EECS 16A Designing Information Devices and Systems I
Fall 2021 Homework 7

This homework is due October 15, 2021, at 23:59.
Self-grades are due October 18, 2021, at 23:59.

Submission Format

Your homework submission should consist of **one** file.

- `hw7.pdf`: A single PDF file that contains all of your answers (any handwritten answers should be scanned)

Submit the file to the appropriate assignment on Gradescope.

1. Reading Assignment

For this homework, please read Notes 13 and 14. Note 13 will refresh you on how simple 1-D resistive touchscreens work, as well as the notion of power in electric circuits. Note 14 will cover a slightly more complicated 2-D resistive touchscreens and how to analyze them from a circuits perspective.

(a) Describe the key ideas behind how the 1D touchscreen works. In general, why is it useful to be able to convert a “physical" quantity like the position of your finger to an electronic signal (i.e. voltage)?

2. [PRACTICE] It’s a Triforce!

Learning Goal: *This problem explores passive sign convention and nodal analysis in a slightly more complicated circuit.*

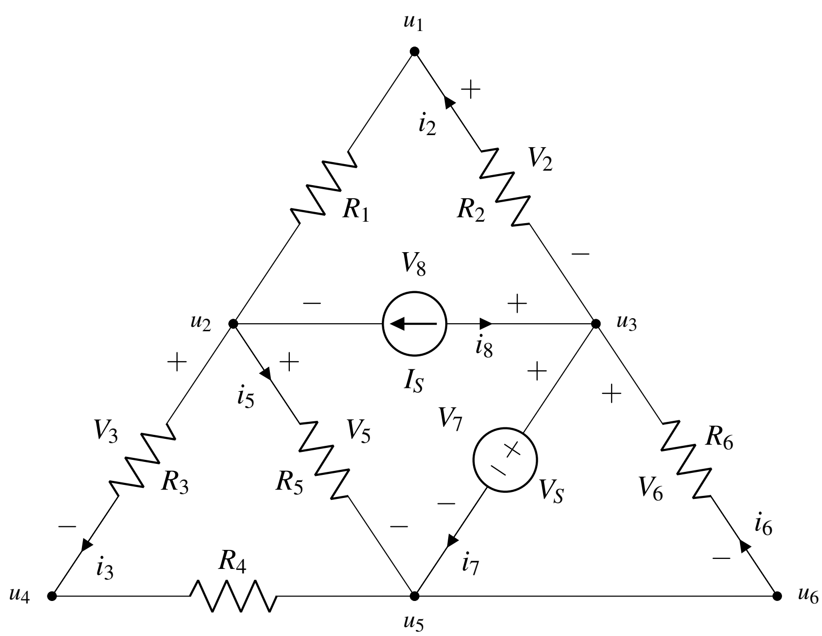


Figure 1: A triangular circuit consisting of a voltage source V_s, current source I_s, and resistors R_1 to R_6.

(a) Which of the elements I_S, V_S, R_2, R_3, R_5, or R_6 in Figure 1 have current-voltage labeling that violates Passive Sign Convention? There could be more than one possible element which violates Passive Sign Convention. Explain your reasoning.

(b) In Figure 1, the nodes are labeled with u_1, u_2, ... etc. There is a subset of u_i's in the given circuit that are redundant, i.e. there might be more than one label for the same node. Which node(s)? Justify your answer.

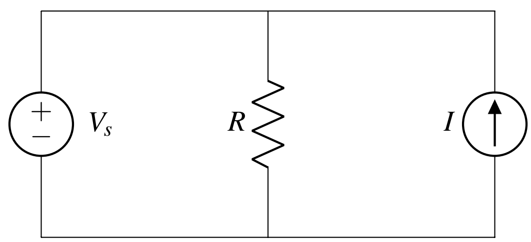
(c) Redraw the circuit diagram by correctly labeling all the element voltages and element currents according to passive sign convention. (The component labels that were violating Passive Sign Convention in part (a), should be corrected by swapping the element voltage polarity. Also, the elements that have not been labeled yet, should be labeled following Passive Sign Convention.)

(d) Write an equation to describe the current-voltage relationship for element R_4 in terms of the relevant i's, R's, and node voltages in this circuit.

