EECS 16A Designing Information Devices and Systems I
Spring 2020 Homework 9

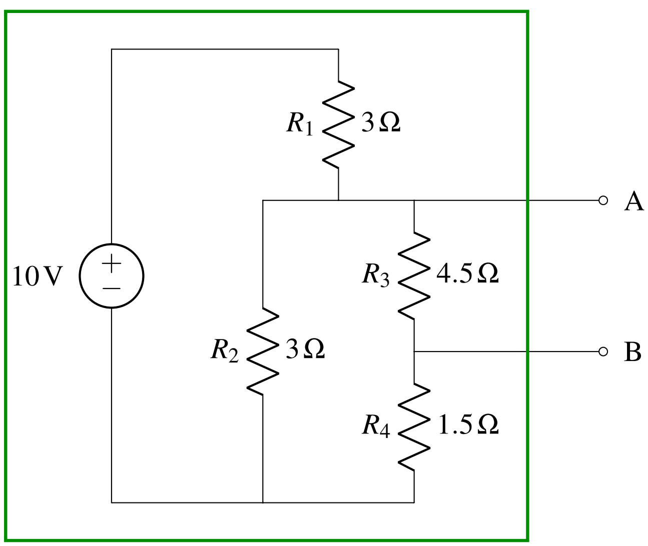
This homework is due April 3, 2020, at 23:59.
Self-grades are due April 6, 2020, at 23:59.

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

- `hw9.pdf`: A single PDF file that contains all of your answers (any handwritten answers should be scanned).
- Practice problems will not be graded. However, they do provide more practice and we encourage you to try them to practice for the midterm.
- We encourage you to turn in self-grades for this HW before the midterm, since looking at the solutionsearlier will help you study for the midterm.

Submit the file to the appropriate assignment on Gradescope.

1. **Thévenin and Norton Equivalent Circuits** Find the Thévenin and Norton equivalent circuits seen from terminals A and B.



2. **Capacitive Touchscreen**

The model for a capacitive touchscreen can be seen in Figure 1. See Table 1 for values of the dimensions. The green area represents the contact area of the finger with the top insulator. It has dimensions w_2 x d_1.

(a) Draw the equivalent circuit of the touchscreen that contains the nodes F, E_1, and E_2 when there no finger present and when there is a finger present. Express the capacitance values in terms of C_0, C_{F-E1}, and C_{F-E2}.

