(l1)

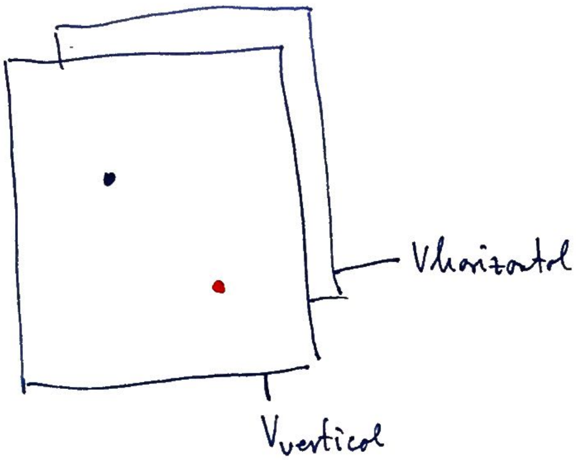
Lecture 6 - Module 2

EE16A

Today: Note 16

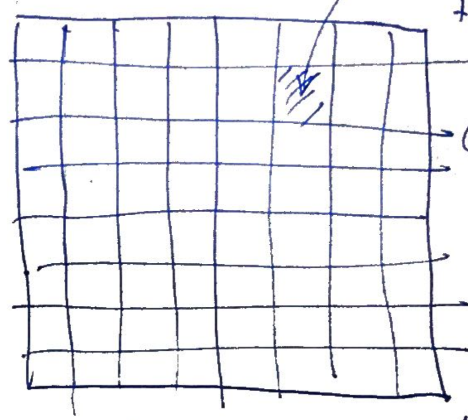
* Capacitive touchscreen
* Capacitor equivalence
* Capacitor physics

An improved touchscreen:



Arbitrary # ⟹ of touch points

Goal: pixel (detect touch or no touch @ each pixel)

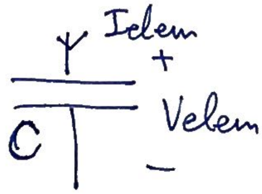


Capacitive touch

Circuit model:

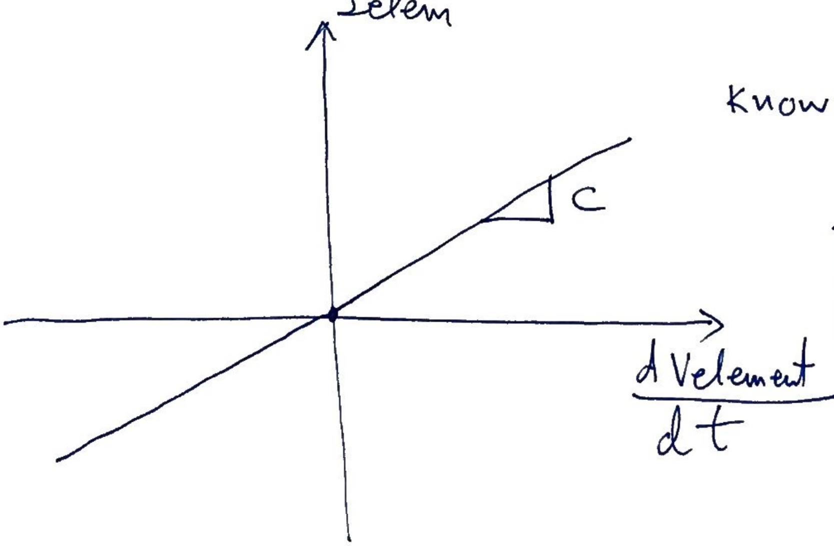
"I-V" element relationships

Capacitor (symbol)



$Q_{elem} = C \cdot V_{elem}$

[C] Coulomb, [F] Farad, [V] Volt



Know: $I_{elem} = \frac{dQ_{elem}}{dt} = C \cdot \frac{dV_{elem}}{dt}$ (C = const in time)

$$\boxed{I_{elem} = C \cdot \frac{dV_{elem}}{dt}}$$

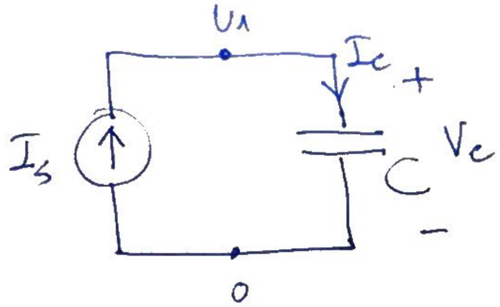
"Ohm's law" for capacitors

⇑

can use the 7-step ckt analysis ...

