

Laboratory 8

The Operational Amplifier

Objectives

- To learn how to use an operational amplifier (OpAmp). Three different amplifier circuits will be simulated: an inverting amplifier, a non-inverting amplifier, and a difference amplifier.
- To learn how the component values affect behavior of OpAmp circuits.
- To learn how to simulate amplifier circuits with SPICE

Equipment and components

- A desk computer
- SPICE software

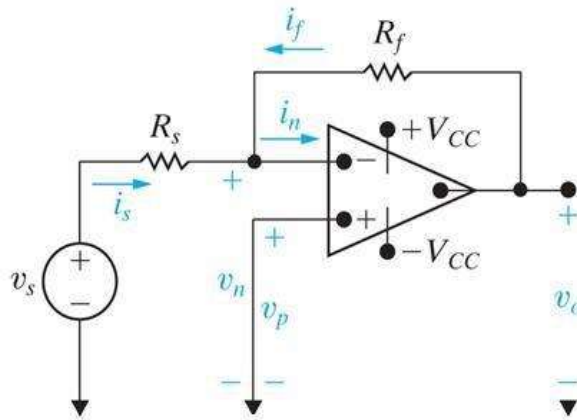
Preliminary

1. Review what you have learned in the previous lab about online SPICE simulator. We will use this tool to analyze the behavior of circuits with OpAmps
2. Read Chap 5 from the textbook, as well as the Lectures about OpAmps, in order to review: i) the principle of operation of OpAmps, and ii) the conditions for the linear operation range of OpAmps

Procedure

Part A. The Inverting Amplifier

The first objective of this assignment is to simulate the behavior of the following inverting amplifier circuit:

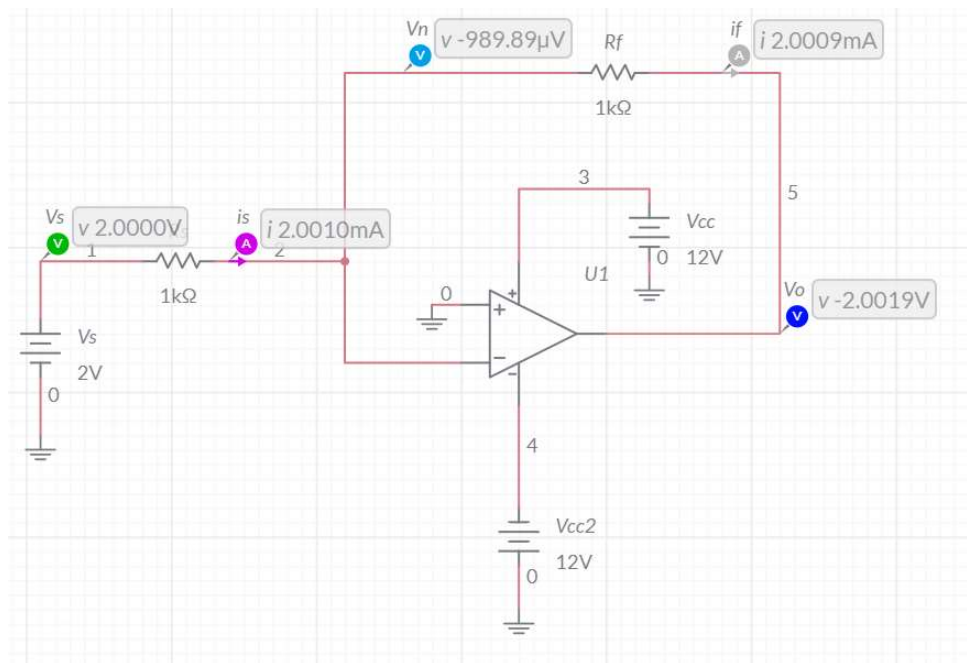


Variables:

- $v_s = 2V$ is the input voltage source
- v_n = voltage of the inverting terminal
- v_o = output voltage
- $V_{cc}=12V$ is the positive voltage supply
- $-V_{cc}$ is the negative voltage supply
- $R_s = 1k\Omega$ is a resistance connected to v_s
- $R_f = 1k\Omega$ is the “feedback” resistance

If the OpAmp is ideal, then the output voltage is $v_o = -\frac{R_f}{R_s} v_s = K v_s$, where $K = -\frac{R_f}{R_s}$ is the closed-loop gain of the circuit.

