Non-ideal effects in operational amplifiers

This time, we look at some properties of real op amps, particularly things that might cause problems in op-amp circuits.

Prior to Lab

1. Look over the data sheets again for the LM 324, TL082, and LMC660 op-amps. This time look at the information relating to the non-ideal effects that we will study: voltage and current limits, gain-bandwidth limits, slew rate limits and offset voltage, offset voltages / bias currents.
2. Perform any calculations that you can before lab.
3. Bring a flash drive so that you can record oscilloscope traces and save Signal Express data.

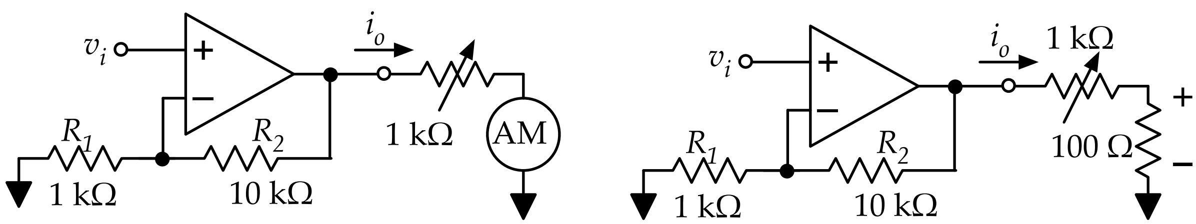
A. Power supplies and output voltage limits

We have seen some of this before.

- Design and build a non-inverting amplifier with a gain of 16, using a 324 op-amp with ±8-V power supplies. For the input signal, use a sinusoid with frequency of 100 Hz. Adjust the amplitude of the input so that the output is clipped. Display the input and output waveforms together on the oscilloscope and record a copy of the traces for your report. Carefully measure (use the cursors, if needed) the upper and lower limits of the output voltage and compare to the power supply values.
- Switch the oscilloscope into *x-y* mode to obtain a plot of the transfer function of the amp. Again, make sure the input voltage amplitude is big enough so that the output is clipped. Save a copy of the trace for your report.
- Repeat all of the above with the 660 op amp. The 660 is a "rail-to-rail" op amp. Note that the difference in the output saturation levels when compared to the 324.
- Both the 660 and 324 op amps can operate off of a single supply. Change the 660 circuit above so that the positive supply is +15 V and the negative supply terminal on the op amp is connected to ground. Adjust the amplitude of the input sinusoid to 0.25 V_{RMS}. Observe the input and output voltages together. There is an obvious problem. (And it shouldn't be too surprising.) Record an image of the badly distorted waveform for your report.
- Fix the problem by adding a DC offset of 0.47 V to the input signal. The offset at the input shifts the output by 7.5 V_{DC}. (If you haven't done this before, there is an offset option when setting the amplitude on the function generator. (In EE 201, some of you would *accidentally* set a DC offset with your input voltage and cause some consternation when trying to making your circuit work. Now, in EE 230, you can intentionally and correctly use the offset feature.) Record an image of the oscilloscope traces for your report. Later, we will look at better ways to design amplifiers when using a single supply.

B. Output current limits

- Using the 324, build an non-inverting amp with a gain of 11. (For example, R_2 = 10 kΩ and R_1 = 1 kΩ.) Use ±8 V power supplies. Set the input at DC value of +0.5 V, so that the output is +5.5 V.
- At the output, attach a 1-kΩ potentiometer along with some means to measure the current. This could be an ammeter, which will measure the current directly. Or you could put a 100-Ω resistor in series with the potentiometer, and determine the output current by measuring the voltage across the fixed resistor. Either approach is fine.

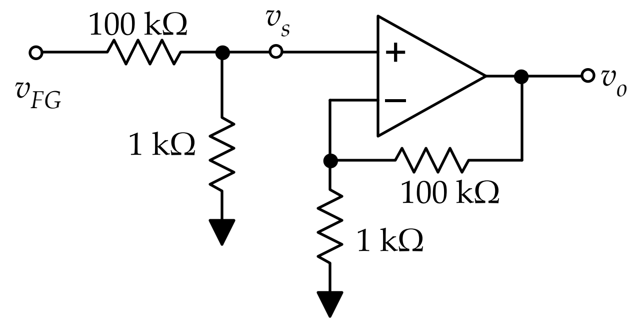


- Start with the potentiometer adjusted to maximum resistance, so that the output current will around 5.5 mA. Then begin slowly decreasing the resistance (increasing the current) while monitoring the current value. At some point, the current will no longer increase, even with further decreases in the load resistance. This is the maximum output current of the op amp. Record this value. Sweep through the potentiometer settings again, but this time watch the output voltage of the amp. At some point, the output voltage will start to drop from the expected value — this occurs at the same point at which the output current level saturates. The output protection circuit in the op amp has kicked to prevent the current from getting too big. A consequence of this is that the output voltage begins to deviate. This will be another form of distortion.
- Repeat the above measurements with one other 324 op amp – use a completely different chip, not just another op amp on the same chip. Also, do these measurements with 2 LMC 660 chips. Record the output current limit for each of these. Compare the measured values to the data sheet values.
- Finally, using either of the op amps (324 or 660) change the source to a sine wave with an amplitude of 0.25 V_{RMS}, remove the potentiometer (or current sensing resistor), and set the potentiometer to the maximum resistance. While observing the output sinusoid on the oscilloscope, decrease the load resistance (increase the output current) until the output current limit is reached. This will be easy to discern, because the waveform will be severely distorted. As with output voltage limits, the current limitations will cause distortions in the output signal. Record a copy of the oscilloscope trace for your report.

