

# EECS 16A Designing Information Devices and Systems I

## Summer 2023 Discussion 5D

### 1. Capacitive Touchscreen

Consider the 2-dimensional capacitive touchscreen in Figure 1. Node  $F$  (green) represents the contact area of the finger with the top insulator. The finger contact area has horizontal width  $w_2$  and depth (into the page)  $d_1$ . The 'top' metal at node  $E_1$  (red) has width  $w_1$  and depth  $d_1$ . The 'bottom' metal at node  $E_2$  (grey) has width  $w$  and depth  $d_2$ , where  $w$  is much larger than  $w_1$  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

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

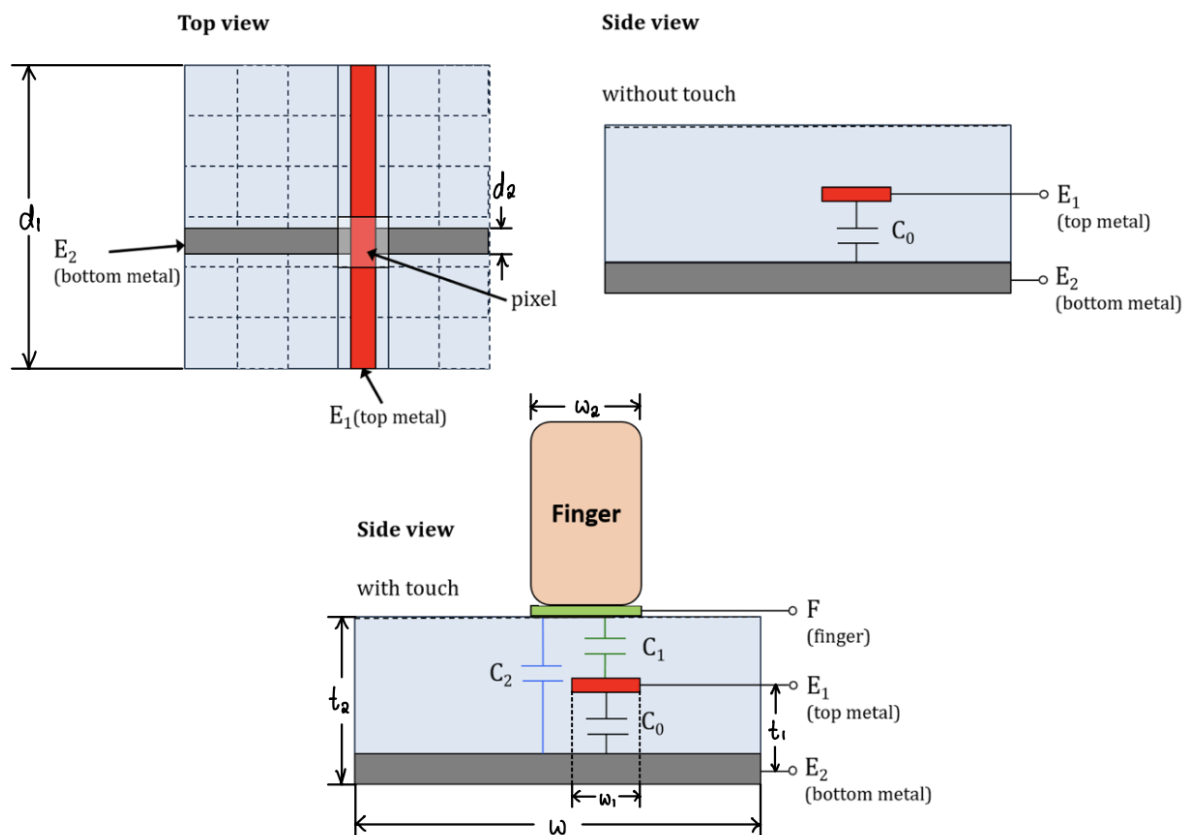


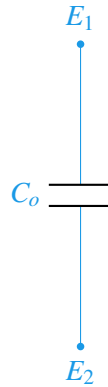
Figure 1: Model of capacitive touchscreen.

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

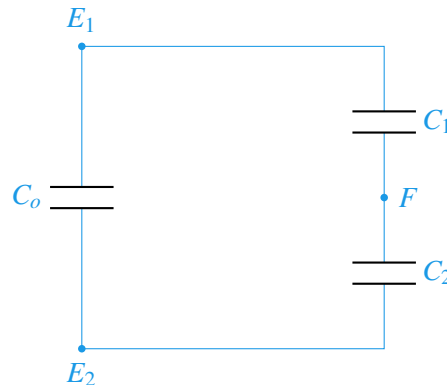
*Hint: Note that node  $F$  represents the finger. When there is no touch node,  $F$  would be non-existent.*

**Answer:**

- i. Equivalent circuit with no finger present



- ii. Equivalent circuit with a finger present



- (b) What are the values of  $C_0$ ,  $C_1$ , and  $C_2$ ? Assume the insulating material has a permittivity of  $\epsilon = 4.43 \cdot 10^{-11} \text{ F/m}$  and 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. Convert your calculated values to femto-Farads (*femto* =  $f = 10^{-15}$ ).

