EECS 16A   Designing Information Devices and Systems I
Fall 2022   Midterm 2

PRINT your student ID: _____

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

PRINT the time of your discussion section and your GSI(s) name: _____

PRINT the student IDs of the person sitting on your right: _____ and left: _____

1. **HONOR CODE**

   Please read the following statements of the honor code, and sign your name (you don't need to copy it).

   I will respect my classmates and the integrity of this exam by following this honor code. I affirm:

   - *I have read the instructions for this exam. I understand them and will follow them.*
   - *All of the work submitted here is my original work.*
   - *I did not reference any sources other than my one reference cheat sheet.*
   - *I did not collaborate with any other human being on this exam.*
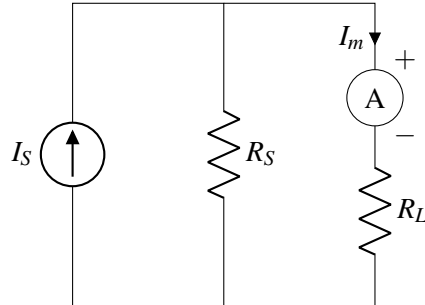
2. **Tell us a joke or pun about circuits (1 point)** *All answers will be awarded full credit.*

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### 3. Why is the ammeter so hot? (14 points)

In the following circuit, we would like to measure the current I_m through resistor R_L using an ammeter.

(a) (4 points) If $I_S = 4\,\text{A}$, $R_S = 3\,\text{m}\Omega$, and $R_L = 1\,\text{m}\Omega$, then what is the measured current I_m? Assume an ideal ammeter.

(b) (4 points) Now suppose we have different values of I_s and R_s such that $I_m = 2\,\text{A}$, then **what is the power dissipated by $R_L = 1\,\text{m}\Omega$? How much energy does R_L dissipate in 20 seconds?**

(c) (6 points) Now assume the ammeter is not ideal and can instead be modeled with equivalent resistance R_A. That is, we can replace the ammeter with a resistor R_A:
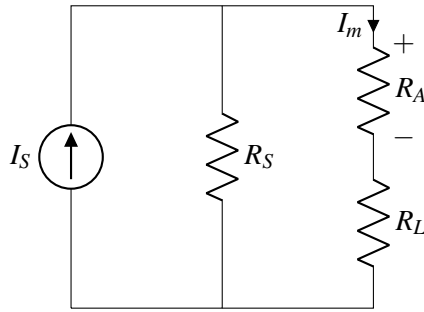

If $I_S = 4\,\text{A}$, $R_S = 3\,\text{m}\Omega$, $R_L = 1\,\text{m}\Omega$, and the current measured by the ammeter (i.e., the current through R_A) is $I_m = 2\,\text{A}$, then **what must be the internal resistance R_A of the ammeter? How much power is dissipated by the ammeter?**

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4. Just Solvin' a Circuit (18 points)

