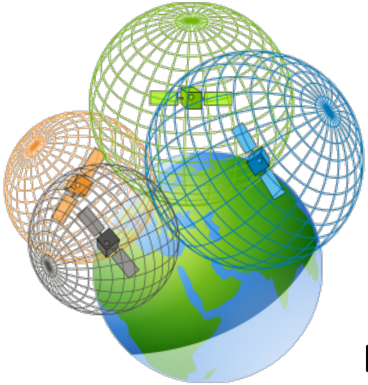
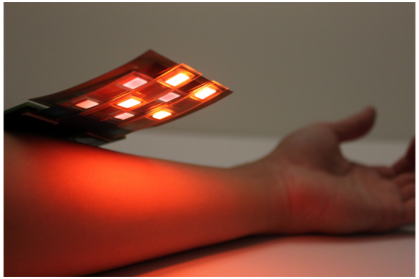




Welcome to EECS 16A!

Designing Information Devices and Systems I

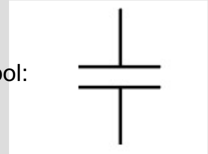
Ana Claudia Arias and Miki Lustig

Fall 2021

Module 2
Lecture 7
Capacitive Touchscreens
(Note 17)

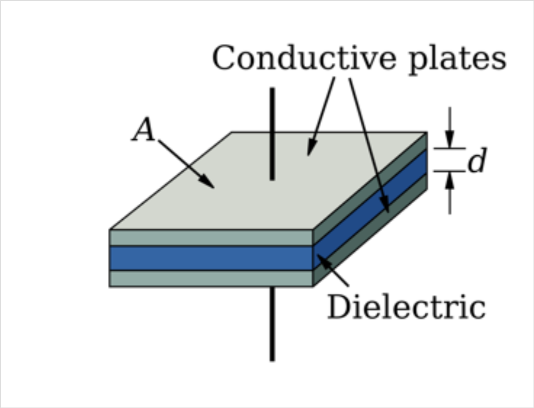
Last lecture: Capacitors

- Charge storage device (like a ‘bucket’ for charge)
- holds electric charge when we apply a voltage across it, and gives up the stored charge to the circuit when voltage removed

Symbol: 

Capacitance: C Units: Farads [F]

IV equation:



Capacitance

$$C = \varepsilon \frac{A}{d}$$

$$[F] = \left[\frac{F}{m}\right]\left[\frac{m^2}{m}\right]$$

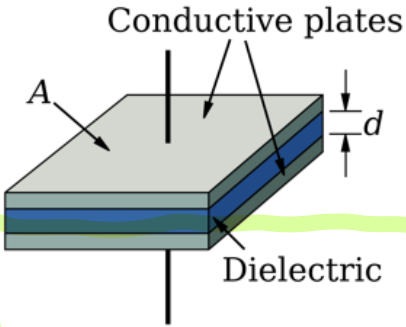
Depends on:

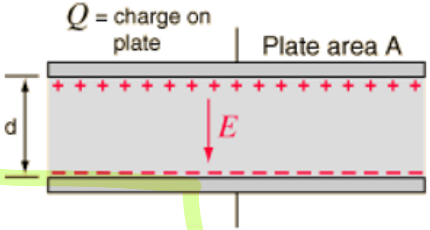
- Materials : ε permitivity

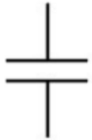
  $\varepsilon_0 = 8.85 \cdot 10^{-12}$ F/m

  $\varepsilon = \varepsilon_0 \varepsilon_r$

- Geometry of Conductors





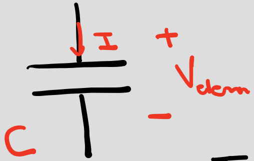
Symbol: 

