Name:_________________________________ UT EID:__________ Instructor_____________________

ECE 302 **Please answer ALL questions**

100 points total.

Fall 2024, Midterm Exam I **Time: 600-800 PM**

26 Sept. 2024

PLEASE ATTEMPT ALL PROBLEMS AND SHOW ALL WORK!

WRITE ALL EXAM SOLUTIONS IN THE SPACES PROVIDED ON THE EXAM SHEETS.

YOU MAY USE THE BACK OF EACH PAGE FOR SCRATCH, BUT ONLY THE FRONT SIDES WILL BE SCANNED AND GRADED.

No class notes, books, homework assignments, or other materials are allowed. You may use a calculator for the exam. Any calculator that does not have phone/communication/photo capability is allowed. Your calculator's memory should not have any information or programs that are not allowed for use on the exam. You have 120 minutes from the start of the exam to complete the exam.
NOTES: Unless otherwise stated, you may assume all numerical quantities given in the exam problems are known to 3 significant figures, and calculate your answers accordingly. You must show all of your work to receive credit. If you need to make an assumption to answer a question, state it explicitly.

<u>Instructions for turning in your exam:</u>

<u>After completing your exam, you may turn on your phones</u>

0) Please write your EID on every page of the exam
1) Log in to Gradescope and find MT1 or Midterm I
2) For each problem:
a. If your response is within the space for the answer, you should choose the option to have Gradescope take a picture of your page. You should scan all pages of this exam booklet including the first page and any blank pages in the correct order. Gradescope will automatically assign your answers to each question according to the template.

b. If your response does not fit in the space for the answer and you used extra sheets, you must take pictures of each page with your camera app and choose the option to upload the solution. You will need to assign the answer for each question in Gradescope.

3) DOUBLE CHECK YOUR SUBMISSION
4) Turn in your paper exam to the proctor (this will be used as a reference)

Q1 (25 points)

(a) (4 points) A lithium-ion battery in a smartphone produces 4 V between its terminals and supplies 1 A of current to the circuitry in the phone. Express your answers to the questions below to three significant digits.

(i) Calculate how many lithium ions must be flowing between the terminals of the battery per second. Lithium ions can be considered to have a positive charge equal to the magnitude of the electron charge = 1.6E-19 coulomb.

6.25E18

(ii) Calculate how much energy in joules is consumed by the phone in 1 day.

3.46E5 J

(b) (8 points) Consider circuit in figure 1b.

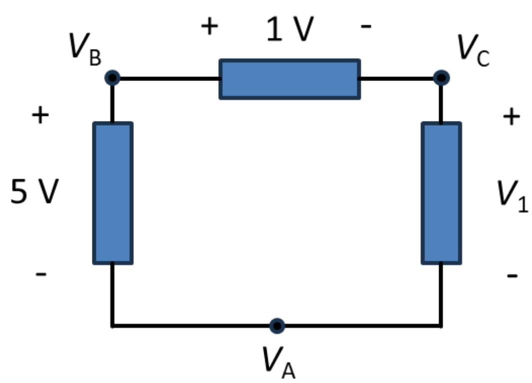

Figure 1b

(i) With A as ground, what are the numerical values of V_B, V_C?

$V_B = 5$ V, $V_C = 4$ V

(ii) With B as ground, what are the numerical values of V_A, V_C?

$V_A = -5$ V, $V_C = -1$ V

(c) (3 points) Consider the circuit in figure 1c.
With $V_{S1} = 1$ V, $I_{S2} = 0$ A you find $V_L = 2$ V.
With $V_{S1} = 0$ V, $I_{S2} = 1$ A you find $V_L = 4$ V.
Write an expression relating V_L, V_{S1} and I_{S2}.

$V_L = 2\ V_{S1} + 4\ I_{S2}$

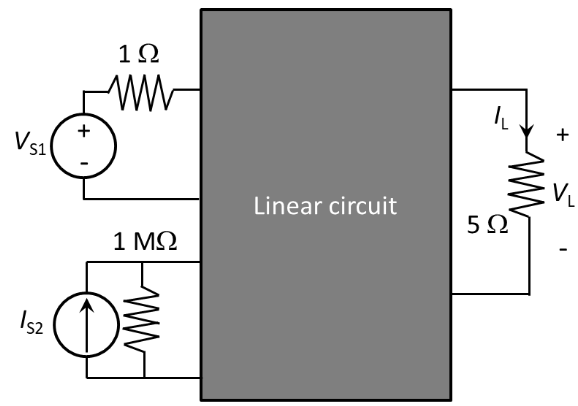

Figure 1c

(d) (5 points) Consider the circuits shown in figure 1d. Draw the Thevenin equivalent circuit making sure to label nodes a, b on your drawings.