(a) (2 points) For **this part only**, consider the following circuit. For *each* element in the circuit **(including the sources!)**, label the missing current or voltage **using passive sign convention**. Please label directly on the given circuit below. Voltage labels should have +/- terminals. For example, the voltage source V_{s_1} has its voltage already labeled (V_5) but is missing its current label.
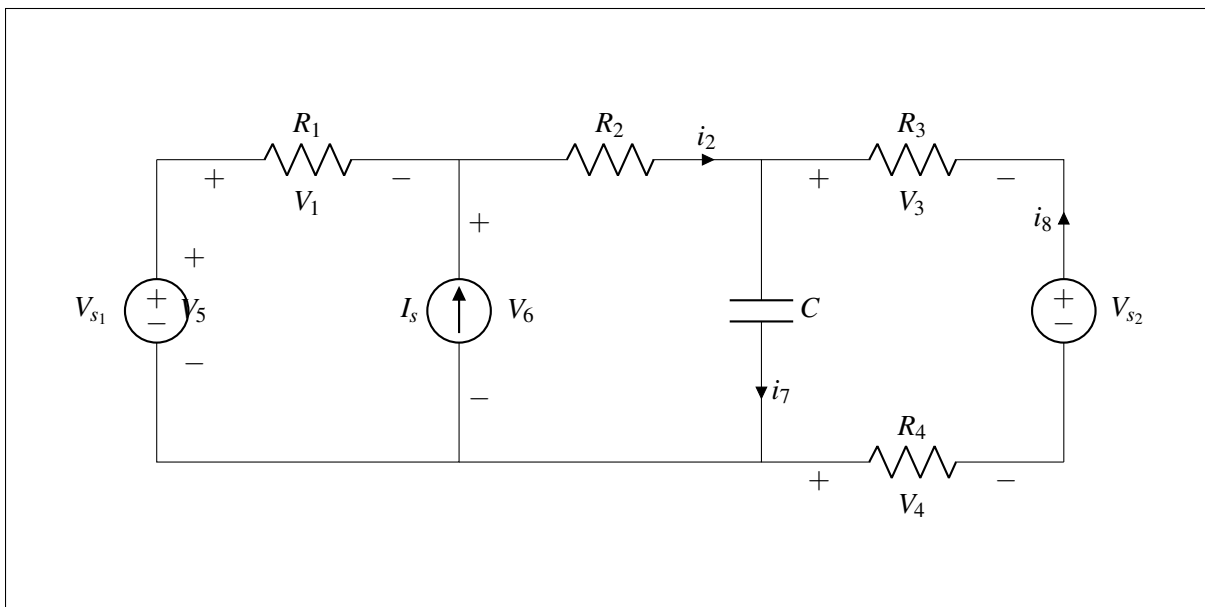
Now, **for the remaining parts**, consider an entirely different circuit which is already labeled.
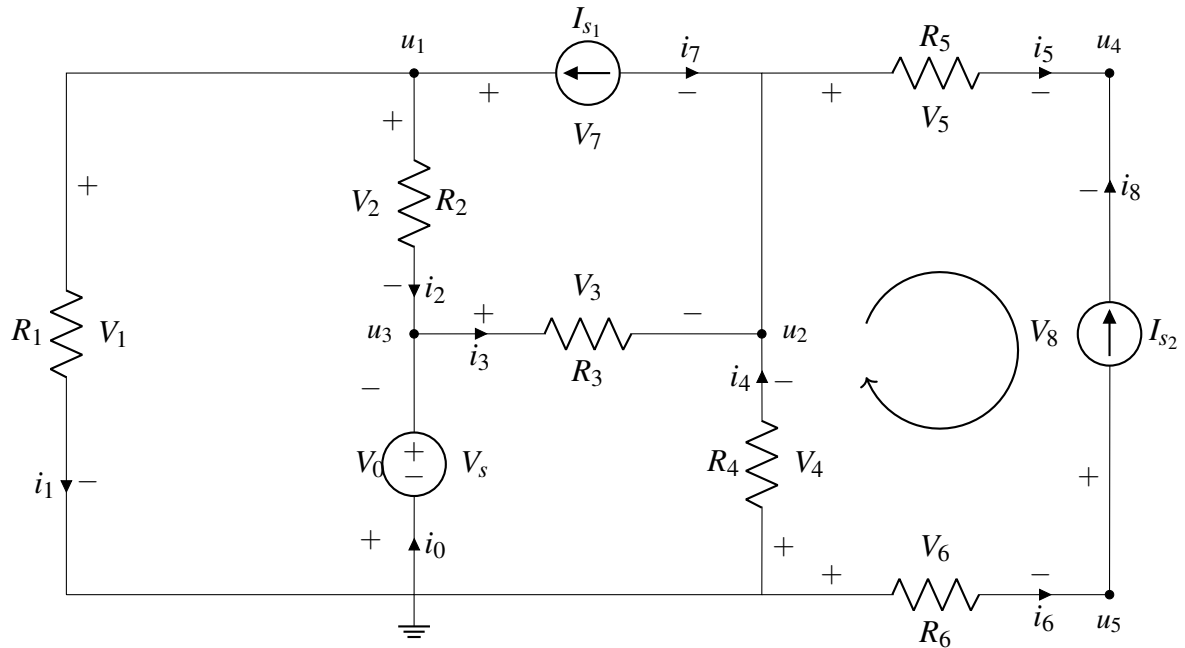
(b) (2 points) Write the KVL equation for the labeled loop in terms of element voltages (V_1, V_2, ... ,V_8) only.