L2

Simple circuit # 1:



KCL: $I_s - I_c = 0$

elem. def. for C: $I_c = C \cdot \dfrac{dV_c}{dt}$

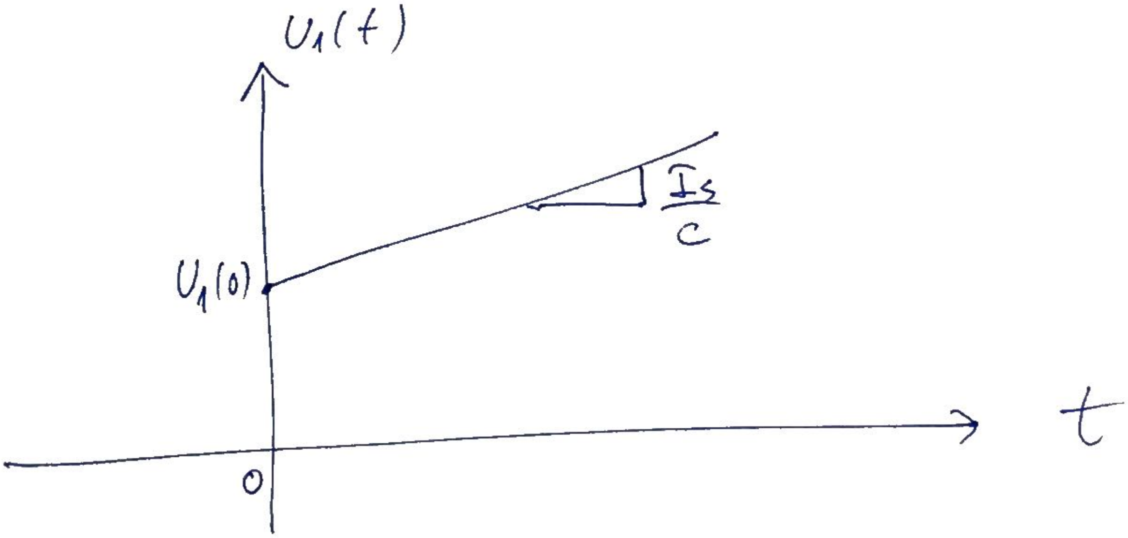
voltage def: $V_c = U_1 - 0 = U_1$

$$\underline{I_s} = C\frac{dV_c}{dt} = \underline{C\frac{dU_1}{dt}}$$

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

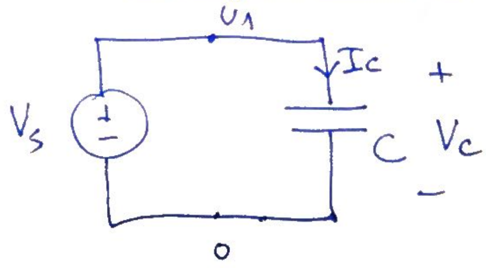
$$I_s \cdot \underbrace{(t-0)}_{t} = C \cdot \left(U_1(t) - U_1(0)\right)$$

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



(l3)

Simple circuit # 2:



$U_1 - 0 = V_S$ (elem. def. source

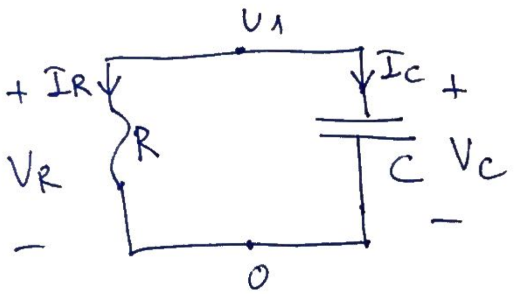
$U_1 - 0 = V_C$ (C. voltage def)

$V_C = V_S$

$I_C = C\dfrac{dV_C}{dt}$ (cap. elem. def)

$I_C = C\cdot\dfrac{dV_C}{dt} = C\cdot\underbrace{\cancel{\dfrac{dV_S}{dt}}}_{\to 0} = 0$

Simple circuit #3:



steady-state means when voltages settle.

