Lab-5, Exploring the Op-Amp

Physics U371/372, Electronics for Scientists, Fall 2007
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This experiment will acquaint you with the robust, not-very-fancy 741 op-amp. It was developed by Fairchild Semiconductor in 1966, yet is still one of the most used today. Op-amps have superior properties compared to equivalent circuits made from discrete components. Op-amps are inexpensive (as low as $0.25), far simpler to use, require less wiring, and occupy a smaller space. In this lab you will measure a number of op-amp properties. In future experiments you will use them in various applications.

As always, before wiring a circuit, you should **draw the circuit diagram**. (To emphasize this point, the circuit diagram is deliberately omitted here.) The circuit diagram should show the relevant pin connections, with the pin numbers and designations indicated. Note that the pin diagram is for the TOP view, opposite to that for the transistor. For example, the pins for the op-amp power are often labeled $V_{cc}= +V_o$ and $V_{ee}= -V_o$. To see what the op-amp requires, refer to the specifications (attached, in textbook, or search the web).

You will encounter the idea of feedback – especially negative feedback – for the first time. This is a powerful concept applied in electronics. (I might add that while in everyday life positive feedback is usually "good" and negative feedback is "bad," in electronics it is usually just the other way around.)

Items needed:

breadboard, wiring kit, resistors, connecting cables
DMM, ±12-15V power supply for $+V_o$=+15V (V_{cc}) and $-V_o$= -15V (V_{ee}),
+5V power supply, function generator, scope
NJM4741 quad op-amp, semiconductor data

I. Preliminary Test

Write down the specifications for the 4741 (maximum values, input/output impedance, input bias/offset, and slew rate)

1. Connect $+V_o$, $-V_o$ (~ ±15 V) to power the 741; and a +5 V supply between the inverting and noninverting inputs of a 741. Don't mistake the power supply voltages ($+V_o$ and $-V_o$) with the inputs denoted as V_+ and V_- in the textbooks.
   Q: What is V_{out}?

2. Reverse the polarity of the 5 V supply across the op-amp inputs.
   Q: What is V_{out} now?
   Q: Are the results what you expect from the open loop gain?

3. Q: Explain why you would not want to use a 741 op-amp for music amplification with an 8ohm speaker.

II. Input Offset Voltage

For ideal op-amps the output should be zero when the inputs are connected together. For real op-amps this is not normally true. The output voltage in this case is called output offset voltage. It may be a problem because it can depend strongly on temperature and supply voltage. Construct an inverting amplifier with a nominal gain of G = -100.

1. **Explain** why you chose the resistors.
2. Measure V_{out} when the input is grounded.
3. Compute the **input offset voltage**.
   Q: Does the input offset voltage agree with the specifications?

III. Frequency Dependence

Devices are often limited in their "gain-bandwidth product." This means that the gain ($G \equiv V_{out}/V_{in}$) decreases as the frequency (f) increases, such that their product is a constant. Here, you will measure the voltage gain of a **sine wave** as a function of the f. Construct an inverting amplifier with a nominal gain of $G_o = -10$.

1. Connect the V_{in} and V_{out} sine waves to the two scope inputs (AC coupling).
2. Starting from f=100 Hz, record the RMS voltage amplitudes while increasing f (by factors of 5 or 10) up to 1 MHz. Note that V_{in} may change with f. Note: always keep the input voltage low enough to limit the output voltage to less than the power supply voltages (~15 V).
3. From a rough plot of the measured G(f) on a log-log graph, see where you need to fill in extra data points, especially near $0.7*G_{max}$.
4. Next, repeat the G(f) measurements with $G_o = -100$.
5. **Plot G(f)** for both G_o's on the same graph.
   Q: At what frequency is the "3-*dB* point", f(3-*dB*), where G_{max} is reduced to $0.707*G_{max}$, (equivalently, where power is reduced by a factor of 0.5)?
   Q: Does f(3-*dB*) agree with the specification graph?
6. Compare the gain-bandwidth product [G_{max} * f(3-*dB*)] for the two G_o's.

IV. Slew Rate

Op-amps and transistors have difficulty swinging large voltages at high frequencies. This is quantified by the time derivative of voltage (V/microsecond) and called "slew rate." Using a G_o = -2.0 circuit, set the input frequency to f_o=40 kHz **sawtooth** waveform.

1. Adjust the input amplitude to get an output amplitude $\mathbf{V_{pp}}$ of about 1 volt and **compute gain**.
   Increase the input amplitude to see where the gain begins to decrease.
   Make sure the output voltage remains below the maximum output voltage of the 741.
2. **Plot gain** versus $\mathbf{V_{pp}}$ in the transition region.
   Q: What is the **value of $\mathbf{V_{pp}}$** where the gain begins to decrease?
3. **Compare** the measured maximum slew rate $(V_{pp}/2)/(T/4)=2f_oV_{pp}$ to the specification.