EECS 16A Designing Information Devices and Systems I
Spring 2020 Homework 7

This homework is due March 13, 2020 at 23:59.
Self-grades are due March 16, 2020, 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. 1-D Resistive Touchscreen

Figure 1 shows the top view of a resistive touchscreen consisting of a conductive layer with resistivity ρ_{t1}, thickness t, width W, and length L. At the top and bottom it is connected to good conductors ($\rho = 0$), represented in the figure by two rectangles. The touchscreen is wired to voltage source V_s.

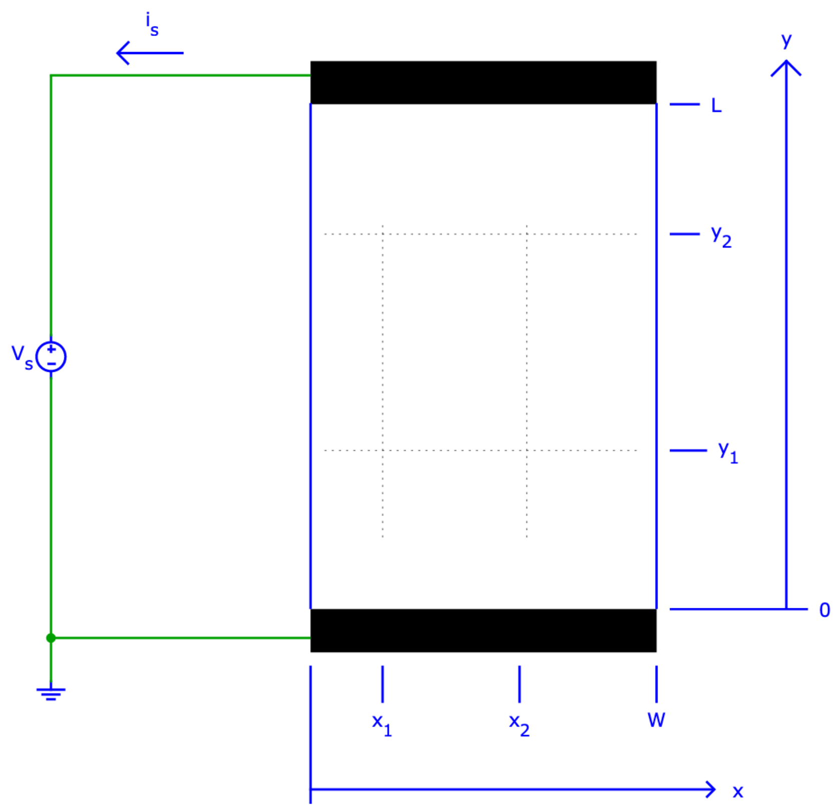


Figure 1: Top view of 1-D resistive touchscreen (not to scale).

Use the following numerical values in your calculations: $W = 50$ mm, $L = 80$ mm, $t = 1$ mm, $\rho_{t1} = 0.5\,\Omega\,\mathrm{m}$, $V_s = 5\mathrm{V}$, $x_1 = 20$ mm, $x_2 = 45$ mm, $y_1 = 30$ mm, $y_2 = 60$ mm.

(a) Draw a circuit diagram representing the touchscreen shown in Figure 1. Remember that circuit diagrams consist of only circuit elements (resistors, current sources, etc) represented by symbols, connecting wires, and the reference symbol.

(b) Calculate the value of current I_s. Do not forget to specify the correct unit as always.

(c) What is the node voltage V_{12} (with respect to the reference node) of the touchscreen at coordinates $(x_1,\ y_2)$? Redraw the circuit diagram from part (a) to include node V_{12}. Specify all component values (resistances, ...) in the diagram. Hint: you need more than one resistor to represent this situation.

(d) Calculate (absolute value of) voltage V_{ab} between touchscreen coordinates (x_1, y_1) and coordinates (x_1, y_2). Suggestion: Draw an augmented circuit diagram and calculate all component values.

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

(f) Calculate (absolute value of) the voltage between touchscreen coordinates (x_1, y_1) and coordinates (x_2, y_2).

(g) Figure 2 shows a new arrangement with two touchscreens. The second touchscreen is identical to the one shown in Figure 1, except for different width, W_2, and resistivity, ρ_{t2}. Use the following numerical values in your calculations: $W = 50$ mm, $L = 80$ mm, $t = 1$ mm, $\rho_{t1} = 0.5\,\Omega\,\mathrm{m}$, $V_s = 5\mathrm{V}$, $x_1 = 20$ mm, $x_2 = 45$ mm, $y_1 = 30$ mm, $y_2 = 60$ mm, which are the same values as before, with $W_2 = 70$ mm, $\rho_{t2} = 0.4\,\Omega\,\mathrm{m}$ for the new touchscreen.