(e) Write the KCL equation for node u_2 in terms of the node voltages and other circuit elements.

3. Power Analysis

Learning Goal: *This problem aims to help you practice calculating power dissipation in different circuit elements. It will also give you insights into how power is conserved in a circuit.*



(a) Find the expressions of power dissipated by each element in the circuit above. Remember to label voltage-current pairs using passive sign convention.

(b) Use $R = 5\text{k}\Omega$, $V_s = 5\text{V}$, and $I = 5\text{mA}$. Calculate the power dissipated by the voltage source (P_{V_s}), the current source (P_I), and the resistor (P_R).

(c) Once again, let $R = 5\text{k}\Omega$, $V_s = 5\text{V}$. What does the value I of the current source have to be such that the current source **dissipates** 40mW? Note that it is possible for a current source to *dissipate* power, i.e. under passive sign convention, $P_I = 40mW$. For this value of I, compute P_{V_s}, P_I, and P_R as well.

As an aside: If the current source were delivering power *it would have been* $P_I = -40mW$*, under passive sign convention, but this is NOT what the question is asking about.*

4. Volt and ammeter

Learning Goal: *This problem helps you explore what happens to voltages and currents in a circuit when you connect voltmeters and ammeters in different configurations.*

Use the following numerical values in your calculations: $R_1 = 1\,\text{k}\Omega$, $R_2 = 2\,\text{k}\Omega$, $R_3 = 3\,\text{k}\Omega$, $R_4 = 4\,\text{k}\Omega$, $R_5 = 5\,\text{k}\Omega$, $V_s = 10V$.

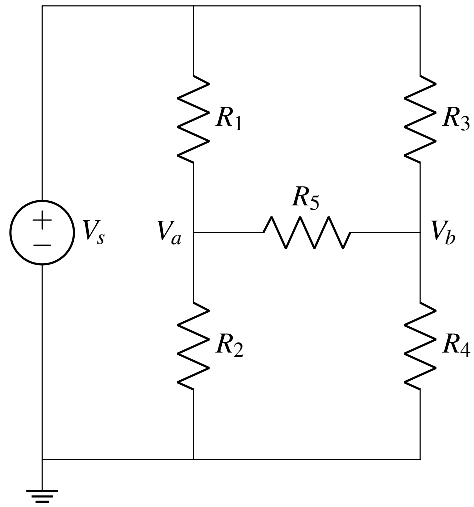


Figure 2: Circuit consisting of a voltage source V_s and five resistors R_1 to R_5

(a) Redraw the circuit diagram shown in Figure 2 by adding a voltmeter (letter V in a circle and plus and minus signs indicating direction) to measure voltage V_{ab} from node V_a (positive) to node V_b (negative). Calculate the value of V_{ab}. You may use a numerical tool such as IPython to solve the final system of linear equations.

(b) Suppose you accidentally connect an ammeter in part (a) instead of a voltmeter. Calculate the value of V_{ab} with the ammeter connected.

(c) Redraw the circuit diagram shown in Figure 2 by adding an ammeter (letter A in a circle and plus and minus signs indicating direction) in series with resistor R_5. This will measure the current I_{R_5} through R_5. Calculate the value of I_{R_5}.

(d) Your friend accidentally connects a voltmeter in part (c) above, rather than an ammeter. Calculate the value of I_{R_5} with the voltmeter connected.

5. [PRACTICE] Bio-Molecule Detector

One application for electronics that has gained a lot of attention over the past several years is in so-called "bio-molecule" detection. The idea is to build a system that detects the presence of specific molecules and/or cells (e.g. specific viruses, proteins, etc.) in a biological sample; if this detection can be performed automatically and using relatively low-cost components, it can have a dramatic impact on a number of areas such as medical diagnosis, drug development, DNA sequencing, etc.

In this problem, we'll look at how some of the techniques we learned about in the touchscreen module can be applied to realize a hypothetical bio-molecule detector. (Real bio-molecule detection systems involve quite a bit more complexity than what we'll include here, but in many designs the same basic principles apply.)