Table 1: Touchscreen Dimension Values

d_1	10 mm
d_2	1 mm
t_1	1 mm
t_2	2 mm
w_1	1 mm
w_2	2 mm

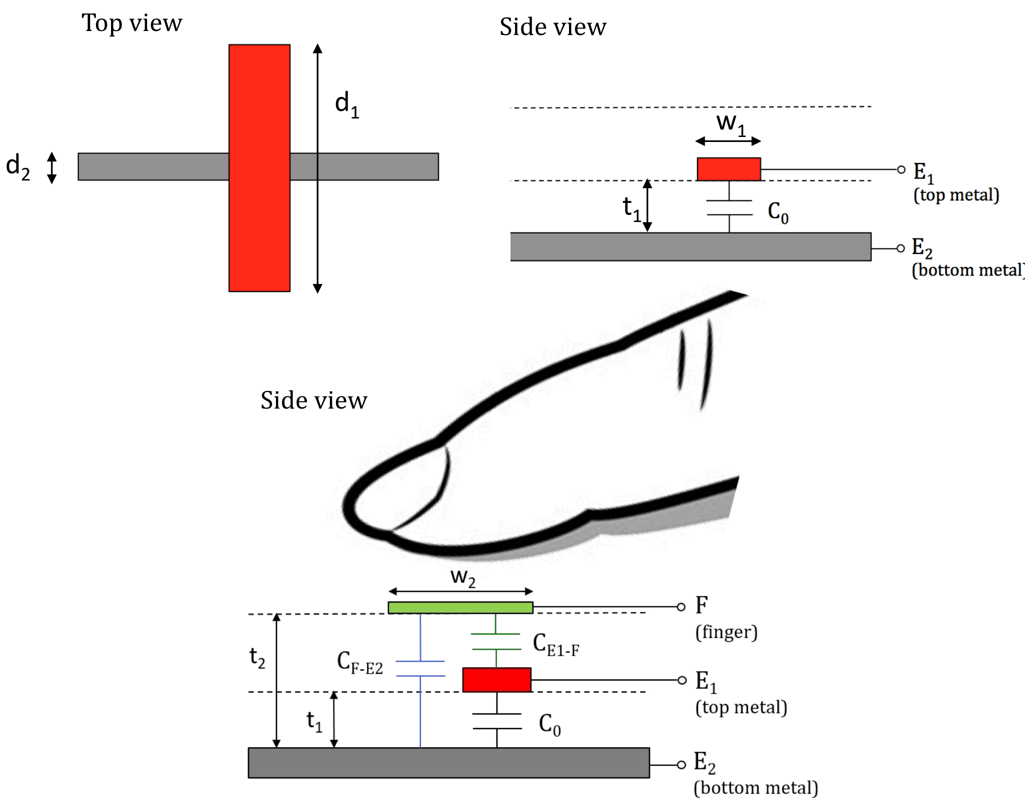


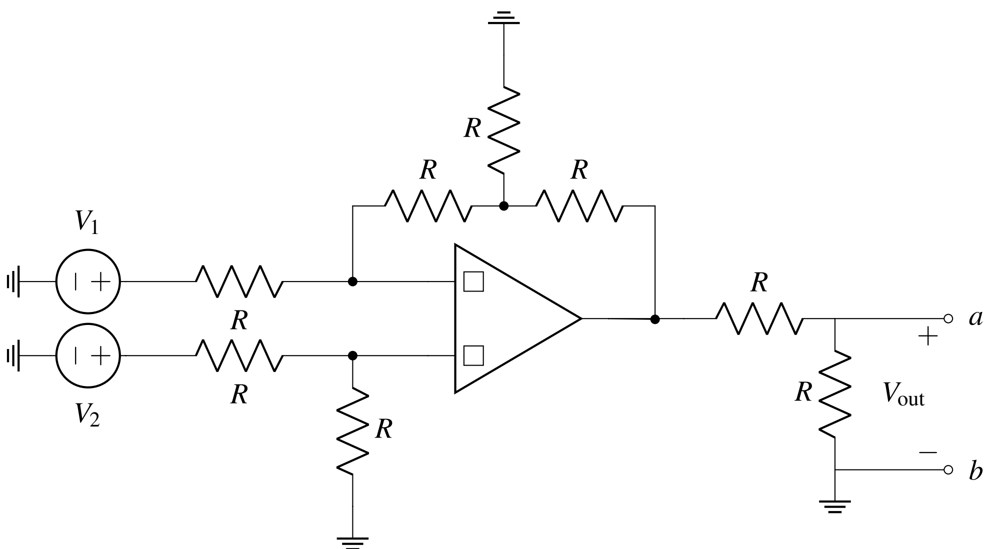
Figure 1: Model of capacitive touchscreen.

(b) What are the values of C_0, C_{F-E1}, and C_{F-E2}? Assume that the insulating material has a permittivity of $\varepsilon = 4.43 * 10^{-11} F/m$ and that the thickness of the metal layers is small compared to t_1.

(c) What is the difference in effective capacitance between the two metal plates (nodes E_1 and E_2) when a finger is present?

3. Op Amp Nodal Analysis

Consider this Op Amp circuit below:



We are interested in analyzing its input-output relationship.

(a) Redraw the circuit with a choice of + and − terminal labelings to guarantee that the circuit is in negative feedback.

Our goal in the succeeding parts will be to find the Thevenin equivalent of this op amp circuit, and make some observations about the resulting equivalent.

(b) Find the open circuit output voltage, V_{out} as a function of the input voltages V_1 and V_2. This will be the Thevenin Voltage, V_{Th}.