(c) (4 points) Write the KCL equations for nodes u_1 and u_2 **ONLY** in terms of I_{s1}, I_{s2}, node voltages (**not element voltages!**), and resistances.
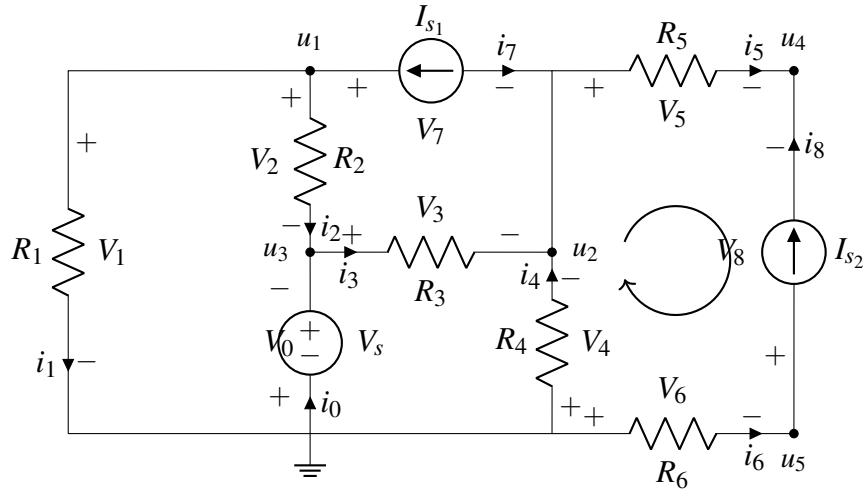
Here the circuit is redrawn for your convenience:
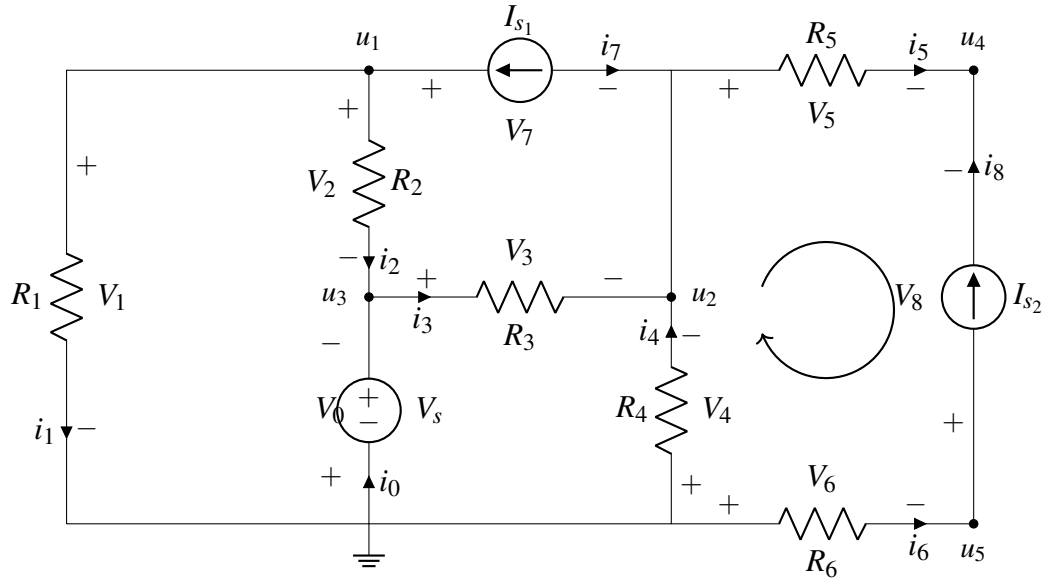
(d) (10 points) Solve for the voltage V_1 across and current I_1 through R_1 given the following values:

$$R_1 = 4\Omega, \ R_2 = 2\Omega, \ R_3 = 1\Omega, \ R_4 = 1\Omega, \ R_5 = 7\Omega, \ R_6 = 4\Omega$$
$$V_s = 6V, \ I_{s1} = 9A, \ I_{s2} = 3A$$

You do **NOT** need to solve for all quantities in the circuit nor use all of the above given values in your answer.

Here the circuit is redrawn for your convenience:

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5. Op Amps and Comparators (17 points)

(a) (2 point) Consider the following op-amp **for this part only**. Notice the + and - signs are missing on the op-amp input. Please label them such that the op-amp is in negative feedback.
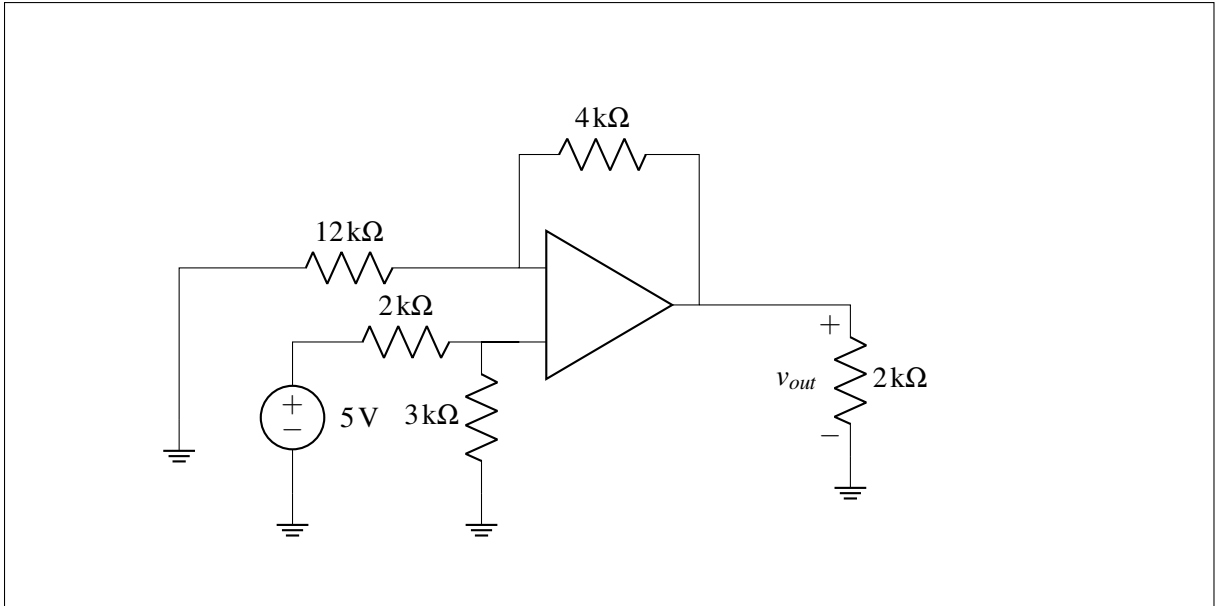
For the next two parts consider an entirely new op-amp circuit. Determine the following (you can assume that the op-amp is ideal and in negative feedback):
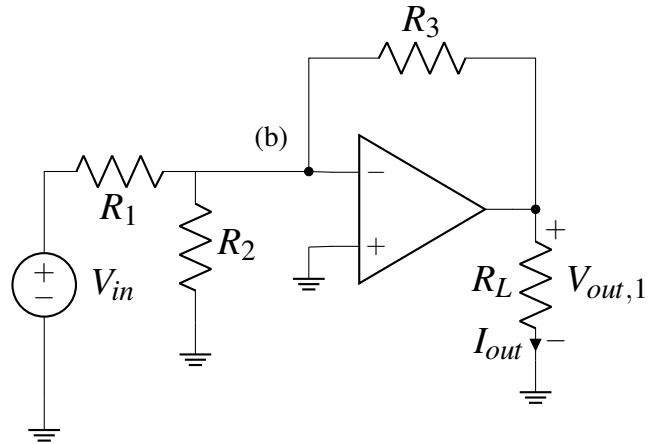