As shown in Figure 3, the detector works by flowing a liquid that may or may not contain the biomolecules through a region in the device that has electrodes on the top and bottom of the liquid channel. The electrodes (E1/E2 in Figure 3) are chemically "functionalized" (using e.g. some appropriately designed antibodies), so that if the specific bio-molecule of interest is present in the fluid sample, one or more of the molecules will get physically trapped between the two electrodes (bottom right of Figure 3). After all of the fluid has been cleared out of the device (i.e., so that if there are no bio-molecules present, there is only air in between the

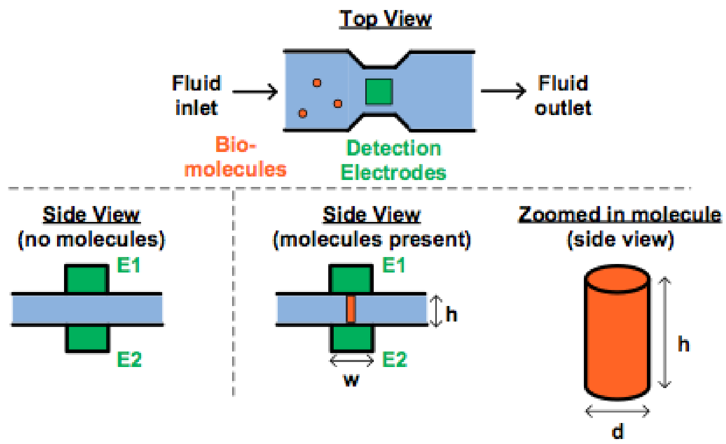


Figure 3: Bio-molecule detector.

two electrodes E1/E2), we can then figure out whether or not one or more bio-molecules were trapped by measuring the resistance between the two electrodes.

(a) Let's first assume that we want to detect the presence of a bio-molecule by measuring resistance. If no bio-molecule is present, what should be the resistance between E1/E2? As shown in Figure 3, if each bio-molecule is a cylinder with diameter $d = 10\,\text{nm}$, height $h = 100\,\text{nm}$, and has a resistivity $\rho = 100\,\mu\Omega\,\text{m}$, what would be the resistance between E1 and E2 if only a single bio-molecule has been trapped? Note that you can assume that the trapped molecule is exactly vertically oriented when it is trapped – i.e., the top and bottom faces of the molecule are both aligned with surfaces of the electrodes.

(b) Using the same numbers for d, h, and ρ as part (a), as a function of the number of trapped bio-molecules $N_{\text{molecules}}$, what is the resistance between E1 and E2? (Note that you can assume that $N_{\text{molecules}}$ is small enough that all of the molecules fit within the electrode area and that all of the molecules are still trapped in an exactly vertical orientation.)

(c) Given your answers to parts (a) and (b), design a circuit that will output a voltage greater than 2.5 V if more than 5 molecules are trapped.

6. Resistive Touchscreen

Learning Goal: *The objective of this problem is to provide insight into modeling of resistive elements. This will also help to apply the concepts from resistive touchscreen.*

In this problem, we will investigate how a resistive touchscreen with a defined thickness, width, and length can actually be modeled as a series combination of resistors. As we know the value of a resistor depends on its length.

Figure 4 shows the top view of a resistive touchscreen consisting of a conductive layer with resistivity ρ_1, thickness t, width W, and length L. At the top and bottom it is connected through good conductors ($\rho = 0$) to the rest of the circuit. The touchscreen is wired to voltage source V_s.

Use the following numerical values in your calculations: $W = 50$ mm, $L = 80$ mm, $t = 1$ mm, $\rho_1 = 0.5\,\Omega\,\text{m}$, $V_s = 5\text{V}$, $x_1 = 20$ mm, $x_2 = 45$ mm, $y_1 = 30$ mm, $y_2 = 60$ mm.

