Intro to ECSE

Quiz 2 Solutions

Fall 2023

1.	**/12**
2.	**/13**
3.	**/8**
4.	**/15**
Total	**/48**

Name ___________________________________

RIN ___________________________________

Section ___________________________________

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.

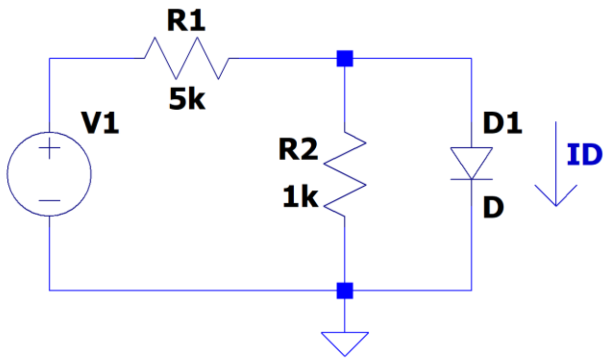
For partial credit on some questions, you may want to re-draw circuit diagrams as you simplify the circuits.

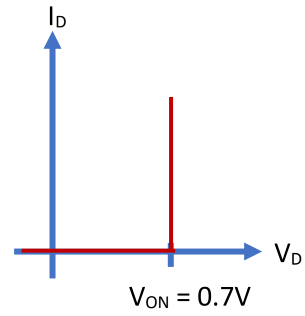
Many problems can be solved using more than one method. check your answers by using a second method.

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.

Problem 1 [12 Points]: Miscellaneous Concepts and Short Answer Questions

1.1 [2 pts] What is the minimum value of V1 that will cause current to flow through the diode such that $I_D > 0$? Assume the simple ideal diode model and $V_{ON} = 0.7V$.





The diode will turn on as soon as $V_D \geq 0.7V$. Since $V_D = V_{R2}$, we have

$$V_{R2} = V_1 \frac{R_2}{R_1 + R_2} \rightarrow \frac{V_{R2}}{R_2}(R_1 + R_2) = V_1$$

If we want $V_{R2} \geq V_{ON}$,

$$V_1 \geq \frac{0.7V}{1000\Omega}(5000\Omega + 1000\Omega) = 4.2V$$

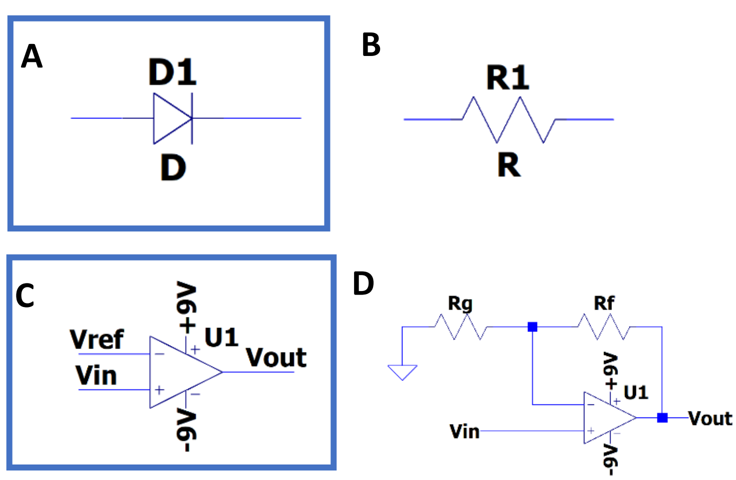
so $\boxed{V_1 \geq 4.2V}$

[-1] Invalid approach or diode model

[-1] Math error

$V_1 \geq$ **4.2** V

1.2 [2 pts] Which of the following circuit blocks or elements are always considered to be functionally non-linear? Circle all that apply. *Note: this means without applying any techniques to make them look linear.*



A. diode: a diode's IV curve is non-linear

B. resistor: a resistor's IV curve is linear

C. comparator: a comparator's transfer characteristic is non-linear, as it primarily consists of two saturation regions and no linear region.