(b) (3 point) What is the voltage held at the negative terminal of the op-amp (the node labeled (b))? Express your answer in terms of the variables shown in the circuit diagram.

(c) (6 points) What is I_{out}, the current flowing through R_L? **Express your answer ONLY in terms of** $V_{in}, R_1, R_2, R_3, R_L$. You **cannot** use $V_{out,1}$ in your final expression.

(d) (3 points)

Now consider attaching an ideal comparator to the output of the op-amp circuit from the previous part.
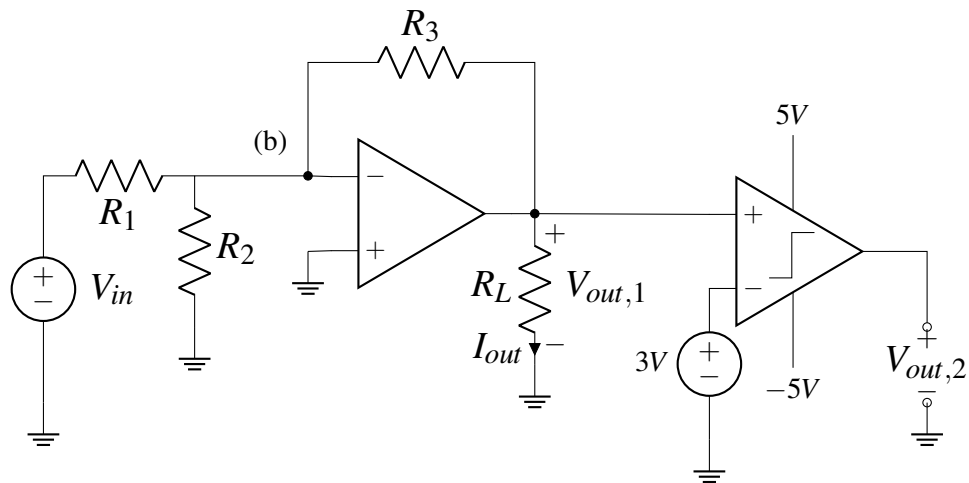
Suppose the output voltage of the op-amp is $V_{out,1} = -2V$ What is $V_{out,2}$, the voltage outputted by the comparator?

(e) (3 points) Sketch the output behavior of the comparator on the plot provided for different values of $V_{out,1}$.
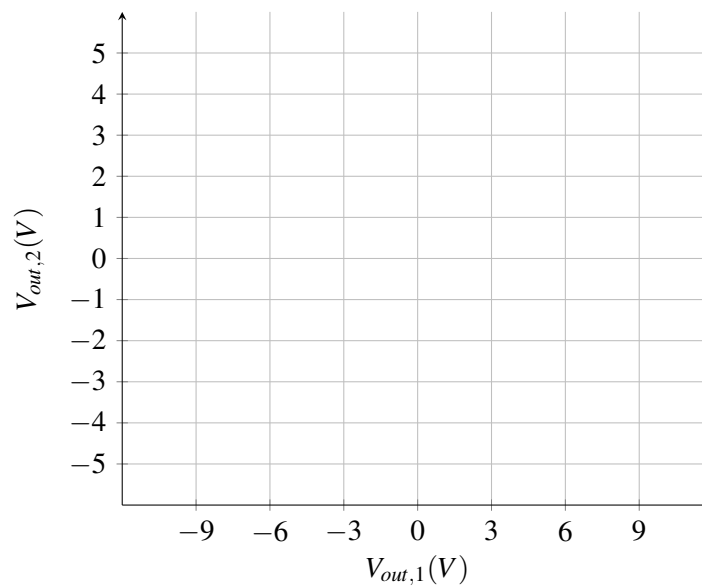
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6. Oski is Soldering a Resistive Touchscreen (12 points)