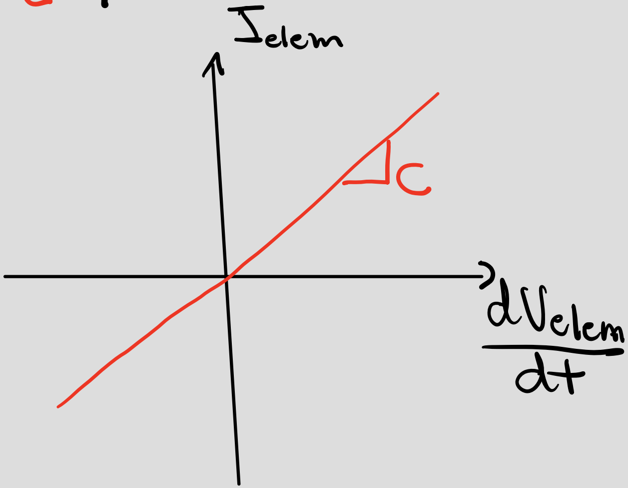
Capacitance: C Units: Farads [F]

IV equation: $I = C \cdot \frac{dV}{dt}$

Circuit Model: IV relationship

Capacitor Symbol





$$\underset{[C]}{Q_{elem}} = \underset{[F]}{C} \cdot \underset{[V]}{V_{elem}}$$

(Farad)

We know : $I_{elem} = \frac{d\,Q_{elem}}{dt}$

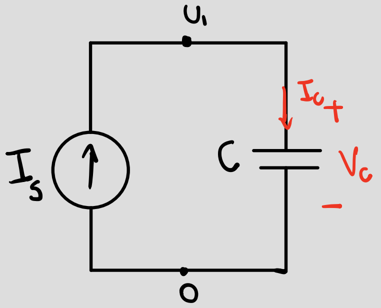
$I_{elem} = \frac{d}{dt} C \cdot V_{elem}$

C = constant over time

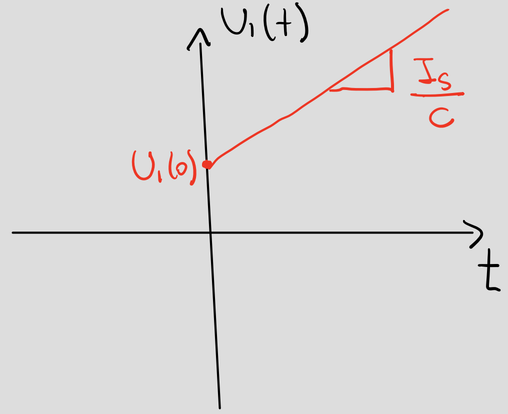
$$\boxed{I_{elem} = C \cdot \frac{d\,V_{elem}}{dt}}$$

↳ Can use the same 7-step analysis.

Simple Circuit 1



$$\boxed{I_s = C\,\frac{dU_1}{dt}} \times dt$$



KCL : $\underline{I_s = I_c}$

Element Def.:

$$\underline{I_c} = C \cdot \frac{dV_c}{dt}$$

Voltage Def:

$$U_1 - 0 = V_c$$

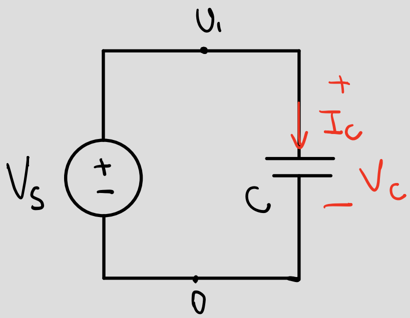
$$I_s \cdot dt = C\, dU_1$$

$$\int_0^t I_s\,dt = \int_{U_1(0)}^{U_1(t)} C \cdot dU_1$$

$$I_s t = C \cdot \left(U_1(t) - U_1(0)\right)$$

$$U_1(t) = \frac{I_s}{C} \cdot t + U_1(0)$$

Simple Circuit 2



$$\left.\begin{aligned} U_1 - 0 &= V_s \\ U_1 - 0 &= V_c \end{aligned}\right\} \text{ Voltage Def.}$$