$\dfrac{dV_i}{dt} = 0$

$\Downarrow$

every $I_C = 0$

KCL: $I_C = -I_R$ or $I_C + I_R = 0$

since $I_C = 0$ (steady-state)

$I_C = -I_R \Rightarrow \boxed{I_R = 0}$

$V_R = R\cdot I_R = 0$

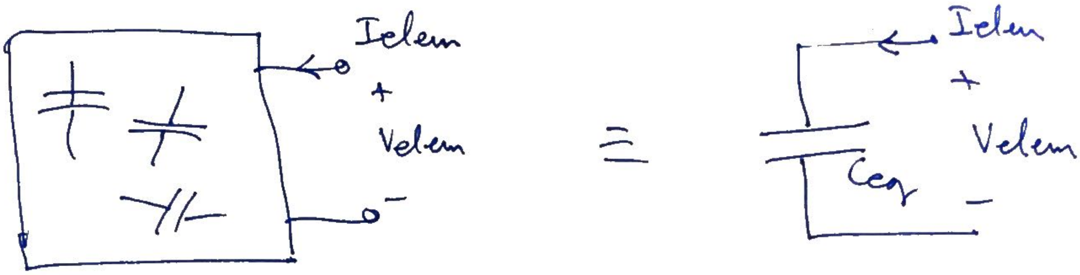
$V_R = U_1 - 0 = \boxed{U_1 = 0}$

(C4)

Equivalent circuits with capacitors:

* Capacitor - only analysis

* step 2 : $C_{eq} = \dfrac{I_{elem}}{\dfrac{dV_{elem}}{dt}} = \dfrac{I_{test}}{\dfrac{dV_{test}}{dt}}$



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

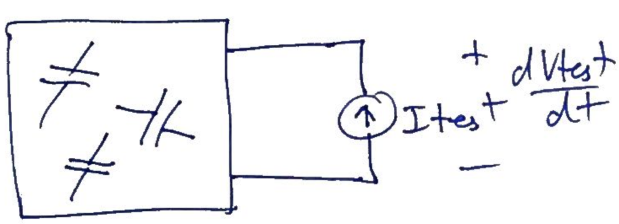
a) Apply I_{test} and measure $\dfrac{dV_{test}}{dt}$

or

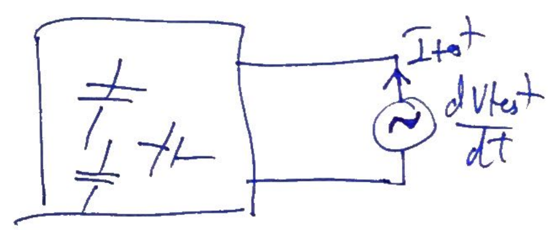
b) Apply $\dfrac{dV_{test}}{dt}$ and measure I_{test}

$\Rightarrow C_{eq} = \dfrac{I_{test}}{\dfrac{dV_{test}}{dt}}$

a)

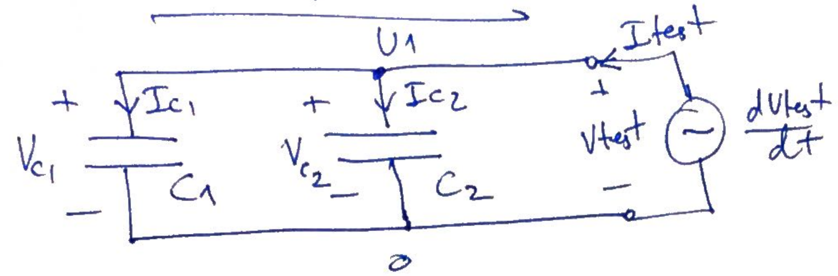


b)



Example 1 :

"capacitors in parallel"



$V_{c1} = U_1$

$V_{c2} = U_1$

$V_{test} = U_1$

$\underbrace{V_{c_1} = V_{c_2} = V_{test}}$

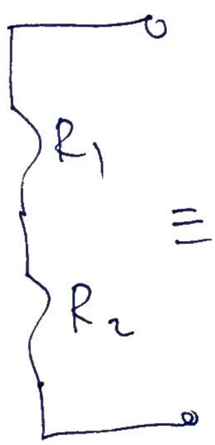
(elem. def) $\quad I_{c1} = C_1 \cdot \frac{dV_{c1}}{dt} = C_1 \frac{dV_{test}}{dt}$