$V_{TH} = 3$ V, $R_{TH} = 2\ \Omega$

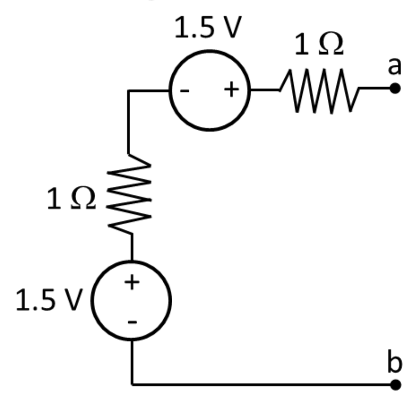

Figure 1d

(e) (5 points) Consider the circuits shown in figure 1e. Draw the Thevenin equivalent circuit making sure to label nodes a, b on your drawings.

$V_{TH} = 1.5$ V, $R_{TH} = 0.5\ \Omega$

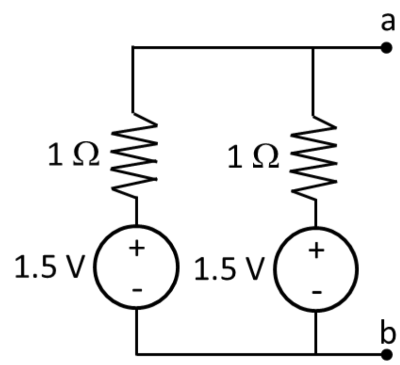

Figure 1e

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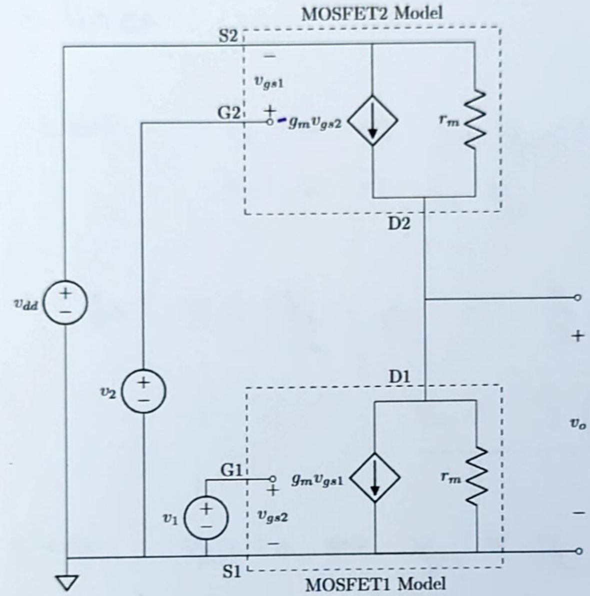
Q2 (25 points) We studied a common-source amplifier in homework, which involves a MOSFET. This problem concerns a common-drain amplifier, which also involves a MOSFET whose behavior is modeled in the circuit below by a resistor r_m in parallel with a current source whose value is a constant g_m times the voltage v_{gs}. The MOSFET's Drain (D), Source (S), and Gate (G) terminals are also labeled.



(a) (6 points) Calculate the output voltage v_o as a function of the three inputs, v_{dd}, v_1, and v_2 using Node Analysis.

$$-g_m(V_2 - V_{dd}) + \frac{V_{dd} - V_o}{r_m} - g_m V_1 - \frac{V_o}{r_m} = 0$$

$$V_o\left(\frac{1}{r_m} + \frac{1}{r_m}\right) = V_o \frac{2}{r_m} = -g_m V_2 + g_m V_{dd} + \frac{1}{r_m} V_{dd} - g_m V_1$$

$$\boxed{V_o = \frac{-g_m r_m}{2} V_1 + \frac{-g_m r_m}{2} V_2 + \frac{1}{2}(1 + g_m r_m) V_{dd}}$$

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(b) (10 points) Is superposition valid for solving this circuit? Why or why not? Calculate the output voltage v_o using superposition and compare with the result of Node Analysis to show that you are right.

Yes - linear.

1) Apply Vdd alone: $V_2 = 0 \Rightarrow g_m V_{gs2} \rightarrow g_m(0 - V_{DD})$
$V_1 = 0 \Rightarrow g_m V_{gs1} \rightarrow 0.$

$$\frac{V_{dd} - V_o}{r_m} + -g_m(-V_{dd}) - \frac{V_o}{r_m} = 0 \Rightarrow \frac{2}{r_m} V_o = \left(\frac{1}{r_m} + g_m\right) V_{dd}.$$

$$\underline{V_o = \frac{1}{2}(1 + g_m r_m) V_{dd}.}$$

2) Apply V_2 alone $V_{dd} = 0 \Rightarrow V_{gs2} = V_2$

$$-g_m V_2 + \frac{0 - V_o}{r_m} - \frac{V_o}{r_m} = 0 \Rightarrow \underline{V_o = \frac{-g_m r_m}{2} V_2}$$

3) Apply V_1 alone $(V_{gs2} = 0)$.

