Project Team Names: Jonathan Lam Victor Zhang (Zhihao)

Lab 2: Operational Amplifiers

I. Introduction.

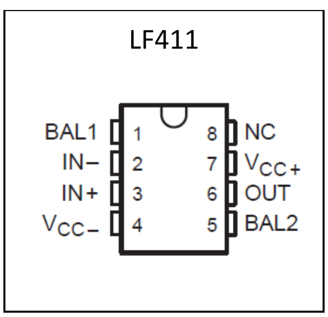
In this lab you will build Operational Amplifier (OPAMP) circuits, characterize their transfer functions, and analyze their performance against ideal circuits. Complete Exercises 2-1 through 2-4 PRIOR to lab on November 7th. The completed lab is due at the start of lab on November 14th. There is no class on November 12th.

	$+V_{CC}$	$-V_{CC}$	R_9	R_{10}	R_{11}	P_3	C_8
Nominal	15V	-15V	1 MΩ	1 MΩ	1 kΩ	100 kΩ	1μF

II. Theory.

Op Amp Integrated Circuit. In this portion of the prelab, you will be analyzing the voltage follower and non-inverting amplifier. The OPAMP comes in several package styles. The version that we will use is the LF411 Op Amp Dual In-Line Package (DIP). A diagram of the chip with its pin assignments, along with a schematic symbol, is shown in Figure 1.

Exercise 2-1 Use the diagram to number the pins on the schematic symbol.



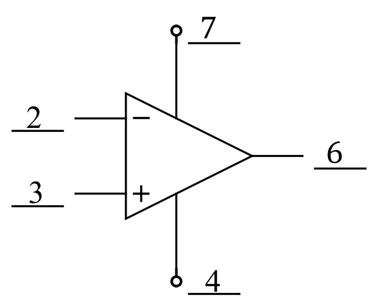
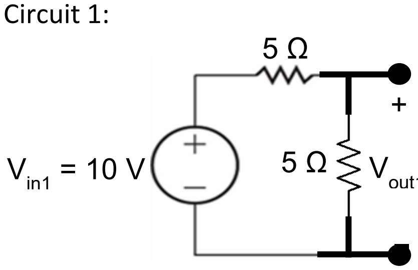


Figure 1. LF4111 Op Amp Dual In-Line Package Pin Connections and Schematic Symbol.

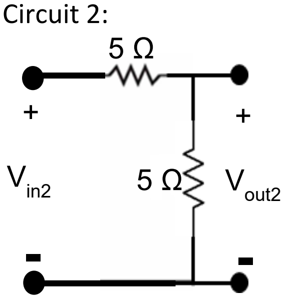
Exercise 2-2 Voltage Follower (Buffer).

1. Given the two circuits below, compute V_{out1} and V_{out2}. Assume $V_{in2} = V_{out1}$

Circuit 1:



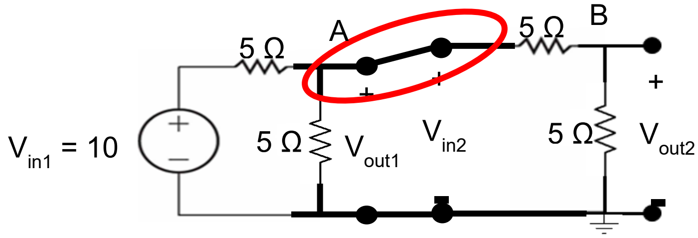
Circuit 2:



$$V_{out1} = 10V \times \frac{5\Omega}{5\Omega + 5\Omega} = 5V$$

$$V_{out2} = V_{out1} \times \frac{5\Omega}{5\Omega + 5\Omega} = 2.5V$$

2. Compute V_{out2} if the two circuits are directly connected:

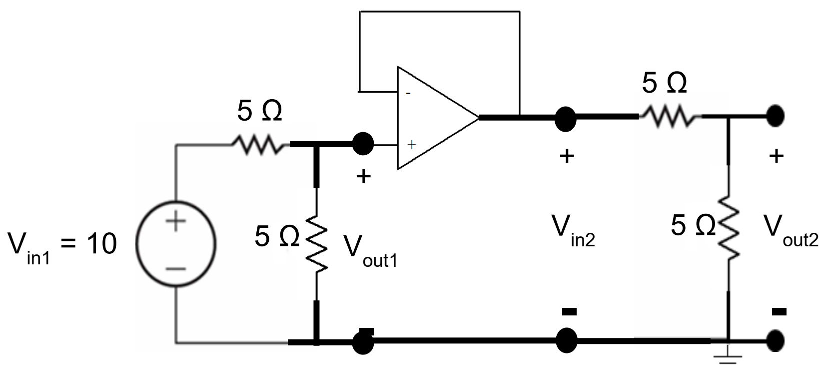


$$R_{eq} = 5\Omega \,||\, (5\Omega + 5\Omega) = \frac{10}{3}\Omega$$

$$V_{out1} = 10V \times \frac{\frac{10}{3}\Omega}{\frac{10}{3}\Omega + 5\Omega} = 4V$$

