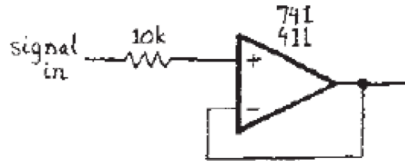


# Physics 120 Lab 5: Operational Amplifiers - Advanced topics

## 5-1 Op-amp Limitations

### a. 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 above for *both* the model LM741 and model LF411 op-amps. Do this in two stages:

#### 1) Square wave input

Drive the input with a *square* wave in the neighborhood of 1 kHz and look at the output with a scope. Measure the slew rate from the slope of the transitions and document with **SCREENSHOTS**.

#### *Suggestions:*

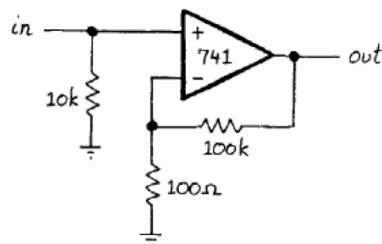
- Find a straight section near  $V_{out} = 0$ ; avoid the regions near the limits of output swing.
- Full slew rate is achieved only when a large difference signal is present at the input.
- The rates for slewing up versus down may differ.

See what happens as the input amplitude is varied for *each of the two amplifiers*. Document with **SCREENSHOTS** at low (0.1 V) and high (10 V) input amplitudes.

#### 2) 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. Is this result consistent with the slew rate that you measured in part 1)? Document your result with a **SCREENSHOT** for each amplifier.

### b. Offset Voltage



**Figure 5.2:** Offset measuring circuit.

Construct the above x1000 non-inverting amplifier with the LF741 op amp. Measure the offset voltage ( $V_{OS}$ ) using the op-amp to amplify the input offset to measurable levels. The trick is to arrange things so that you can eliminate effects of *bias current* (although these are very small). You need to think what to do with the “*in*” terminal so as to make the effects of  $I_{bias}$  negligible. Compare your measured offset voltage, documented with a **SCREENSHOT** and description of the measurement, with the specifications for this op-amp:  $V_{OS} = 0.8$  mV (typical) to 2 mV (maximum).

Trim the offset voltage to zero, using the recommended network below.

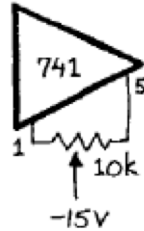


Figure 5.3: 741 Offset trimming network.

## 5-2 Integrator

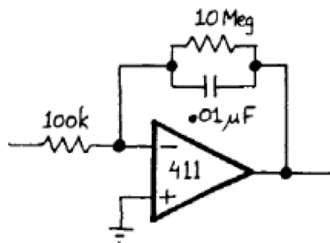


Figure 5-4: Integrator.

Construct the active integrator shown above. Try driving it with a 1 kHz square wave. This circuit is sensitive to small DC offsets of the input waveform (its gain at DC is 100); if the output appears to go into saturation near the  $\pm 15$  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<sub>pp</sub> (peak-to-peak), 500 Hz square wave input. Then try it and document your result, including a **SCREENSHOT**.

What is the function of the 10 M $\Omega$  resistor? What would happen if you were to remove it? Try it! Now have some "fun" playing with the function generator's DC offset; this circuit will help you gain a gut feeling for the meaning of an integral!

## 5-3 Differentiator

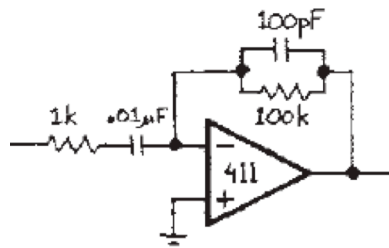


Figure 5-5: Differentiator

The circuit above is an active differentiator. Try driving it with a 1 kHz triangle wave with a 1 V amplitude. Document and describe your results, including a **SCREENSHOT**.

*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.

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 to an integrator at high frequencies; see class Notes. Note the effect of this network is a deviation of the phase shift, at some frequencies, from the  $90^\circ$  that you would expect.

## 5-4 AC amplifier: Microphone amplifier

Here we introduce the “single-supply” op amp. It that allows you to operate with a single + 5 Volt supply; this is a common computer voltage. The op amp, the LM358 dual, can operate with  $V_+ = +15$  and  $V_- = -15$  Volts. However, it can also be operated with  $V_- = \text{GND}$  since the input operating 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, a signal of  $< 20 \text{ mV}$ , to generate output swings of a few volts. The op amp is configured as an “AC amplifier”, with an adjustable Gain  $\approx 10$  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.

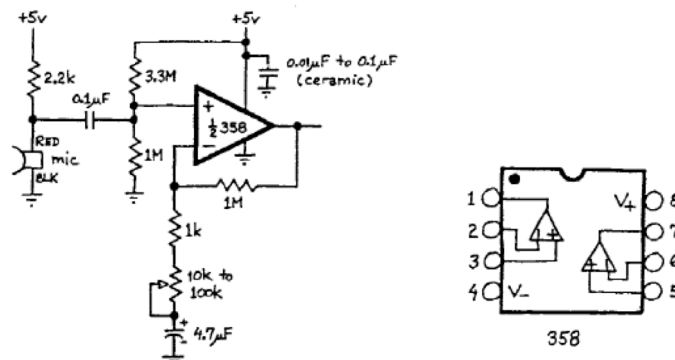


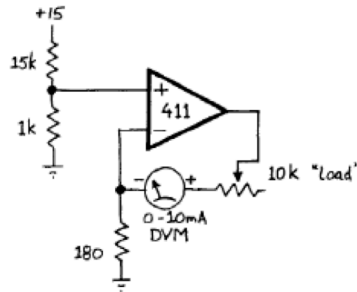
Figure 5-6: Single-supply microphone amplifier

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  $Q = CV$  so  $\Delta V \propto \Delta d$ . 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  $2.2 \text{ k}\Omega$  pull-up resistor, so the output impedance of the microphone is just  $2.2 \text{ k}\Omega$ .

*Construction hint:* Build the microphone amplifier 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 and visualized on the oscilloscope. For voice, it may be useful to use the “Untriggered Roll” at low sweep rates with the oscilloscope trigger set at “Auto”. Save your results as one or more illustrative **SCREENSHOTS** that show both the input and output. Estimate, through your measurements, the frequency response of the microphone system, and briefly describe the calculation that led to your estimate.

## 5-5 Current Source



**Figure 5.8:** Current source

Build the op-amp current source shown above for a floating load. What should the current be? Derive or write an expression and evaluate using the values for the component.

Vary the "load" potentiometer and monitor the current, using the benchtop multimeter 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?

2) What is the maximum load for this circuit?

3) What happens to the voltage on the "V<sub>-</sub>" input (pin 2) as the load is varied? Why?

## 5-6 LED Driver

With reference to the circuit in Figure 5.8. replace the voltage divide at on the "V<sub>+</sub>" input (pin 3) with a 0 V to 1V peak-to-peak 2 Hz triangle wave from your signal generator (this requires that you use an offset) and replace the "load" potentiometer with a light emitting diode (LED), *i.e.*, a device that emits light when current flows in the forward direction. The intensity of the emitted light is linearly proportional to the current that flows in the forward direction

1) What is the polarity of the LED?

2) Why is it wise to run an LED from a current source rather than a voltage source?

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