D. non-inverting amplifier: if operated in the linear region, the amplifier behaves linearly.

[-1] One incorrect

[-1] Two incorrect

1.3 [2 pts] Which of the following are true about measuring currents and voltages? Circle all that apply.

a) When measuring **current**, the multimeter is placed in **series** with the circuit element whose current you want to measure.

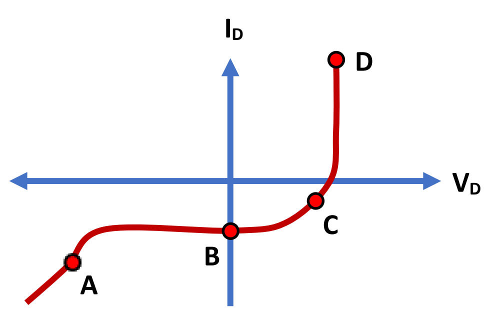
b) When measuring **current**, the multimeter is placed in **parallel** with the circuit element whose current you want to measure.

c) When measuring **voltage**, the multimeter is placed in **series** with the circuit element whose current you want to measure.

d) When measuring **voltage**, the multimeter is placed in **parallel** with the circuit element whose current you want to measure.

[-1] One incorrect
[-2] Both incorrect

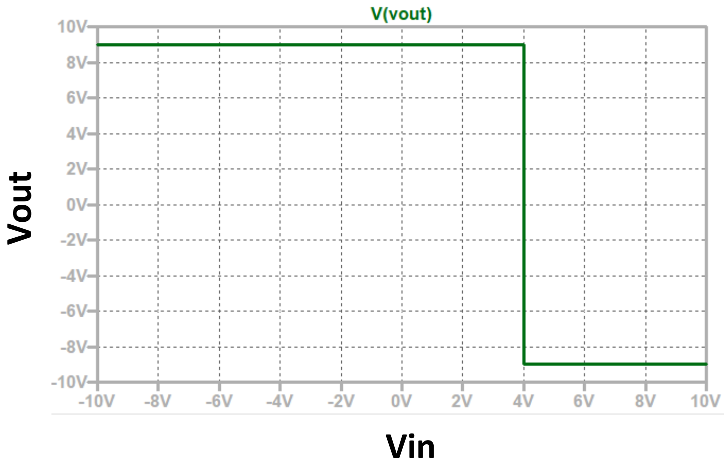
1.4 [2 pts] Shown below is the IV characteristic of a fictional device. Where is the differential resistance R_{diff} approximately zero? Circle all that apply.



Point A **Point B** **Point C** **Point D**

Since differential resistance is defined as $R_{diff} = \frac{dV}{dI}$, it is inversely proportional to the slope of an IV characteristic with V on the x-axis and I on the y-axis. As a result, R_{diff} is approximately zero where the slope is approximately infinite, which is at Point D. [-2] Incorrect

1.5 [4 pts] The transfer characteristic for a comparator circuit is shown below. Using the transfer characteristic, answer the following questions:



i. Which type of comparator is this?

Since V_{out} is low when $V_{in} > V_{ref}$ and V_{out} is high when $V_{in} < V_{ref}$, this is an inverting comparator.

[-1] Incorrect

ii. What is the reference voltage for this comparator?

The output voltage switches at $V_{in} = 4V$, so $V_{ref} = 4V$.

[-1] Incorrect

iii. What is the Vs^+, the positive (or larger) supply voltage for the comparator?

$V_S^+ = +9V$ [-1] Incorrect

iv. What is the Vs^-, the negative (or smaller) supply voltage for the comparator?