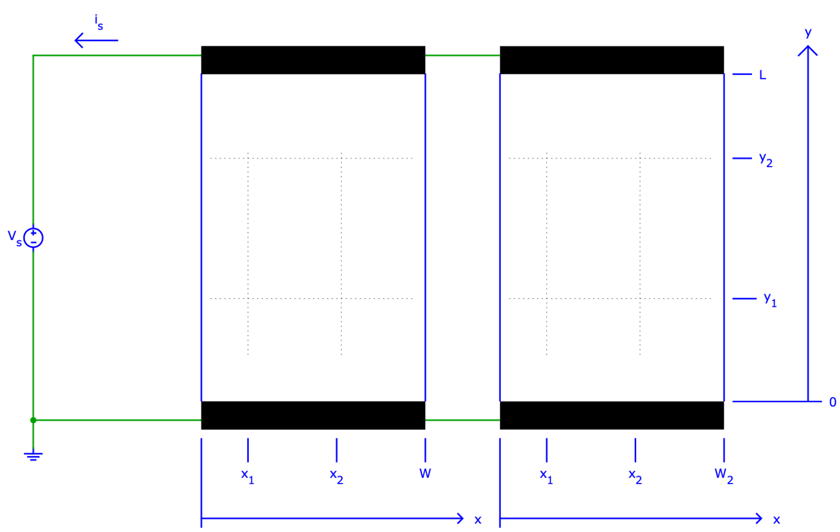


Figure 2: Top view of two touchscreens wired in parallel (not to scale).

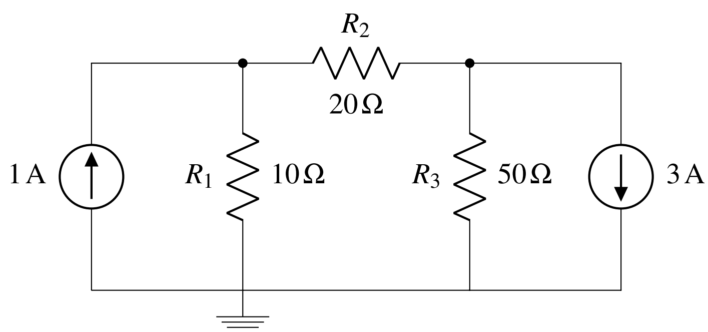
Draw a circuit diagram representing the two touchscreens shown in Figure 2.

(h) Calculate the value of current I_s for the two touchscreen arrangement.

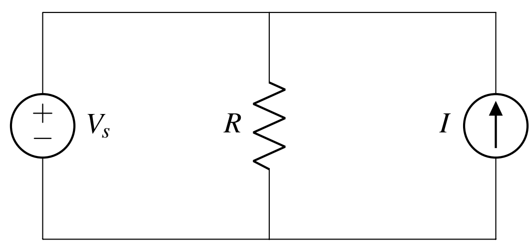
(i) Now assume a wire is connected between coordinates (x_1, y_2) in the touchscreen on the left, and (x_2, y_2) in the touchscreen on the right. Calculate the current I_{12} flowing through this wire.

2. Circuit Analysis

Solve the circuit given below for all the currents and all the node voltages.



3. Power Analysis



(a) Find the power dissipated by each element in the circuit above. Remember to label voltages using passive sign convention.

(b) Use $R = 5\text{k}\Omega$, $V_s = 5\text{V}$, and $I = 5\text{mA}$. Calculate P_{V_s}, P_I, and P_R.

(c) Repeat part (b) but change the value I of the current source such that it **dissipates** 40mW. Calculate I, P_{V_s}, P_I, and P_R.

4. Cell Phone Battery

As great as smartphones are, one of their drawbacks is that their batteries don't last a long time. For example, a Google Pixel phone, under typical usage conditions (internet, a few cat videos, etc.) uses 0.3W. We will model the battery as an ideal voltage source (which maintains a constant voltage across its terminals regardless of current) except that we assume that the voltage drops abruptly to zero when the battery is discharged (in reality the voltage drops gradually, but let's keep things simple).

Battery capacity is specified in mAh, which indicates how many mA of current the battery can supply for one hour before it needs to be recharged. The Pixel's battery has a battery capacity of 2770mAh at 3.8V. For example, this battery could provide 1000mA (or 3.8W) for 2.77 hours before the voltage abruptly drops from 3.8V to zero.

(a) How long will a Pixel's full battery last under typical usage conditions?

(b) How many coulombs of charge does the battery contain? How many usable electrons worth of charge are contained in the battery when it is fully charged? (An electron has 1.602×10^{-19} C of charge.)

(c) Suppose the cell phone battery is completely discharged and you want to recharge it completely. How much energy (in J) is this? Recall that a J is equivalent to a W s.

(d) Suppose PG&E charges \$0.12 per kWh. Every day, you completely discharge the battery (meaning more than typical usage) and you recharge it every night. How much will recharging cost you for the month of October (31 days)?

