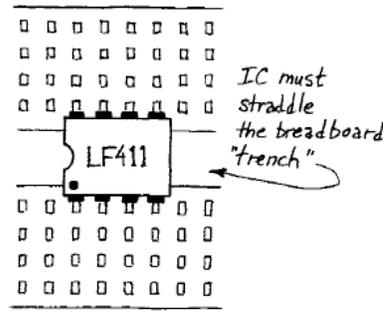


Physics 120 Lab 4 (2019) - Operational Amplifiers - Basics

Today we move into the world of feedback and use operational amplifiers (op-amps) as a powerful approach. But before then we ask you to build your first op-amp circuit we wish to remind you of two points:

- First, note how the integrated circuit (IC) package goes into the breadboard; it straddles the trench. The package style is called dual in-line package ("DIP"). The "dot" marks pin 1 and the numbering proceeds counterclockwise across bottom and then wraps around to the top, *i.e.*, 1 to 4 and then 5 to 8 for the IC below.



- Second, the op-amp *always* needs power applied at two pins. This usually means $\pm 15\text{ V}$. Circuit diagrams ordinarily *omit* the power connections. On the other hand, many op-amp circuits make no direct connection between the chip and ground, yet the circuit always includes a ground that is also the common lead of the $\pm 15\text{ V}$ dual supply.

4-1. Open-loop test circuit

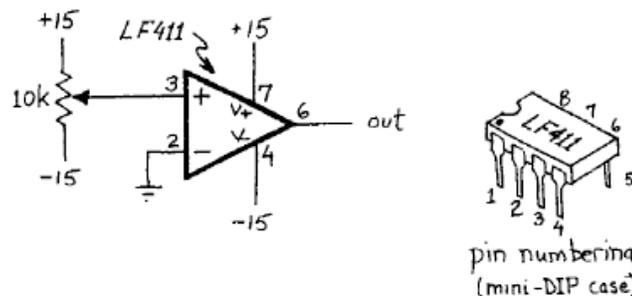


Figure 4.1: Open-loop test circuit.

Build the circuit in Figure 4.1. Connect up two DMMs configured as Voltmeters, one at the input (pin 3) and one at the output (pin 6). Astound (!) yourself by watching the output voltage as you *very* slowly advance the potentiometer with a fine screw driver, trying to apply 0 Volts. Take a **SCREENSHOT (2 pts)**. *Hint: Zoom out on the horizontal scale so that the time base of the oscilloscope is sweeping, and use a more sensitive range for the Input (e.g., 50 mV/div) than the Output (e.g., 5 V/div). You should see the output swing as you dither the input near 0V; freeze the screen and take the SCREENSHOT.*

Is the behavior consistent with the LF411 or, equivalently, AD711 specification that "Gain (typical) = 200 V/mV", *i.e.*, $A(\text{DC}) = A(\omega \rightarrow 0) = 2 \times 10^5$ or equivalently, $A(\text{DV})=200\text{V/mV}$. Explain (1 pt).

4-2. Voltage follower

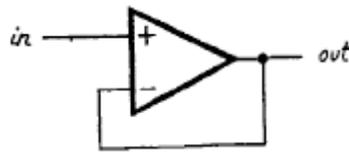


Figure 4.2: Op-amp follower.

Build the voltage follower shown in Figure 4.2, using a LF411 or AD711 op-amp. What is the voltage gain, including the sign (1 pt)? Try a 1 kHz sine wave with a 10 V amplitude as the input signal. Document the input/output relation with a **SCREENSHOT** (1 pt). How high in frequency can you go with a sine wave before the gain falls-off by a factor of $1/\sqrt{2}$? Document your conclusion with a **SCREENSHOT** (1 pt).

4-3. Non-inverting amplifier

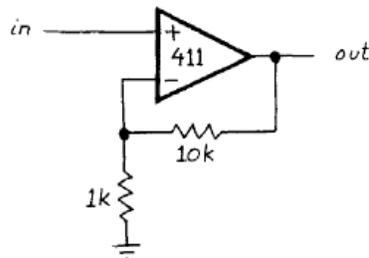


Figure 4.3: Non-inverting amplifier.