$V_S^- = -9V$ [-1] Incorrect

Problem 2 [13 Points]: Nodal Analysis

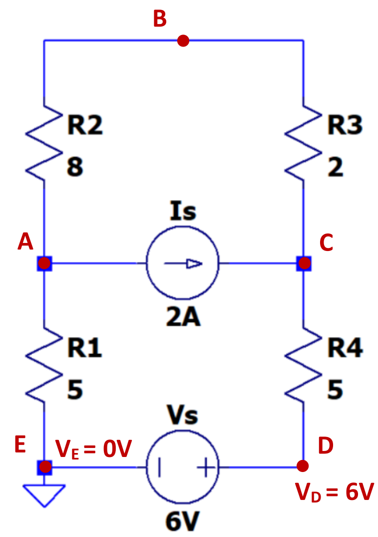


Figure 1

a. [2 pts] How many voltage nodes in total (both known and unknown) are in this circuit? Label them on the circuit schematic.

nodes : 5 [-2] Incorrect; [-1] not labeled

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

known nodal voltages: $V_D = 6V$; $V_E = 0V$ [-2] Incorrect; [-1] not labeled

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

eqns needed = # nodes - # voltage sources - 1

= 5 - 1 - 1 = 3 [-2] Invalid approach/Incorrect

[-1] Math error

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.

· at node A:

$$\frac{V_A}{R_1} + I_s + \frac{V_A - V_B}{R_2} = 0 \rightarrow (1/R_1 + 1/R_2)V_A + (-1/R_2)V_B = -I_s$$

$$(1/5 + 1/8)V_A + (-1/8)V_B = -2$$

[-1] Equation incorrect

· at node B:

$$\frac{V_B - V_A}{R_2} + \frac{V_B - V_C}{R_3} = 0 \rightarrow (-1/R_2)V_A + (1/R_2 + 1/R_3)V_B + (-1/R_3)V_C = 0$$

$$(-1/8)V_A + (1/8 + 1/2)V_B + (-1/2)V_C = 0$$

[-1] Equation incorrect

· at node C:

$$\frac{V_C - V_B}{R_3} + (-I_s) + \frac{V_C - V_D}{R_4} = 0 \rightarrow (-1/R_3)V_B + (1/R_3 + 1/R_4)V_C = \frac{V_D}{R_4} + I_s$$

$$= (-1/2)V_B + (1/2 + 1/5)V_C = 6/5 + 2$$

[-1] Equation incorrect

e. [4 pts] Write the equations from 1.d in matrix form with numerical values for circuit elements inserted (i.e. numbers for all resistances, known voltages, and known currents). You do not need to numerically solve the matrix equation.

$$\begin{bmatrix} (1/5 + 1/8) & (-1/8) & 0 \\ (-1/8) & (1/8 + 1/2) & (-1/2) \\ 0 & (-1/2) & (1/2 + 1/5) \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} -2 \\ 0 \\ 6/5 + 2 \end{bmatrix}$$

[-2] Incorrect coefficients matrix

[-1] Incorrect unknowns vector

[-1] Incorrect constants vector

$$\begin{bmatrix} 0.325 & -0.125 & 0 \\ -0.125 & 0.625 & -0.5 \\ 0 & -0.5 & 0.7 \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} -2 \\ 0 \\ 3.2 \end{bmatrix} \rightarrow \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} -3.5 \\ 6.9 \\ 9.5 \end{bmatrix}$$

Problem 3 [8 Points]: Superposition

Solve for VR1, the voltage across R1, in the circuit below ***using the superposition method*** of circuit analysis.

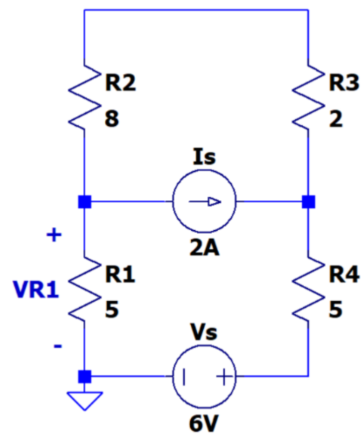
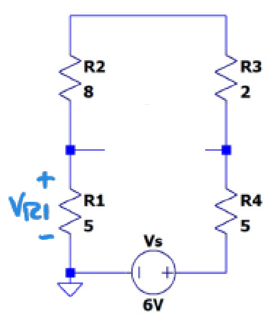


Figure 2

a. [3 pts] Find $VR1_{VS}$, the voltage across R1 due to *Vs* only.

