ECE 214 - Lab #4
OpAmp Circuits with Negative Feedback

18 February 2019

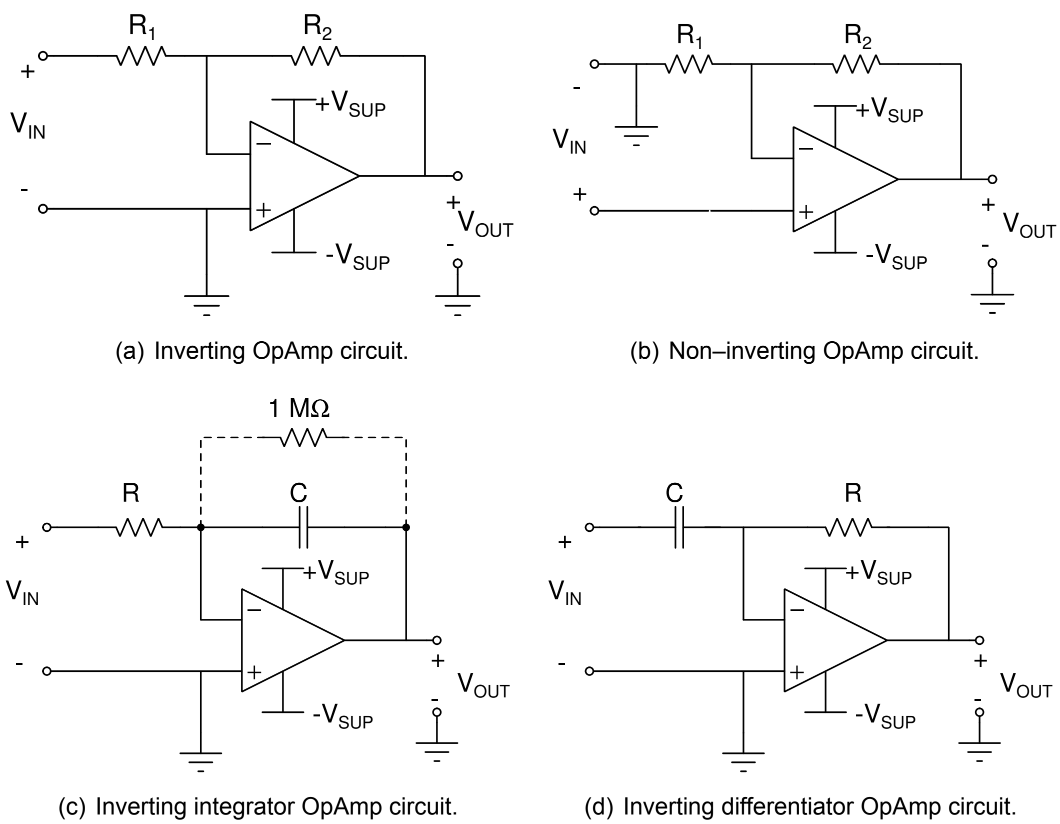
Note: Before starting this lab, update the LM741 OpAmp model in NGspice as described in class.

Introduction: The TL082 Operational Amplifier (OpAmp) and the Texas Instruments “Analog System Lab Kit Pro” evaluation board are used to explore basic OpAmp circuits. The ideal OpAmp is compared to a real OpAmp. Negative feedback is used to generate the inverting amplifier, non-inverting amplifier, inverting integrator and inverting differentiator. Positive feedback is used to generate a Schmitt trigger.

Pre–Lab:

1. Review the ideal OpAmp circuits from ECE 210 and make sure you are able to calculate the $V_{OUT}(t)$ as a function of $V_{IN}(t)$ for each of the four OpAmp configurations shown in Figure 1. These OpAmps use dual-rail voltages, and negative feedback to achieve amplification within the active region of operation.

2. Design an inverting OpAmp circuit, shown in Figure 1(a), to produce a gain of -4.7 V/V.



(a) Inverting OpAmp circuit. (b) Non–inverting OpAmp circuit.

(c) Inverting integrator OpAmp circuit. (d) Inverting differentiator OpAmp circuit.

Figure 1: Four basic OpAmp circuits using negative feedback.

3. Simulate the OpAmp circuit. Use the TL082 OpAmp model. You can use the `Sample .m MATLAB file for Lab 3` and the `HSPC Template file for Lab 3` as template files for the simulations.

   (a) Set the power supply voltages to ± 10 V.
   (b) Set the input signal to a sine wave, with an amplitude of 0.5 Vp, at a frequency of 2 kHz.
   (c) Plot V_{OUT} and V_{IN} as a function of time. What is the gain and phase shift of the output with respect to the input? How do these compare with an ideal OpAmp?
   (d) Increase the amplitude of the input signal until the OpAmp saturates. Determine the positive and negative saturation voltage. How do the saturation voltages differ from an ideal OpAmp.
   (e) Decrease the amplitude to 0.5 Vp, and increase the frequency of the input signal to 10 kHz. 20 kHz, and then 50 kHz. Do the gain and phase shift change with frequency? How does the frequency response of the TL082 OpAmp differ from an ideal OpAmp?

