EECS 16A Designing Information Devices and Systems I
Fall 2016 Babak Ayazifar, Vladimir Stojanovic **Midterm 2**

Exam location: 1 Pimentel, Last Name: Lin-Wang

PRINT your student ID: ________________________________

PRINT AND SIGN your name: ________________, ________________ ____________________
(last) (first) (signature)

PRINT your Unix account login: ee16a-____________

PRINT your discussion section and GSI(s) (the one(s) you attend): ________________________________

Name and SID of the person to your left: ________________________________

Name and SID of the person to your right: ________________________________

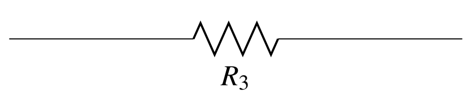
Name and SID of the person in front of you: ________________________________

Name and SID of the person behind you: ________________________________

Section 0: Pre-exam questions (2 points)

1. **What do you like to do in your free time? (1 pt)**

2. **Label the current in any direction through this resistor, using the element name as the subscript. Follow this convention throughout the exam. (1 pt)**

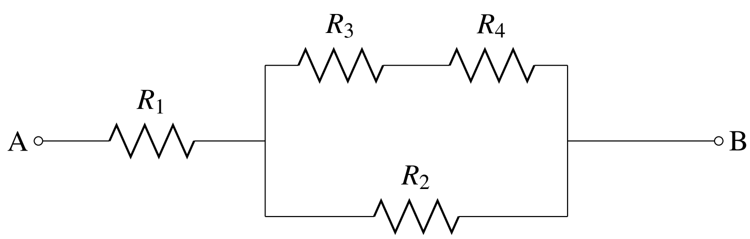


Do not turn this page until the proctor tells you to do so. You can work on Section 0 above before time starts.

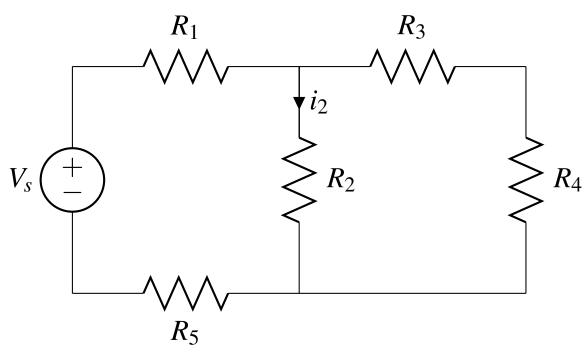
Section 1 (54 points)

3. Resistor Combinations (10 points)

(a) **(4 points)** What is the equivalent resistance between nodes A and B? Write your solution in terms of R_1, R_2, R_3, and R_4. Use the parallel operator $||$ wherever applicable. What is the equivalent resistance if R_4 approaches infinity?



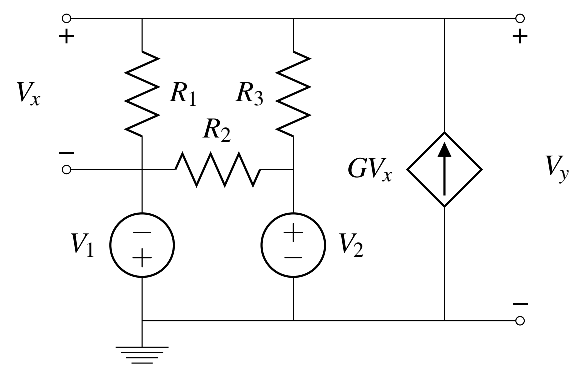
(b) **(6 points)** What is the current i_2 through R_2? Write your solution in terms of R_1, R_2, R_3, R_4, R_5, and V_s. Use the parallel operator $||$ in your expression wherever applicable.



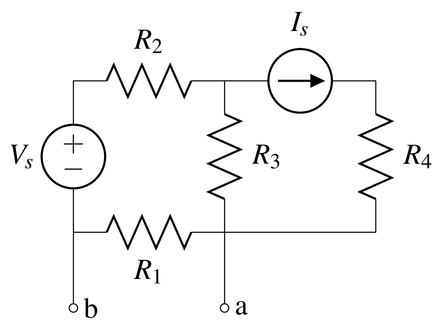
4. Take Node of the Voltage Sources (8 points)

Use nodal analysis to solve for the voltages V_x and V_y. Use the following values for numerical calculations. **Note the polarity on the voltage sources. Solutions that solve the circuit without using nodal analysis will not be awarded full credit.**

$$V_1 = 5 \text{ V} \quad R_1 = 10\ \Omega$$
$$V_2 = 5 \text{ V} \quad R_2 = 50\ \Omega$$
$$G = \tfrac{1}{4} \text{ S} \quad R_3 = 40\ \Omega$$



