Physics 120 Lab 5 (2019) - Operational Amplifiers - Advanced topics

Now that we had our fun working with op-amps as idealized components, we will expose their limitations as well as consider interesting circuit applications.

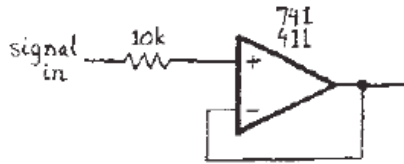## 5-1. Op-amp limitations: Slew rate

Figure 5.1: Slew rate measuring circuit; the series resistor prevents damage if the input is driven beyond the supply voltages.

Begin by measuring slew rate, *i.e.*, the rate of change of the output, with the circuit in Figure 5.1 for *both* the model LM741 and model LF411 (or AD711) op-amps. Do this in two stages:

Square wave input

Drive the input with a *square* wave in the neighborhood of 1 kHz and look at the output with an oscilloscope at low (~ 0.1 V) and high (~ 10 V) input amplitudes. Measure the slew rate from the slope of the transitions and document with **SCREENSHOT**s. A few pointers:

- Find a straight section near $V_{out} = 0$; avoid the regions near the limits of output swing.

- Full slew rate is achieved only when a large difference signal is present at the input.

- The rates for slewing up versus down may differ.

Document with four **SCREENSHOT**s, i.e., low and high input amplitudes for each amplifier (**4 pts**) and estimates of the slew rate for each condition (**4 pts**).

Sine input

Switch to a *sine* wave, and measure the frequency at which the output amplitude begins to drop for an input level of 0.1 Volt for each amplifier (**2 pts**); document your result with a **SCREENSHOT** for each amplifier Are these results consistent with the slew rate that you measured for the square wave input for each amplifier (**2 pts**)?

5-2. Op-amp limitations: Offset voltage

Real op-amps have an offset voltage (V_{OS}) to the input, as illustrated in Figure 5.2. Measure the offset voltage (V_{OS}) using the op-amp to amplify the input offset.
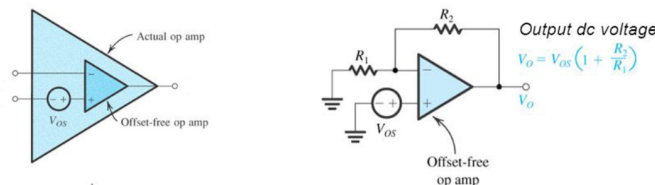

Figure 5.2: Voltage offset model for an op-amp.

Construct a x1000 non-inverting amplifier with the LF741 op-amp (Figure 5.3). The trick is to eliminate effects of the bias currents (I_B), i.e., currents that flow from the V_- and V_+ terminals toward ground, much as these are very small. Is the resistor $R_{in} = 10$ kΩ at V_+ small enough to avoid problems from the additional voltage drop $R_{in}I_B$ (**1 pt**)? If not, what should you do as to make the effects of I_B

negligible (**1 pt**)? Finally, compare your measured offset voltage with the manufacturers specifications for this op-amp (**1 pt**), i.e., $V_{OS} = 0.8$ mV (typical) to 2 mV (maximum).
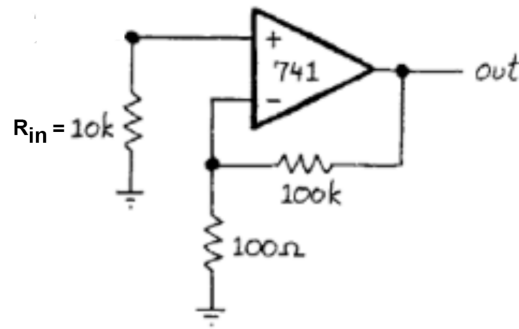

Figure 5.3: Offset measuring circuit.

Trim the offset voltage to zero using the recommended network (Figure 5.4). Document your result (**1 pt**).

Figure 5.4: 741 Offset trimming network.
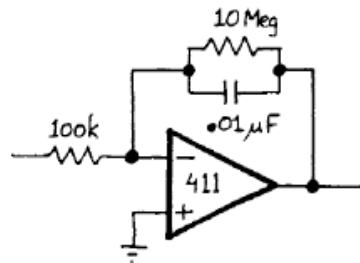
5-3. Integrator

Figure 5.5: Integrator.