V_{R1} due to V_s only. Turning off I_s yields an open circuit.



This gives a series circuit, so

$$V_{R1} = V_s \frac{R_1}{R_1 + R_2 + R_3 + R_4}$$

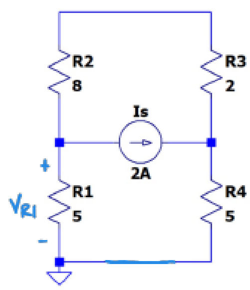
$$= 6V \frac{5}{20} = \frac{6V}{4} = \underline{1.5V}$$

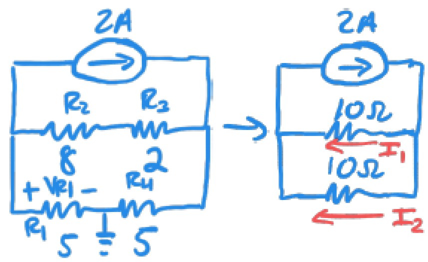
[-2] I_s not turned off properly

[-1] Error in finding V_{R1}

b. [3 pts] Find $VR1_{IS}$, the voltage across R1 due to *Is* only.

V_{R1} due to I_s only. Turning off V_s yields a short circuit. This this gives a parallel circuit





· Since the resistance of both current paths is the same, the current is split evenly between them: $I_1 = I_2 = 1A$

I_2 is opposite to how V_{R1} is defined

· $V_{R1} = -I_2 \cdot R_1 = -1A \cdot 5\Omega = \boxed{-5V}$

c. [2 pts] Using $VR1_{VS}$ and $VR1_{IS}$, find VR1 as indicated in Figure 2 above.

$$V_{R1} = V_{R1,V_s} + V_{R1,I_s}$$
$$= 1.5V - 5V = \boxed{-3.5V}$$

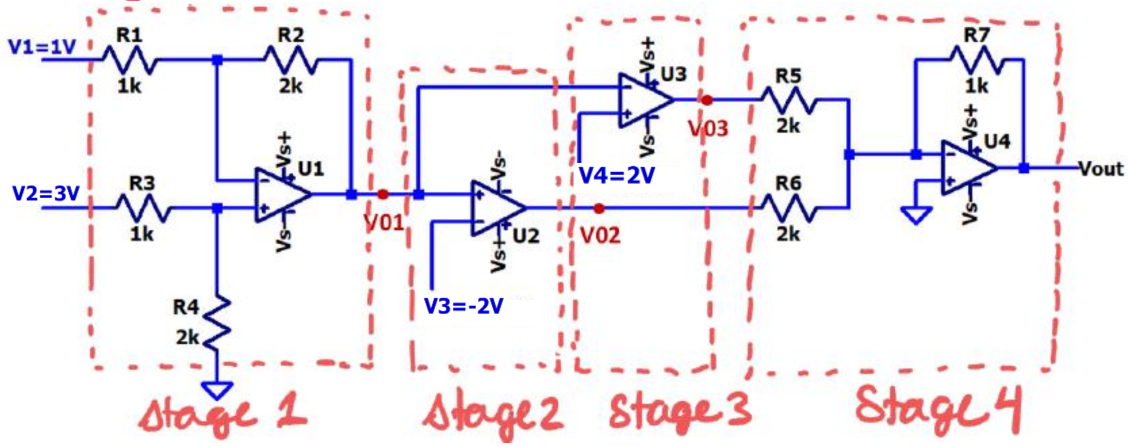
[-1] Incorrect approach to finding V_{R1}

[-1] Math error

Problem 4 [15 Points]: Cascaded Op-Amp Circuit

Determine the value of Vout. The supply voltages Vs+ and Vs- for the op-amps are **+5V** and **-5V**.

