Electric Circuits I

Laboratory 8 – Operational Amplifier Circuits

Objective:

- Design and implement standard OpAmp circuits.
- Design and implement cascaded OpAmp circuits.

I. Equipment:

- DC Power Supply (Keysight EDU36311A)
- Digital Multimeter (Keysight EDU34450A)
- Waveform Generator (Keysight EDU33221A)
- Digital Oscilloscope (Keysight EDUX1052G)
- Breadboard for connecting resistors
- 5 resistors between 1kΩ to 30kΩ.
- Resistance Decade R_{dec}.
- 1 Operational Amplifier (μ741).

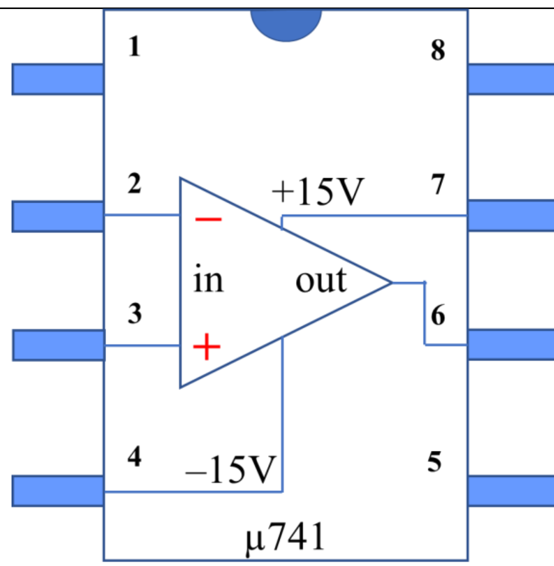
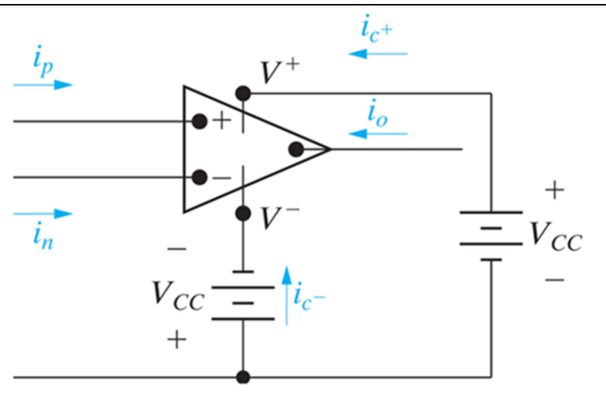


Figure 1 – Operational Amplifier Diagram

II. Background & Theory

An *operational amplifier* (OpAmp) is an integrated circuit that can amplify weak electric signals. Each OpAmp has two inputs and one output. It also has two input pins for the DC power supply. The primary role of OpAmp is to amplify the voltage difference between the two inputs and produce a result at the output pin. Three of the most common applications of OpAmp are inverting amplifiers, non-inverting amplifiers, and voltage followers. Ideally, the input impedance for plus and minus terminals is infinite, and the output impedance is 0. However, for a practical µ741 OpAmp, the input impedance is large (~2MΩ), and the output impedance is about 75Ω. The function of the voltage follower is to overcome the loading effect. In simplifying the analysis process, we assume that OpAmps are ideal, as shown below:



- In an ideal op-amp, the input resistance is infinite:

$$i_p = i_n = 0$$

- The voltages at the inverting and non-inverting input terminals are the same

$$v_p = v_n$$

From the ideal condition of OpAmps, we can apply KCL at the V^+ or V^- terminal of an OpAmp to derive the expressions of the output voltages for inverting and non-inverting amplifiers.

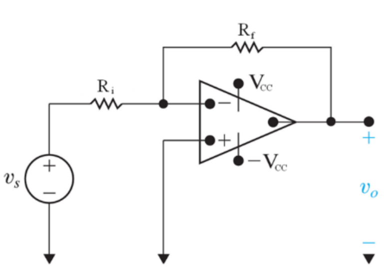
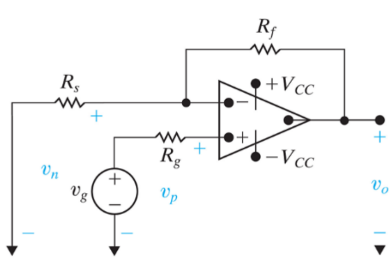
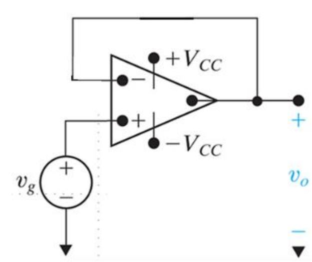
Inverting Amplifier	Non-inverting Amplifier	Voltage Follower
		
$v_0 = -\left(\frac{R_f}{R_i}\right) v_s$	$v_0 = \left(\frac{R_f}{R_s} + 1\right) v_g$	$v_0 \simeq v_s$
$Gain = \frac{v_0}{v_s} = -\left(\frac{R_f}{R_i}\right)$	$Gain = \frac{v_0}{v_s} = \left(\frac{R_f}{R_s} + 1\right)$	$Gain = \frac{v_0}{v_s} \simeq 1$

Figure 2 – Operation Amplifier Applications

In many OpAmp circuits, OpAmps are often connected in stages where the output of an

OpAmp in stage 1 becomes the input for OpAmp 2 in stage 2, shown in **Figure 3**.