$V_{dd} = 0,\ V_2 = 0$ $$\frac{0 - V_o}{r_m} - g_m V_1 - \frac{V_o}{r_m} = 0$$

$$\Rightarrow \underline{V_o = -\frac{g_m r_m}{2} V_1}$$

$$\boxed{V_o = \frac{-g_m r_m}{2} V_1 + \frac{-g_m r_m}{2} V_2 + \frac{1}{2}(1 + g_m r_m) V_{dd}.}$$

(c) (3 points) A given change in v_1 will result in a change in v_o (Δv_o). This circuit's gain is defined as $\Delta v_o / \Delta v_1$. What is the gain for this circuit? What happens to the gain as $g_m \rightarrow \infty$?

$$\text{Gain} = -\frac{g_m r_m}{2}$$

As $g_m \rightarrow \infty$, Gain $\rightarrow \infty$. (generally a good thing).

(d) (3 points) A given change in power supply voltage v_{dd} (Δv_{dd}) will result in a change in v_o (Δv_o). A circuit's Power Supply Rejection Ratio is defined as $\Delta v_{dd} / \Delta v_o$. What is the PSRR for this circuit? What happens to the PSRR as $g_m \rightarrow \infty$? Is high or low g_m desirable for this property and why?

$$\text{PSRR} = \frac{2}{1 + g_m r_m}$$

As $g_m \rightarrow \infty$, PSRR $\rightarrow 0$

High g_m is not desirable.
(High v_o response to supply voltage change).

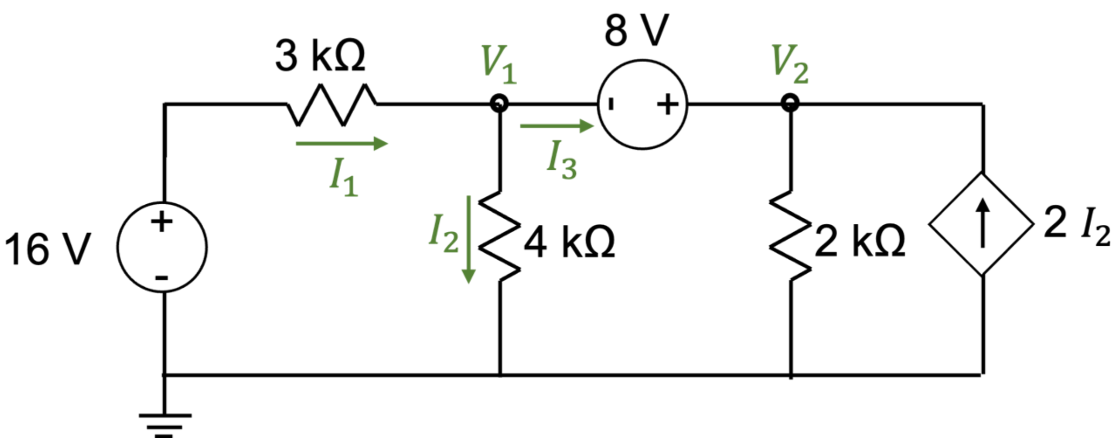
(e) (3 points) What is the Thevenin/output resistance of the circuit? What happens to the output resistance as $g_m \rightarrow \infty$? Is high or low g_m desirable for this property and why?

$R_{TH} = \frac{r_m}{2}$ by superposition.

R_{TH} is unaffected by g_m.

Q3 (25 points)

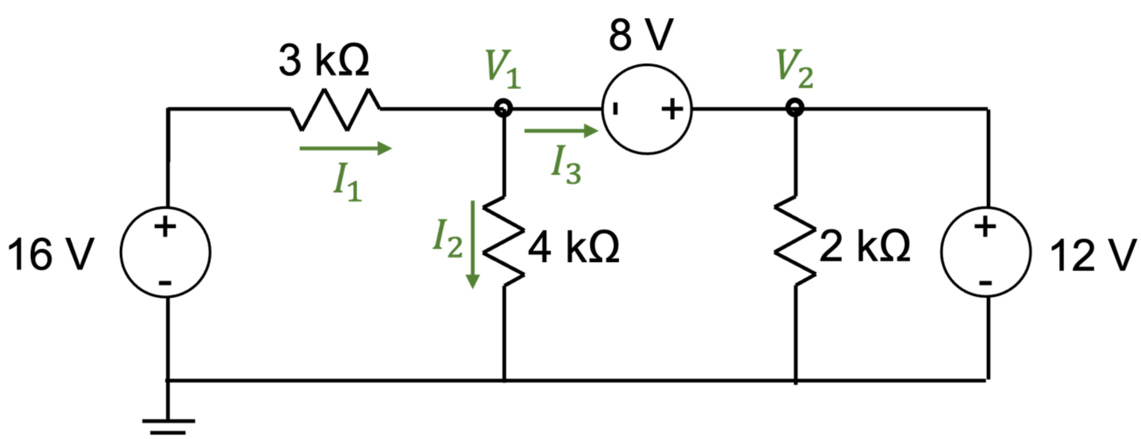
(a) (20 points) Solve the following circuit for V_1, V_2, I_1, I_2, and I_3 using node-voltage method.