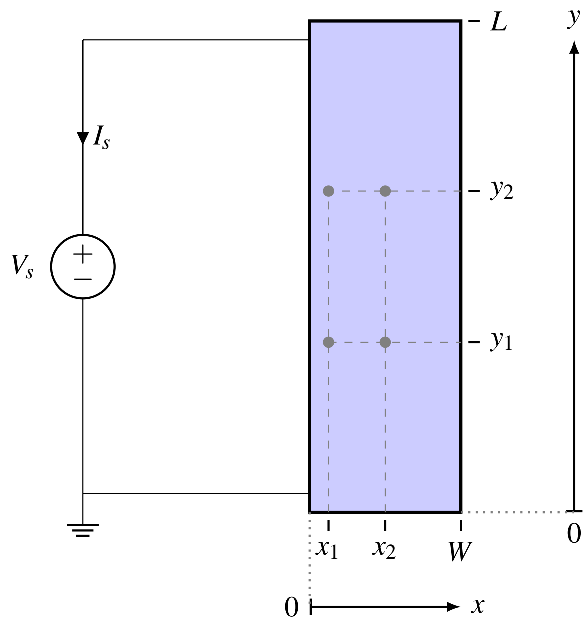


Figure 4: Top view of resistive touchscreen (not to scale). z axis i.e. the thickness not shown (into the page).

(a) Draw a circuit diagram representing Figure 4, where the touchscreen is represented as *a resistor*. **Note that no touch is occurring in this scenario.** Remember that circuit diagrams in general consist of only circuit elements (resistors, sources, etc) represented by symbols, connecting wires, and the reference/ ground symbol. Calculate the value of current I_S based on the circuit diagram you drew. Do not forget to specify the correct unit as always.

(b) Let us assume u_{12} is the node voltage at the node represented by coordinates (x_1, y_2) of the touchscreen, as shown in Figure 5. What is the value of u_{12}? You should first draw a circuit diagram representing Figure 5, which includes node u_{12}. Specify all resistance values in the diagram. Does the value of u_{12} change based on the value of the x-coordinate x_1?

Hint: You will need more than one resistor to represent this scenario.

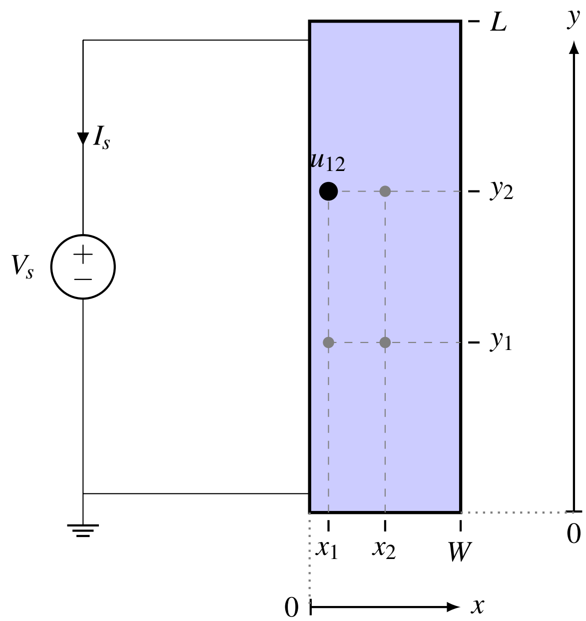


Figure 5: Top view of resistive touchscreen showing node u_{12}.

(c) Assume V_{ab} is the voltage measured between the nodes represented by touchscreen coordinates (x_1, y_1) and coordinates (x_1, y_2), as shown in Figure 6. Calculate the absolute value of V_{ab}. As with the previous part, you should first draw the circuit diagram representing Figure 6, which includes V_{ab}. Calculate all resistor values in the circuit. *Hint: Try representing the segment of the touchscreen between these two coordinates as a separate resistor itself.*

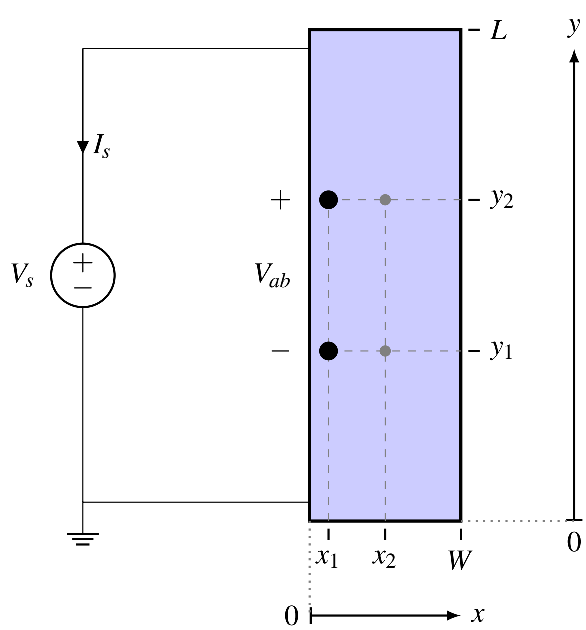


Figure 6: Top view of resistive touchscreen showing voltage V_{ab}.