The non-inverting amplifier is a generalization of the follower, excepts that only part of the output voltage is feed back to the input. Build the non-inverting amplifier shown in Figure 4.3. What is the expected voltage gain (1 pt)? Try a 1 kHz, 1-Volt sine wave as the input. Document the gain with a **SCREENSHOT** (1 pt).

Let's measure the circuit's input impedance, with both resistive (R_{in}) and reactive (C_{in}) components, at 1 kHz. Note: R_{in} is so large that $1/(i\omega C_{in})$ dominates. Put a $1\text{ M}\Omega$ resistor in series with the input. You can calculate the value of C_{in} from the observed value of f_{3dB} (using sine waves) or the observed decay constant τ (using a low frequency square wave); pick one or the other and document your result with a **SCREENSHOT** (2 pts).

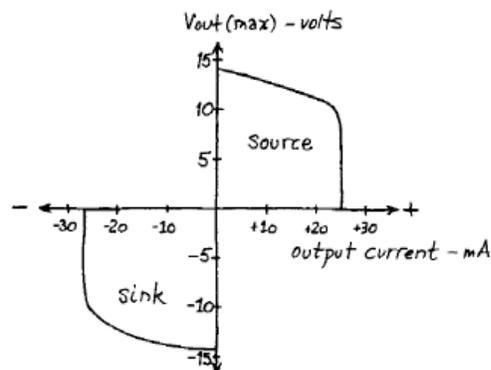


Figure 4.4: Effects of limit on op amp output current. The current is limited to $\pm 25\text{ mA}$ over an output range of 10 V and you get less current if you push the output to swing to a value close to either supply voltage.

Attempt to measure the output impedance using the resistance substitution box to form load resistors of different value. Note: You probably can do no more than confirm that Z_{out} is very low. Do not mistake the op amp's limited current output, which will clip a waveform, for high Z_{out} . Keep the 1 kHz input signal small here, say 0.02 V, to avoid (if possible!) running into this current limit

(Figure 4.4). Document your effort with one or more **SCREENSHOTS (2 pts)**. What happens the output impedance as the frequency increases (**1 pt**)?

4-4. Current-to-voltage converter

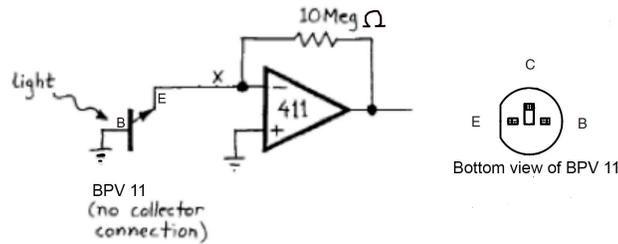


Figure 4.5: Photodiode photometer circuit.

Use a BPV 11 phototransistor as a photodiode in the circuit in Figure 4.5; the lead with the arrow is the emitter (E) and the lead that is grounded is the base (B). Here, light is converted directly into an electrical current and thus the photodiode serves as a source of current. Why does the above configuration of the op-amp approximate an ideal ammeter (**1 pt**)?

Look at the output signal with room light and if the DC level is more than 5 Volts, reduce the feedback resistor to 1 MΩ. What is the average DC output level (**1 pt**)? What is the percentage “modulation” by the fluorescent room lights? Document your effort with a **SCREENSHOT (1 pt)**; this is a rare time to have the same signal input into "AC" and "DC" coupled channels. What input photocurrent does the output voltage level correspond to (**1 pt**)?

Try covering the phototransistor with your hand to modulate the light level. Look at the “summing junction” (point X) with the scope as V_{out} varies. What should you see? What do you see? Document your effort and conclusions with a **SCREENSHOT (1 pt)**.

(Note that you will rebuild this circuit for use in Laboratory Exercise 5.7)

4-5. Inverting amplifier

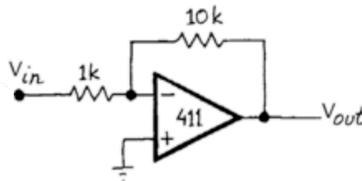


Figure 4.6: Inverting amplifier.