(elem) $\quad I_{c2} = C_2 \frac{dV_{c2}}{dt} = C_2 \cdot \frac{dV_{test}}{dt}$

(KCL) $\quad I_{test} = I_{c_1} + I_{c_2} = C_1 \frac{dV_{test}}{dt} + C_2 \frac{dV_{test}}{dt}$

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

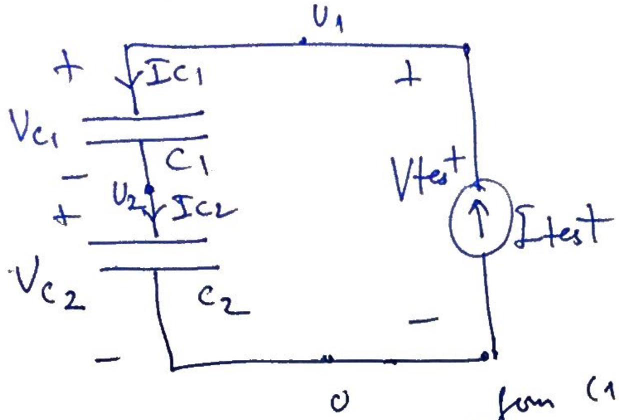
$$C_{eq} = \frac{I_{test}}{\frac{dV_{test}}{dt}} = \underbrace{C_1 + C_2}$$



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

Example 2:

"capacitors in series"



KCL: $\underline{I_{test}} = I_{C1} = \underline{I_{C2}}$ (1)

elements: $I_{C1} = C_1 \dfrac{dV_{C1}}{dt}$ (2)

$\rightarrow I_{C2} = C_2 \dfrac{dV_{C2}}{dt}$ (3)

voltage defs:

$V_{C1} = U_1 - U_2$ (4)

$V_{C2} = U_2 - 0$ (5)

$V_{test} = U_1 - 0$ (6)

from (1), (3) & (5)

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

$$\frac{dV_{C1}}{dt} \overset{(4)}{=} \frac{dU_1}{dt} - \frac{dU_2}{dt} \overset{(2)}{=} \frac{I_{C1}}{C_1}$$

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

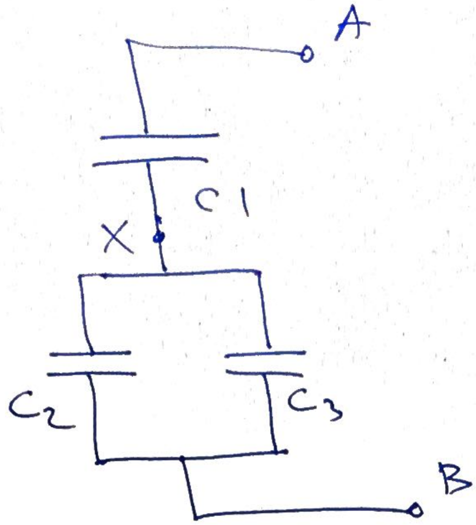
$$\frac{dU_{test}}{dt} = \left(\frac{1}{C_1} + \frac{1}{C_2}\right) I_{test}$$

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

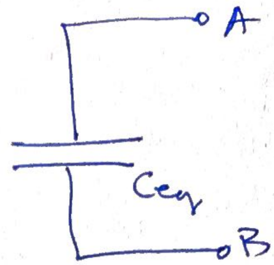
$$C_{eq} = C_1 || C_2$$

parallel operator

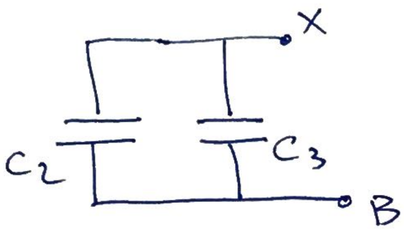
Example #3:



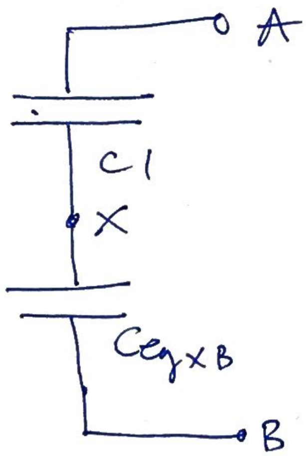
$\equiv$



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



$\Rightarrow \; C_{eq_{XB}} = \underbrace{C_2 + C_3}$

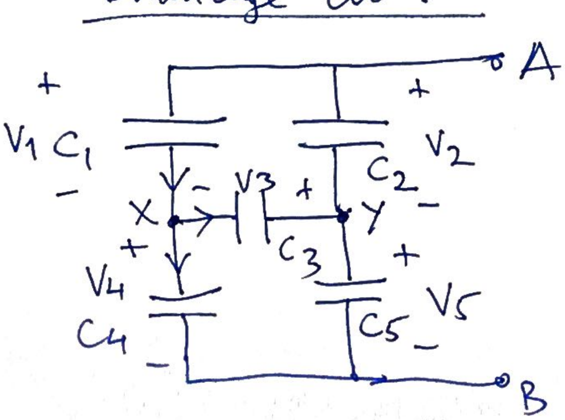


$$\equiv \; C_{eq_{AB}} = C_1 \,||\, C_{eq_{XB}}$$

$$= C_1 \,||\, (C_2 + C_3)$$

$$= \frac{C_1 (C_2 + C_3)}{C_1 + (C_2 + C_3)}$$

challenge ckt:



$C_{eq_{XY}} =$

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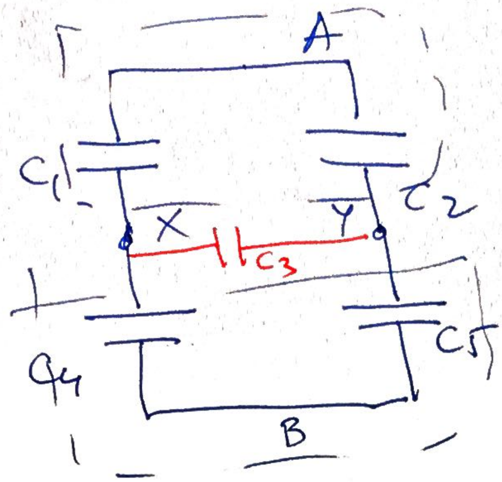
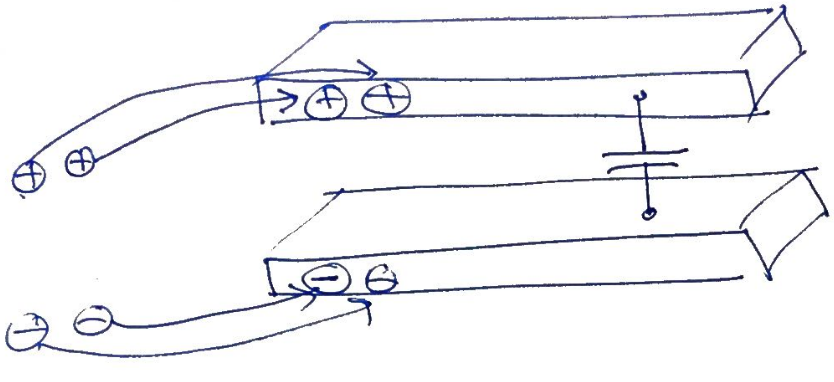


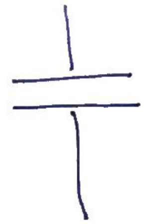
$$C_{XY} = (C_1 \| C_2) + (C_4 \| C_5) + C_3$$

16A Capacitor physics

Capacitor : Any two conductors separated by an insulator (cannot carry current)



$\equiv$



$Q = C \cdot V$

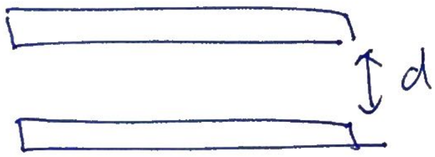
$$\frac{dE}{dq} = V$$

Capacitor is a "bucket" for charge

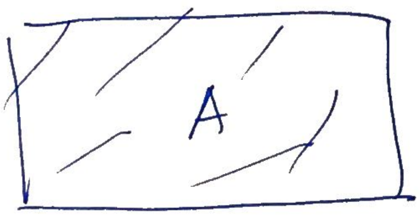
Capacitance depends on : 1) geometry of the conductor

2) material properties of the isolator

side view :



top view :



$$C = \varepsilon \frac{A}{d} \quad \left[\frac{m^2}{m} = m\right]$$

$[F]$ $\uparrow$ permitivity $\left[\frac{F}{m}\right]$

$$\varepsilon_0 = 8.85 \, \frac{pF}{m}$$

$p = \text{pico} = 10^{-12}$