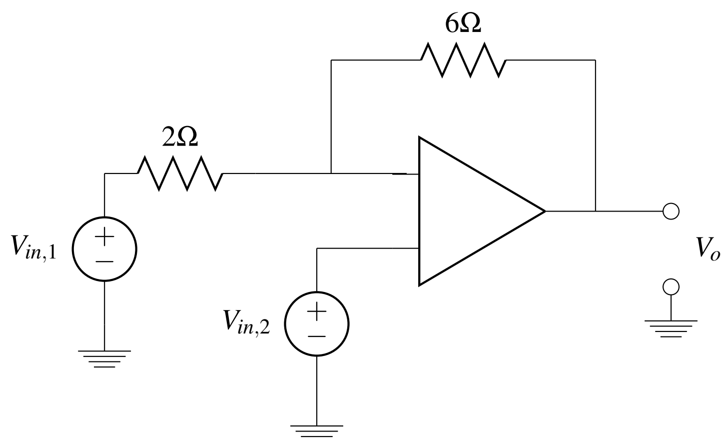
5. Thévenin and Norton Equivalence (10 points)



(a) **(4 points)** Redraw the circuit with all sources nulled, then calculate R_{th} between terminals a and b.

(b) **(6 points)** Find the Thévenin voltage between the terminals a and b. Hint: superposition may be useful.

6. Superposition and Op-Amps (8 points)

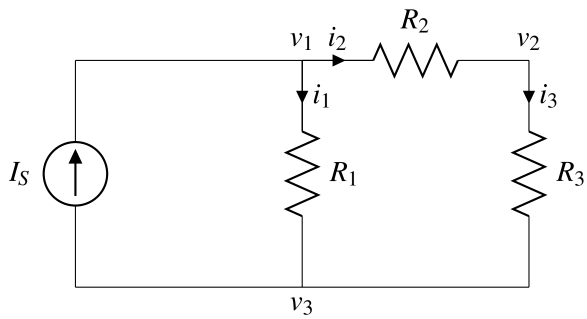


(a) **(2 points)** For the circuit above, label the polarity of the terminals of the op-amp such that there is negative feedback.

(b) **(6 points)** Find V_o in terms of $V_{in,1}$ and $V_{in,2}$. (**Hint**: Assume the op-amp is in negative feedback, then use superposition and golden rules)

7. 16A-Spice (10 points)

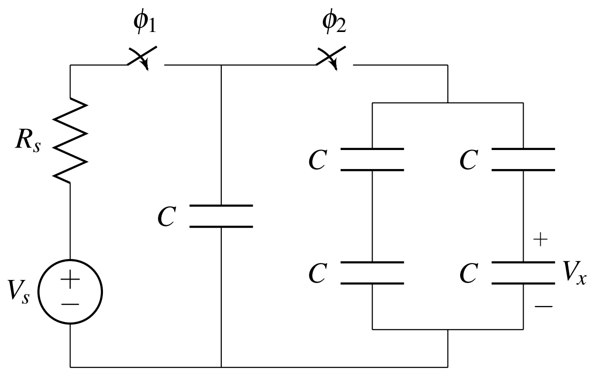
(a) **(5 points)** Write down the incidence matrix, **F** of this circuit. Let node v_n correspond to column n in your incidence matrix, and current i_m correspond to row m.



(b) **(5 points)** Determine the rank of **F**, and a basis for the null space of **F**.

8. Charge-Sharing (8 points)

Initially, all capacitors are uncharged, and have the same capacitance C. For $t < 0$, the switch ϕ_1 is *on* and ϕ_2 is *off* and the circuit has achieved steady state. Later, at $t = 0$, ϕ_1 is *off* and ϕ_2 is *on*; then the system is allowed to reach steady state.

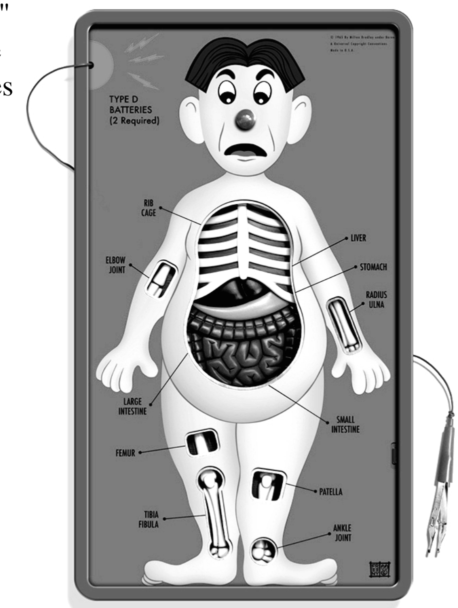


What is the voltage V_x at $t \gg 0$?

