Lab #6

Op-Amps Gain-Bandwidth-Product, Slew Rate and DC Offsets

Purpose

This lab will explore the finite frequency response of the op-amp in more detail, and introduce Gain-Bandwidth Product and Slew Rate limitations. The lab also considers input offset voltage and bias currents

Skills to develop

After completing this lab you should be able to:

- measure an amplifier's gain-bandwidth product
- measure an op-amp's input offset voltage
- design an amplifier with prescribed input impedance and gain

New Materials you will need

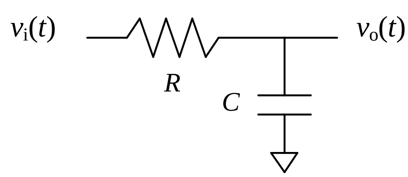
- no new parts this week

Other materials you will need (but should already have)

- proto board and jumper wires
- 741 op-amp
- resistor kit

Preliminary work

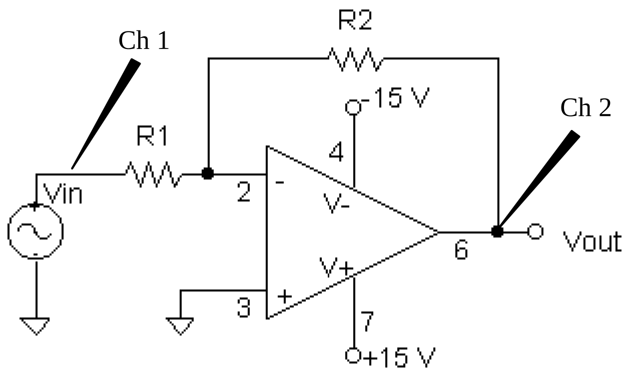
1) Sketch a Bode magnitude plot for an amplifier that has a single pole low-pass response with DC gain A_o=200,000, and unity-gain frequency of 1 MHz.
2) Sketch the setup you will use, including the resistor divider, and show the nodes where you will measure Vin and Vout for parts 1(c) and 1(d).
3) Derive an expression for the output time-domain signal $v_o(t)$ in response to a voltage step input with amplitude V_{pp} for a simple R-C low pass filter as shown:



Find the slope of the resulting waveform at its steepest point (time = 0), and express it in terms of $\omega_o = 1/RC$.

Experiments

1) Gain-Bandwidth Product



In class, we saw that the 3-dB bandwidth f_o for the closed loop amplifier is equal to the amplifier gain-bandwidth product f_t divided by (1+R2/R1). This first experiment measures f_t for your amplifier.

Connect the circuit shown using R1=1kΩ and R2=10kΩ. Use the function generator to provide Vin. Use the 10x probes to measure Vin and Vout on channel 1 and channel 2. Adjust the function generator so that Vout is 1 Vpp at 100 Hz.

☐ a) Measure the voltage gain Vout/Vin at 100 Hz (low frequency gain of circuit).
☐ b) Find the 3-dB frequency for your amplifier (output voltage drops to 0.707 relative to low frequency output amplitude). Make sure that the output remains sinusoidal without distortion. If you observe distortion, reduce the amplitude of Vin until you find the 3-dB frequency with the output undistorted.

In your lab notebook, sketch the setup you used to take this data.

For parts (c) and (d) use a divide-by-100 resistor divider between the function generator and Vin.

In your lab notebook, sketch this setup and show the nodes where you will measure Vin and Vout for the gain and 3-dB frequency measurements.

☐ c) Repeat parts (a) and (b) with R1=1kΩ and R2=100kΩ. Adjust Vin so that Vout is 10 Vpp at 100 Hz to make the low frequency gain measurement. Then reduce Vin so that Vout is 1 Vpp to find the 3-dB frequency.

☐ d) Repeat parts (a) and (b) with R1=1kΩ and R2=1MΩ. Adjust Vin so that Vout is 10 Vpp at 100 Hz to make the low frequency gain measurement. Then reduce Vin so that Vout is 1 Vpp to find the 3-dB frequency.

In your lab notebook (and report)…

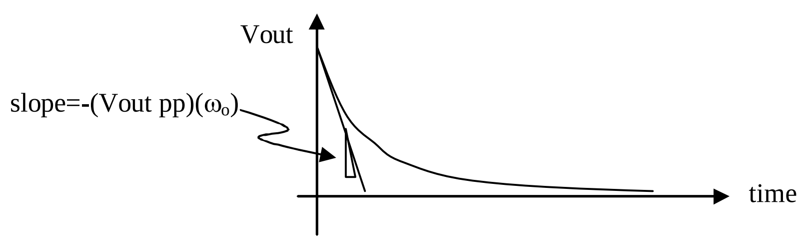
1) Make a table with columns for R1, R2, Low frequency gain, 3-dB frequency, and gain-bandwidth product, summarizing the results of your measurements. What is the average gain-bandwidth product for your three measurements?

2) Draw a Bode magnitude plot for the open-loop response of the amplifier, assuming low frequency open loop gain A_o=200,000. Plot the closed-loop response of each of the three amplifiers you built, all superposed on the same plot. What is the op-amp unity-gain frequency? Compare this value to the datasheet specification.

