
EECS 16A Designing Information Devices and Systems I

Spring 2022 Homework 9

This homework is due Friday, April 1, 2021 at 23:59.

Self-grades are due Monday, April 4, 2021 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).

Submit the file to the appropriate assignment on Gradescope.

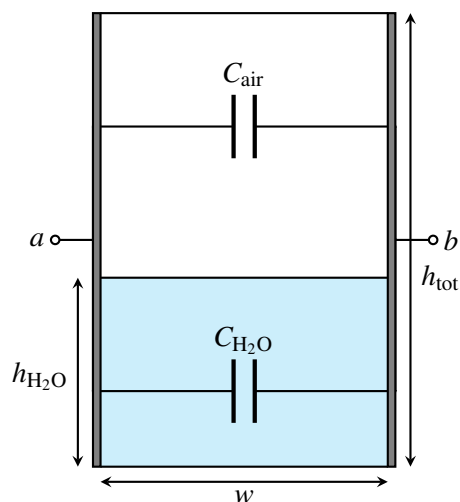
1. Reading Assignment

For this homework, please read Notes 16, 17 (17.1 - 17.2, specifically) and 17B. Note 16 will provide an introduction to capacitors (a circuit element which stores charge), capacitive equivalence, and the underlying physics behind them. Sections 17.1 - 17.2 in Note 17 will provide an overview of the capacitive touchscreen and how to measure capacitance. Note 17B will provide a walkthrough of the charge-sharing algorithm.

- (a) Describe the key ideas behind how a capacitor works. How are capacitor equivalences calculated? Compare this with how we calculate resistor equivalences.
- (b) Consider the capacitive touchscreen. Describe how it works, and compare and contrast it to the resistive touchscreens we have seen in previous lectures and homeworks.
- (c) In the charge sharing algorithm, what property of charge is applied in connecting phase 1 calculations to phase 2 calculations?

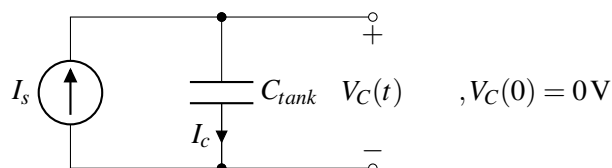
2. It's finally raining!

A lettuce farmer in Salinas Valley has grown tired of weather.com's imprecise rain measurements. Therefore, they decided to take matters into their own hands by building a rain sensor. They placed a rectangular tank outside and attached two metal plates to two opposite sides in an effort to make a capacitor whose capacitance varies with the amount of water inside.



The width and length of the tank are both w (i.e., the base is square) and the height of the tank is h_{tot} .

- What is the capacitance between terminals a and b when the tank is full? What about when it is empty?
Note: the permittivity of air is ϵ , and the permittivity of rainwater is 81ϵ .
- Suppose the height of the water in the tank is $h_{\text{H}_2\text{O}}$. Modeling the tank as a pair of capacitors in parallel, find the total capacitance between the two plates. Call this capacitance C_{tank} .
- After building this capacitor, the farmer consults the internet to assist them with a capacitance-measuring circuit. A fellow internet user recommends the following:



In this circuit, C_{tank} is the total tank capacitance that you calculated earlier. I_s is a known current supplied by a current source.

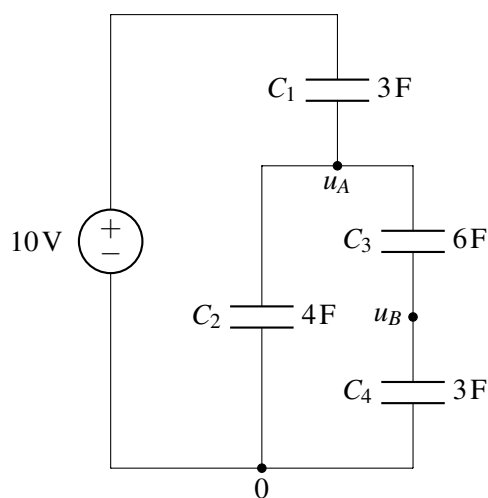
The suggestion is to measure V_C for a brief interval of time, and then use the difference to determine C_{tank} .