Note: $V_2 = 2V$ in the exam. This was an error.



a. [3 pts] Identify how many stages are in this op-amp circuit. Draw a box around each stage and label them "Stage 1", "Stage 2", etc.

There are 4 stages

[-1] Incorrect # of stages

[-1] Stages delineated incorrectly

[-1] Stages labeled incorrectly

b. [4 pts] Label each stage of the circuit with what type of circuit it is. *Note*: for all stages, be sure to specify if it is "non-inverting" or "inverting" when applicable.

Stage 1: difference amplifier

Stage 2: non-inverting comparator

Stage 3: inverting comparator

Stage 4: inverting, weighted summer

c. [4 pts] For each stage, write the transfer function as a numerical value. In cases in which a transfer function cannot be written for a stage, state this clearly, and write the expression for the output voltage of that stage in terms of the input voltage instead. *Hint*: Vin for a stage may be the sum or difference of two voltages; in this case, also state what you consider to be Vin for that stage.

Stage 1: $\underline{H_1} = \frac{R_2}{R_1} = 2$, where $V_2 - V_1 = V_{in}$

Stage 2: $\underline{V_{o2}} = \begin{cases} +5V & \text{if } V_{o1} > -2V \\ -5V & \text{if } V_{o1} < -2V \end{cases}$

Stage 3: $\underline{V_{o3}} = \begin{cases} +5V & \text{if } V_{o1} < 2V \\ -5V & \text{if } V_{o1} > 2V \end{cases}$

Stage 4: $V_{o4} = -\frac{R_7}{R_5} V_{o3} - \frac{R_7}{R_6} V_{o2}$

$$= -\frac{1}{2} V_{o3} - \frac{1}{2} V_{o2}$$

$$= -\frac{1}{2}(V_{o3} + V_{o2})$$

so $\underline{H_4 = -\frac{R_7}{R_6} = -\frac{1}{2}}$, where $V_{o3} + V_{o2} = V_{in}$

[-1] for each Vo or transfer function

[-0.5] for math errors in each stage

d. [4 pts] Calculate Vout.

Stage 1: $\begin{cases} V_{in} = V_2 - V_1 = 2V \\ H_1 = 2, \text{ so} \\ V_{o1} = 2 \cdot 2V = \underline{4V} \end{cases}$

Stage 2 : $V_{o2} = \underline{+5V}$ because $V_{o1} > -2V$

Stage 3 : $V_{o3} = \underline{-5V}$ because $V_{o1} > 2V$

any Value between $-5V$ and $+5V$ for V_{o3} is accepted due to the error in the exam $(V_{in2} = V_{ref2} = 2V)$

Stage 4 : $\begin{cases} V_{in} = V_{o3} + V_{o2} = 0V \\ H_4 = -\frac{1}{2} \\ V_{out} = -\frac{1}{2}(0V) = \underline{0V} \end{cases}$

[-1] for each incorrect output voltage from a stage

e. [4 pts] Bonus: Write the expression for Vout in terms of V1 and V2 in general. In your own words, what is the function of this circuit (overall, what does it do)?

$$V_{out} = \begin{cases} -5V, \text{ if } & -1V < V_{in} < +1V \\ 0V, \text{ if } & V_{in} < -1V \text{ or } V_{in} > +1V \end{cases}$$

where $V_{in} = V_2 - V_1$

- This circuit outputs $-5V$ if $|V_2 - V_1| < 1V$ and 0 otherwise.

[+1] correct Vout for $-1V < V_{in} < 1V$

[+1] correct Vout for $V_{in} < -1V$

[+1] correct Vout for $V_{in} > +1V$

[+1] Valid description of what circuit does overall