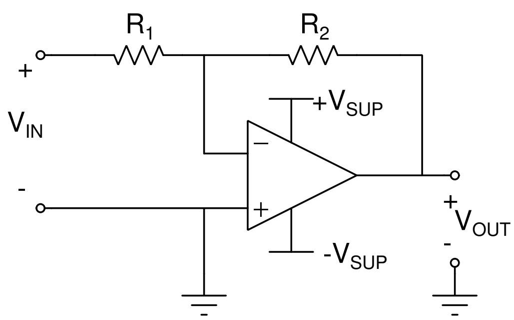
ECE 214 - Lab #4
OpAmp Circuits with Negative and Positive Feedback

14 February 2017

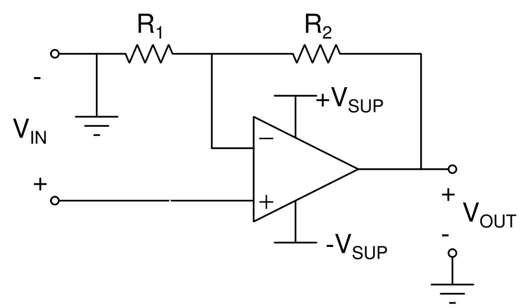
Introduction: The TL082 Operational Amplifier (OpAmp) and the Texas Instruments "Analog System Lab Kit Pro" evaluation board are used to explore basic OpAmp circuits. The ideal OpAmp is compared to a real OpAmp. Negative feedback is used to generate the inverting, non-inverting, inverting integrator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

Pre Lab:

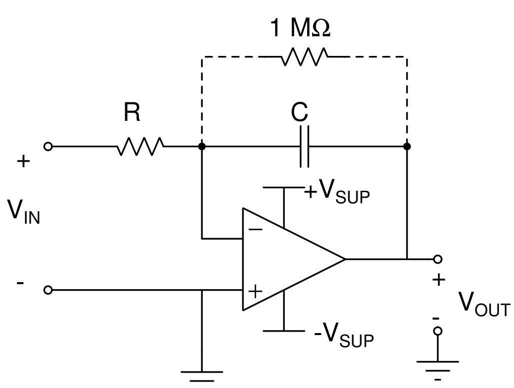
1. Review the ideal OpAmp circuits from ECE 210 and make sure you are able to calculate the $V_{OUT}(t)$ as a function of $V_{IN}(t)$ for each of the four OpAmp configurations shown in Figure 1. These OpAmps use negative feedback to achieve amplification within the active region of operation.



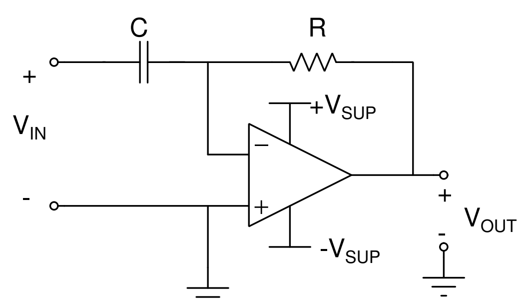
(a) Inverting OpAmp circuit.



(b) Non–inverting OpAmp circuit.



(c) Inverting integrator OpAmp circuit.



(d) Inverting differentiator OpAmp circuit.

Figure 1: Four basic OpAmp circuits using negative feedback.

2. Use NGspice to analyze the inverting OpAmp circuit in Figure 1(a) for both the ideal OpAmp and the TL082 OpAmp.
   (a) Design the inverting OpAmp circuit to produce a gain of -4.7.
   (b) Set the power supply voltages to ±10 V.