2) Slew Rate

Connect the inverting amplifier circuit again, using R1=1kΩ and R2=1kΩ. Use the function generator to provide a square wave input signal at 20 kHz, adjusted for 1 Vpp at the op-amp output.

a) Verify that the output waveform looks like an exponential decay function. Scale your oscilloscope output waveform so that you can make an accurate measurement of the slope of the early part of the exponential curve. Recall that this slope is equal to (Vpp)(ω_o) [V/s], where ω_o is the 3 dB frequency of a single time constant circuit (like your inverting amplifier). Estimate the 3-dB frequency ω_o from the slope of the output voltage curve.



b) Display both input and output waveforms on the oscilloscope, with appropriate scaling so that you can measure the initial slope of the output waveform. Capture this waveform to disk.

In your lab notebook, sketch the setup you used to take this data, and be sure to record the voltage amplitudes that were used. Leave room to paste in a copy of your voltage plot from the oscilloscope.

c) Increase Vin until Vout measures 20 Vpp. You should see a change in the appearance of the output waveform. What is the slope of the output waveform now? This is the *slew rate* of the amplifier (again in [V/s]).

d) Display both input and output waveforms on the oscilloscope, with appropriate scaling so that you can measure the slope of the output waveform. Capture this waveform to disk. Leave room in your notebook to paste a copy in later.

e) Adjust your function generator for a sine wave input near 1 kHz, so that the output waveform of your inverting amplifier is 20 Vpp. Increase the frequency of Vin until the output waveform begins to distort (stops looking sinusoidal). This frequency is called the full-power bandwidth.

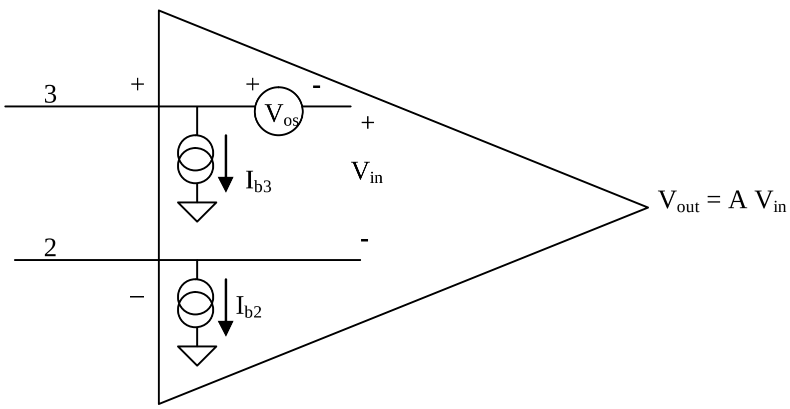
In your lab notebook you should address the following (also in your report)…

1) Print your output waveform for the small signal case (part b), and show the initial waveform slope on the plot (just use a pen if you like). What is your calculated 3-dB frequency ω_o? What is the steepest slope of your output voltage waveform, in [V/μs]?

2) Print your output waveform for the large signal case (part d). What is the steepest slope in [V/μs] in this plot? Record this value as the slew rate of your amplifier. How does it compare to the data sheet specification for slew rate?
3) Assuming the same 3-dB frequency as in the small signal measurement, what is the steepest slope of an exponential waveform with 20 Vpp magnitude? If the slew rate of the amplifier is less than this value, we say that the amplifier is *slew rate limited.* If the slew rate is larger than this value, then the output waveform looks like an exponential and we say it is *time constant limited*.
4) Record your measured value for the full power bandwidth. Compare this value to the small signal bandwidth measured in part (a). What is the maximum slope of the output waveform at the maximum full power frequency? Recall that a sine wave has max slope given by (Vampl)(ω) = (Vpp/2)(ω). How does this max slope compare the the amplifier slew rate you calculated in part (c)?

3) Input Offset Voltage and Bias Currents

Use the following model for the input portion of your op-amp.



☐ a) Connect a non-inverting amplifier circuit, using R1=100Ω and R2=100kΩ (R2 is the feedback resistor). Ground Vin, and measure the output DC voltage using the DMM. This voltage is mostly due to V_{os}.

☐ b) Now replace R2 with a 1kΩ resistor, and replace the ground connection at the non-inverting input to the amplifier with a 10MΩ resistor to ground. Measure the output DC voltage using the DMM. This voltage is mostly due to I_{b3}.

Sketch your measurement setup in your lab notebook.

In your lab report…
1) What is the gain for the offset voltage measurement in part (a)? (What is your input voltage signal, and what amplifier configuration are you using?) Is the gain sufficiently smaller than the open loop DC gain of the amplifier A_o for us to ignore the effect of finite amplifier gain? What do you calculate for the input offset voltage of the amplifier V_{os}? How does it compare to the data sheet specification?
2) In part (b), assume all of the measured voltage is due to the input bias current I_{b3} passing through the 10MΩ resistor. What is I_{b3}? Assuming that I_{b2} is comparable to I_{b3}, can you ignore the contribution of I_{b2} and V_{os} when making this measurement (assume that you want 10% accuracy in your measurement, for instance).