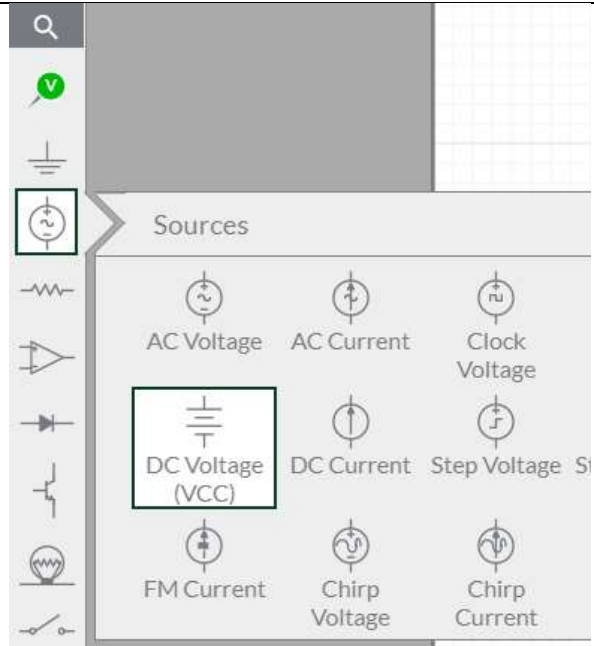
1. Create the following inverting amplifier circuit in the online SPICE simulator (check previous lab for details on how to use the online simulator)



When creating the circuit, please consider the following instructions:

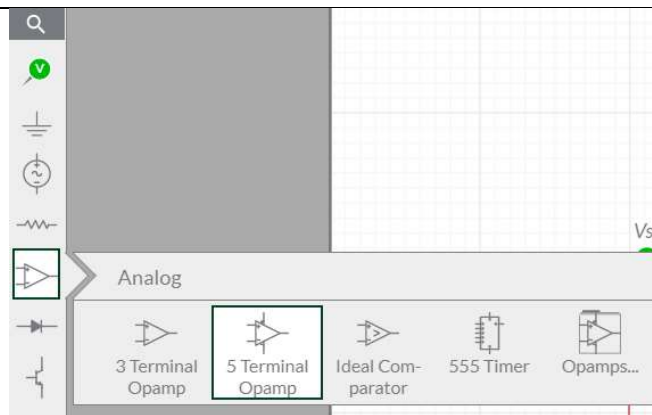
Employ a DC (constant) voltage source ($V_s = 2V$) in the circuit.

This DC voltage source is available in the second row of the Sources library (see figure on the right)



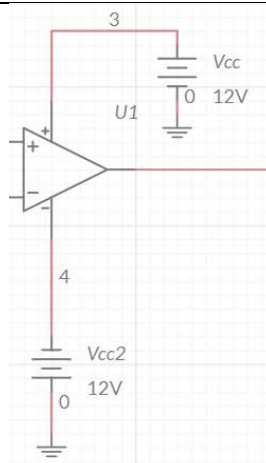
The OpAmp component is available in the Analog library.

