ECE 214 - Lab #4
OpAmp Circuits with Negative Feedback

22 February 2021

Introduction

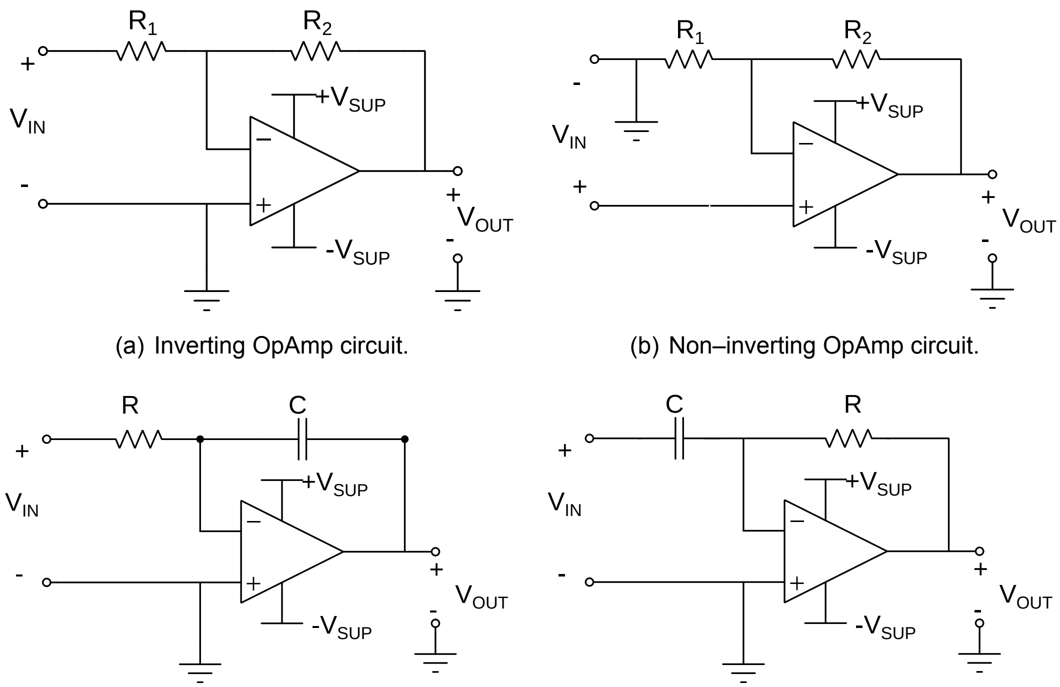
The LM741 Operational Amplifier (OpAmp) from Texas Instruments is used to explore basic OpAmp circuits. The ideal OpAmp is compared to a real OpAmp. Negative feedback is used to generate the inverting amplifier, non-inverting amplifier, inverting integrator and the inverting differentiator.

Parts List

1. LM741 OpAmp (2)
2. 1 kΩ resistors (1)
3. 0.1 μF capacitor (1)
4. Breadboard wires for Powerbrick (2)
5. Resistors and capacitors for the inverting, non-inverting, and integrating amplifier designs

Pre–Lab

1. Review the ideal OpAmp circuits from ECE 210 and make sure you are able to calculate the transfer function, 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 ($\pm$V$_{SUP}$), 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 -8 V/V.
3. Simulate the inverting OpAmp circuit designed in Pre-Lab item 2.
   (a) To compare the LM741 OpAmp with the ideal OpAmp models, perform the simulation using both the ideal OpAmp and the LM741 OpAmp models.
   (b) Set the power supply voltages to ± 12 V. Use the MATLAB® file `http://davidkotecki.com/ECE214/docs/Matlab/ECE214_2020_Lab4.m` for the simulations.
   (c) Set the input signal to a sine wave, with an amplitude of 0.5 Vp, and a frequency of 2 kHz. Plot V$_{OUT}$ and V$_{IN}$ as a function of time. What are the gain and phase shift of the output signal with respect to the input signal? How do the results from the LM741 OpAmp compare with an ideal OpAmp?
   (d) Decrease the amplitude of the sine wave to: 0.05, 0.005, and 0.001 Vp, and plot V$_{OUT}$ and V$_{IN}$ as a function of time. For each input voltage, note the gain and phase shift of the output with respect to the input. Note any anomalies in the simulations. How do the results from the LM741 OpAmp differ from an ideal OpAmp?



(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.

(e) Increase the amplitude of the input signal until the OpAmp saturates. Determine the positive and negative saturation voltage. Note that there are two saturation voltages, one positive and one negative. How do the saturation voltages of the LM741 OpAmp differ from an ideal OpAmp?

(f) Set the amplitude of the sine wave to 0.5 Vp. Simulate the output signal when the frequency of the input signal is: 10 kHz, 20 kHz, 25 kHz, and 50 kHz. Do the gain and phase shift change with increasing frequency? How does the frequency response of the LM741 OpAmp differ from an ideal OpAmp?

4. Design a non-inverting OpAmp circuit, shown in Figure 1(b), to produce a gain of +10 V/V.

5. Verify the design by simulating the non-inverting OpAmp circuit designed in Pre-Lab item 4. Set the input signal to a sine wave, with an amplitude of 0.5 Vp, and a frequency of 2 kHz. Plot V_{OUT} and V_{IN} as a function of time. What are the gain and phase shift of the output with respect to the input? How do the results from the LM741 OpAmp compare with an ideal OpAmp?

6. Design an inverting integrator OpAmp circuit, shown in Figure 1(c), to produce a gain of -5 V/V when the input is a sine waveform with a frequency of 2 kHz.

7. Verify the design by simulating the inverting integrator OpAmp circuit designed in Pre-Lab item 6. Set the input signal to a sine wave, with an amplitude of 0.5 Vp, and a frequency of 2 kHz. Plot V_{OUT} and V_{IN} as a function of time. What are the gain and phase shift of the output with respect to the input? How do the results from the LM741 OpAmp compare with an ideal OpAmp?

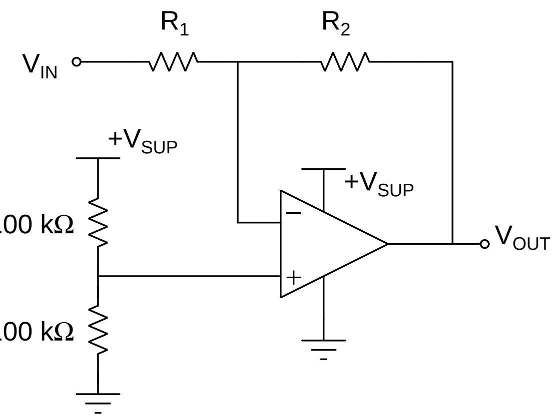


Figure 2: Inverting OpAmp circuit operated from a single power supply.

8. OpAmp circuits can be modified to operate from a single rail voltage. This is illustrated in Figure 2 for the inverting amplifier configuration. In this circuit, $-V_{SUP} = 0$ V, and the non-inverting input (v_n) is biased at $+V_{SUP}/2$. This circuit will be utilized in Lab 5. 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 the inverting OpAmp circuit designed in Pre-Lab item 2.
   (a) Connect the pin labeled +5 V on AD2 to the $+V_{IN}$ terminal of the Digilent 12 V powerBRICK. (Alternatively, connect a USB cable between the Digilent powerBRICK and a laptop.) Connect the $+V_{OUT}$ and $-V_{OUT}$ pins of the powerBRICK to the $+V_{SUP}$. and $-V_{SUP}$ terminals of the OpAmp respectively.
   (b) Use a DVM to verify that the correct voltages have been established at both rails of the OpAmp.
   (c) Adjust the WG to produce a sine wave, with an amplitude of 0.5 Vp and a frequency of 2 kHz. Connect the WG to the input of the OpAmp circuit.
   (d) Connect one channel of the oscilloscope to the output of the WG and the other channel to the output of the OpAmp. Measure the gain and phase shift of the output signal of the OpAmp with respect to the input. How do these results compare with simulated predictions?
   (e) Increase the amplitude of the WG signal until the OpAmp saturates. Note that there are two saturation voltages, one positive and one negative. What are the maximum and minimum output voltages from the OpAmp? What does the output signal look like when the input signal is too large? How do these results compare to the simulated results?
   (f) 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?
   (g) Increase the frequency until the phase shift goes from $-180°$ to $-225°(+135°)$. What is the gain at this frequency?

2. Build the non-inverting OpAmp circuit designed in Pre-Lab item 4.
   (a) Repeat steps 1c and 1d above.
   (b) Increase the frequency until the phase shift goes from $0°$ to $-45°$. What is the gain at this frequency?
3. Build the inverting integrator circuit designed in Pre-Lab item 6.
   (a) Set the input signal to a sine wave with an amplitude of 0.5 Vp and a frequency of 2 kHz. What are the gain and phase shift of the output signal with respect to the input signal? How do these results compare to the simulation results?
   (b) You may need to set the DC offset on the WG to stabilize the DC component of the output signal. Was a DC offset voltage needed to keep the output signal centered around 0 V?
   (c) Increase the frequency of the input signal. What happens to the output signal?
   (d) Change the WG to produce a square, triangular and sawtooth waveform. Record the output of the integrator. Does the circuit integrate properly?
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?
   (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 an ideal OpAmp. What are the major differences between the real and ideal OpAmp?
2. Simulate the behavior of the inverting integrator circuit that was built in the Lab Procedure item 3. Set the input signal to a square wave, triangular wave, and sawtooth wave. Compare the simulated results to the experimental results from step 3d.
3. Make sure all schematics, simulation results, and measured results have been recorded in your notebook.