Construct the active integrator shown in Figure 5.5 using a LF411 or AD711 op-amp. Try driving it with a 1 kHz square wave. *Note: this circuit is sensitive to small DC offsets of the input waveform, i.e., its gain at DC is 100. If the output appears to go into saturation near the ±15 V supply voltages, you may have to adjust the function generator's **OFFSET** control.* From the component values, predict the peak-to-peak triangle wave amplitude at the output that should result from a 2 V_{pp} (peak-to-peak), 500 Hz square wave input (**1 pt**). Then try it and document your result, including a **SCREENSHOT** (**1 pt**). Do the predicted and measured values agree? Why or why not (**1 pt**)?

What is the function of the 10 MΩ resistor in the circuit in Figure 5.4 (**1 pt**)? What would happen if you were to remove it? Try it and document your result with a **SCREENSHOT** (**1 pt**)! Have "fun" twiddling the function generator's DC offset; this circuit will help you gain a gut feeling for the meaning of an integral!

5-4. Differentiator

The circuit in Figure 5.6 is an active differentiator. Build it and drive it with a 1 kHz triangle wave with a 1 V amplitude. Document and describe your results, including **SCREENSHOT**s (**2 pts**).

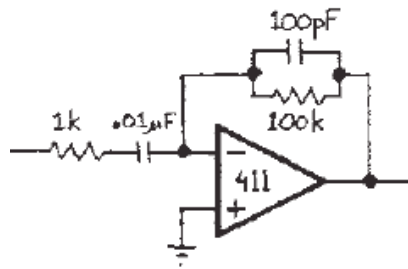Triangle waves and square waves are obvious choices as inputs; you should specify the expected and measured results (**2 pts**).

Figure 5-6: Differentiator.

A note on stability

      Differentiators are inherently unstable because a true differentiator would have a rising response that scales as voltage proportional to frequency. This will violate the stability criterion for feedback amplifiers as small fluctuations at high frequency will be phase shifted and amplified. To circumvent positive feedback, it is traditional to include a series resistor at the input, and a parallel capacitor across the feedback resistor, to convert the differentiator (output $\propto f$) to an integrator (output $\propto 1/f$) at high frequencies; see class notes.

5-5. AC amplifier: Microphone amplifier

      Here we introduce the "single-supply" op-amp. It that allows you to operate with a single + 5 V supply; this is a common computer voltage. The op-amp, the LM358 dual (Figure 5.7), can operate with $V_+ = +15$ V and $V_- = -15$ V. However, it can also be operated with $V_- = $ GND since the input common-mode range includes V_-. Further, the output can swing all the way down to V_-.

      The LM358 is used to amplify the output of a microphone in the circuit of Figure 5.7, a signal of < 20 mV, to generate output swings of a few volts. The op-amp is configured as an "AC amplifier", with an adjustable Gain ≈ 10 to 100, that further passes the input bias voltage to the output without amplification (Gain = 1 at DC). The voltage divider serves to bias the input part-way on the positive swing, i.e., between $V_- = 0$ V and $V_+ = +5$ V.

      The microphone is an "Electret" type. The sound sensor is capacitive; sound pressure varies the spacing (d) and thus capacitance (C) between two plates, the charge on the plates is held nearly constant, so the output voltage of the capacitor changes with sound pressure according to $V = Q/C$ so $\Delta V \propto \Delta d \propto \Delta$(pressure) for small deviations. It includes a FET buffer within the microphone package;

think of the FET as an infinite resistance input to maintain the charge on the sound sensor. The FET's output current is converted to an voltage by the 2.2 kΩ pull-up resistor, so the output impedance of the microphone is just 2.2 kΩ.
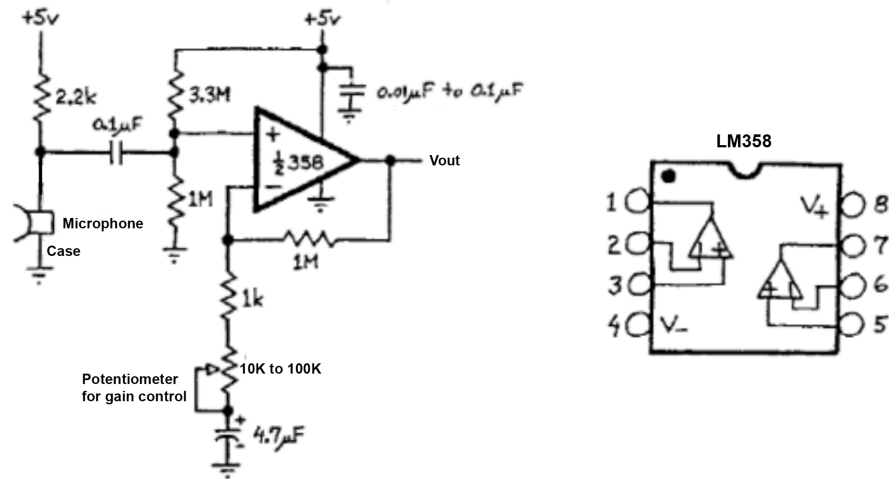