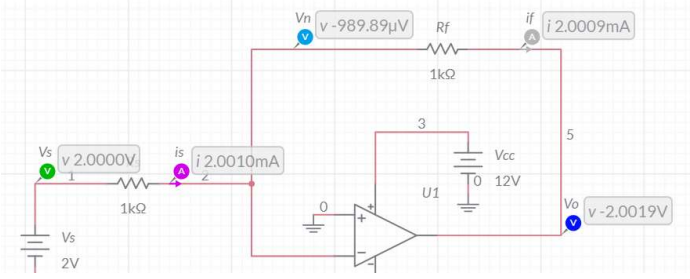
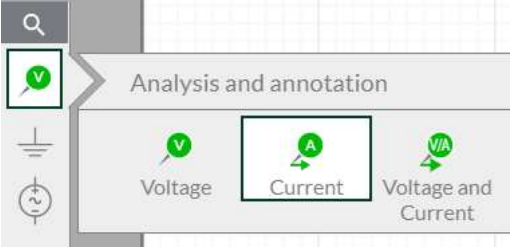

Use the “5 Terminal Opamp” (see Figure on the right)



When connecting the voltage supply to the OpAmp (V_{cc} and $-V_{cc}$), check the polarity. This is critical for the negative voltage supply (see V_{cc2} in the right figure)

Also check the location of the “inverting” and “noninverting” terminals of the OpAmp.



<p>Create three voltage probes to measure</p> <ul style="list-style-type: none"> the input voltage (v_s), the voltage of the inverting OpAmp terminal (v_n) the output voltage (v_o) 	
<p>Create two current probes to measure</p> <ul style="list-style-type: none"> input current (i_s) current in the feedback resistor (i_f) <p>Current probes are available in the “Analysis and annotation” library (See right figure)</p>	
<p>You can easily simulate the behavior of the circuit in “Interactive Mode”</p>	

2. You will now investigate the behavior of the circuit when R_f is varied from $0.1k\Omega$ to $10k\Omega$. Fill up the following table for different values of R_f .

	$R_f(k\Omega)$	0.1	0.5	1	4	6	8	10
Theoretical values (ideal OpAmp assumption)	$v_s(V)$	2 V	2 V	2 V	2 V	2 V	2 V	2 V
	$v_n(V)$	0	0	0	0	0	0	0
	$v_o(V)$	-0.2 V	-1 V	-2 V	-8 V	-12 V	-16 V	-12 V
	v_o/v_s (gain)	-0.1 V	-0.5 V	-1 V	-4 V	-6 V	-8 V	-6 V
Simulated values (from SPICE)	$v_s(V)$	2 V	2 V	2 V	2 V	2 V	2 V	2 V
	$v_n(V)$	1.02 mV	1.039 mV	1.039 mV	1.067 mV	127 mV	689 mV	800 mV
	$v_o(V)$	- 1.98 V	- 0.999 V	-2 V	-7.998 V	-11.3 V	11.75	-11.29
	v_o/v_s (gain)	-0.0995V	-0.497 V	-1	-3.999 V	-5.89 V	-7.86 V	-5.72 V

- What do you observe? Are the ideal OpAmp assumptions reasonable?

According to the principle of the inverting operational amplifier, there gains of the data are true and reasonable for the output are negatives and the gains data are similar to that of the stimulated gain by dividing the output voltage with the input voltage.

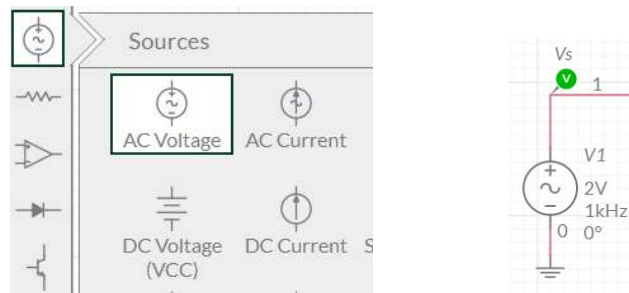
3. Calculate the currents i_s and i_f based on the voltages in the table above and fill up the table below.
- Double check the reference direction of the current probes (especially for i_f).