$$V_{out2} = V_{out1} \times \frac{5\Omega}{5\Omega + 5\Omega} = 2V$$

3. Now compute V_{out2} when the two stages are connected via a voltage follower buffer:



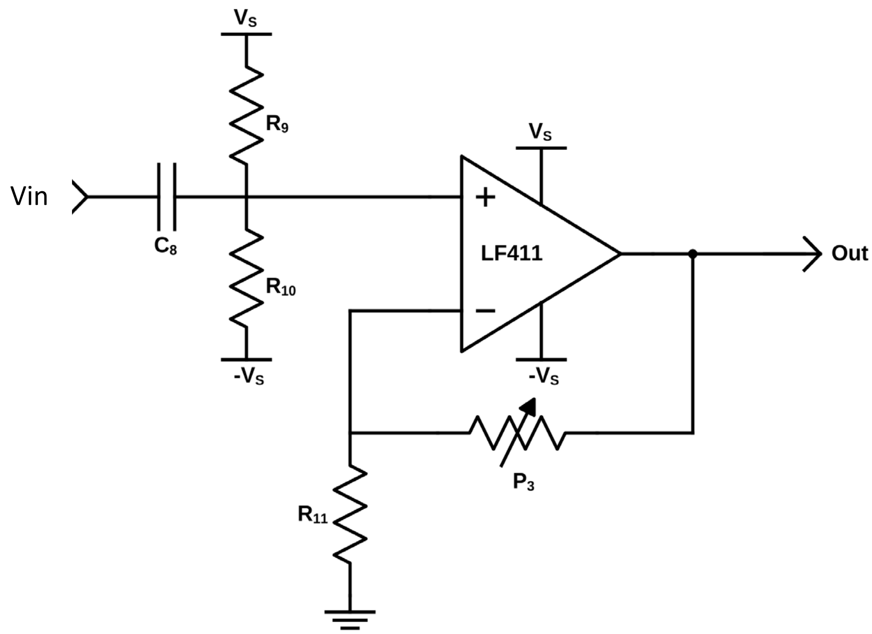
$$V_{out1} = 10V \times \frac{5\Omega}{5\Omega + 5\Omega} = 5V$$

$$V_{out2} = V_{out1} \times \frac{5\Omega}{5\Omega + 5\Omega} = 2.5V$$

4. What effect did the buffer have?

The buffer gives circuit V_{out1} impedance $R_{imp} = \infty\Omega$

Exercise 2-3 **Non-Inverting Amplifier**. Number the pins on the schematic symbol for the non-inverting amplifier.



Compute the range of Voltage gain, Vout/Vin. For the low end, assume the potentiometer is set to 1kΩ. For the max gain, assume the potentiometer is set to 100kΩ:

$$V_+ = V_{in} = V_-$$

$$V_{out} = V_{in} \times \frac{R_{11} + P_3}{R_{11}}$$

$$\frac{V_{out}}{V_{in}} = \frac{R_{11} + P_3}{R_{11}}$$

$$P_3 = 1k\Omega$$

$$\frac{V_{out}}{V_{in}} = \frac{1k\Omega + 1k\Omega}{1k\Omega} = 2$$

$$P_3 = 100k\Omega$$

$$\frac{V_{out}}{V_{in}} = \frac{100k\Omega + 1k\Omega}{1k\Omega} = 101$$

<u>Exercise 2-4</u> Voltage Gain Graph for non-inverting amplifier. Choose a value of the non-inverting amplifier's voltage gain, A_v, within the range which you calculated in Exercise 2-3. Plot V_{out} versus V_{in}. Label both the saturation and linear regions. **Remember that a real-world OPAMP will reach saturation approximately 1.5V below the supply voltages, so show that here.**