$$V_s = V_c$$

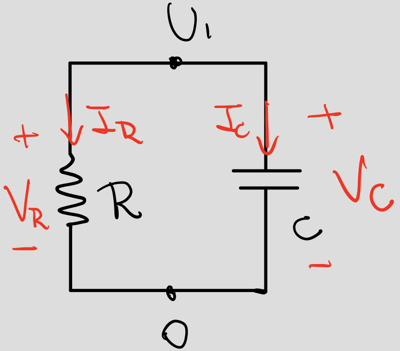
$$I_c = C\frac{dV_c}{dt} \quad \text{(capacitor Def.)}$$

$$I_c = C\frac{dV_c}{dt} = C \cdot \cancel{\frac{dV_s}{dt}}^{\,0} = 0$$

Current in a capacitor is zero when a constant Voltage source is across it.

Hint: We like zeros... they make our lives easier!

Simple Circuit 3



$U_1 = ?$

Steady State: means the Voltages settled.

Looking for U_1 value when

$V_c = \text{const.}$ (steady-state)

$I_c = C \dfrac{dV_c}{dt} = 0$

KCL: $\cancel{I_c} + I_R = 0$

$I_R = 0$

Ohm's Law: $V_R = \cancel{I_R} R = 0$

Voltage Def: $U_1 - 0 = \cancel{V_R}$

$\boxed{U_1 = 0}$

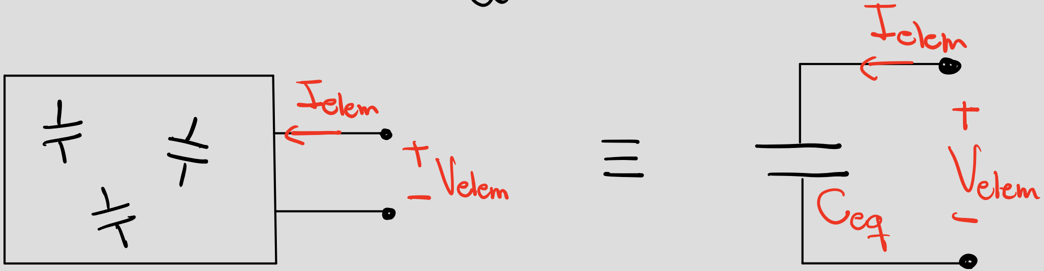
If current is zero ⇒ 

Equivalent Circuits with Capacitors

* Capacitor-only circuits

~~Step 1: find Vth and INo~~ no source

Step 2: $C_{eq} = \dfrac{I_{elem}}{\dfrac{dV_{elem}}{dt}}$



Only if $\left(\text{match } \dfrac{dV_{elem}}{dt}\right)$

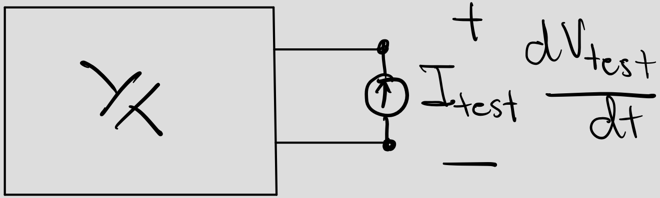
Two Methods:

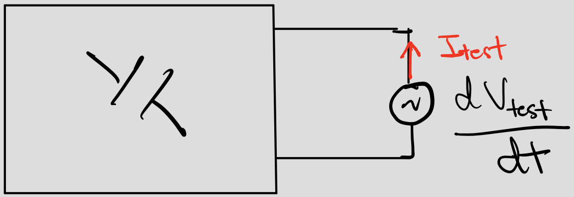
a) Apply I_{test} and measure $\frac{dV_{test}}{dt}$

b) Apply $\frac{dV_{test}}{dt}$ and measure I_{test}

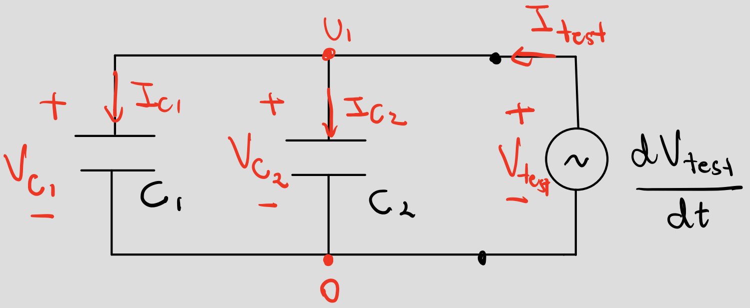
$$= C_{eq} = \frac{I_{test}}{\frac{dV_{test}}{dt}}$$

(a)





Example 1



$V_{C_1} = U_1$, $V_{C_2} = U_1$ and

$U_1 = V_{test}$

$$\frac{dU_1}{dt} = \frac{dV_{test}}{dt}$$

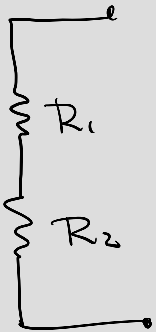
$$\text{Elem def: } I_{C_1} = C_1 \frac{dV_1}{dt} = C_1 \frac{dU_1}{dt} = C_1 \frac{dV_{test}}{dt}$$

$$\text{Elem def: } I_{C_2} = C_2 \frac{dV_2}{dt} = C_2 \frac{dU_1}{dt} = C_1 \frac{dV_{test}}{dt}$$

$$\text{KCL: } I_{test} = I_{C_1} + I_{C_2} = C_1 \frac{dV_{test}}{dt} + C_2 \frac{dV_{test}}{dt}$$

$$I_{test} = (C_1 + C_2)\frac{dV_{test}}{dt}$$

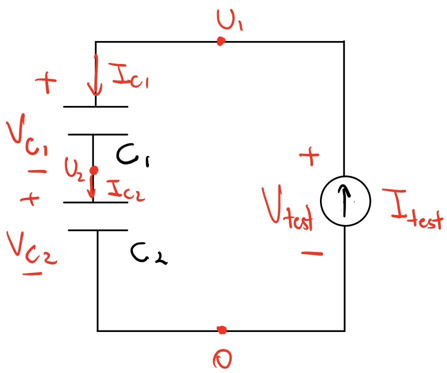
$$\boxed{C_{eq} = \frac{I_{test}}{\frac{dV_{test}}{dt}} = C_1 + C_2}$$



$$\equiv R_{eq} = R_1 + R_2$$

Series

Example 2 : "Capacitors in series"



$\underline{KCL}$: $I_{C_1} = I_{C_2} = I_{test}$

$\underline{\text{Elements}}$:

$$I_{C_2} = C_2 \frac{dV_{C_2}}{dt}$$

$$I_{C_1} = C_1 \frac{dV_{C_1}}{dt}$$

$\underline{\text{Voltage Def}}$:

$$V_{C_2} = U_2 - 0$$

$$V_{C_1} = U_1 - U_2$$

$$V_{test} = U_1 - 0$$

For V_{C_2}:

$$I_{C_2} = C_2 \frac{dV_{C_2}}{dt}$$

$$I_{test} = C_2 \frac{dU_2}{dt} \equiv \frac{dU_2}{dt} = \frac{I_{test}}{C_2}$$

For V_{C_1}

$$I_{C_1} = C_1 \frac{dV_{C_1}}{dt}$$

$$\frac{dV_1}{dt} = \frac{I_C}{C_1} = \frac{dU_1 - dU_2}{dt} = \frac{I_{test}}{C_1}$$