(e) The battery has internal circuitry that prevents it from getting overcharged (and possibly exploding!). We will model the battery and its internal circuitry as a resistor R_{bat}. We now wish to charge the battery by plugging into a wall plug. The wall plug can be modeled as a 5 V voltage source and $200\,\text{m}\Omega$ resistor, as pictured in Figure 3. What is the power dissipated across R_{bat} for $R_{\text{bat}} = 1\,\text{m}\Omega$, $1\,\Omega$, and $10\,\text{k}\Omega$? (i.e. how much power is being supplied to the phone battery as it is charging?). How long will the battery take to charge for each of those values of R_{bat}?

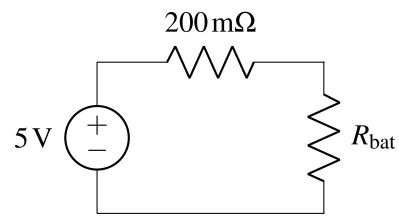
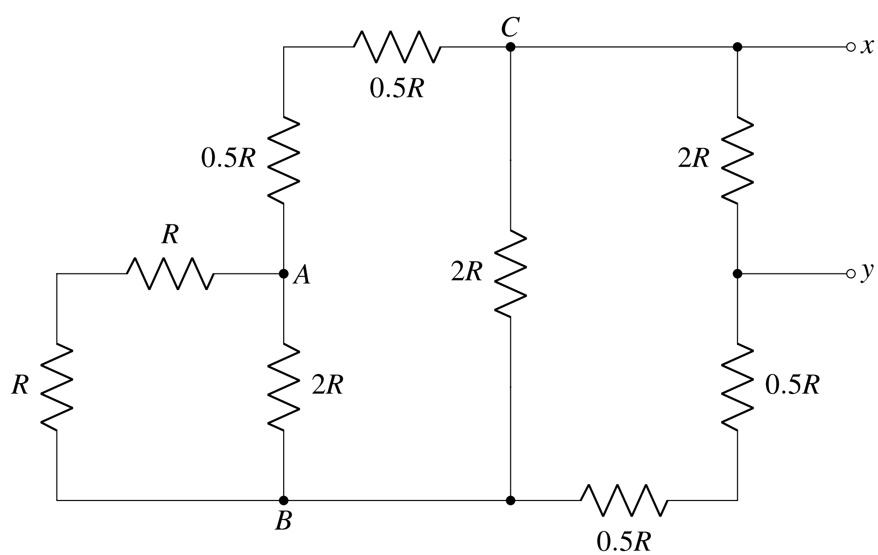


Figure 3: Model of wall plug, wire, and battery.

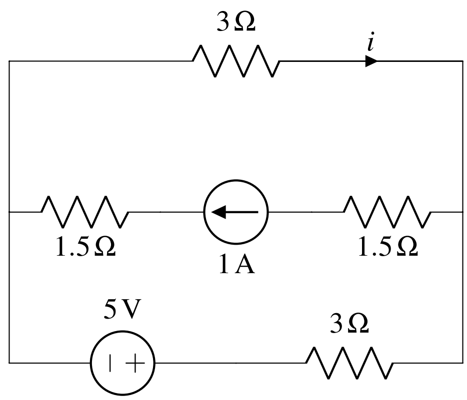
5. Equivalence

For the circuit shown below, find the equivalent resistance looking in from points x and y.



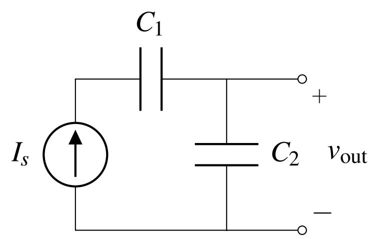
6. Superposition

Find the current i indicated in the circuit diagram below using superposition.



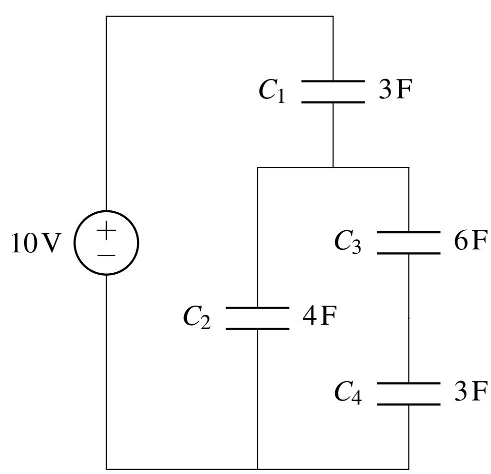
7. Current Sources And Capacitors

For the circuit given below, give an expression for $v_{\text{out}}(t)$ in terms of I_s, C_1, C_2, and t. Assume that all capacitors are initially uncharged, i.e. the initial voltage across each capacitor is 0 V.



8. (Practice) Mechanical Circuits with Capacitors

Find the voltages across and currents flowing through all of the capacitors at steady state.



9. Homework Process and Study Group

Who else did you work with on this homework? List names and student ID's. (In case of homework party, you can also just describe the group.) How did you work on this homework?