ENGR 065 Circuit Theory

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

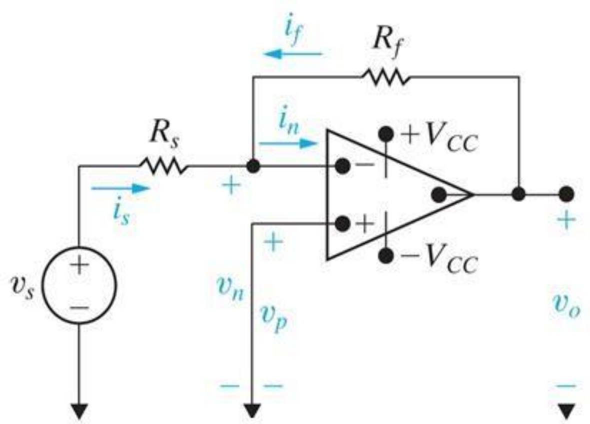
Preliminary

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:

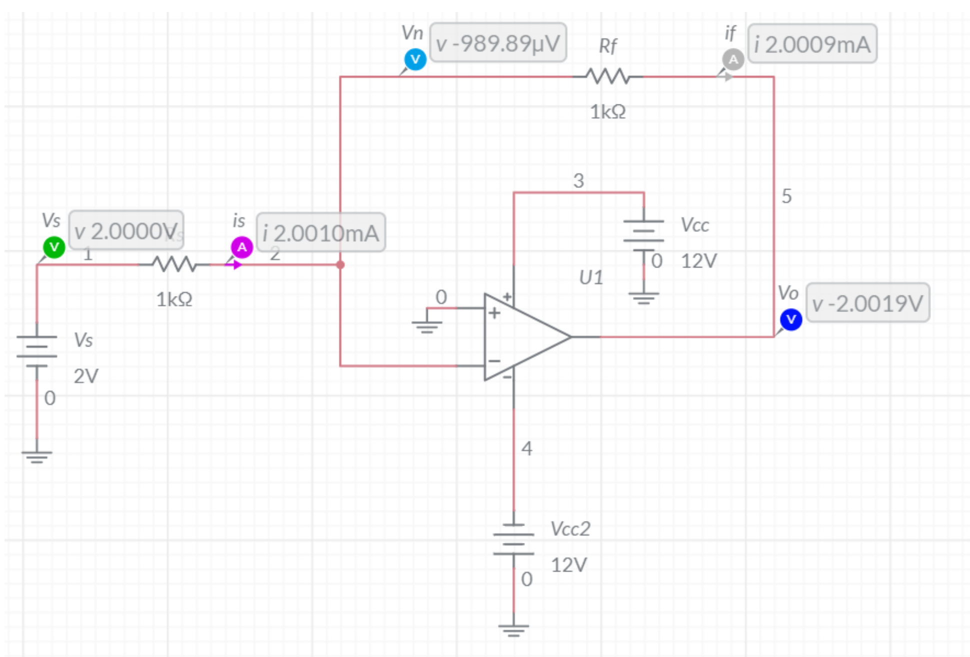


Variables:

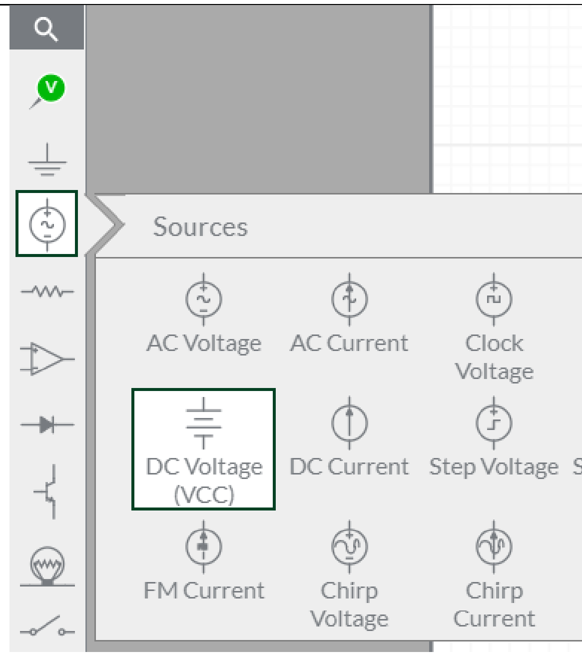
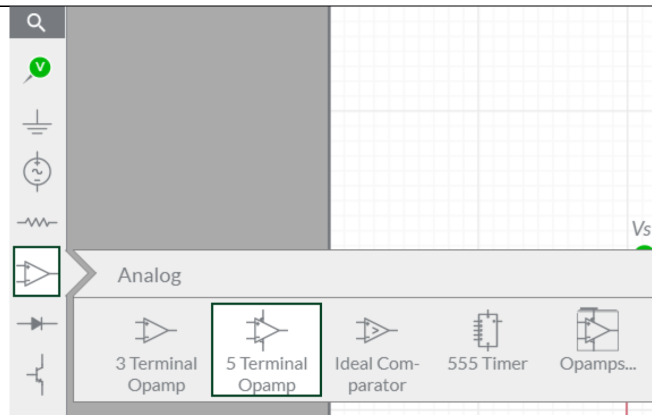
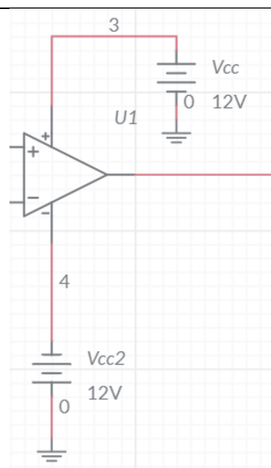
- $v_s = 2V$ is the input voltage source
- v_n = voltage of the inverting terminal
- v_o = output voltage
- V_{cc}=12V is the positive voltage supply
- $-V_{cc}$ is the negative voltage supply
- $R_s = 1k\Omega$ is a resistance connected to v_s
- $R_f = 1k\Omega$ is the “feedback” resistance

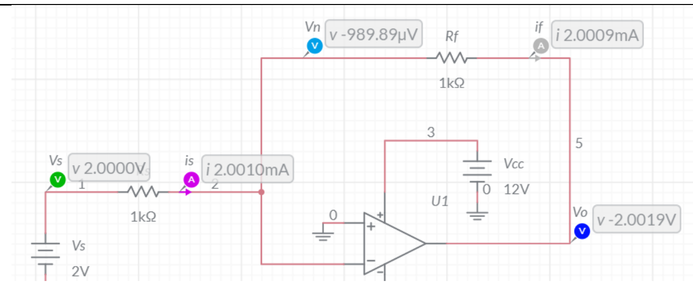
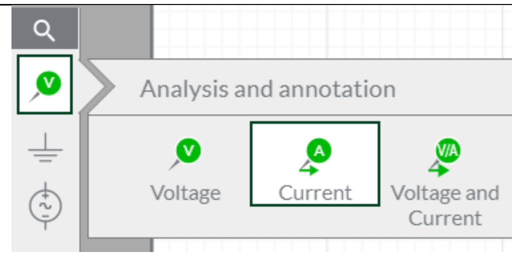
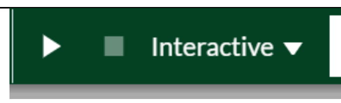
If the OpAmp is ideal, then the output voltage is $v_o = -\frac{R_f}{R_s} v_s = K v_s$, where $K = -\frac{R_f}{R_s}$ is the closed-loop gain of the circuit.

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 (Vcc and -Vcc), check the polarity. This is critical for the negative voltage supply (see Vcc2 in the right figure) Also check the location of the "inverting" and "noninverting" terminals of the OpAmp.	

