we build are deliberately and accurately set to relatively low frequencies by external resistors and capacitors. In Fig. 1 below, these are $R_3$, $R_4$, $R_5$, $R_6$, $C_1$, $C_2$ and $C_3$.

## Experiment

### Part 1:

a. Build the amplifier shown in Fig. 1. Use resistors and capacitors within ±10% of the values shown in Fig. 1. However, you are to accurately measure and record your component values for later use in calculations. You may use any general purpose op amp, like a 741. Power supplies should be ±10V.

b. Measure both the gain and phase vs. frequency of your amplifier over a frequency range from 100 Hz to 20 kHz. Record data every 100 Hz from 100 Hz to 1 kHz and every 1 kHz from 1 kHz to 20 kHz.

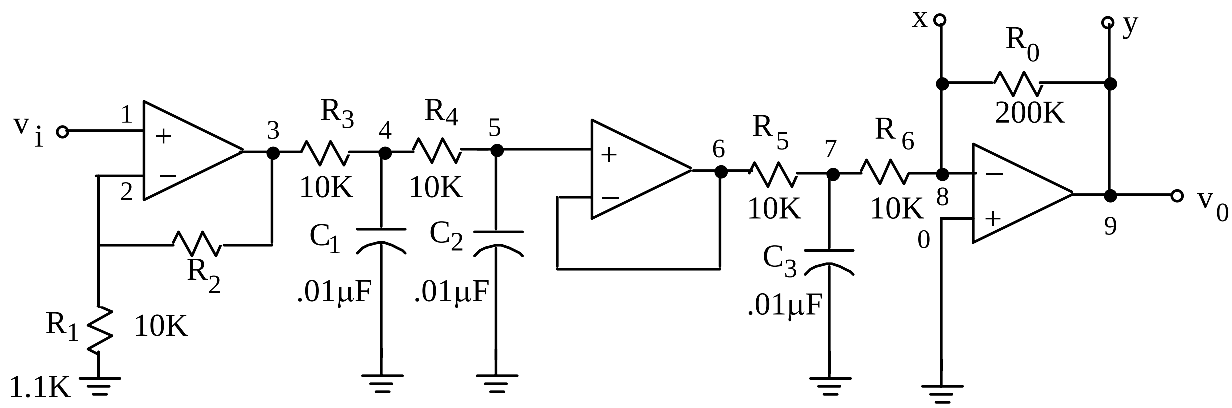


Fig. 1.

The midband voltage gain of this amplifier is about 100 and the ±10 volt power supplies limit the output voltage to a range less than ±10 volts so the input voltage must be less than ±100 mV to prevent distortion. Use sufficient precision that your gain measurements will be accurate to two significant figures.

c. Apply a 50 Hz square wave of amplitude about 50 mV peak-to-peak. Measure and plot the output in sufficient detail that you can determine the rise and fall times.

**Part 2:**

**The circuit you just built in Part 1 is meant to act as an op-amp, where $v_i$ (in Fig. 1) is the negative input, and the positive input is implicitly grounded.** This circuit has a high input resistance, low output resistance, and reasonably high gain. The capacitors $C_1$-$C_3$ limit the high-frequency response of this amplifier, playing the role that internal transistor parasitic capacitances play in actual IC (integrated circuit) op-amps.

In this part of the experiment we will close a feedback loop around the amplifier in several different ways and characterize its performance for each different feedback example. You will find that stability is not always assured, and the frequency-dependent properties of the op-amp (our Fig. 1 circuit) have a large effect on this stability or instability.

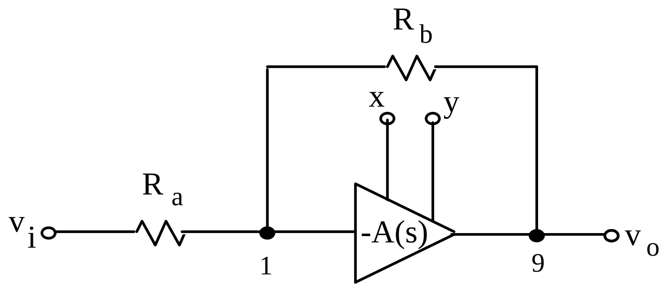


Fig. 2. Uncompensated shunt feedback amplifier.

a. **Shunt Feedback**

Connect a shunt feedback network around the amplifier, as shown in Fig. 2. The triangular block represents the entire 3-stage amplifier of Fig. 1 (i.e., our "op-amp"). Note that this corresponds to the familiar "inverting amplifier" op-amp configuration. What would you expect the gain to be in this case? Note that terminals x and y should be left open, and the 200-Kilohm resistor labeled $R_0$ in Fig. 1 should **not** be removed.

First, referring to Fig. 2, let $R_a$ = 1 kΩ and $R_b$ = 3.3 kΩ (measure their exact values). Observe the output with your oscilloscope with $v_i$ = 0 (connect the input to ground). Does the feedback amplifier oscillate? If so, sketch the waveform at $v_o$, and record peak amplitudes (both positive and negative, with your scope coupling set to dc) and the period.