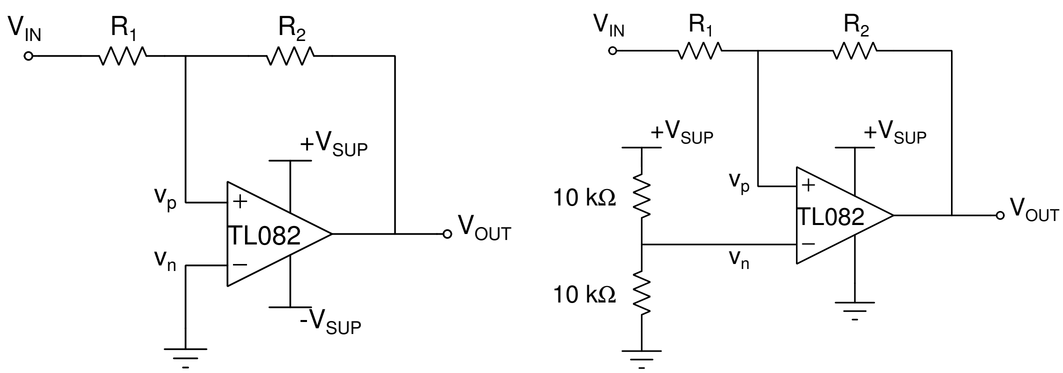
(c) Set the input to a sinusoidal signal with an amplitude of 0.5 Vp at a frequency of 10 kHz.

(d) 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 the gain and phase shift differ between the ideal OpAmp and the TL082 OpAmp.

(e) Increase the amplitude of the input signal until the OpAmp saturates. There is a positive and a negative saturation voltage. How do these saturation voltages differ between the ideal OpAmp and the TL082 OpAmp.

(f) Reduce the amplitude back to 0.5 Vp and increase the frequency of the input signal. Does the gain or phase shift change with frequency? How do the results from the TL082 OpAmp differ from the ideal OpAmp?

3. There are many ways to implement a Schmitt trigger. One implementation is shown in Figure 2(a). This circuit uses positive feedback. The output ($\mathrm{V_{OUT}}$) is connected through



(a) Schmidtt trigger circuit.

(b) Schmitt trigger with a single rail voltage.

Figure 2: Example of a Schmitt trigger circuit using an Op Amp with positive feedback.

resistor $\mathrm{R_2}$ to the non-inverting input ($\mathrm{v_p}$) of the OpAmp. When an Op Amp is configured with positive feedback: $\mathrm{v_p} \neq \mathrm{v_n}$. Rather $\mathrm{V_{out}}$ takes on one of only two values: $+\mathrm{V_{SUP}}$ or $-\mathrm{V_{SUP}}$. The output voltage $\mathrm{V_{OUT}} = +\mathrm{V_{SUP}}$ when $\mathrm{v_p} > \mathrm{v_n}$, and $\mathrm{V_{OUT}} = -\mathrm{V_{SUP}}$ when $\mathrm{v_p} < \mathrm{v_n}$. $\mathrm{V_{OUT}}$ transitions between $-\mathrm{V_{SUP}}$ and $+\mathrm{V_{SUP}}$ when $\mathrm{v_p} = \mathrm{v_n}$.

4. Assume the OpAmp in Figure 2(a) is ideal and $\mathrm{R_1} = 3\ \mathrm{k\Omega}$ and $\mathrm{R_2} = 10\ \mathrm{k\Omega}$.

(a) Sketch the transfer function as Vin increases from $-\mathrm{V_{SUP}}$ V to $+\mathrm{V_{SUP}}$ V.

(b) Sketch the transfer function as Vin decreases from $+\mathrm{V_{SUP}}$ V to $-\mathrm{V_{SUP}}$ V.

5. All of the OpAmps shown in Figure 1 and the circuit shown in Figure 2(a) can be modified to operate from a single rail voltage. This is illustrated for the Schmitt trigger circuit in Figure 2b. In this circuit $-\mathrm{V_{SUP}} = 0$ V and the inverting input ($\mathrm{v_n}$) is biased at $+\mathrm{V_{SUP}}/2$. Make a sketch the schematic for the OpAmp configurations in Figure 1 when operated from a single rail voltage.