	$R_f(k\Omega)$	0.1	0.5	1	4	6	8	10
Theoretical values (ideal OpAmp assumption)	$i_s(mA)$	2 mA	2 mA	2 mA	2 mA	2 mA	2 mA	2 mA
	$i_f(mA)$	2 mA	2 mA	2 mA	2 mA	2 mA	2 mA	2 mA
Simulated Values (from SPICE)	$i_s(mA)$	2.001 mA	2.001 mA	2.001 mA	2.001 mA	2.001 mA	1.29 mA	1.55 mA
	$i_f(mA)$	2.00 mA	2.001 mA	2 mA	2.001 mA	2.001 mA	1.289 mA	1.55 mA

- What do you find from the data in the table above?

4. Bonus question¹

- Replace the DC voltage source (v_s) with a sinusoidal voltage source, 2V peak value and 1kHz frequency. The sinusoidal voltage source can be found under “Sources\ AC Voltage” (see Figure below)



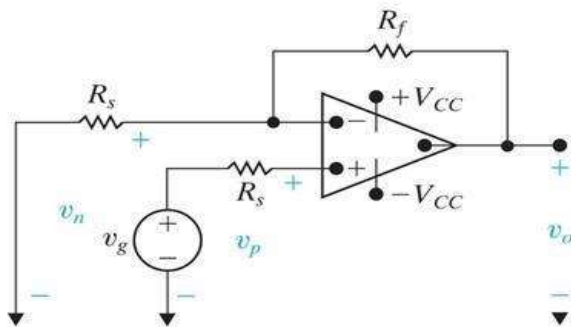
- Plot the input (v_s) and output voltages (v_o) of the modified circuit for $R_f = 4k\Omega$ and $R_f = 10k\Omega$. What can you conclude from these plots?

Will be included within lab report

¹ You can get extra points by answering the bonus question.

Part B. The Noninverting Amplifier

The second objective of this assignment is to simulate the behavior of the following noninverting amplifier circuit:



Variables and Values

- $v_g = 2V$ is the input voltage source
- v_n = voltage of the inverting terminal
- v_o is the output voltage
- $V_{cc}=12V$ is the positive voltage supply
- $-V_{cc}$ is the negative voltage supply
- $R_f = 1k\Omega$ is the “feedback” resistance
- $R_s = 1k\Omega$

If the OpAmp is ideal, then the output voltage is $v_o = (1 + \frac{R_f}{R_s})v_g = Kv_g$, where $K = 1 + \frac{R_f}{R_s}$ is the closed-loop gain of the circuit.

1. Create the above noninverter amplifier circuit in the online SPICE tool. Include voltage probes for the input voltage (v_g), voltage of the inverting terminal (v_n) and output voltage (v_o).
 - The values of v_g, R_s, V_{cc}, R_f are defined in the section “variables and values” (see right part of the above figure)
2. Investigate the behavior of the circuit when R_f is varied from $0.1k\Omega$ to $10k\Omega$. Fill up the following table for different values of R_f .

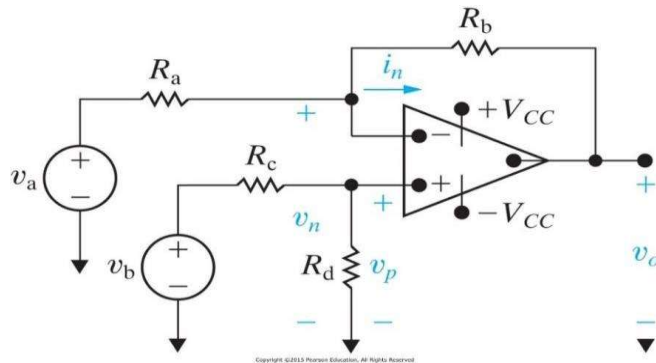
	$R_f(k\Omega)$	0.1	0.5	1	4	6	8	10
Theoretical values (ideal OpAmp assumption)	v_g (V)	2 V	2 V	2 V	2 V	2 V	2 V	2 V
	v_n (V)	2 V	2 V	2 V	2 V	2 V	2 V	2 V
	v_o (V)	2.2 V	3 V	4 V	10 V	14 V	18 V	21 V
	v_o/v_g (gain)	1.1 V	1.5 V	2 V	5 V	7 V	9 V	11 V
Simulated values (from SPICE)	v_g (V)	2 V	2 V	2 V	2 V	2 V	2 V	2 V
	v_n (V)	1.9889 V	1.899 V	1.998 V	1.9989 V	1.789 V	1.46 V	1.10 V
	v_o (V)	2.1897 V	2.9967 V	3.997 V	9.978 V	12.51 V	12.481 V	12.053 V
	v_o/v_g (gain)	1.099 V	1.478 V	1.998 V	4.998 V	6.0225 V	6.056 V	6.023 V