Determine $V_C(t)$, where t is the number of seconds elapsed since the start of the measurement. You should assume that before any measurements are taken, the voltage across C_{tank} , i.e. V_C , is initialized to 0V , i.e. $V_C(0) = 0$.

- If we can measure $V_C(t)$ and knowing the result of part (c), how could we derive the value of C_{tank} ? Then, using the result from part (b), write $h_{\text{H}_2\text{O}}$ as a function of C_{tank} and other constants.

3. Circuit with Capacitors

Find the voltages at nodes u_A and u_B , and currents flowing through all of the capacitors at steady state. Assume that before the voltage source is applied, the capacitors all initially have a charge of 0Coulombs .



4. 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 $w_2 \times d_1$, where w_2 is the horizontal width of the finger contact area and d_1 is the depth (into the page) of the finger contact area. The top metal (red area) has dimensions $w_1 \times d_1$. The bottom metal (grey area) has dimensions $w \times d_2$, where w is larger than both w_1 and w_2 . The vertical distance between the top metal (red) and bottom plate (grey) is t_1 , and the vertical distance between the finger (green) and the bottom plate (grey) is t_2 .

Table 1: Touchscreen Dimension Values

d_1	10 mm
d_2	1 mm
t_1	2 mm
t_2	4 mm
w_1	1 mm
w_2	2 mm

- (a) Draw the equivalent circuit of the touchscreen that contains the nodes F , E_1 , and E_2 when: (i) there no finger present; and (ii) when there is a finger present. Express the capacitance values in terms of C_0 , C_1 , and C_2 .

Hint: Note that node F represents the finger. When there is no touch node F would be non-existent.

Hint: Treat E_1 as the "top node", E_2 as the "bottom node", and the finger F as an intermediate node when present.

- (b) What are the values of C_0 , C_1 , and C_2 ? Assume that the insulating material has a permittivity of $\epsilon = 4.43 \times 10^{-11} \text{ F/m}$ and that the thickness of the metal layers is small compared to t_1 (so you can ignore the thickness of the metal layers). Also assume that the right edge of the top metal (red area) in the diagram is aligned with the right edge of the finger (green area) in the diagram.
- (c) What is the difference in effective capacitance between the two metal plates (nodes E_1 and E_2) when a finger is present?
- (d) What are the advantages of capacitive touchscreen over resistive touchscreen?
Hint: Can we do multi-fingers detections using capacitive touchscreen? What about resistive touchscreen?