Figure 5-7: Single-supply microphone amplifier. The microphone has a polarity; the case, connected to one of the pins with a tab, is grounded.

Construction hint

For circuits with multiple modules, like the microphone circuits and amplifier, build the circuit in sections and test each section separately, i.e., the microphone part and then the non-inverting amplifier part. Combine the working sections.

Plot traces of your voice, or music, fed into the microphone, visualized on the oscilloscope and saved as **SCREENSHOT**s (**2 pts**). For voice, it may be useful to use the "Untriggered Roll" at low sweep rates with the oscilloscope trigger set at "Auto" (remember to return it to "Normal") and use the "Stop" key as desired. Estimate, through even crude measurements, the frequency response of the microphone system, and briefly describe the calculation that led to your estimate (**2 pts**).

Bonus (**1 pt**). What happens to sound, in terms of harmonics, as the output of an op amp saturates? Try an experiment if need be!

Bonus (**2 pts**). Use the Fourier Transform feature under MATH on the oscilloscope and show, with a **SCREENSHOT**, the spectrum of a signal with roughly pure tones, e.g., Chamber music).
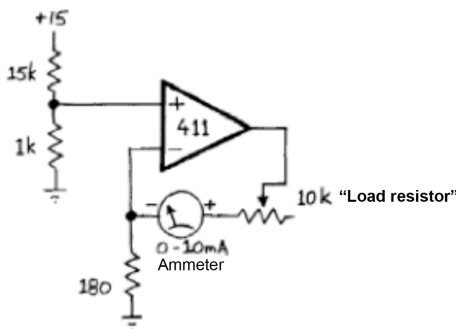
5-6. Current source

Figure 5.8: Current source for a floating load.

Build the op-amp current source for a floating load (Figure 5.8) using a LF411 or AD711 op-amp. Derive or write an expression for the expected current and evaluate using the values for the given components (**1 pt**).

Vary the "load" potentiometer and monitor the current, using the bench top DMM as an Ammeter. Record your measurements. Answer these questions:

1) What feature of the amplifier limits the maximum load (maximum resistance) that the Op Amp can supply with current (**1 pt**)?

2) What is the maximum load for this circuit (**1 pt**)?

3) What happens to the voltage on the "V₋" input (pin 2) as the load is varied (**1 pt**)? Why (**1 pt**)?
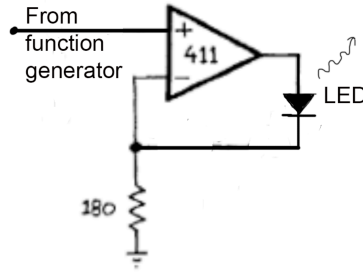
5-7. LED driver

Figure 5.9 Current source as LED driver.

Our current source can be readily used to driven a light emitting diode (LED), *i.e.*, a device that emits light when current flows in the forward direction with an intensity that is linearly proportional to the current (Figure 5.9). Use a 0 V to 1V peak-to-peak 2 Hz triangle wave from your function generator; this requires that you use an offset.

Construct the circuit with the LED close to the phototransistor of the (saved) circuit of Laboratory Exercise 4.4 and use the output of the phototransistor circuit to show that the LED is driven by the function generator (**2 pts**).

Why is it wise to run an LED from a current source rather than a voltage source (**1 pt**)?

Change from a triangle to a square wave and vary the frequency. At approximately what frequency does the light go from "flickering" to "fusion" **1 pt**?

37 points total

3 points bonus!