EE321 Lab

Operational Amplifiers, Part 1 — Frequency Characteristics

The purpose of this lab is to examine the frequency response of the operational amplifier. Its finite frequency response will be investigated using a simple inverting operational amplifier circuit. The inverting amplifier will be found to behave like a single time constant low pass (LP) filter.

Inverting Amplifiers

1. Construct an inverting amplifier (designed as part of the pre lab) having an input resistance of 1 kΩ and a gain of about 5. Use the 741 op-amp with ±15 Volt supply voltages. Employ good breadboard technique by using the long bus lines on your protoboard for each of the supply voltages and ground.
2. Apply a 1 kHz sine wave to the input. Display both the input and output on the scope.
   (a) Measure the gain and compare with the theoretical gain.
   (b) Confirm that the op-amp inverts the input by displaying both input and output on the scope (sketch waveforms).
   (c) Vary the DC level of the input sine wave (offset) to confirm that the amplifier responds to DC inputs.
   (d) Increase the input amplitude to determine the DC output voltage levels at which the output ‘saturates’.

   These tests can be quickly done to make sure your amplifier is working correctly.

Slew Rate

3. Change the input to a square wave. At 100 Hz adjust the output to be 20 V p-p with no saturation or DC level. Now increase the signal frequency to about 100 kHz. What has happened to the output? The output of the op-amp can not change faster than a certain rate, called the ‘slew rate’. (See Figure 2.29 of Sedra & Smith.) Measure the slew rate of this 741 op-amp (the slope in Volts/μs). Compare with the value given in the op-amp specs.
4. Change the input back to a sine wave. Decrease the frequency until the 20 V p-p sinusoidal output can be obtained without distortion. Find the frequency f_M where the distortion just begins (don't try to get too close). This is related to the slew rate of the op-amp as measured in the preceding part. SR=$\omega_M V_{o\max}$, where $V_{o\max}$ is the amplitude of the output voltage (p. 100 of Sedra and Smith). Check this relationship.
5. Repeat either one of these slew rate measurements for the 411 op-amp. Compare this result to the data sheet.

Open Loop Gain - The gain of the op-amp itself.

6. The finite open-loop gain of an op-amp in the inverting configuration may be determined by measuring the small voltage at the inverting (-) input of the op-amp.
   (a) Re-construct the 741 inverting amplifier and increase the gain to 10. Set the output voltage to be 20 V p-p sine wave at a frequency of 1 kHz. Sketch the circuit. Measure the voltage at the inverting input of the op-amp with the X1 probe.
   (b) What open loop gain does this imply (it should be near 1000)?
   (c) Repeat at frequencies of 10 kHz and 100 kHz. If necessary decrease the output if the slew rate causes distortion.
   (d) How does the op-amp gain appear to vary with frequency?
   (e) Plot $|A|(dB)$ vs. frequency on log scale, find where $|A|$ is 0 dB.

7. At 10 kHz note the phase shift between V_{out} and V_{-}. What is its approximate value, and why is it present?

Frequency Response of the Inverting Amplifier with Gain of 10

8. Use the same circuit as used in 6) and 7). To make sure there won't be any distortion during this measurement, set the output voltage to be near 0.1 V p-p at a frequency of 1 MHz. If necessary, decrease the signal amplitude, so that the slew rate does not cause distortion. Measure the cutoff frequency f_0 of the circuit by adjusting the frequency until the gain is .707 of its low frequency value (measure the output at 100 Hz, then increase the frequency until the output drops by a factor of 0.707).

   Why is the cutoff frequency f_0 also called the 'half power' frequency or the '3dB' frequency ($f_{3\text{dB}}$)?

   Find f_t, the unity-gain bandwidth of the op-amp itself, using Eq (2.27) in Sedra and Smith (f_0 is the same as $f_{3\text{dB}}$). Compare your f_t to that in the data sheet.

9. Find the unity gain bandwidth f_t for the 411 using the same method.

10. Use a different circuit to determine the unity gain bandwidth f_t of the 741 op-amp. Connect it as a unity gain follower and measuring the 3 dB (half power) frequency. Use the X10 probe for measurements above 1 MHz. Keep the output amplitude small to ensure that the **slew rate** is not affecting the signal amplitude. Compare with specs.

    NOTE – The breadboard does not work at high enough frequencies to be able to use this method for the 411.

Comparison of op-amps.

11. From the data obtained so far, which type of op-amp, the 741 or 411, is better and why? Which is closer to an ideal op-amp? Which has a more informative spec sheet?

Extra credit

12. Given the measured value of f_t, what 3 dB frequency would you expect for the 411 connected to have a **non-inverting** gain of 10 and 100? Test one of these predictions by actual measurement.

Pre-Lab

Read the lab before answering these questions.

1. Design an inverting amplifier having an input resistance of 1 kΩ and a gain of about 5. Check the 741 spec sheet for the pin connections to the op-amp package, and label the pin numbers on your circuit diagram.
2. Sketch the distortion to a square wave caused by slew rate. How can this wave form be used to find the value of the slew rate?
3. Sketch the distortion to a sine wave caused by slew rate. How can the sine wave be used to find the value of the slew rate? Use a different method than was used for the square wave.
4. Find the slew rate for the 411 and 741 from their data sheets.
5. What is the difference between the open-loop gain of the op-amp and the gain of the inverting amplifier built from it?
6. What is the phase shift of a single time constant LP filter at a frequency much higher than the cutoff frequency?
7. How are f_t of the op-amp and f_0 of the inverting amplifier circuit related? Define both frequencies. How does the relationship differ for inverting and non inverting amplifiers?
8. Find f_t for the 411 and 741 from their data sheets.