

# Intro to ECSE

## Quiz 2

Spring 2023

<b>1.</b>	<b>/13</b>
<b>2.</b>	<b>/13</b>
<b>3.</b>	<b>/9</b>
<b>4.</b>	<b>/10</b>
<b>Total</b>	<b>/</b>

Name \_\_\_\_\_

Notes:

**SHOW ALL WORK. BEGIN WITH FORMULAS, THEN SUBSTITUTE VALUES AND UNITS.** No credit will be given for numbers that appear without justification.

Use the backs of pages if there is not enough room on the front.

For partial credit on some questions, you may want to re-draw circuit diagrams as you simplify the circuits.

Many problems can be solved using more than one method. check your answers by using a second method.

At least skim through the entire quiz before you begin and then start with the problems you know best. The proctor will only answer clarification questions where wording is unclear or where there may be errors/typos. No other questions will be responded to.

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Problem 1: Nodal Analysis [13 Points]

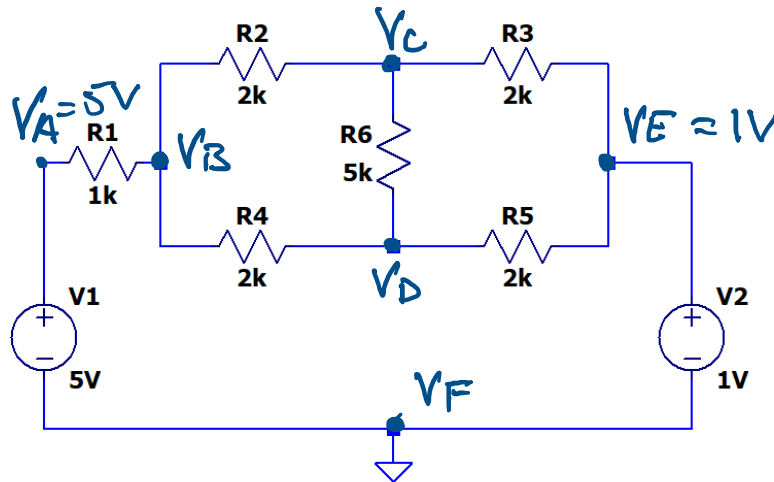


Figure 1

- a. [2 pts] How many voltage nodes are in this circuit? Label them on the circuit schematic.

*6 nodes total +1: # of nodes  
+1: labeled correctly*

- b. [2 pts] Which of these node voltages are already known (if any)? Write their numerical values on the circuit schematic.

*$V_A = 5V$  +1: correctly identified  
 $V_E = 1V$  +1: correctly labeled  
 $V_F = 0V$*

- c. [2 pts] How many linearly independent equations are needed to solve for all unknowns in this circuit? How do you know your equations are linearly independent?

*3 equations are needed. They are linearly independent if there is no equation in the set that can be made by combining the other equations in the set.  
+1: correct # of eqn's; +1: valid justification*

- d. [3 pts] Write down the KCL equation for each node in terms of the nodal voltages you labeled on the schematic in 1.a and 1.b.

$$\text{node B: } \frac{V_B - 5}{1\text{k}\Omega} + \frac{V_B - V_C}{2\text{k}\Omega} + \frac{V_B - V_D}{2\text{k}\Omega} = 0$$

$$\text{node C: } \frac{V_C - V_B}{2\text{k}\Omega} + \frac{V_C - 1}{2\text{k}\Omega} + \frac{V_C - V_D}{5\text{k}\Omega} = 0$$

$$\text{node D: } \frac{V_D - V_B}{2\text{k}\Omega} + \frac{V_D - V_C}{5\text{k}\Omega} + \frac{V_D - 1}{2\text{k}\Omega} = 0$$

+1 for each equation

- e. [4 pts] Write the equations from 1.d in matrix form. You do not have to numerically solve them.

$$\begin{bmatrix} (1/1\text{k} + 1/2\text{k} + 1/2\text{k}) & (-1/2\text{k}) & (-1/2\text{k}) \\ (-1/2\text{k}) & (1/2\text{k} + 1/2\text{k} + 1/5\text{k}) & (-1/5\text{k}) \\ (-1/2\text{k}) & (-1/5\text{k}) & (1/2\text{k} + 1/5\text{k} + 1/2\text{k}) \end{bmatrix} \begin{bmatrix} V_B \\ V_C \\ V_D \end{bmatrix} = \begin{bmatrix} 5/1\text{k} \\ 1/2\text{k} \\ 1/2\text{k} \end{bmatrix}$$

+2
↑ +1
↑ +1

**Problem 2: Operational Amplifiers [13 Points]**

A multi-stage op-amp circuit is shown below. Assume that U1, U2, and U3 are ideal op-amps. For all parts of this problem, the positive ( $V_{s+}$ ) and negative ( $V_{s-}$ ) supply voltages are +5V and -5V. V1 is a sinusoidal wave with an amplitude of -1V and V2 is a sinusoidal wave with an amplitude of +1V.