4. Design a non-inverting OpAmp circuit, shown in Figure 1(b), to produce a gain of +8 V/V.

5. Repeat the simulation described in Pre-Lab section 3 above.

6. All OpAmp circuits can be modified to operate from a single rail voltage. This is illustrated for the inverting amplifier in Figure 2. In this circuit, $-V_{SUP} = 0$ V, and the non-inverting input (v_n) is biased at $+V_{SUP}/2$. Draw the schematic of the non-inverting OpAmp configuration shown in Figure 1(b) when operated from a single rail voltage.

Lab Procedure:

1. Build an inverting OpAmp circuit, using dual rail voltages, and a gain of -4.7.

   (a) Turn on the Dual Voltage Supply (PS) and turn all voltages down to zero. Set the Tracking Ratio knob fully clockwise till it clicks. Attach the ends of extra long wires between (a) the PS common, adjustable +20, and adjustable -20 volt terminals, and (b) the ground, $+V_{SUP}$. and $-V_{SUP}$ terminals in your circuit.

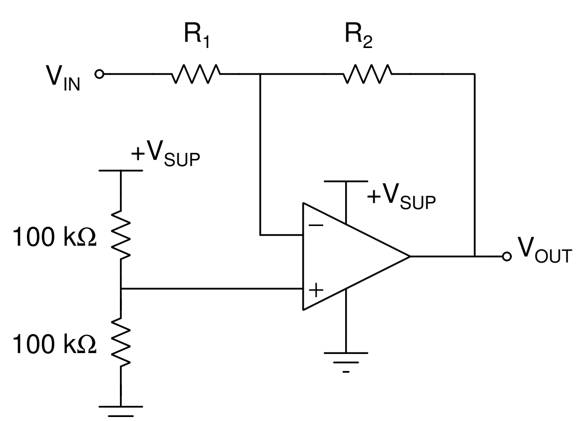


Figure 2: Inverting OpAmp circuit operated from a single power supply.

(b) Monitor the voltage on the display and adjust the voltage to +10 V. If none of the components on your board get hot and no smoke appears, things are going well. Use a DVM to verify that the correct voltages have been established at the rails of the OpAmp.

(c) Connect the function generator (FG) to the input of the OpAmp circuit. Adjust the FG to output a sine wave of 0.5 Vp at a frequency of 2 kHz. Connect one channel of the oscilloscope to the FG output and the other channel to the output of the OpAmp. What are the gain and phase shift of the output with respect to the input? How do these results compare with simulated predictions? Record the results in you notebook.

(d) Increase the amplitude of the input signal until the OpAmp saturates. Note that there are two saturation voltages, one positive and one negative. What does the output signal look like when the input signal is too large? Sketch the output of the OpAmp in saturation in your notebook. What is the maximum and minimum output voltage from the OpAmp? Record the results in your notebook and compare to the simulated results.

(e) Reduce the input signal back to 0.5 Vp and examine the OpAmp's behavior at frequencies below 2 kHz. Does the gain or the phase shift change? Now look at frequencies above 2 kHz. Does the gain or the phase shift change? Briefly describe the results in your notebook as the frequency is decreased and increased.

(f) Increase the frequency until the phase shift goes from $-180°$ to $-225°(+135°)$. What is the gain at this frequency? Record the frequency and gain in your notebook. Reference this result in your table of contents.

2. Build a non-inverting OpAmp circuit, using dual rail voltages, and a gain of +8.

   (a) Repeat steps 1c through 1e above.

   (b) Increase the frequency until the phase shift goes from $0°$ to $-45°$. What is the gain at this frequency? Record the frequency and gain in your notebook.

3. Build the inverting integrator circuit in Figure 1(c) with R$=1$ kΩ and C$=0.1$ μF. The 1 MΩ resistor across the capacitor provides a DC path from the output to ground. What is the relationship between V$_{OUT}$ and V$_{IN}$ for this circuit?

   (a) Connect a 1 Vp sine wave signal with a frequency of 1 kHz to the input of the integrator. Use the DC offset on the FG to stabilize the DC component of the output signal. What DC offset voltage was needed to keep the output signal centered around 0 V? What does the output signal look like? Is the amplitude and phase what you expect? Record the results in your notebook.

   (b) Increase the frequency of the input signal. Explain and record in your notebook what happens to the output signal. You may need to utilize AC coupling and ensure you trigger the scope from the sine wave input signal, or use external triggering, to obtain a stable output signal.

   (c) Experiment with square, triangular and sawtooth waves as inputs to the integrator. Does the circuit integrate properly? Record the input and output signals in your notebook.

4. Build the inverting differentiator shown in Figure 1(d) with R$=1$ kΩ and C$=0.1$ μF. What is the relationship between V$_{OUT}$ and V$_{IN}$ for this circuit?

   (a) Connect a 1 Vp sine wave signal with a frequency of 1 kHz to the input of the differentiator circuit. What does the output signal look like? Is the amplitude and phase what you expect? Record the results in your notebook.

(b) Input a triangular signal into the differentiator circuit. Does the circuit differentiate properly? Record the input and output signals in your notebook.

Post–Lab:

1. Compare the behavior of the LM741 OpAmp with the ideal OpAmp. What are the major differences between the Ideal and Real OpAmps?
2. Simulate the behavior of the inverting integrator circuit that was built in step 3 of the lab when the input signal to the integrator is a sine wave, square wave, triangular wave, and sawtooth wave. Compare the simulated results to the experimental results from step 3c of this lab. Record the simulation schematic and results in your notebook.
3. Make a entry for this Post Lab in the table of contents of your Lab Notebook.