C. Gain-bandwidth product

In this exercise. we observe the gain-bandwidth limitations of a 660 op amp. In the steps described below, we will be making amplifiers with fairly high gain. In order to avoid clipping, the input voltage must be very small. To achieve small input voltage easily, use the function generator followed by a 100-to-1 voltage divider (100 kΩ together with a 1 kΩ).

Because the amps have high gain, offset voltages may cause a problem. Before doing any AC measurements, be sure to check the output waveforms on the oscilloscope to make sure that there is no clipping. If offset voltages are causing problems, it may be necessary to reduce the input sinusoid amplitude even further or perhaps try a different op amp. Note that the small input voltages can be measured easily with the multi-meter, but it will be hard to see with the oscilloscope.



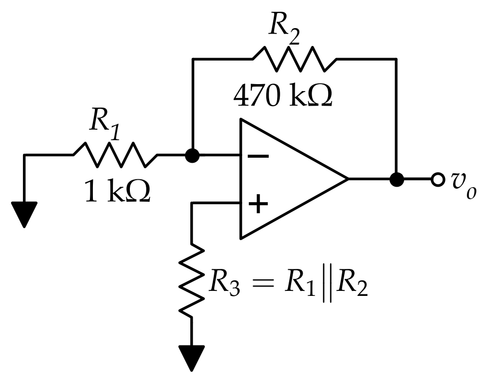
- Build a simple non-inverting amp with gain of 101 (R_2 = 100 kΩ and R_1 = 1kΩ) using the 660 op-amp with ±8-V power supplies, with a source voltage divider as shown above.
- Measure the gain at a frequency of 100 Hz. (Remember the source voltage should be measured at the input to the op-amp, not at the output of the function generator.) This is the low-frequency gain of the amp, G_o.
- Then increase the frequency until the gain is reduced to 70.7% of the low-frequency value. This is the closed-loop low-pass corner frequency, f_{cl}.
- Calculate the product $G_o f_{cl}$, which should be equal to the gain-bandwidth product of the amplifier.
- Now use the Signal Express software to set up and run a frequency response measurement from 10 Hz to 100 kHz. Save the data to put into a Bode plot using Excel.
- Repeat all of the above steps, but change the gain to 221 (R_2 = 220 kΩ and R_1 = 1kΩ). Set the function generator amplitude to 1.0 V_{RMS} so that the input to the amplifier is 10 mV_{RMS}, after being divided down.
- Repeat one more time, but change the gain to 471 (R_2 = 470 kΩ and R_1 = 1kΩ). Set the function generator amplitude to 0.5 V_{RMS} so that the input to the amplifier is 5 mV_{RMS}, after being divided down.
- Make Bode plots of the three frequency responses together on one set of axes. (You can download a copy of the Excel spreadsheet used in lab 2 or make your own.)

D. Slew rate

- Use the 324 op-amp to build an inverting amplifier with a gain of –1 ($R_2 = R_1 \geq 1$ kΩ). Use ±8 V supplies.
- It is easiest to see slew rate limits using square waves. Make the input a square wave with frequency of about 1 kHz and amplitude of 2 V (4 VPP). Observe both the input and output waveforms on the oscilloscope and concentrate on an edge (either high-to-low or low-to-high). You will probably have to decrease the time base to shorter times in order to see the transitions. Note that the output changes much more slowly than the input. This is due to the slew rate limit of the op amp. Save a copy of the trace to include in your report(s).
- Measure the slew rate, which is the slope of the output waveform in the transition region. (The voltage and time cursors will help with this measurement.)
- Replace the 324 with the 660. Record a trace showing the 660 slew rate then measure slew rate of the 660.
- Repeat once more, using the TL082 op amp.

E. Offset voltages and bias currents

Note: For this section, measure your resistors carefully and try to use resistors that are as well matched as possible.



- Build the circuit shown using the 324 op amp. Use ±8 V power supplies. Measure the DC voltage at the output, which is primarily the result of the offset voltage. Calculate the offset voltage. (Remember that V_{OS} is defined at the input, so you need to take the measured output and divide by the gain of the circuit.)
- Remove resistor R_3 (the parallel combination) and measure v_o again. Now, the output voltage should be due to the offset voltage *and* any bias current at the inverting terminal. In other words, the *difference* in voltage between this measurement and the previous one should be the result of the bias current.
- Calculate the offset voltage and bias current for the 324 op amp.
- Repeat the above measurements and calculations for the 660 op amp. (Note that the bias current of the 660 amp is ridiculously small, so there probably won't much difference between the two measurements.)
- Repeat one more time using the TL082 op amp. (This also has small input bias currents.)

Reporting

Prepare and submit a report after you have finished the lab. A template is available. Each lab group is required to submit a report (i.e. one report for two people). Be sure to include all the calculations, the various oscilloscope screen shots, and the Bode plot for part C. The report is due in one week at the usual lab time.