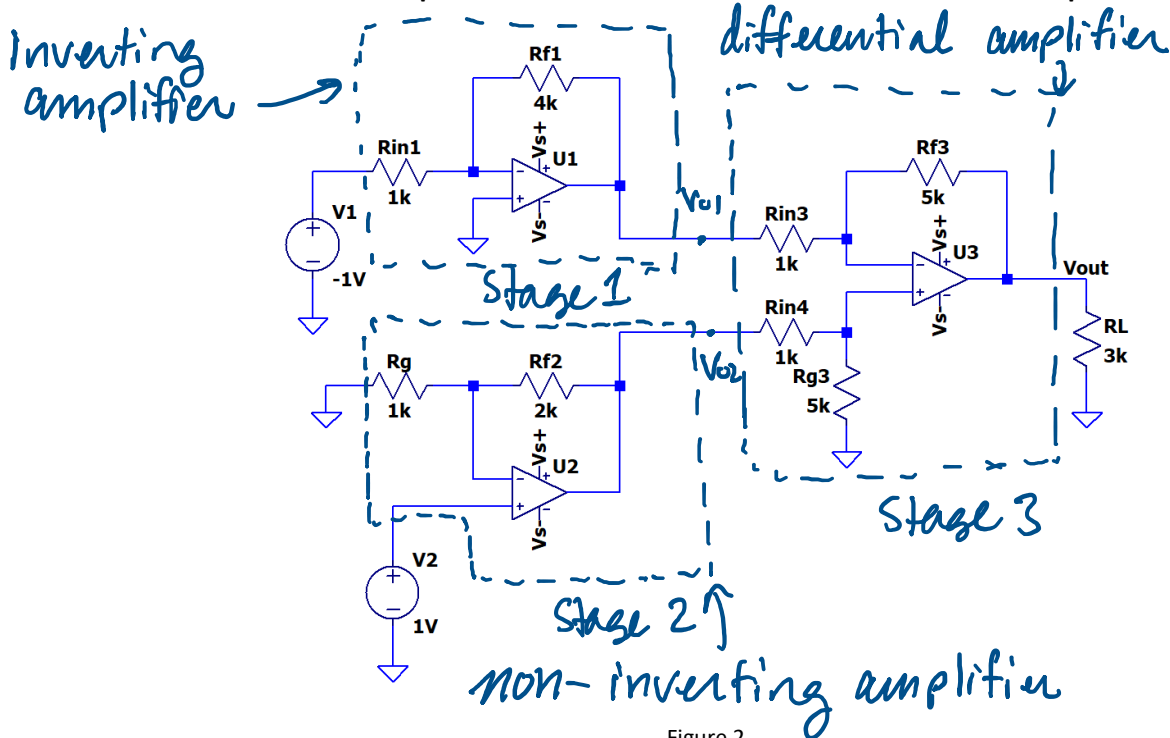


Figure 2

- a. [3 pts] How many stages are in this circuit? Draw a box around each of them and label them as "Stage 1", "Stage 2", etc.

There are 3 stages  
 +1: correct # of stages  
 +1: correctly delineated  
 +1: correctly labeled

- b. [3 pts] Label each stage of the circuit with what type of circuit it is.