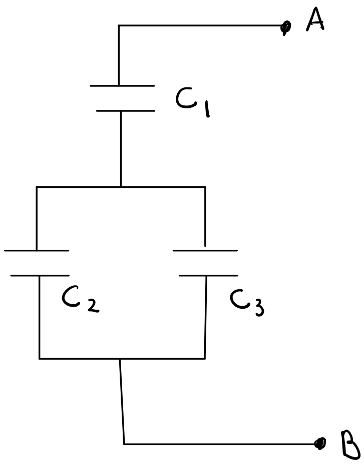
$$\frac{dU_1}{dt} = \frac{dU_2}{dt} + \frac{I_{test}}{C_1} = \frac{I_{test}}{C_2} + \frac{I_{test}}{C_1}$$

$$\frac{dU_1}{dt} = \frac{dV_{test}}{dt} = I_{test}\left(\frac{1}{C_2} + \frac{1}{C_1}\right)$$

$$C_{eq} = \frac{I_{test}}{\frac{dV_{test}}{dt}} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}} = \frac{C_1 C_2}{C_1 + C_2} = C_1 \| C_2$$

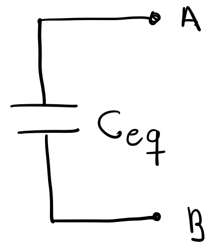
$C_{eq} = C_1 \| C_2$ ($\|$ − parallel mathematical operator)