(d) Calculate (the absolute value of) the voltage between the nodes represented by touchscreen coordinates (x_1, y_1) and coordinates (x_2, y_1).

(e) Calculate (the absolute value of) the voltage between the nodes represented by touchscreen coordinates (x_1, y_1) and coordinates (x_2, y_2).

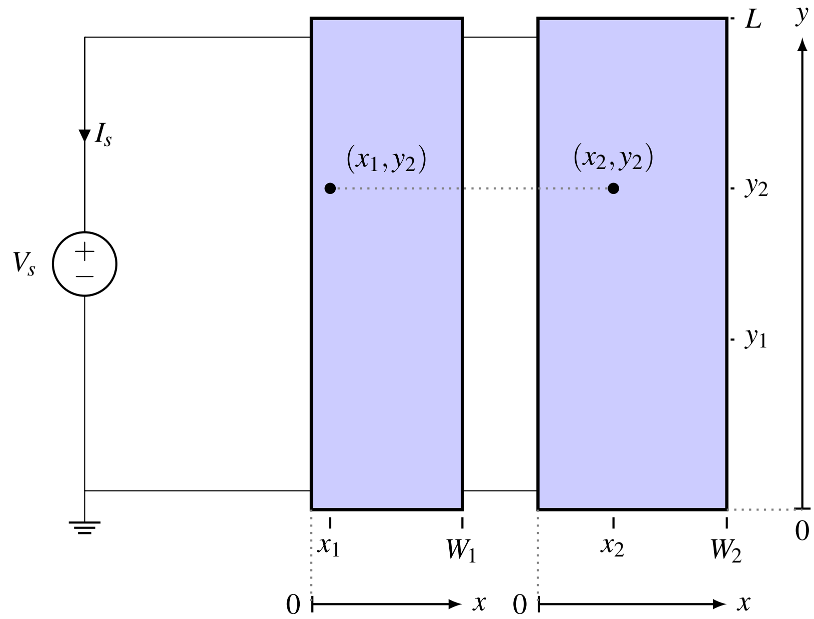


Figure 7: Top view of two touchscreens wired in parallel (not to scale). z axis not shown (into the page).

(f) Figure 7 shows a new arrangement with two touchscreens. The two touchscreens are next to each other and are connected to the voltage source in the same way. The second touchscreen (the one on the right) is identical to the one shown in Figure 4, except for different width, W_2, and resistivity, ρ_2.

Use the following numerical values in your calculations: $W_1 = 50$ mm, $L = 80$ mm, $t = 1$ mm, $\rho_1 = 0.5\,\Omega\,\text{m}$, $V_s = 5\text{V}$, $x_1 = 20$ mm, $x_2 = 45$ mm, $y_1 = 30$ mm, $y_2 = 60$ mm, which are the same values as before. The new touchscreen has the following numerical values which are different: $W_2 = 85$ mm, $\rho_2 = 0.6\,\Omega\,\text{m}$.

Draw a circuit diagram representing Figure 7, where the two touchscreens are represented as *two separate resistors*. **Note that no touch is occurring in this scenario.**

(g) Calculate the value of current I_s for the two touchscreen arrangement based on the circuit diagram you drew in the last part.

(h) Consider the two points: (x_1, y_2) in the touchscreen on the left, and (x_2, y_2) in the touchscreen on the right in Figure 7. Show that the node voltage at (x_1, y_2) is the same that at (x_2, y_2), i.e. the potential difference between the two points is 0. You can show this without explicitly calculating the node voltages at the two points.

If you were to connect a wire between the two coordinates (x_1, y_2) in the touchscreen on the left, and (x_2, y_2) in the touchscreen on the right, would any current flow through this wire?

7. Homework Process and Study Group

Who did you work with on this homework? List names and student ID's. (In case you met people at homework party or in office hours, you can also just describe the group.) How did you work on this homework? If you worked in your study group, explain what role each student played for the meetings this week.