See schematic  
 +1: each correctly labeled circuit

- c. [4 pts] Write the transfer function of each stage of the circuit in terms of the resistor names and as a numerical result. Additionally, specify what you consider to be  $V_{in}$  for Stage 3. *Hint:*  $V_{in}$  for a stage may be the sum or difference of two voltages.

$$H_1 = -\frac{R_{f1}}{R_{in1}} = -4 \quad +1: \text{each } H \text{ in terms of resistor names}$$

$$H_2 = \left(1 + \frac{R_{f2}}{R_g}\right) = 3 \quad +1: \text{correct math for numerical values}$$

$$H_3 = \frac{R_{f3}}{R_{in3}} = \frac{R_{g3}}{R_{in4}} = 5 \rightarrow V_{in} = V_{o2} - V_{o1}$$

- d. [3 pts] What is  $V_{out}$  for the circuit? Give your answer in terms of the amplitude of the sinusoidal wave.

$$\text{Stage 1: } V_{in1} = -1V, V_{out} = H_1 \cdot V_{in1} = (-4)(-1V) = 4 = V_{o1}$$

$$\text{Stage 2: } V_{in2} = 1V, V_{out} = H_2 \cdot V_{in2} = (3)(1V) = 3 = V_{o2}$$

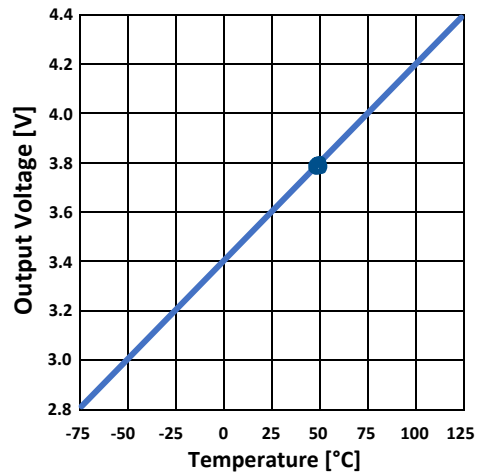
$$\text{Stage 3: } V_{in3} = V_{o2} - V_{o1} = 4V - 3V = 1V$$

$$V_{out} = H_3 \cdot V_{in3} = (5)(1V) = \underline{5V}$$

+1: correct equation for calculating  $V_{out}$  of each stage

### Problem 3: Temperature Sensing Circuit [9 Points]

In this problem you are tasked with designing a circuit that detects whether the ambient temperature is above a certain value. Shown below is the sensitivity curve from the datasheet of the sensor, which gives voltage output from the sensor at different temperatures.



- a. [2 pts] The circuit should detect if the temperature is above or below 50°C. What should the threshold voltage of your circuit be?

at  $T = 50^\circ\text{C} : V_{\text{ref}} = 3,8\text{V}$

+1: using plot to find  $V_{\text{ref}}$

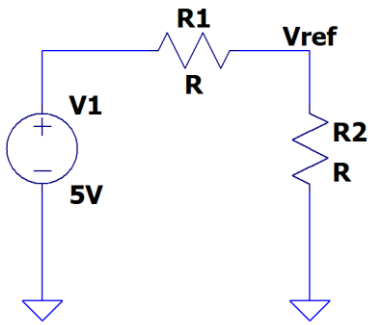
+1: valid choice for  $V_{\text{ref}}$

- b. [1 pts] The circuit should output a high voltage when the temperature exceeds the threshold value and a low voltage when the temperature is below the threshold value. What kind of op-amp circuit do you need in your circuit design?

we would use a non-inverting comparator

+1: correct circuit

- c. [2 pts] Choose values for  $R_1$  and  $R_2$  will generate the reference voltage ( $V_{ref}$ ) that you determined in part a). As a voltage supply, you have +5V DC available and you may choose any resistor values you'd like.



$$V_{ref} = V_1 \frac{R_2}{R_1 + R_2}$$

Choose  $R_1 = 1k\Omega$

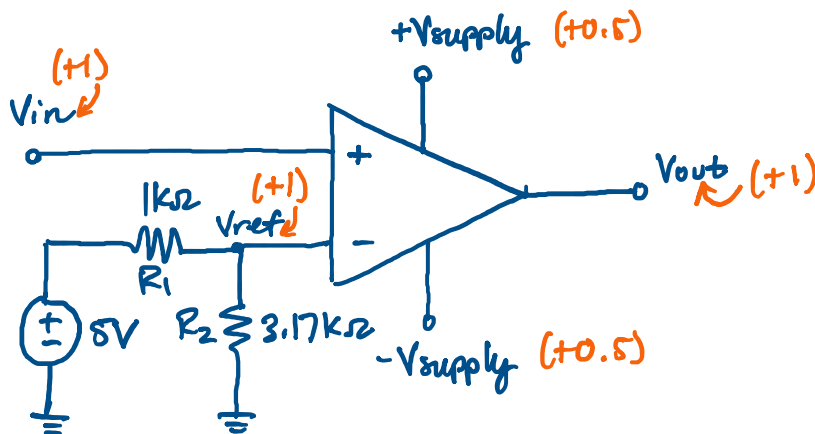
$$3.8V = 5V \frac{R_2}{1k\Omega + R_2}$$