(c) Turn off all independent sources ($V_1 = V_2 = 0V$). What is the equivalent resistance as seen between terminals a and b? This will be your Thevenin resistance, R_{Th}. (Hint: Consider what the voltage at the output of the op amp becomes and use a test source, or replace the op amp with its internal model where it has a dependent source.)

(d) Use what you found in parts b and c to draw the Thevenin equivalent.

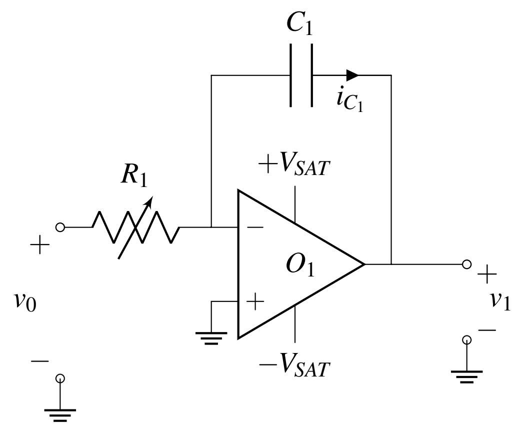
(e) **Practice (Optional)**: Does the Thevenin resistance depend on all the resistors or a strict subset? What might explain this?

4. Integration using Op-amps

As we have seen already it is useful in several applications to create triangular voltages (also known as voltage ramps). Remember for instance the HW 8 problem where we built a circuit that could measure the level of water in a tank by "integrating" current on a capacitor whose value changed with the level of water in the tank. In this problem, you will be analyzing a circuit that produces a voltage ramp using a voltage source and an op-amp in negative feedback.

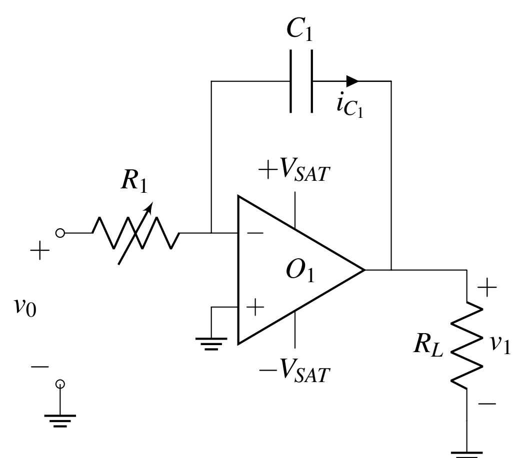
(a) One of the circuit blocks you can use to generate the triangular waveform is the integrator. An integrator outputs the integral of the input signal. For the circuit given below express v_1 in terms of R_1, C_1, v_0, and t, assuming v_0 is not varying with time. What is the slope of this voltage ramp? You may also assume that capacitor C_1 has $0V$ across it at time $t = 0$.

Hint: You will have to apply KCL, and use the fact that the current flowing through a capacitor is given by $I = C\frac{dV}{dt}$.

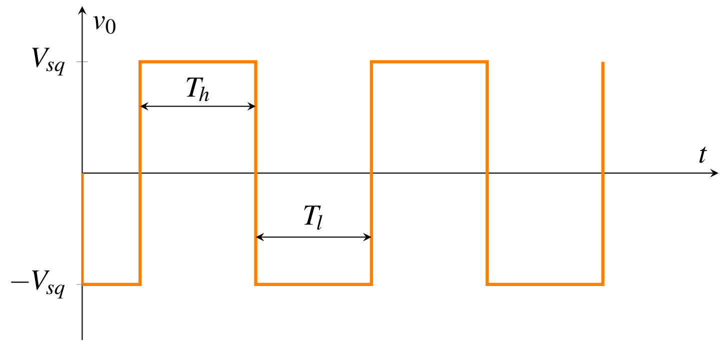


(b) What is the value of the current i_{C_1} flowing through capacitor C_1? How does the capacitor current change if we double C_1? How does the slope of the ramp change if we double capacitor C_1?
Note: the current direction is specified in the figure above.

(c) If we connect a load resistance at the output of the circuit, as shown in the figure below, does the output voltage v_1 change, from what you calculated in part (a)? Why or why not?