(a) (4 points) Oski attended Touchscreen 2 lab and was able to make a resistive touchscreen model that supports 9 touches. The schematic of the touchscreen bottom mesh is shown on Fig. 1.
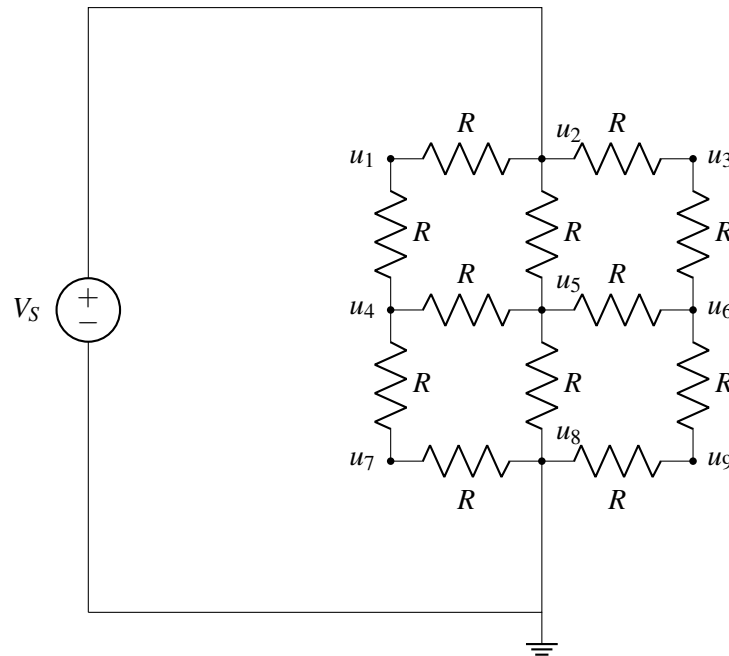
Fig. 1: The bottom mesh of a 2D touchscreen schematic.

Knowing that the lab model suggests to take all 12 resistors to have the same value, and $V_s = 8V$, what are the voltage values on each node? Fill out the table:

node name	voltage (V)
u1	8
u2	$\frac{16}{3} \approx 5.33$
u3	4
u4	$\frac{16}{3} \approx 5.33$
u5	4
u6	$\frac{8}{3} \approx 2.67$
u7	4
u8	$\frac{8}{3} \approx 2.67$
u9	0

(b) (2 points) The lab Oski is in only has a two different types of resistor, R_1 and R_2. They are both 4-band resistors but have different colored bands: R_1 has yellow-violet-red-gold and R_2 has red-violet-yellow-gold. What are the values of resistances **R_1 (yellow-violet-red-gold)** and **R_2 (red-violet-yellow-gold)**. Include the tolerance value in your answer (you may leave it as a percentage). You may put your answer in scientific notation. Refer to Fig. 2 for the color code convention.
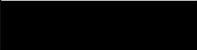
Color	Color	1st Band	2nd Band	3rd Band Multiplier	4th Band Tolerance
Black		0	0	x1Ω	
Brown		1	1	x10Ω	±1%
Red		2	2	x100Ω	±2%
Orange		3	3	x1kΩ	
Yellow		4	4	x10kΩ	
Green		5	5	x100kΩ	±0.5%
Blue		6	6	x1MΩ	±0.25%
Violet		7	7	x10MΩ	±0.10%
Grey		8	8	x100MΩ	±0.05%
White		9	9	x1GΩ	
Gold				x0.1Ω	±5%
Silver				x0.01Ω	±10%

Fig. 2: 4-band resistor color code convention table.