6. For the Schmitt trigger shown in Figure 2(b), assume the OpAmp is ideal and $+\mathrm{V_{SUP}} = 10$ V. Analyze this circuit to determine values of resistors $\mathrm{R_1}$ and $\mathrm{R_2}$ such that:

(a) The Schmitt trigger levels are separated by more than 3.5 V but less than 4.5 V.

(b) The maximum current through any resistor is less than 10 mA.

With the chosen values of R_1 and R_2, what are the two Schmitt trigger levels?

7. Use NGspice to simulate the transfer function of the Schmitt trigger circuit in Figure 2(b) with the resistor values you calculated in step 6. Set the power supply voltage to 10 V. Set the input to a DC voltage. Analyze the behavior of this circuit using both the ideal OpAmp and the TL082 OpAmp.

   (a) Simulate the output voltage as the input voltage is increased from $-V_{SUP}$ V to $+V_{SUP}$ V.

   (b) Simulate the output voltage as the input voltage is decreased from $+V_{SUP}$ V to $-V_{SUP}$ V.

   (c) What are the trigger levels for the Ideal and TL082 OpAmps.?

   Make sure all axes on your graphs are properly labeled.

8. Do the simulated results for the TL082 OpAmp meet the requirement in step 6a? If not, adjust the values of R_1 and R_2 so that the trigger levels are separated by more than 3.5 V but less than 4.5 V. Record the final values of R_1 and R_2 in your notebook.

Lab Procedure:

1. Locate the "OpAmp Type II Full" circuit on the TI evaluation board. Use this circuit for all measurements described below.

2. Design and build an inverting OpAmp circuit with a gain of -4.7. (Use only components that are available "OpAmp Type II Full" circuit on the TI evaluation board.)

3. 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 "Main Power" GND, +10V, and -10V terminals on the TI evaluation board.

4. 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. The power LEDs on the evaluation board should be illuminated. Use a DVM to verify that the correct voltages have been established at the rails of the OpAmp.

5. 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 10 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.

6. 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.

7. Reduce the input signal back to 0.5 Vp and examine the OpAmps behavior at frequencies below 10 kHz. Does the gain or phase shift change? Now look at frequencies above 10 kHz. Briefly describe the results in your notebook as the frequency is decreased and increased.
8. 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.
9. Design and build a non-inverting OpAmp circuit with a gain of +11. (Use only components that are available on the TI evaluation board.)
10. Repeat steps 5 through 7 above.
11. 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.
12. 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?
13. 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.
14. 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.
15. 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.
16. 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?
17. 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.
18. Input a triangular signal into the differentiator circuit. Does the circuit differentiate properly? Record the input and output signals in your notebook.
19. Build the Schmitt trigger circuit shown in Figure 2(b) with the resistor values you determined in step 8 of the Pre Lab.
    (a) Set the power supply to 10 V and measure the voltage before connecting it to the circuit.
    (b) Set the function generator to produce a 8 V peak–to–peak triangular signal with a 5 V DC offset at a frequency of 500 Hz. Check the signal on the scope before connecting it to the circuit. It should oscillate between 1 V and 9 V.
    (c) Determine if the Schmitt trigger works by measuring V_{OUT} and V_{IN} on the scope. Record in your lab notebook what you observe on the scope and make sure to measure the trigger levels that cause the output to change.

(d) Do your results agree with your Pre Lab simulations? If not, adjust the values of R_1 and R_2 so that the trigger levels are separated by at least 3.5 V but not more than 4.5 V. Record the final values of R_1 and R_2 in your notebook.

Post Lab:

1. Compare the behavior of the TL082 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 of step 12 using NGspice when the input to the integrator is a sine wave, square wave, triangular wave, and sawtooth wave. Compare the simulated results to the experimental results from step 15 of this lab. Make sure to record the NGspice circuit, the Matlab® ".m" file, the `hspc` file, and all simulation results in your notebook.
3. Make a entry for this Post Lab in the table of contents of your Lab Notebook: