EE 220/220L Circuits I (Fall 2019)
Laboratory Project 9 The Operational Amplifier

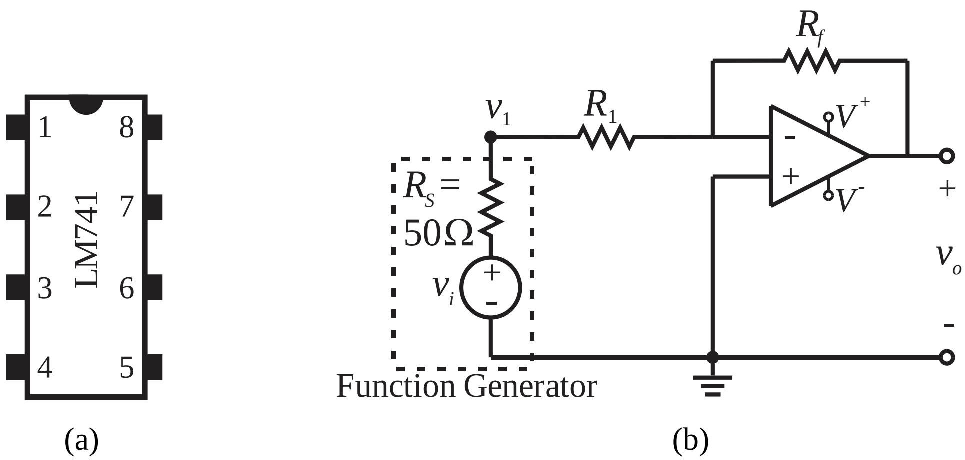

Figure 1 (a) operational amplifier IC package and (b) inverting amplifier.

Preliminary

1) Obtain the datasheet for an LM741 operational amplifier (op-amp) made by Texas Instruments (TI). In this lab, we will be using a PDIP (Plastic Dual In-line Package) LM741CN/NOPB op-amp.
   a) Label op-amp pin connections on Fig. 1a above and insert relevant information from datasheet.
   b) Find and insert the table of electrical characteristics for the LM741CN op-amp. Using the table, find and record the typical input resistance R_i and open-loop (AKA large signal) gain A.
   c) Find and insert the table of operating conditions for LM741CN op-amps. Using the table, find and record the nominal and maximum ranges for DC supply voltages (i.e., V^+ & V^-) as well as the minimum and maximum operating temperatures (°C and °F).
   d) Find and insert the circuit diagram for the LM741. How many transistors N_Q and resistors N_R does the LM741 include? [Warning: Do <u>not</u> trust the component numbering on diagram.]
2) Find the typical output resistance R_o for an LM741. Assume room temperature, nominal supply voltages, and a frequency < 10 kHz. **Hint:** Search internet, TI datasheet does not have this item.
3) Assuming the op-amp is ideal, calculate the closed-loop gain $A_v = v_o / v_i$ of the circuit (Fig. 1b) when $R_1 = 2.7\ \text{k}\Omega$ and $R_f = 11\ \text{k}\Omega$. Will the function generator resistance R_S make a difference?
4) Assuming an ideal op-amp using the nominal DC supply voltages (V^+ & V^-) and an input signal $v_i(t) = V_m \cos(\omega t)\ \text{V}$, what is the maximum input voltage **magnitude** $V_{m,\max}$ that can be used with this inverting amplifier without experiencing clipping distortion in the output voltage $v_o(t)$?
5) For the specified resistors, assuming an ideal op-amp (unlimited power), write out the equation for $v_o(t)$ for a general sinusoidal input voltage $v_i(t) = V_m \cos(\omega t)\ \text{V}$ where $\omega = 2\pi f$.
6) Have the lab instructor or a TA sign your preliminary before you do the experiment.

Note: Bring a USB flash drive! Use default FAT32 file format.

Experiment

1) Measure and record resistances R_1 & R_f. Calculate the expected closed-loop gain $A_{v,e}$ for the <u>experimental</u> circuit.

2) With the function generator connected directly to the oscilloscope (DC coupling), adjust the function generator to produce a 834 Hz sinusoidal input signal $v_i(t)$ with a 1.8 V magnitude (3.6 V_{pp}), i.e., $v_i(t) = 1.8\cos(1668\pi t)\,\text{V}$. Display ~2 cycles of $v_i(t)$ (CH1) along with the measured peak-to-peak & average voltages as well as frequency, save screen shot (i.e., bitmap) to an USB flash drive, and print & insert in logbook. What percentage of $V_{m,\max}$ is 1.8 V? Using $A_{v,e}$, write out predicted equation for $v_o(t)$.

3) Set, measure, & record nominal DC supply voltages V^+ & V^- **with respect to ground**. Then, on a breadboard, build the inverting amplifier with R_1, R_f, and LM741 op-amp driven by the function generator. Using oscilloscope, display ~2 cycles of $v_1(t)$ (CH1) & $v_o(t)$ (CH2) along with measured peak-to-peak voltages (i.e., $V_{pp(1)}$ & $V_{pp(2)}$), save bitmap, and print & insert in logbook with $v_1(t)$ & $v_o(t)$ labeled. Using $V_{pp(1)}$ and $V_{pp(2)}$, calculate measured gain $A_{v,a} = -V_{pp(2)} / V_{pp(1)}$. How does $V_{pp(1)}$ for $v_1(t)$ compare to $V_{pp(1)}$ in the previous step for $v_i(t)$? Was there a voltage drop across R_S?

   Notes: 1) Tie all ground connections together (e.g., oscilloscope, supply voltages ...).
   2) For computing gains, we will assume $v_1(t) \approx v_i(t)$ and a minus sign from the 180° phase shift.

4) Adjust the function generator to produce an input signal $v_i(t)$ with a 4.5 V magnitude (9 V_{pp}), i.e., $v_i(t) = 4.5\cos(1668\,\pi\,t)\,\text{V}$. What percentage of $V_{m,\max}$ is 4.5 V? Using $A_{v,e}$, write out predicted equation for $v_o(t)$. Display $v_1(t)$ (CH1) & $v_o(t)$ (CH2) along with $V_{pp(1)}$ & $V_{pp(2)}$, save bitmap, and print & insert in logbook with $v_1(t)$ & $v_o(t)$ labeled. Calculate measured gain $A_{v,b} = -V_{pp(2)} / V_{pp(1)}$.

5) Adjust function generator to **experimentally** find maximum peak-to-peak amplitude of the input $v_i(t)$ for which $v_o(t)$ is **not** distorted. Display $v_1(t)$ (CH1) & $v_o(t)$ (CH2) along with $V_{pp(1)}$ & $V_{pp(2)}$, save bitmap, and print & insert bitmap in logbook with $v_1(t)$ & $v_o(t)$ labeled. Measure and record $V_{m,c} = V_{m,\max,\text{exp}} = V_{pp(1)} / 2$. Calculate measured gain $A_{v,c} = -V_{pp(2)} / V_{pp(1)}$.

6) Adjust function generator to produce a 834 Hz sinusoidal signal of 1.5 V magnitude with a 0.25 V DC offset, i.e., $v_i(t) = 0.25 + 1.5\cos(1668\pi t)\,\text{V}$. Using $A_{v,e}$, write out the predicted equation for $v_o(t)$. Display $v_1(t)$ (CH1) & $v_o(t)$ (CH2) along with $V_{pp(1)}$ & $V_{pp(2)}$, save bitmap, and print & insert in logbook with $v_1(t)$ & $v_o(t)$ labeled. Next, display $v_1(t)$ (CH1) & $v_o(t)$ (CH2) along with $V_{avg(1)}$ & $V_{avg(2)}$, save bitmap, and print & insert in logbook with $v_1(t)$ & $v_o(t)$ labeled. Using $V_{pp(1)}$ & $V_{pp(2)}$ and $V_{avg(1)}$ & $V_{avg(2)}$, find the measured AC and DC gains ($A_{v,d,\text{AC}}$ & $A_{v,d,\text{DC}}$).

Analysis and Conclusions

- In a table, list the measured gains $A_{v,x}$ for each input and compare with the expected gain $A_{v,e}$. Format- column 1 variable name, column 2 $A_{v,x}$, column 3 $A_{v,e}$, and column 4 percent difference. Discuss results. Were measured gains constant and consistent with expectations? Why/why not?
- How does $V_{m,\max,\text{exp}}$ compare with $V_{m,\max}$ from preliminary? If different, comment on reasons. **Hint:** How do the measured maximum output voltage magnitudes compare to V^+ & V^-?
- For each input signal in the experimental portion, was the output voltage $v_o(t)$ as predicted by theory? Why/why not?
- Did the ideal operational amplifier model produce reasonably accurate results? Why or why not?