Create three voltage probes to measure • the input voltage (v_s), • the voltage of the inverting OpAmp terminal (v_n) • the output voltage (v_o)	
Create two current probes to measure • input current (i_s) • current in the feedback resistor (i_f) Current probes are available in the "Analysis and annotation" library (See right figure)	
You can easily simulate the behavior of the circuit in "Interactive Mode"	

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

	R_f(kΩ)	0.1	0.5	1	4	6	8	10
Theoretical values (ideal OpAmp assumption)	$v_s(V)$							
	v_n (V)							
	v_o (V)							
	v_o/v_s (gain)							
Simulated values (from SPICE)	$v_s(V)$							
	v_n (V)							
	v_o (V)							
	v_o/v_s (gain)							

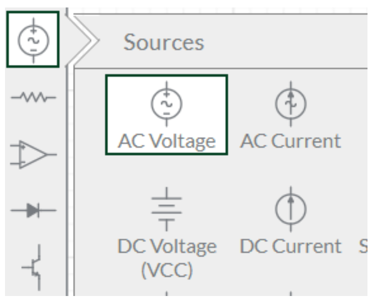
- What do you observe? Are the ideal OpAmp assumptions reasonable?

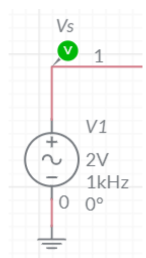
3. Calculate the currents i_s *and* i_f based on the voltages in the table above and fill up the table below.
   - Double check the reference direction of the current probes (especially for i_f).

	R_f(kΩ)	0.1	0.5	1	4	6	8	10
Theoretical values (ideal OpAmp assumption)	$i_s(mA)$							
	i_f(mA)							
Simulated Values (from SPICE)	$i_s(mA)$							
	i_f(mA)							

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

4. **Bonus question**[1]
   - 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)



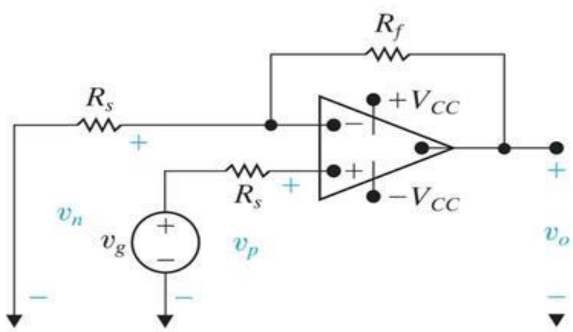


   - Plot the input (v_S) and output voltages (v_o) of the modified circuit for $R_f = 4k\Omega$ and $R_f = 10k\Omega$. What can you conclude from these plots?

[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.

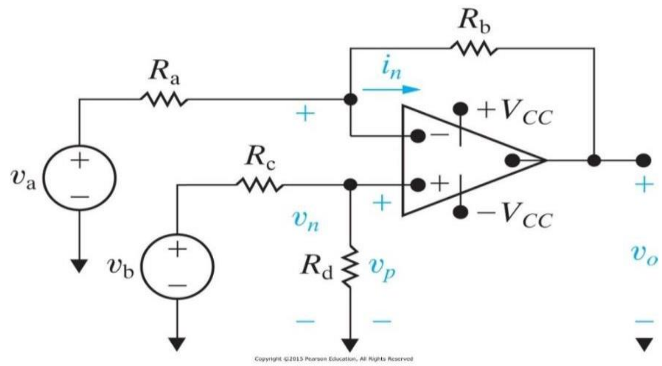
1. Create the above noninverter amplifier circuit in the online SPICE tool. Include voltage probes for the input voltage (v_g), voltage of the inverting terminal (v_n) and output voltage (v_o).
    - The values of v_g, R_s, V_{cc}, R_f are defined in the section “variables and values” (see right part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

	R_f(kΩ)	0.1	0.5	1	4	6	8	10
Theoretical values (ideal OpAmp assumption)	v_g (V)							
	v_n (V)							
	v_o (V)							
	v_o/v_g (gain)							
Simulated values (from SPICE)	v_g (V)							
	v_n (V)							
	v_o (V)							
	v_o/v_g (gain)							

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

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 <u>inverting terminal voltage (v_n), noninverting terminal voltage (v_p)</u> and <u>output voltage (v_o)</u>.
   - 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)	$v_n\ (V)$						
	$v_p\ (V)$						
	$v_o(V)$						
	$\frac{v_o}{v_b - v_a}$ (Gain)						
Simulated values (from SPICE)	$v_n\ (V)$						
	$v_p\ (V)$						
	$v_o(V)$						
	$\frac{v_o}{v_b - v_a}$ (Gain)						

- What do you find from the simulation results?

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