**Solution/Answer:**

For two unequally sized parallel plates, capacitance is formed only by their overlapping area (when neglecting fringing effects).

**Answer:**

$$C_0 = \epsilon \frac{d_2 w_1}{t_1} = 2.215 \cdot 10^{-14} \text{ F} = 22.15 \text{ fF}$$

$$C_1 = \epsilon \frac{d_1 w_1}{t_2 - t_1} = 2.215 \cdot 10^{-13} \text{ F} = 221.5 \text{ fF}$$

$$C_2 = \epsilon \frac{d_2(w_2 - w_1)}{t_2} = 1.108 \cdot 10^{-14} \text{ F} = 11.08 \text{ fF}$$

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

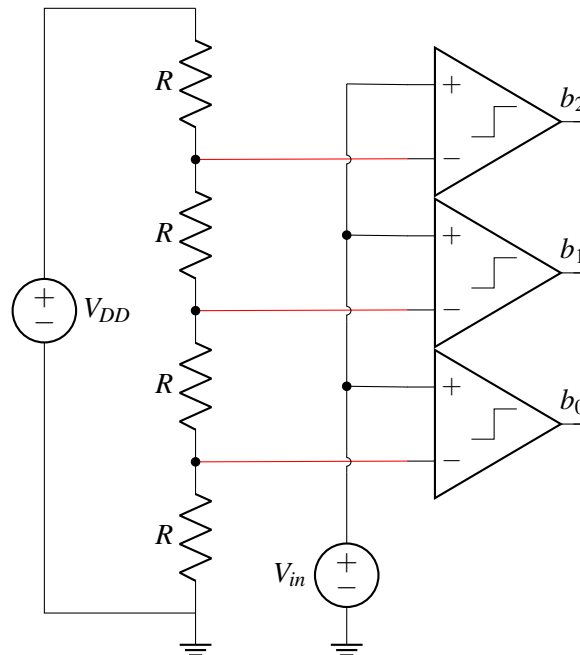
**Answer:**

The effective capacitance  $C_e$  between the two plates is  $C_0 = 2.215 \cdot 10^{-14} \text{ F}$  when there is no finger. When there is a finger,  $C_0$  is in parallel with the series combination of  $C_1$  and  $C_2$ , giving an additional capacitance  $C_1 || C_2 = 1.055 \cdot 10^{-14} \text{ F}$ .

Therefore, the total effective capacitance (with finger) is  $C_e = C_0 + C_1 || C_2 = 3.270 \cdot 10^{-14} \text{ F}$ .

## 2. Data Conversion Circuits

- (a) The dual to DAC circuits are analog-to-digital converters, or ADC circuits. Here is an example of one, called a "Flash ADC," using resistors and comparators:



*Note: The red wires in the diagram are regular wires, but have been colored to show that they do not touch the crossing black wires.*

The resistor ladder gives us a set of reference voltages to compare against. We use a set of comparators to compare the input voltage  $V_{in}$  against these reference levels, and we get out a corresponding digital code  $b_0$ ,  $b_1$ , and  $b_2$ .

Assume that  $V_{DD} = 1 \text{ V}$ , and that the comparators are connected to rails  $V_{DD} = 1 \text{ V}$  and  $V_{SS} = 0 \text{ V}$ . If  $V_{in}$  is  $0.3 \text{ V}$ , **what are the outputs  $b_0$ ,  $b_1$ , and  $b_2$ ?**

**Solution/Answer:** The reference voltages for the comparators, from bottom to top, are  $\frac{1}{4}V_{DD} = 0.25 \text{ V}$ ,  $\frac{1}{2}V_{DD} = 0.5 \text{ V}$ , and  $\frac{3}{4}V_{DD} = 0.75 \text{ V}$ . Each comparator checks if  $V_{in}$  is greater than the reference voltage, outputting  $V_{DD}$  if it is greater and  $V_{SS}$  if not. We are given  $V_{in} = 0.3 \text{ V}$ , so  $b_0 = V_{DD} = 1 \text{ V}$ ,  $b_1 = V_{SS} = 0 \text{ V}$ ,  $b_2 = V_{SS} = 0 \text{ V}$ .

If you left your answer in terms of 1s and 0s, i.e.  $b_0 = 1, b_1 = 0, b_2 = 0$ , that is valid too.