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
10 mm	1 mm	1 mm	2 mm	2 mm	4 mm

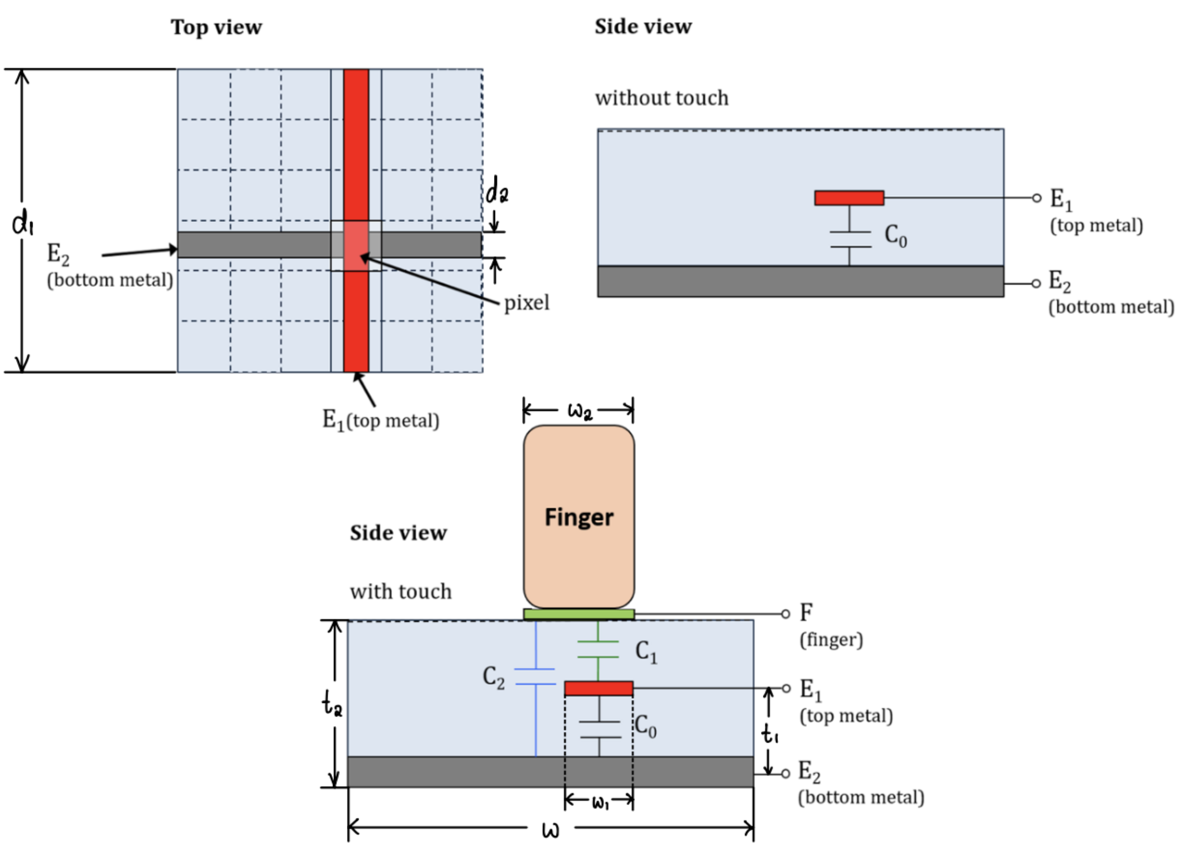


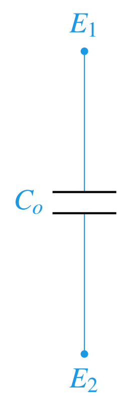
Figure 1: Model of capacitive touchscreen.

(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.

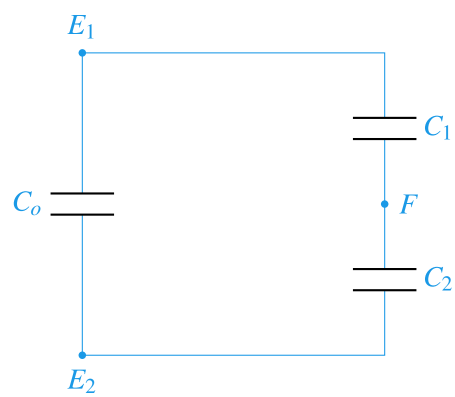
Hint: Note that node F represents the finger. When there is no touch node, F would be non-existent.

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 $\varepsilon = 4.43 \cdot 10^{-11}\,\mathrm{F/m}$ 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 ($femto = f = 10^{-15}$).

Answer:

$$C_0 = \varepsilon \frac{d_2 w_1}{t_1} = 2.215 \cdot 10^{-14}\,\mathrm{F} = 22.15\,\mathrm{fF}$$

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

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

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

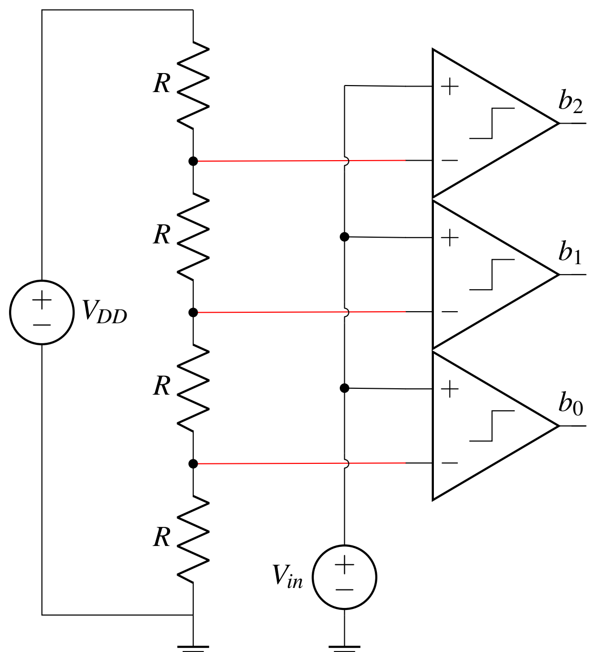
Answer:

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?