$V_1 = \frac{16}{7} V = 2.29\ V$, $V_2 = 10.29\ V$, $I_1 = 4.57\ mA$, $I_2 = 0.57\ mA$, and $I_3 = 4\ mA$

3 (a) answer continued:

(b) The right dependent current supply is replaced with a voltage source, as shown below. Solve for V_1 and V_2 of this modified circuit (here, any method is OK).

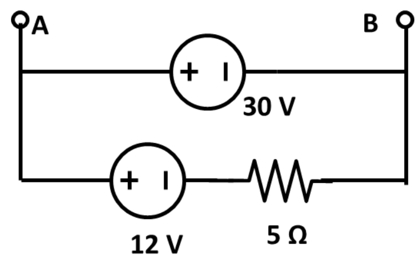


$V_1 = 4\ V, V_2 = 12\ V$

Q4. (25 points) Please find the Thevenin equivalent (Vth and Rth) of the following four circuits. **Please clearly specify the method and reasonings for each step**. **For the final answer, please label the node names in the Thevenin circuit.**

(a) (5 points) Draw Thevenin equivalent circuit (Vth and Rth) between nodes A and B in figure Q4(a)

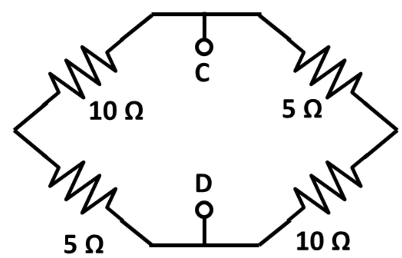
Vth = 30V, if node A being positive, Rth = 0 ohm. Equivalent circuit is just Vth.



Q4 (a)

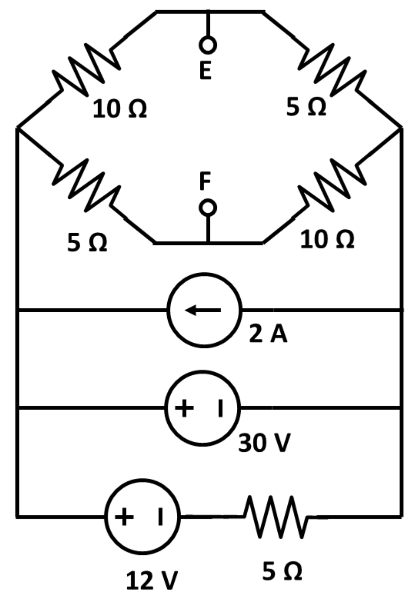
(b) (5 points) Draw Thevenin equivalent circuit (Vth and Rth) between nodes C and D in figure Q4(b)

Vth = 0V, Rth = (10+5)//(10+5)=7.5 ohm. No independent source.



Q4 (b)

(c) (10 points) Draw Thevenin equivalent circuit (Vth and Rth) between nodes E and F in figure Q4(c)



Q4 (c)

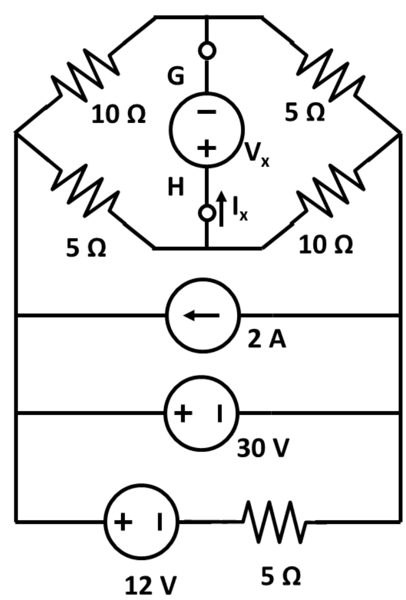
Vth =-10V if the node E being positive, or Vth=10V if the node F being positive

Rth = (10//5)+(10//5)=6.67 ohm

4(c) answer continued:

(d) (5 points) We add a voltage source Vx between nodes E and F in Q4(c) to get the circuit in figure Q4(d). If the current Ix is 0 A, please find out the value of Vx. Hint: you may use the Thevenin equivalent circuit you found in Q4(c).

Vx = 10V



Q4 (d)