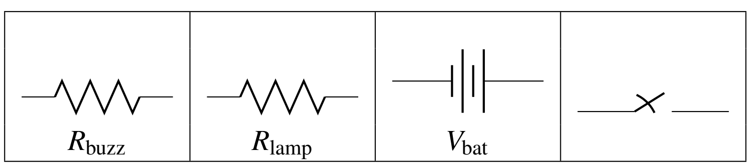
Section 2 (44 points)

9. Operation™ (10 points)

You're an intern at Hasbro working on improvements to the game Operation. Operation is a board game that consists of an "operating table" (the board), overlaid with a drawing of the "patient". In the surface of the board/patient are a number of metal-lined cavities filled with plastic bones and other body parts. The player tries to remove these objects with metal tweezers without touching the edge of the cavity opening. Touching the cavity opening turns on a light and causes a loud buzzer to go off.
You are given the following supplies:



- buzzer: This can be modeled as a resistor, and it buzzes when a voltage is applied across it.
- lamp: The lamp can be modeled as a resistor, and it lights up when current runs through it. The brightness of the lamp is directly proportional to the current passing through it.
- battery: An ideal voltage source.
- switch: When the player makes a mistake and touches the cavity opening with the tweezers, the tweezers act as a switch and close the circuit.



(a) **(4 points)** Design a circuit that makes the buzzer buzz and the lamp turn on when the player makes a mistake.

(b) **(6 points)** Market research has shown that buzzers scare small children, so you've been told to remove the buzzer and use two identical lamps instead of just one. **Assuming all power dissipated by the lamps is converted to light, design a circuit that maximizes the total light emitted by the lamps. Calculate the power P dissipated by the lamps.** *Note: You do not need to rigorously prove that your circuit maximizes the light emitted, but explain your design choices.*

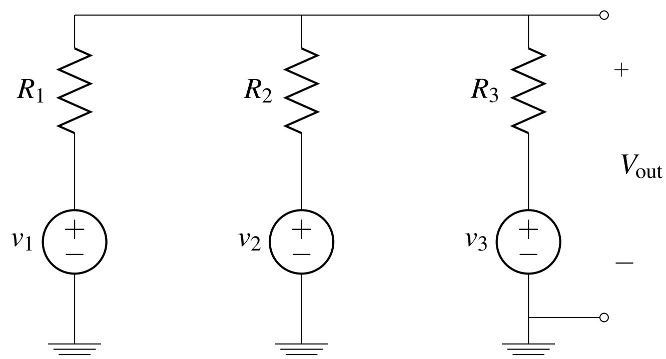
10. This Is Your Brain on EE (18 points)

Medical instruments such as electroencephalograms (EEG) take very small electric signals from the body and scale them into a voltage that we can measure. EEG's take voltage readings from the scalp and are used to determine brain activity. There are some challenges in designing a circuit for measuring the brain:

- The human body is very noisy, so we have to take multiple sensor readings and average them.
- The brain's electrical signals are very small, usually in the microvolt range.

In this problem you will design an EEG circuit that will tackle these problems.

(a) **(4 points)** In the circuit below, determine V_{out} in terms of v_1, v_2, v_3, R_1, R_2, and R_3. Use the parallel operator $\|$ wherever applicable.



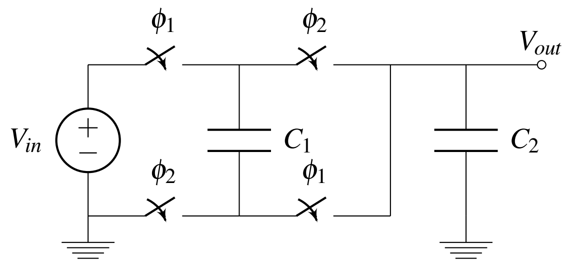
(b) **(7 points)** Suppose we want to mitigate noise and interference from our circuit and body by averaging the reading across multiple areas of our scalp. Design a circuit that takes the average of three EEG readings. Model the k^{th} EEG reading as a voltage source labelled v_k in series with a source resistance of $1k\Omega$. Also, provide an equation for V_{out} in terms of the v_k's. You may use resistors on any value for this design.

Hint: the circuit from part (a) might be useful.

(c) **(7 points)**Let the typical voltage range of values for EEG signals be from $-10mV$ to $10mV$. Design a circuit that takes the output of your circuit in part (b) and scales the EEG signal, while maintaining the sign, to a voltage range of $-2.5V$ to $2.5V$. Give an equation that relates the output to the input. You may use any combination of resistors or ideal op-amps for this question.

11. Voltage Regulators (16 points)

In this problem we will explore how we can use charge sharing to make a better voltage regulator.



(a) **(4 points)** Switches ϕ_1 are both *on* in Phase 1. All other switches are *off*. Find the charge on and voltage across each capacitor as a function of V_{in}, C_1, and C_2. Assume the capacitors are uncharged before Phase 1.

(b) **(4 points)** In Phase 2, switches ϕ_2 are both *on*, all other switches are *off*. What are the charges on C_1 and C_2 in Phase 2 as a function of V_{out}, C_1, and C_2?

(c) **(4 points)** Find V_{out} as a function of V_{in}, C_1, and C_2.

(d) **(4 points)** Assume we have chosen $C_1 = C_2 = C$. One of the most important metrics in voltage regulators is efficiency. For a switching circuit such as this, we calculate efficiency as the total energy stored in the capacitors in Phase 2 divided by the total energy stored in the capacitors in Phase 1. Find the efficiency of this circuit.

You may use this page for scratch work but **it will not be graded.**

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