Lab 5: Introduction to Operational Amplifiers

Parts List

- Resistors: 50, 1k, 10k, 10k potentiometer
- Capacitors: (2×) 0.1 - 1 μF
- OpAmps: 741, 411

5.1 Goals of this Lab

A first look at operational amplifiers ("op-amps"), their properties, and two fundamental op-amp circuit configurations. We will use the two op-amp types, the 741 and the 411, which have identical external connections and are essentially the same except that the 411 has JFET input transistors and the 741 has BJT inputs.

5.2 Op-amp Connections and Offset Voltage

Figure 1 gives the connections for the 741 or 411 op-amps housed in the 8 pin dual-in-line (DIP) package, as we will use in lab. We will begin by setting up a 741 op-amp.

Obtain a 741 "chip" and connect it in the inverting amplifier configuration shown in Fig. 2. The input DC power connections, \( V^+ \) and \( V^- \), should be connected to +15 V and −15 V, respectively. The 10 kΩ variable resistor should be connected to the offset inputs as shown. It is probably easiest to use one of the small pots that you can put right into your breadboard. This potentiometer is used to trim out any small offset between the op-amp inputs, so that the output will be zero if the inputs are equal. Zero any DC offset in the output by grounding the input, observing the output on the oscilloscope (DC coupled!), and adjusting the variable resistor as necessary. If the output is unstable, try placing bypassing capacitors (≈ 0.1 – 1 μF) across the input power connections to ground; this can eliminate pickup of unwanted high frequency noise. (Be sure the capacitors are rated for 15 V.)

5.3 Inverting Amplifier

Replace the 100 kΩ resistor with 10 kΩ in the preceding circuit. Input a 1 kHz sine wave. Measure the voltage gain. What is the maximum amplitude ("swing") of the output? In particular, does the output go all the way to the ±15 V rails? Turn down the input amplitude so that the output isn’t more than 5V peak-to-peak. How well does the output reproduce input if you use a triangle or square
wave forms? Switch back to a sine wave and increase the frequency of the input. At what frequency (approximately) does the amplifier no longer reproduce the input well? It may be easier to start at the highest frequency the function generator can produce, observe a distorted output, and then reduce the frequency until the distortion mostly goes away.

5.3.1 Input Impedance

Measure the input impedance by putting an additional 1 kΩ resistor in series at the input. This forms a voltage divider with the input impedance. (Note that here you are measuring the $Z_{in}$ of the entire inverting amplifier circuit, not the intrinsic $Z_{in}$ of the op-amp, which is very large.) Use a 1 kHz sine wave as the input signal. Use the observed amplitude ratio to measure the input impedance and compare this measurement with what you would expect from Fig. 2.

5.3.2 Output Impedance

Try measuring the output impedance by loading the output with a 50Ω resistor. To see anything, you will likely need to replace the 10 k feedback resistor with the original 100 k resistor to boost the gain, turn down the input amplitude so that you aren’t clipping, and make sure you have a 1 kHz sine wave input. You may still not be able to see any effect, in which case estimate an upper limit on $Z_{out}$.

5.4 Slew Rate

Figure 3 shows an op-amp in a configuration analogous to the transistor emitter follower. It is used here to study op-amp “slew rate”, which is a measure of the speed of the device. To study this, we will input a square wave, and note the slope of the transitions between the two levels of the square wave on $V_{out}$ with an oscilloscope. This slope, usually reported in units of V/µs, is the slew rate.

5.4.1 741 Slew Rate

Start by measuring the slew rate of the 741 op-amp. To obtain a good measurement, use a square wave input with large but not saturated outputs (±15 V). You will likely need to adjust the offset of the input square wave to get the signal centered around ground. The “up” and “down” slewing may be different. Compare with the claimed 741 slew rate of 0.5V/µs. Note that there may appear to be two different slopes, including a faster response right after the voltage starts changing in the positive direction, then a slower response as the output voltage catches up with the input. The early, fast response is largely due to stray capacitance, both in the op-amp but also in the breadboard which

Figure 2: Inverting amplifier using 741 op-amp.
is helping the op-amp provide current. The later, slower slope is the direct op-amp slew we want to measure. The Fairchild 741 datasheet shows this effect in the response to a square wave quite clearly.

5.4.2 411 Slew Rate

Repeat the measurement of the slew rate for a 411 op-amp. Compare with the claim of $15V/\mu s$. Input a sine wave and note at what frequency the output begins to drop for a large, but non-saturated output. For a slew rate $S$, the op-amp amp should be able to deliver a sine wave of constant amplitude $A_0$ up to a maximum frequency $f_{\text{max}} = S/(2\pi A_0)$. Check that this roughly agrees with the slew rate measured with the square wave.

5.5 Non-inverting Amplifier

Construct the non-inverting amplifier of Fig. 4. Determine its voltage gain using a 1 kHz sine wave input. Measure the input impedance, as before, using an input series resistor (in the 100 k to 1 M range). In this case we are measuring the intrinsic $Z_{\text{in}}$ of the op-amp. Beware of the limitations of your measuring device: Is its $Z_{\text{in}}$ large compared to the op-amp? Also, the $Z_{\text{in}}$ could have a capacitive, as well as a resistive, component. Check this by varying the input frequency.