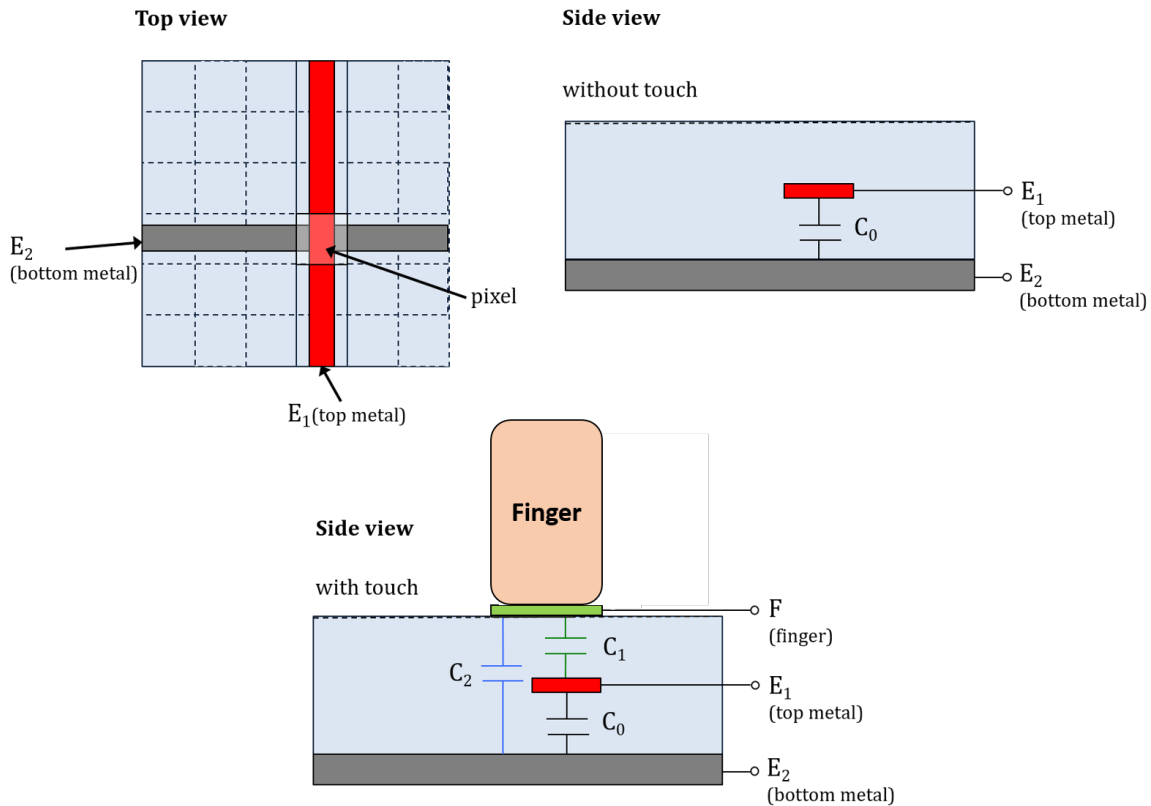
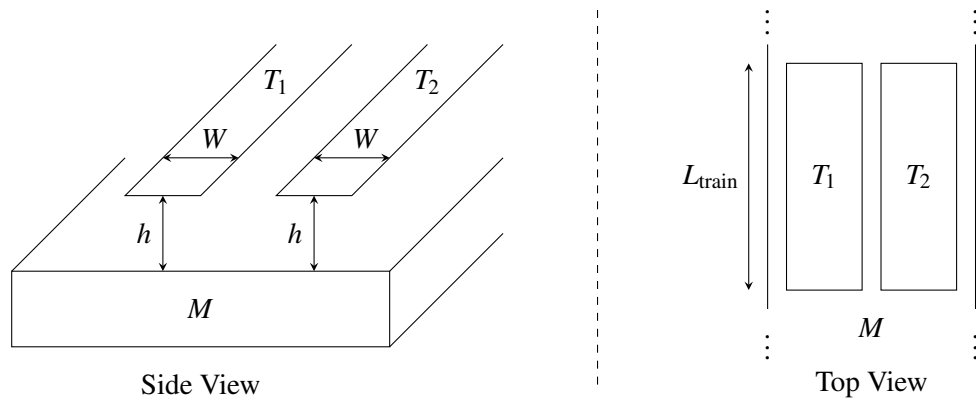


Figure 1: Model of capacitive touchscreen.

5. Maglev Train Height Control System

One of the fastest forms of land transportation are trains that actually travel slightly elevated from the ground using magnetic levitation (or “maglev” for short). Ensuring that the train stays at a relatively constant height above its “tracks” (the tracks in this case are what provide the force to levitate the train and propel it forward) is critical to both the safety and fuel efficiency of the train. In this problem, we’ll explore how maglev trains use capacitors to stay elevated. (Note that real maglev trains may use completely different and much more sophisticated techniques to perform this function, so if you get a contract to build such a train, you’ll probably want to do more research on the subject.)

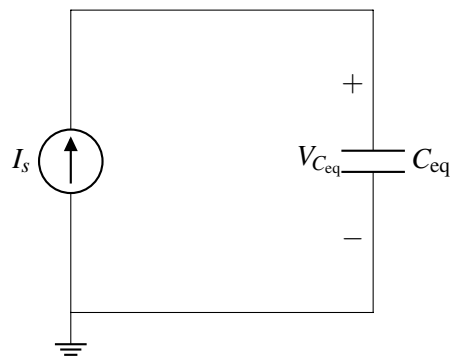
- (a) As shown below, we put two parallel strips of metal (T_1 , T_2) along the bottom of the train and we have one solid piece of metal (M) on the ground below the train (perhaps as part of the track).