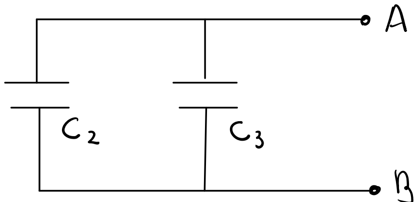
Example 3



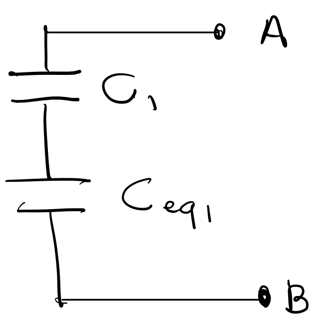
$$C_{eq} = C_1 \,||\, (C_2 + C_3)$$

$\equiv$



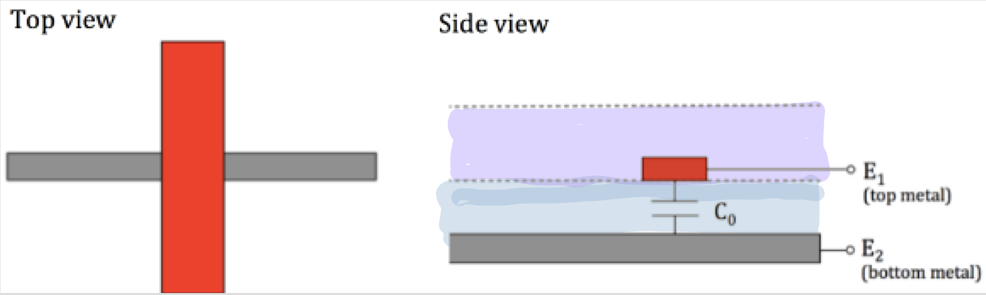


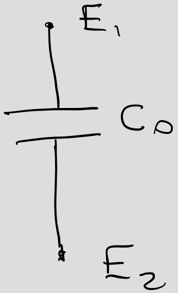
$\Rightarrow$ $C_{eq_1} = C_2 + C_3$



$$C_{eq} = C_1 \,||\, C_{eq_1}$$

Capacitive Touchscreen – Model without touch

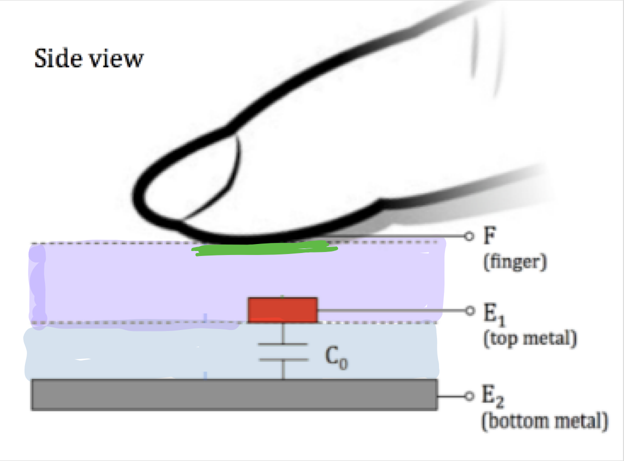


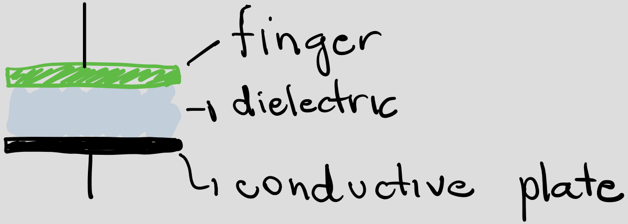


$$C_0 = \varepsilon \cdot \frac{A}{d}$$

Capacitive Touchscreen – Model with touch

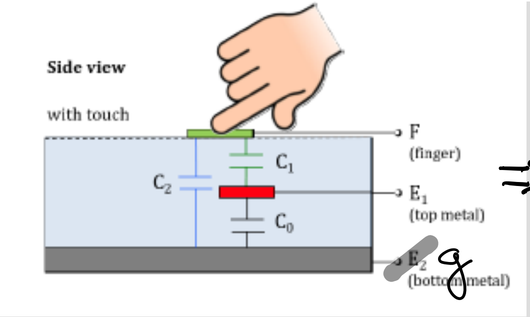
When there is a touch, it makes a capacitor!



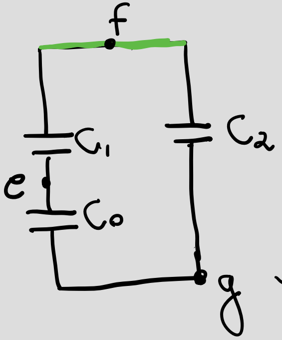


Problem: How can Voltage/Current when the finger is one of the terminals?

Solution: Models / Good architecture

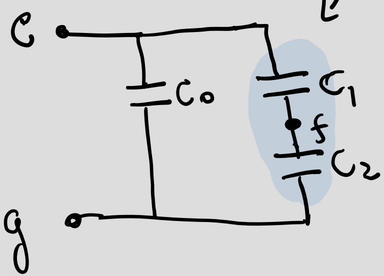


$\Rightarrow$ circuit model

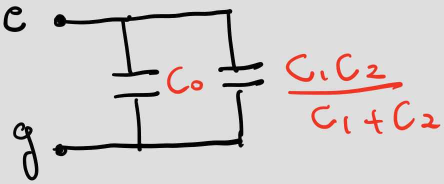


We only have acess to nodes e and g, not f

Redraw to focus on terminals (nodes) e and g.

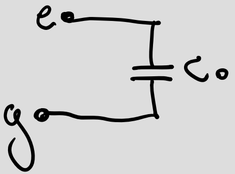


Equivalent capacitance for C_1 in series with C_2

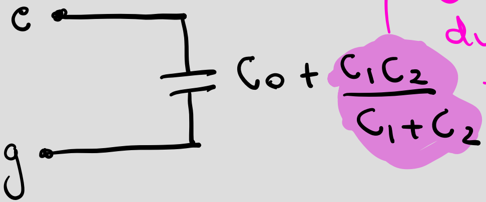


$\Rightarrow$ Equiv. Capacitance for C_0 in parallel to $\frac{C_1C_2}{C_1+C_2}$

when no touch:



with touch:



Extra Capacitance due to touch!