- What do you observe? Explain them by using what you learned in class.

In regard to non-inverting operational amplifier, positive voltage input should have positive voltage output value differ to that of inverting amplifier which is exemplify within the data above.

Part C. The Difference Amplifier

The third objective of this assignment is to simulate the behavior of the following difference-amplifier circuit:



Variables and Values

- $v_a = 1V, v_b = 0.5V$ are the (default) input voltage sources
- v_o is the output voltage
- v_n = voltage of the inverting terminal
- v_p = voltage of the non-inverting terminal
- $V_{cc} = 12V$ is the positive voltage supply
- $-V_{cc}$ is the negative voltage supply
- $R_a = R_b = R_c = R_d = 1k\Omega$

If the OpAmp is ideal and $\frac{R_a}{R_b} = \frac{R_c}{R_d}$ then the output voltage is given by: $v_o = \frac{R_b}{R_a}(v_b - v_a)$, which means the output voltage is proportional to the difference of the two inputs.

1. Create the above amplifier circuit in the online SPICE tool. Include voltage probes for the inverting terminal voltage (v_n), noninverting terminal voltage (v_p) and output voltage (v_o).
 - The values of $v_a, v_b, R_a, R_b, R_c, R_d, V_{cc}$, are defined in the section “variables and Values” (see right part of the above figure)
2. Investigate the behavior of the circuit when v_a and v_b are varied. Fill up the following table.

	$v_a(V)$	0.5	0.5	0.5	0.5	0.5	0.5
	$v_b(V)$	-0.5	0	0.5	1	5	15
Theoretical values (ideal OpAmp assumption)	$v_n(V)$	-0.25 V	0 V	0.5	0.5 V	2.5 V	15 V
	$v_p(V)$	-0.25 V	0 V	0.25 V	0.5 V	2.5 V	7.5 V
	$v_o(V)$	-1 V	0.5 V	0.25 V	0.5 V	4.5 V	14.5 V
	$\frac{v_o}{v_b - v_a}$ (Gain)	-1 V	-1 V	undefined	-1 V	-1 V	-1 V
Simulated values (from SPICE)	$v_n(V)$	-252.0 mV	-1.03 mV	245.87 mV	499.99 mV	2.4989 V	6.25 V
	$v_p(V)$	-250.12 mV	-45.07 uV	248.95 mV	499.95 mV	2.55 V	7.52 V
	$v_o(V)$	-1.002 V	-502.02 mV	-2.034 mV	497.96 mV	4.498 V	12.061 V
	$\frac{v_o}{v_b - v_a}$ (Gain)	-1.002 V	-1.004 V	undefined	-0.995 V	-0.98 V	-0.831 V

- What do you find from the simulation results?

Within the stimulation result, it shows that both V_p and V_n should be the same to each other which is apparent within the data table. Additionally, the for the difference of operational amp the output should be the same to the difference of between the two input voltage source which is also present within the data table.

- Summarize your findings of this assignment in the lab report. Include screenshots of the circuit created with the online SPICE simulation.