Construct the inverting amplifier in Figure 4.6. Drive the amplifier with a 1 kHz sine wave with a 1-Volt amplitude. What is the expected gain (**1 pt**)? What is the measured gain (**1 pt**); document with a **SCREENSHOT**? What is the maximum output swing (**1 pt**); document with a **SCREENSHOT**?

Let us now address linearity. Try a triangle wave. What do you see (**1 pt**); document with a **SCREENSHOT**? Try *sine* waves of different frequencies. Note that at some fairly high frequency that amplifier cease to work well, *i.e.*, a *sine* in does not produce a *sine* out. Document your effort with a pair of **SCREENSHOTS**, one at low frequency and one at the approximate break frequency (**2 pts**). Is the break frequency consistent with the manufacturers stated gain-bandwidth for the LF411 or, equivalently, AD711 (**1 pt**)?

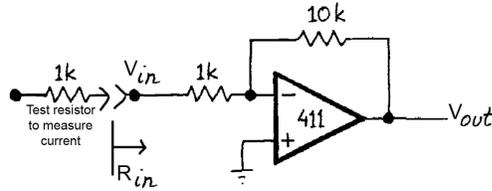


Figure 4.7: Inverting amplifier.

Again drive the circuit with a *sine* wave at a frequency of 1 kHz. Measure the input impedance (R_{in}) of this amplifier circuit, *i.e.*, from the V_{in} terminal, by adding an additional 1 k Ω test resistor in series with the input (Figure 4.7) and measuring both input voltage *and* input current (via the voltage drop across the test resistor). *Hint: Recall that you will need to measure the voltage difference across two test probes.* Document your effort with a **SCREENSHOT**, being careful to label voltage and (equivalent) current scales. (2 pts).

4.6. Summation with an inverting amplifier

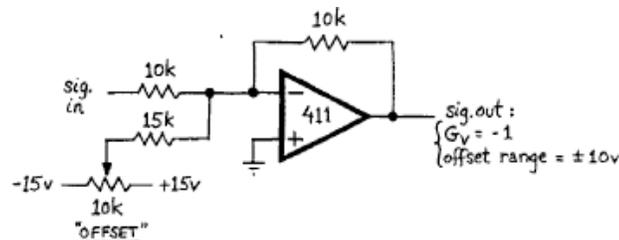


Figure 4.8: Summing circuit: DC offset added to signal.

The circuit in Figure 4.8 sums a DC level ("offset") with the input signal. Thus it lets you add a DC offset to a signal. Build the circuit using a potentiometer and document, through a pair of **SCREENSHOTS**, the summation of a 10 kHz signal with both positive and negative DC offsets (2 pts).

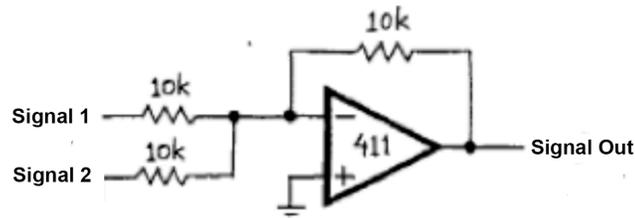


Figure 4.9: Summing circuit: Addition of two signals.

The circuit in Figure 4.9 sums two oscillatory signals through equal gains. Build the circuit using a 10.0 kHz signal and a 10.1 kHz signal from the second generator. Keep the amplitude of the two inputs the same and in the range of Volts, not fractions of a Volt. What is the shape of the waveform (1 pt)? Document with a **SCREENSHOT** and explain what you observe (2 pts).

How would you extract a waveform at the difference frequency of 10.1 kHz - 10.0 kHz = 100 Hz from the above output; document your proposed additional circuitry (2 pts)? *Hint: think of diodes, resistors, and capacitors.* Build your circuit and demonstrate your result with a **SCREENSHOT** and a brief description of the observed waveform (2 pts).

36 points total