Now change $R_b$ to 10 kΩ (measure its exact value). What would you expect the gain to be in this case? Measure the low-frequency gain with a sinusoidal signal applied to the input. Then do a frequency sweep to measure the gain vs. frequency. Measure the peak gain and the frequency at which it occurs. Plot the results.

Change the input to a 100-mV 50-Hz square wave and observe the output with your oscilloscope. Sketch $v_i(t)$ and $v_o(t)$, being careful to note any "ringing" around the transitions of the waveform. You might have to increase the sweep speed and/or the beam intensity of your oscilloscope to properly see the ringing. Feel free to change the frequency of the input square wave to get a good display (but don't cut off any of the ringing). Record the steady-state output voltage (flat portion of the waveform), and the voltage of the first (+) and second (-) peaks, and the ringing period. Also note the input levels. Your measurements must be in sufficient detail that you can compare them in detail with SPICE simulations.

b. **Dominant Pole Compensation**

Compensation is a technique used to make op-amps stable under closed-loop feedback conditions. Typically, a pole is introduced which is lower than the other high-frequency poles in the circuit. Will compensate our “op-amp” from Fig. 1 by adding a capacitance $C_x$ across terminals x and y as shown in Fig. 3. Calculate the required value of $C_x$ as outlined below.

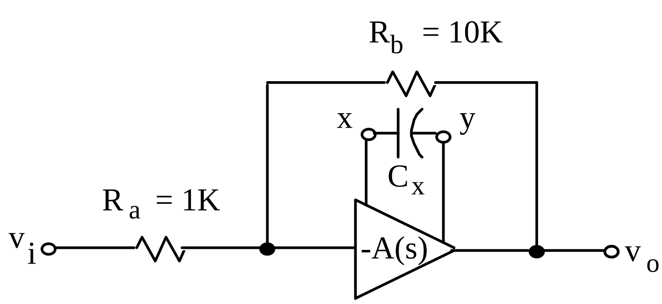


Fig. 3. Dominant pole compensated feedback amplifier.

First, derive an expression for A(s). Note that the open- and short-circuit time constants approximate method does not work well for this circuit. Use ideal models for the opamps and write node equations to solve for A(s). It will be useful to break up the circuit into several subsections and solve for the gain of each one independently [i.e., $A(s) = A_1(s)A_2(s)A_3(s)$]. Then make a Bode magnitude plot using your measured component values and determine the dominant pole frequency. Then find the value of $C_X$ as outlined on pp. 849-850 of the text. Wire $C_X$ (using the closest available standard value) into the circuit between terminals x and y, as shown in Fig. 3.

Apply a square wave to the input with a magnitude low enough to prevent distortion of the output. Accurately measure and plot $v_o(t)$. The output should "ring". Your data should include accurate measurements of the magnitude and time of the first (+) and second (-) peaks of the ringing.

Now check the sensitivity of the amplifier closed-loop gain to the open-loop gain, by temporarily changing $R_2$ in Fig. 1 to 20K (a 100% change in open loop gain). Measure the resulting closed-loop gain.

c. **Dominant Pole Compensation with Zero Cancellation**

A slightly more complex compensation scheme is illustrated in Fig. 4. Compute the required values of $R_X$ and $C_X$. Using the nearest available standard values (measure them!), wire the circuit of Fig. 4, and apply a 100-mV, 50-Hz square wave (as before), and measure the steady state value along with the first (+) and second (-) peaks (as before).

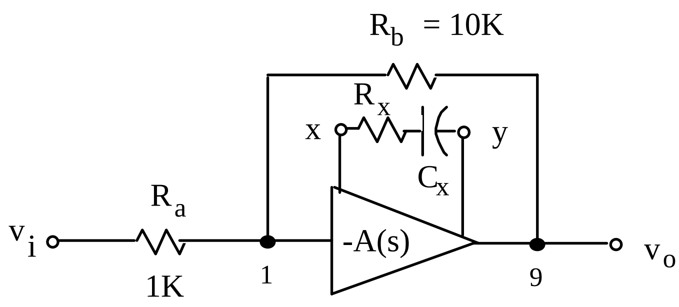


Fig. 4. Zero cancellation compensation.

Change the fixed resistor $R_X$ to a variable one (with a potentiometer or decade box) and repeat the above measurements after adjusting $R_X$ for optimum performance, that is minimum overshoot consistent with smallest ringing and fastest rise and fall time. Now make $C_X$ variable (use a decade capacitance box) and simultaneously adjust $R_X$ and $C_X$ for optimum performance. What would you consider "optimum" performance?

Measure the rise and fall time and overshoot of the waveform you consider optimum. Include a plot of the output waveform from the scope. Record the corresponding values of $R_X$ and $C_X$.

**Report**

1. Create Bode plots (magnitude and phase response) of the open loop amplifier of part 1, showing simulated response, measured response, and calculated (theoretical) response on the same set of axes. Also compare the simulated and measured values for the rise and fall time from part 1, section c.
2. For part 2, sections a-c, report and compare the measured vs. simulated values for the steady state voltage, and the $1^{st}$ (+) and $2^{nd}$ (-) peaks of the ringing.
3. Discuss the concepts of feedback and stability this lab introduced.