$$\rightarrow R_2 = \underline{3.17k\Omega}$$

+1: voltage divider

+1: valid  $R_1$  and  $R_2$

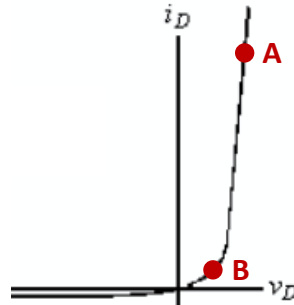
- d. [4 pts] Draw your temperature comparison circuit, including the circuit that provides your reference voltage. Be sure to label the op-amp supply voltages, input voltage, reference voltage, and output voltage. You have two DC supply voltages available for the op-amp: 0V DC (ground) and +5V DC.



+1: correctly connected/ labeled  $V_{ref}$  circuit  
( $R_1$  and  $R_2$  don't need numerical values)

**Problem 4: Various Concepts and Short Answer Questions [10 Points]**

a. [2 pts] Shown below is the IV characteristic of a diode.

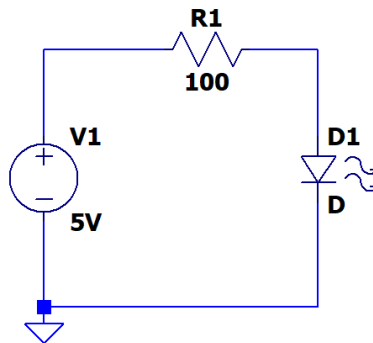


Which of the following statements is true regarding the differential resistance  $R_D$  at points A and B?  
Circle one:

- a)  $R_D$  at point A is infinity
- b)  $R_D$  at point A is zero
- c)  $R_D$  at point B is infinity
- d)  $R_D$  at point B is zero
- e)  $R_D$  at point A is larger than  $R_D$  at point B
- f)  $R_D$  at point A is smaller than  $R_D$  at point B

*$R_D \propto 1/\text{slope of IV curve, so}$   
 $R_D @ A < R_D @ B$*

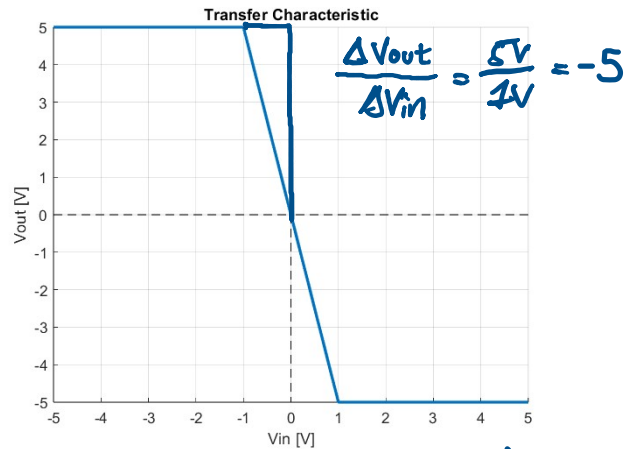
b. [2 pts] Explain why a resistor is needed in the circuit below:



*A resistor is needed to limit the current through the diode so that it is not damaged due to too much current flowing through it.*

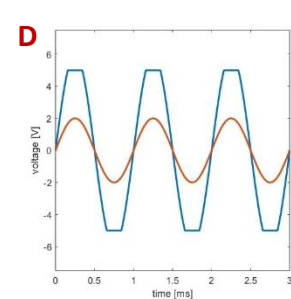
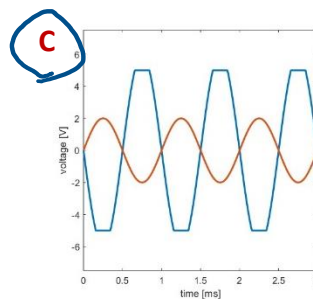
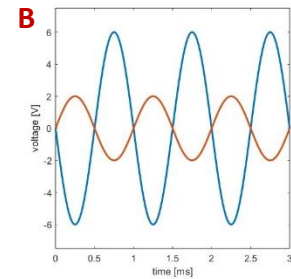
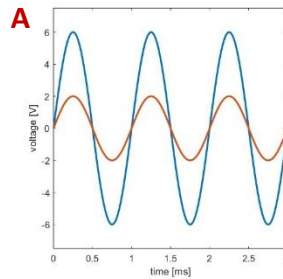
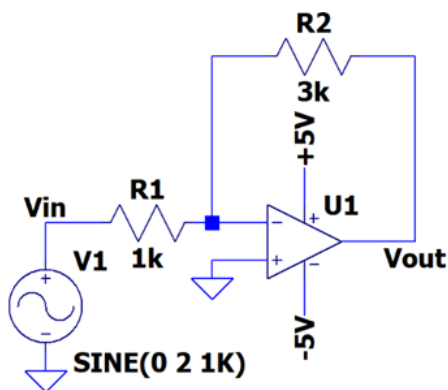