$A_v = 5$

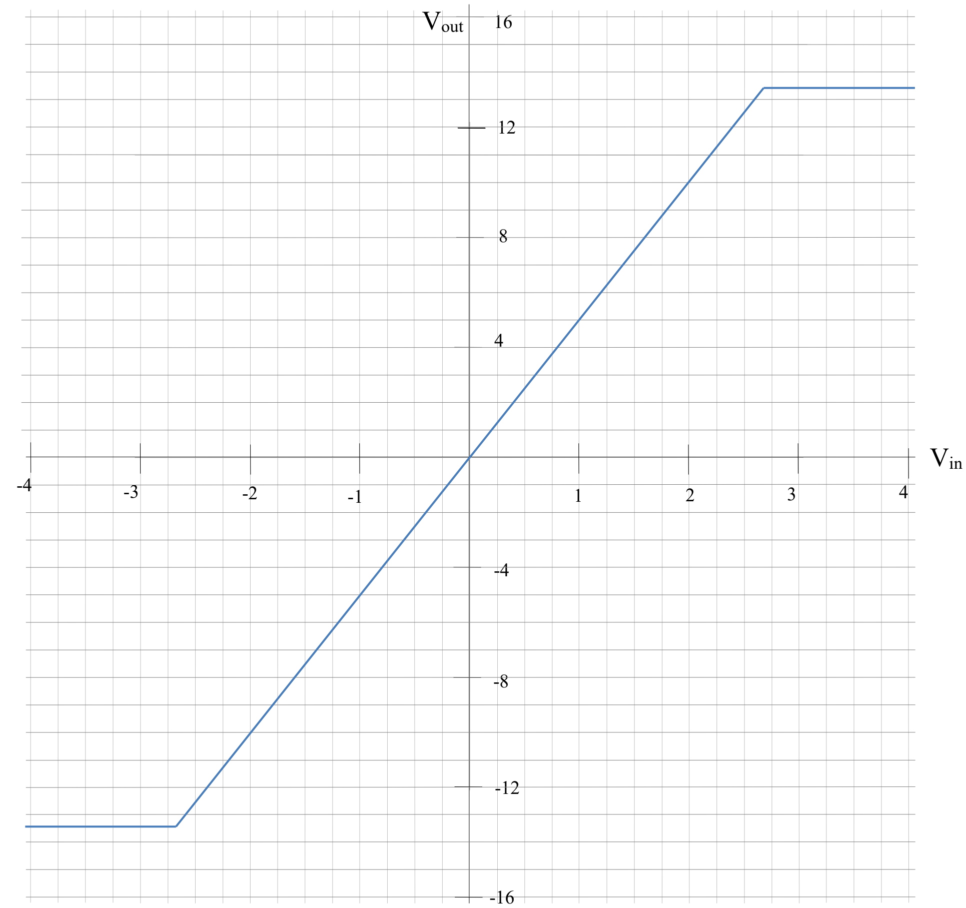


Figure 2. Plot of Av.

Based on your plot of A_v in Figure 2, what is the maximum positive input voltage that can be applied to the non-inverting amplifier before saturation occurs?

$V_{in\ max} = \frac{V_{out}}{A_v} = \frac{13.5V}{5} = 2.7V$

III. Test Procedure and Equipment

A. Measured component values. For each component measure the actual voltage, resistance or capacitance. These will be the measured values used in theoretical calculations. Enter the measured values in the table below:

	$+V_{CC}$	**$-V_{CC}$**	**R_9**	**R_{10}**	**R_{11}**	**P_3**	**C_8**
Nominal	15V	-15V	1 MΩ	1 MΩ	1 kΩ	100 kΩ	1μF
Measured	15.04V	-15.11V	1.002 MΩ	0.995MΩ	983Ω	103.4 kΩ	1.0031 μF

B. Non-Inverting Amplifier Gain and Phase.

- On the same protoboard as the rest of your Theremin, build the non-inverting OPAMP circuit from Exercise 2-3.
- DO NOT connect it to the rest of the Theremin.
- Set the potentiometer to 1kΩ (Record actual value : 988Ω)
- Apply a small (100mV) sinusoidal input at 100kHz.
- Record the amplitude of both the input and the output signals and their relative phase.
- Set the potentiometer to max value (~100kΩ, whatever you measured for P3 above)
- Record the amplitude of both the input and the output signals and their relative phase. If necessary, decrease the input to avoid saturation.
- Increase the input voltage amplitude until saturation occurs.
- Record the amplitude of both the input and the output signals and their relative phase.

Trial	Input Voltage	Output Voltage	Phase
1 : linear region, P_3 at ~1kΩ	330mV	740mV	0
2 : linear region, P_3 at ~100kΩ	290mV	3.86V	0.14π
3 : saturation	1.33V	25.7V	0.26π

C. **Currents and Voltages.** Measure and record the voltages at the inverting and noninverting terminals (v_- and v_+).

v_-	v_+
0.013V	0.176V

Measure and record the current flowing into each OPAMP terminal.

i_-	i_+
-0.028mA	0.001mA

V. Results and Discussion

Using the measured component values, calculate the **theoretical** voltage gain, A_v, of each amplifier you built, and enter it in the table below. Now record your **measured** gain for each amplifier and calculate your % error.

Reminder: $$\%Error = \left|\frac{Theoretical - Measured}{Theoretical}\right| \text{ x } 100\%$$

Voltage Gain	Theoretical A_v	Experimental A_v	%Error
Non-inverting Amp. linear	2.04	2.24	9.9%
Non-inverting Amp. saturated	N/A	19.32	N/A

Was your % error acceptable? Discuss the likely sources of error you encountered in this lab:

The % error is 9.9% when the potentiometer is set to minimum. Since the % error is bigger than 3%, the error is not acceptable. The sources of error might include measurement error caused by the P3 value and uncertainty of its position due to friction and modeling error of the amplifier (not ideal).

Do the voltage and current measurements in part IV C agree with ideal op-amp theory? Explain why or why not.

The ideal op-amp theory states that the voltage difference should be 0V and current through two input should be 0A. The voltage difference measured in part IV is 0.163V, the current is close to 0A. Hence, the measured value does not agree with ideal op-amp because the ideal op-amp has nullator between the two input pins which does not exist in real world.