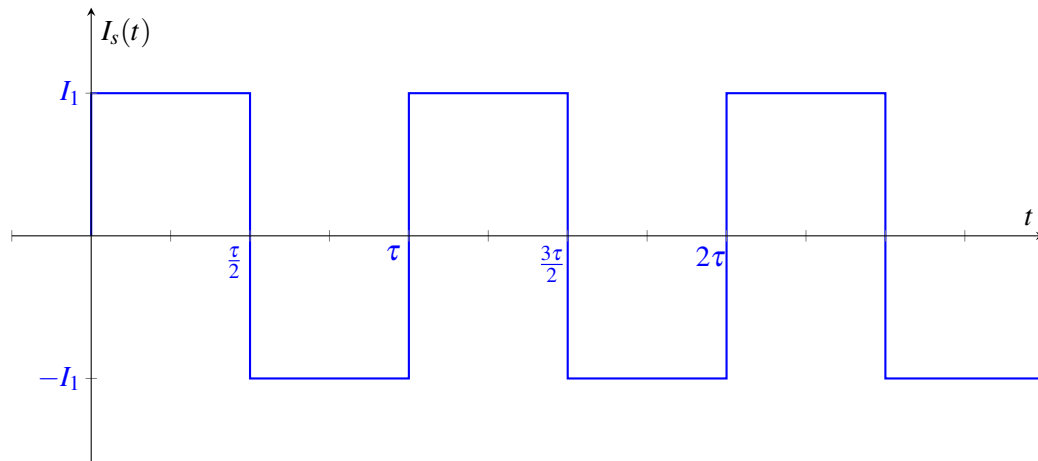


Assuming that the entire train is at a uniform height above the track and ignoring any fringing fields (i.e., we can use the simple equations developed in lecture to model the capacitance), as a function of L_{train} (the length of the train), W (the width of T_1 and T_2), and h (the height of the train off of the track), what is the capacitance between T_1 and M ? What is the capacitance between T_2 and M ?

- (b) Any circuit on the train can only make direct contact at T_1 and T_2 . Thus, you can only measure the equivalent capacitance between T_1 and T_2 . Draw a circuit model showing how the capacitors between T_1 and M and between T_2 and M are connected to each other.
- (c) Using the same parameters as in part (a), provide an expression for the equivalent capacitance between T_1 and T_2 .
- (d) We want to build a circuit that creates a voltage waveform with an amplitude that changes based on the height of the train. Your colleague recommends you start with the circuit as shown below, where I_s is a periodic current source, and C_{eq} is the equivalent capacitance between T_1 and T_2 . The graph below shows I_s , a square wave with period τ and amplitude I_1 , as a function of time.

Find an equation for and draw the voltage $V_{C_{\text{eq}}}(t)$ as a function of time. Assume the capacitor C_{eq} is discharged at time $t = 0$, so $V_{C_{\text{eq}}}(0) = 0 \text{ V}$.



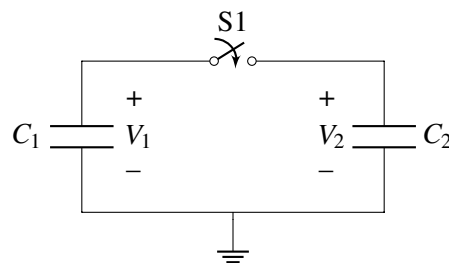


6. Charge Sharing

In the circuit below, switch S_1 is initially open. Capacitor $C_1 = 10^{-3}\text{F}$ is initially charged to $V_1 = 3\text{V}$ and capacitor $C_2 = 3 \times 10^{-3}\text{F}$ is initially charged to $V_2 = 2\text{V}$.

Now S_1 is closed. Calculate the new value of V_2 .

Hint: Remember that charge is conserved at floating nodes.



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.