(c) (6 points) It turns out that Oski's bottom mesh does not work as it is proposed in the lab. Looking at the photo of Oski's circuit in Fig. 3, we see that Oski accidentally used R_2 instead of R_1 on the right side of the circuit. As a result, not all the resistor values are the same, which was a requirement we saw in part (a). Regardless of the values in the previous parts, assume that $R_1 = 1k\Omega$ and $R_2 = 2k\Omega$ and the voltage source $V_s = 8V$ remains the same as part a). What are the voltages at nodes u_3 and u_6?
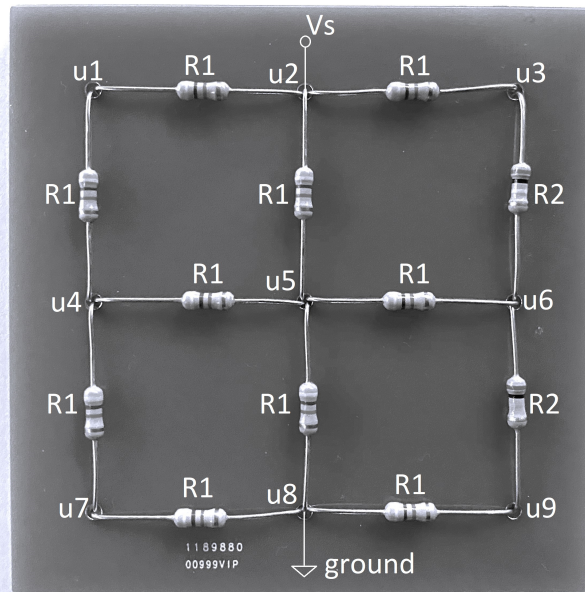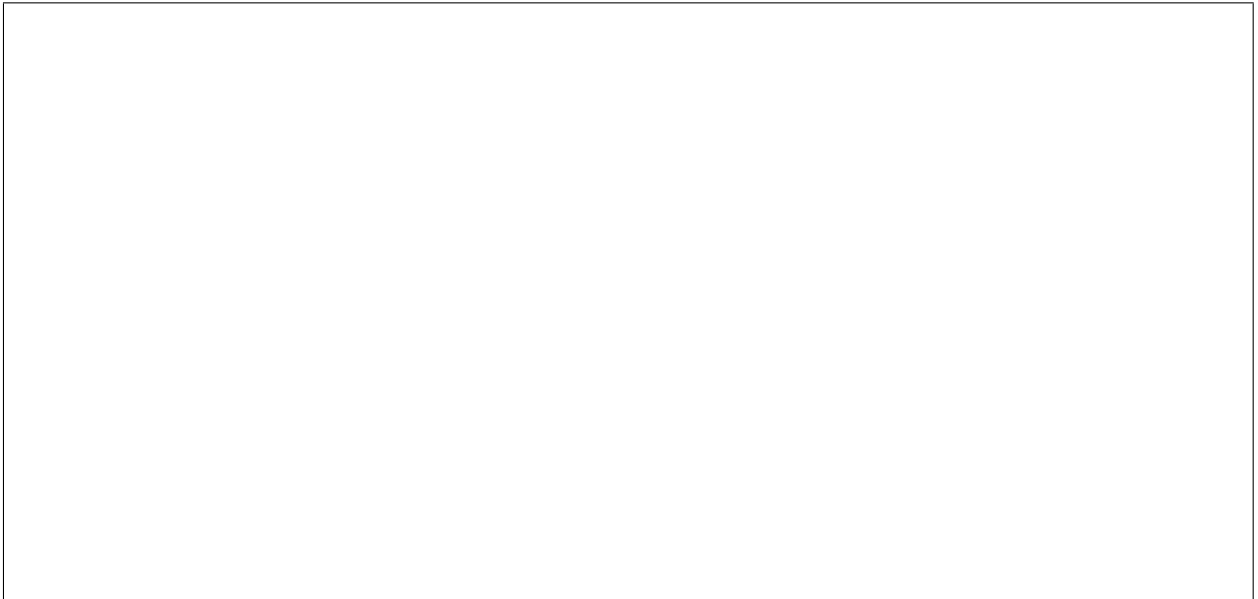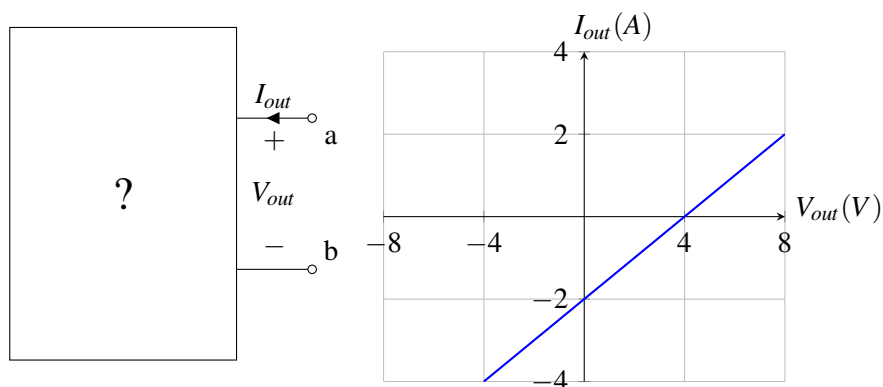

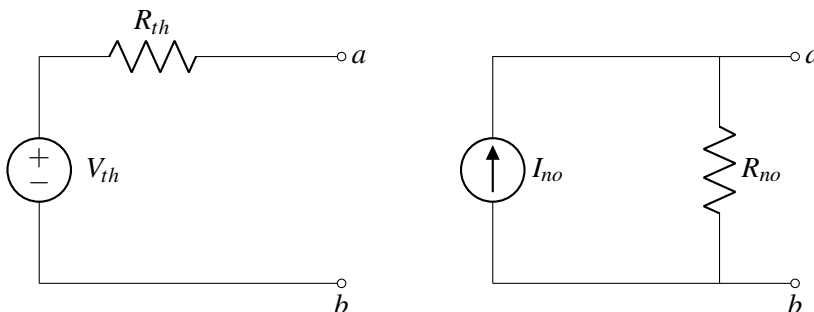Fig. 3: A buggy bottom mesh of a 2D touchscreen.