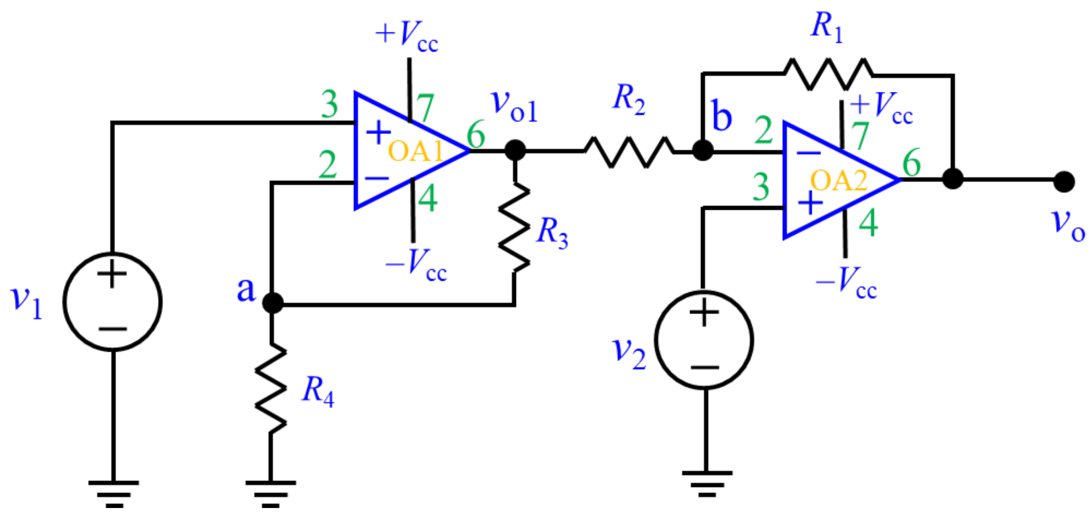


Figure 3 – Operation Amplifier Circuit

Note that the green numbers are the pin numbers of OpAmps.

Table 1 – Standard Resistor Values

(K = x 1,000, M = x 1,000,000)

1.0	5.6	33	160	820	3.9K	20K	100K	510K	2.7M
1.1	6.2	36	180	910	4.3K	22K	110K	560K	3M
1.2	6.8	39	200	1K	4.7K	24K	120K	620K	3.3M
1.3	7.5	43	220	1.1K	5.1K	27K	130K	680K	3.6M
1.5	8.2	47	240	1.2K	5.6K	30K	150K	750K	3.9M
1.6	9.1	51	270	1.3K	6.2K	33K	160K	820K	4.3M
1.8	10	56	300	1.5K	6.6K	36K	180K	910K	4.7M
2.0	11	62	330	1.6K	7.5K	39K	200K	1M	5.1M
2.2	12	68	360	1.8K	8.2K	43K	220K	1.1M	5.6M
2.4	13	75	390	2K	9.1K	47K	240K	1.2M	6.2M
2.7	15	82	430	2.2K	10K	51K	270K	1.3M	6.8M
3.0	16	91	470	2.4K	11K	56K	300K	1.5M	7.5M
3.3	18	100	510	2.7K	12K	62K	330K	1.6M	8.2M
3.6	20	110	560	3K	13K	68K	360K	1.8M	9.1M
3.9	22	120	620	3.2K	15K	75K	390K	2M	10M
4.3	24	130	680	3.3K	16K	82K	430K	2.2M	15M
4.7	27	150	750	3.6K	18K	91K	470K	2.4M	22M
5.1	30								

III. Prelab Assignment:

The prelab assignments should be completed and submitted to Camino before the lab.

Create a MATLAB script, assuming that all OpAmps are ideal,

a. Design an inverting amplifier in **Figure 2** for a gain of 2.0 with 2 resistors (R_i and R_{f1}) from the standard resistor values in **Table 1** between 1kΩ to 30kΩ.

b. Design a non-inverting amplifier in **Figure 2** for a gain of 2.5 with 2 resistors (R_s and R_{f2}) from the standard resistor values in **Table 1** between 1kΩ to 30kΩ.

c. Calculate the output voltage v_o of the OpAmp circuit in **Figure 3** with 4 resistors (R_1 to R_4) from the standard resistor values in **Table 1** between 1kΩ to 30kΩ and $v_1 = v_2 = 1V$.

IV. Laboratory

Verify the results of MATLAB scripts of your prelab assignment with the TA before working on the lab procedures.

1. Use the digital multimeter to measure resistors chosen in the prelab assignments. Record their measured values in **Table 2** below.