(d) If v_0 varies with time as shown in the following diagram, plot v_1 for $t = 0$ to $t = 1.5T$, where $T = 2T_h = 2T_l$. In your plot indicate an algebraic expression for the slope (as a function of R_1, C_1 and v_{sq}) and add tick marks on the x and y axis indicating the time and voltage values where the ramp slope changes. You may assume again that capacitor C_1 has 0V across it at time $t = 0$.



(e) **Practice (Optional):** Prove that the units of RC in SI are seconds.

5. Cool For The Summer

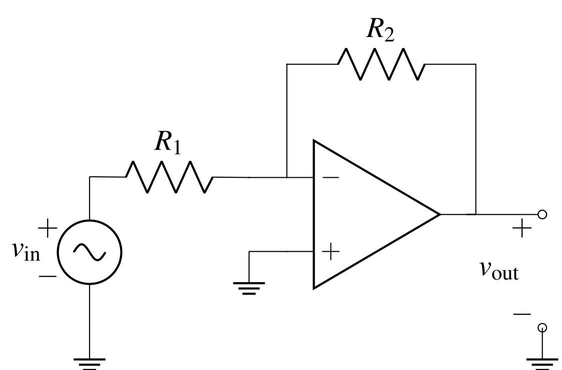
You and a friend want to make a box that helps control an air conditioning unit using both your inputs. You both have individual dials where you can set a control voltage: input of 0 means that you want to leave the temperature as it is. Negative voltage input would mean that you want to reduce the temperature. (It's hot, so we will assume that you never want to increase the temperature – so, we're not talking about a Berkeley summer...)

Your air conditioning unit, however, responds to positive voltages. The higher the magnitude of the voltage, the stronger it runs. At zero, it is off. You also need a system that sums up both you and your friend's control inputs.

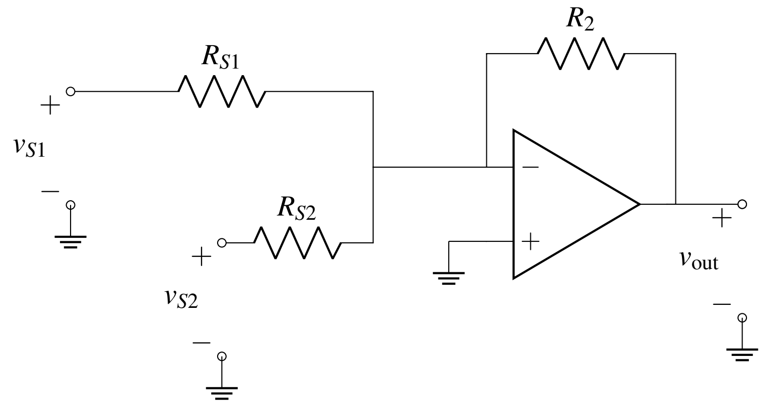
Therefore, you need a box that is **an inverting summer** – *it outputs a weighted sum of two voltages where the weights are both negative*. The sum is weighted because each of you has your own subjective sense of how much to turn the dial down, so you need to compensate for this.

This problem walks you through designing this inverting summer using an op-amp.

(a) As a first step, derive v_{out} in terms of R_2, R_1, v_{in}.



(b) Now we will add a second input to this circuit as shown below. Find v_{out} in terms of v_{S1}, v_{S2}, R_{S1}, R_{S2} and R_2.



(c) Let's suppose that you want $v_{out} = -\left(\frac{1}{4}v_{S1} + 2v_{S2}\right)$ where v_{S1} and v_{S2} represent the input voltages from you and your friend. Select resistor values such that the circuit implements this desired relationship.

(d) Now suppose that you have a new AC unit that you want to use with your control inputs v_{S1} and v_{S2}. This unit, however, functions opposite to the previous unit; it responds to negative voltages. The higher the magnitude of the negative voltage, the stronger the AC runs.
Now design a circuit that *outputs a weighted sum of two control input voltages where both weights are positive*. Specifically, add another op-amp based circuit to your circuit in part (b), so that you invert the output of the circuit from part (b).

6. 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?