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7. Making circuits equivalent (18 points)

(a) (8 points) Suppose you are given a mysterious circuit element shown below. You are also given the IV curve of the circuit at nodes a and b (also shown below).


Now you would like to model this mysterious circuit two different ways. One with each circuit below:

Find the values V_{th}, R_{th}, I_{no}, and R_{no} such that all 3 circuits (the mystery circuit and the two above) are equivalent. **Note the direction of I_{out} in the mysterious circuit!**

(b) (10 points) Suppose now we are given a new circuit (shown below), but this time we know all the components except one resistor R:
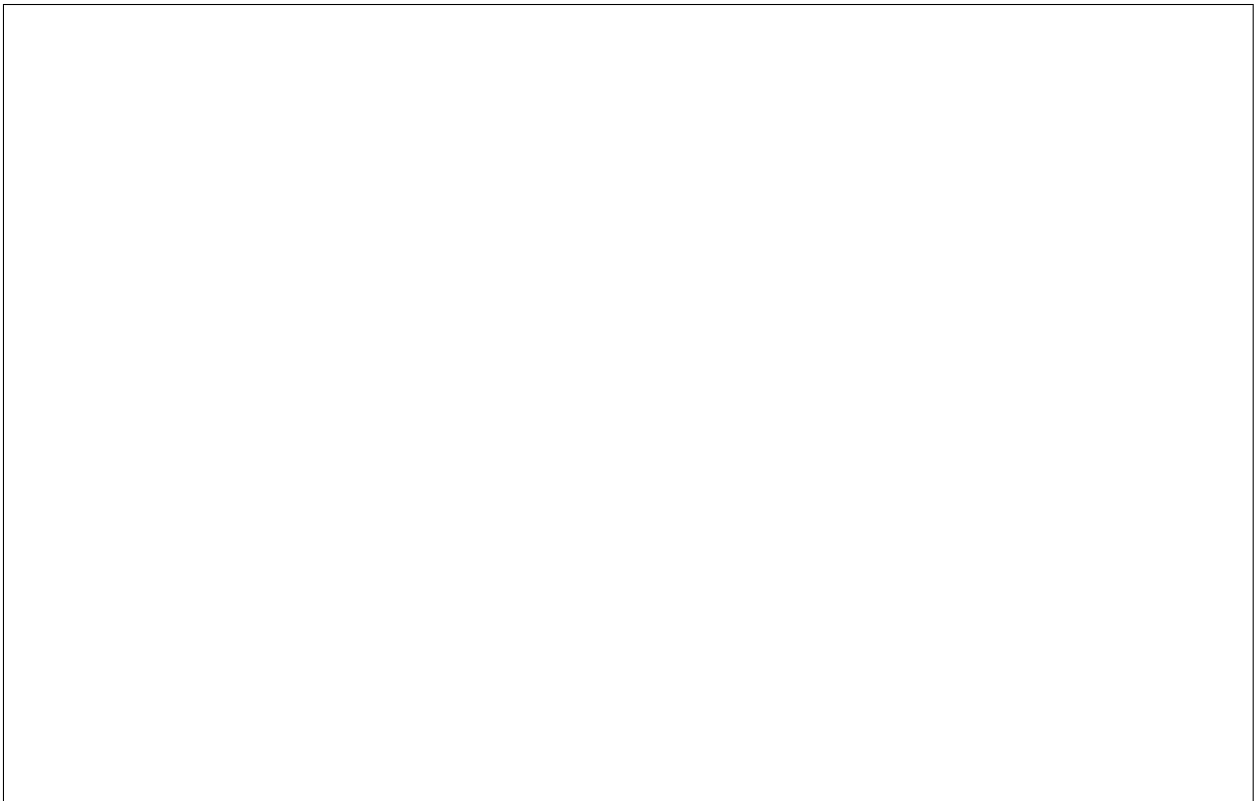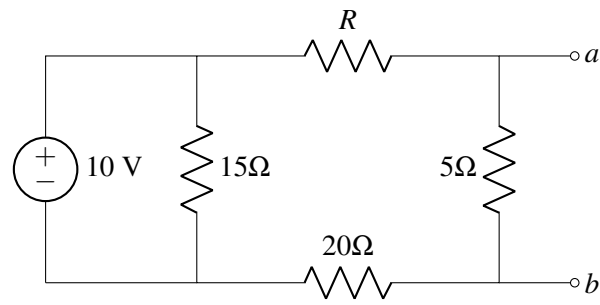
$$R$$