Table 2 – Resistance Values

	R_i	R_{f1}	R_s	R_{f2}	
Nominal Values					kΩ
Measured Values					kΩ

2. With the measured values of R_i, R_{f1}, R_s, and R_{f2} calculate the gains of OpAmp circuits again and record the calculations in **Table 3**.
3. Build the inverting circuit in **Figure 2** with ±15V for $+V_{cc}$ and $-V_{cc}$. The pin numbers are in **Figure 1**. Connect the third power supply output (v_s) to the input of the amplifier and set it to +1V. Measure v_o, calculate the gain (vo/ vs), and record the result in **Table 3**.
4. Build the non-inverting circuit in **Figure 2** with ±15V for $+V_{cc}$ and $-V_{cc}$. Connect the third power supply output (v_s) to the input of the amplifier and set it to +1V. Measure v_o, calculate the gain (vo/ vs), and record the result in **Table 3**.

Table 3 – Gain of Operational Amplifier Circuits

	Expected Gain	Measured Gain	% Error
Inverting OpAmp			
Non-inverting OpAmp			

5. Build the voltage follower in **Figure 2** with ±15V for $+V_{cc}$ and $-V_{cc}$.
6. Set the function generator to produce a sine wave (v_g) of 500Hz and 1V amplitude and connect to the input of the voltage follower.
7. Connect CH1 and CH2 of the oscilloscope to the voltage follower's input and output. Observe the results.
8. Build a circuit in **Figure 4a** with $R_s = 1\text{k}\Omega$. Use CH1 and CH2 of the oscilloscope to measure the amplitudes of v_g and v_{out} with different values of R_{dec}. Record the measurements in **Table 4**. Add a voltage follower as shown in **Figure 4b** and repeat the same process.

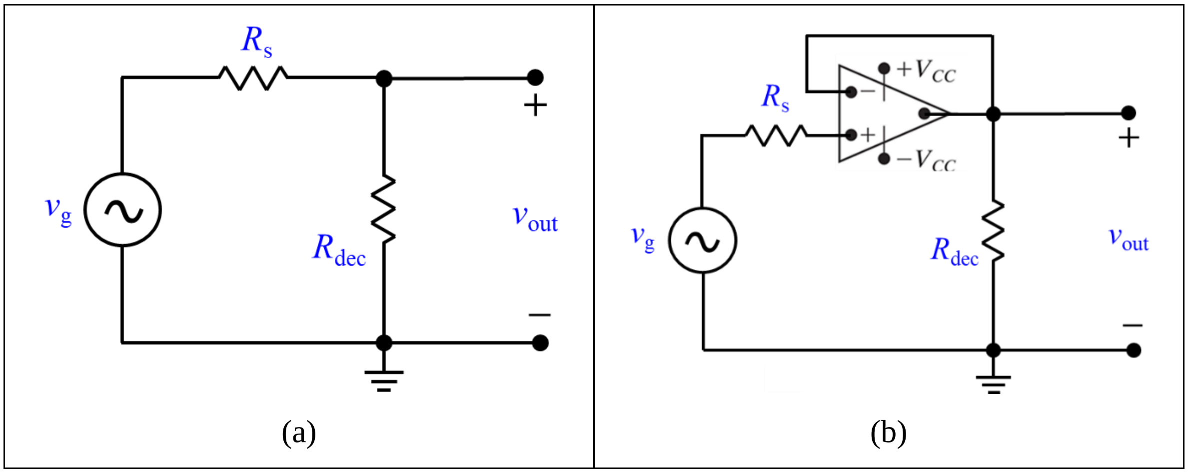


Figure 4 – Overcoming Loading Effect with Voltage Follower

Table 4 – Voltage Amplitude

R_{dec} (Ω)	v_g (V)	v_{out} (V)	v_{out} with voltage follower (V)
5,000			
3,000			
1,000			
800			
400			
200			
100			
50			

9. Explain the results.
10. Use the digital multimeter to measure resistors chosen in the prelab assignments. Record their measured values in **Table 5** below.

Table 5 – Resistance Values

	R_1	R_2	R_3	R_4	
Nominal Values					kΩ
Measured Values					kΩ

11. Build the OpAmp circuit in **Figure 3** with ±15V for $+V_{cc}$ and $-V_{cc}$. Notice the plus and minus inputs of the two OpAmps. The pin numbers are in **Figure 3**. Set $v_1 = v_2 = 1$V. Use MATLAB to recalculate the theoretical voltages with measured values of resistors. Measure the voltages and record them in **Table 6**.

Table 6 – Voltages of Operational Amplifier Circuit

	Theoretical (V)	Measured (V)	% Error
v_a			
v_{o1}			
v_b			
v_o			

12. If there are any discrepancies, explain them.
13. Derive comments or conclusions from the results.

Make sure to check off with the TA before leaving the lab section.

V. Laboratory Report:

Include the measurements, computations, and answers to questions from the laboratory procedure. Clearly label all steps.