- c. [2 pts] Shown below is the transfer characteristic of an op-amp amplifier circuit. What is the gain of this circuit assuming it is operating in the linear region?



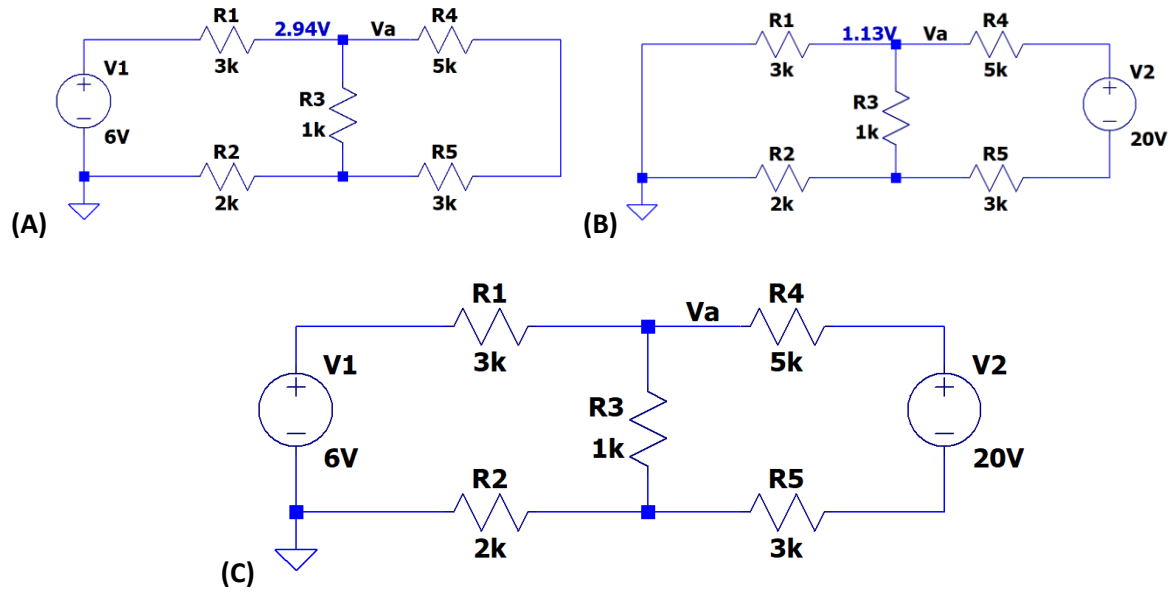
The transfer function (also the gain of an amplifier) is  $\frac{V_{out}}{V_{in}}$ , so gain = slope of the transfer characteristic:  $\underline{-5}$

- d. [2 pts] In the circuit below,  $V_{in}$  is a 1 kHz sine wave with an amplitude of 1V. Which plot shows the correct output voltage for this op-amp circuit? Circle one.



$$H = -\frac{R_3}{R_2} = \frac{3k\Omega}{1k\Omega} = -3, \text{ so } V_{out} = (-3) \cdot 2V = -6V$$
  
 but  $V_{supply} = \pm 5V$ , so the maximum/minimum  $V_{out}$  is  $\pm 5V$ .

- e. [2 pts] In the circuits below, the voltage at node A ( $V_a$ ) in circuit A is 2.94V and the voltage at node A in circuit B is 1.13V.



What is the voltage at node A in circuit C?

4.07V

$$\begin{aligned}
 \text{Using superposition, } V_{R3C} &= V_{R3A} + V_{R3B} \\
 &= 2.94V + 1.13V \\
 &= \underline{4.07V}
 \end{aligned}$$