$$10 \text{ V} \quad 15\Omega \quad 5\Omega$$

$$20\Omega$$
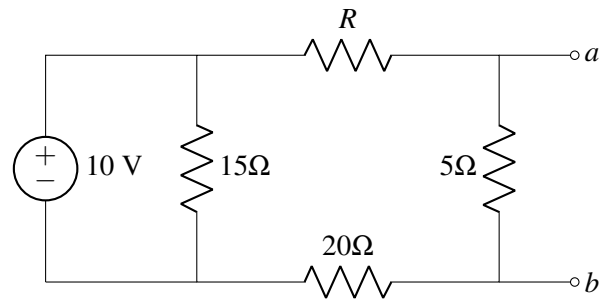
We also know that we can model the circuit at nodes a and b using the following equivalent circuit:

$$I_{eq} \quad R_{eq}$$
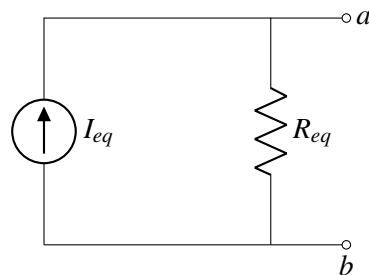
Find the resistor value R in the new circuit such that $I_{eq} = 0.25A$.

The circuit is redrawn here for your convenience:

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8. Capacitors in the Wild (20 points)

(a) For the following circuit, find the equivalent capacitance between the specified nodes in terms of the given capacitors, C_i. You may use the *parallel operator* $\parallel$ for simplification (e.g. a valid answer format could be $C_{eq} = C_6 + (C_7 \parallel (C_8 + C_9))$).
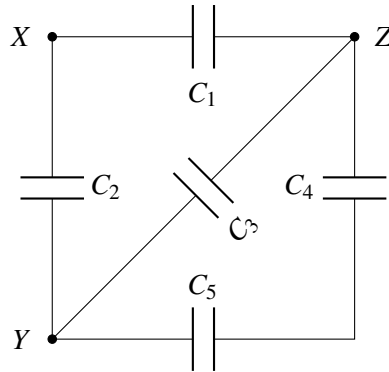

i. (4 points) Find the equivalent capacitance between nodes X and Y.

ii. (4 points) Find the equivalent capacitance between nodes Y and Z.

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(b) (12 points) In the following circuit, switches labeled ϕ_1 are closed during phase 1 and open during phase 2; switches labeled ϕ_2 are closed during phase 2 and open during phase 1. Assume before phase 1 all capacitors are fully discharged. Each phase is long enough that the circuit reaches steady-state. **Find V_{out} in phase 2 in terms of** $V_s, C_1, C_2, C_3,$ **and** C_4. You may use the *parallel operator* $\parallel$ in your final answer.
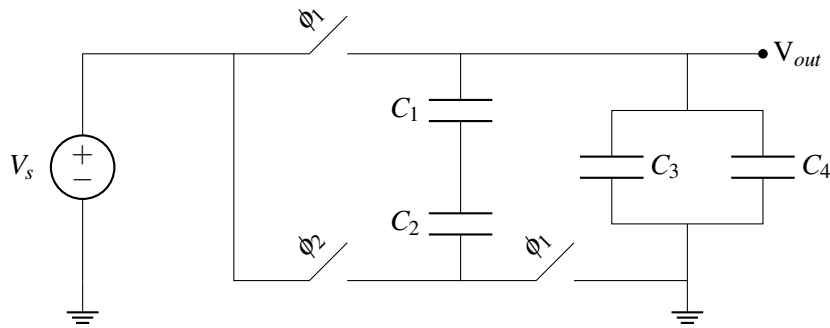
The circuit is redrawn here for your convenience.
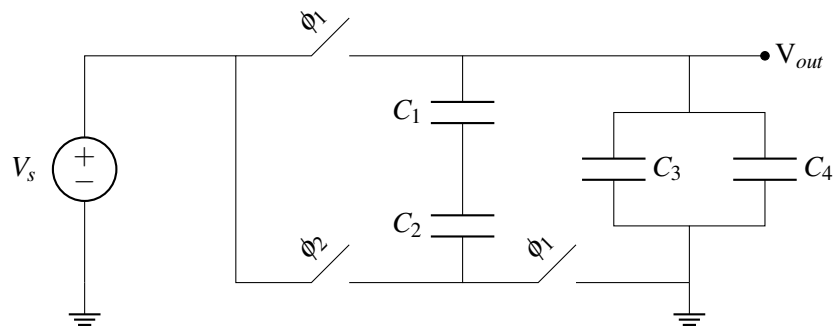
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Extra page for scratchwork.
Work on this page will NOT be graded.

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