EE16A

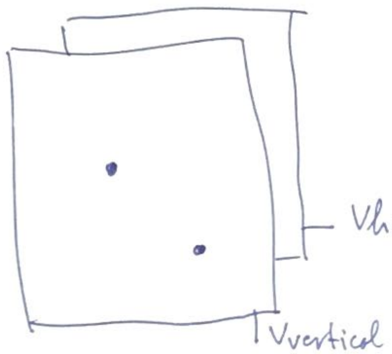
Lecture 6 - Module 2

Today:

Note 16

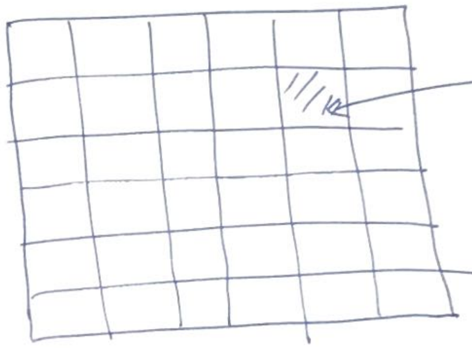
* Capacitive touchscreen
* Capacitor equivalence
* Capacitor physics

An improved touchscreen:



Resistive touch

Arbitrary # $\Rightarrow$ of touch points



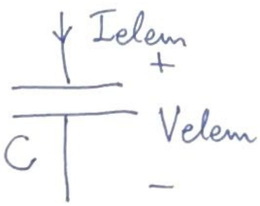
pixel (detect touch or no touch @ the pixel level)

Capacitive touch

Circuit model:

"I - V" element relationship

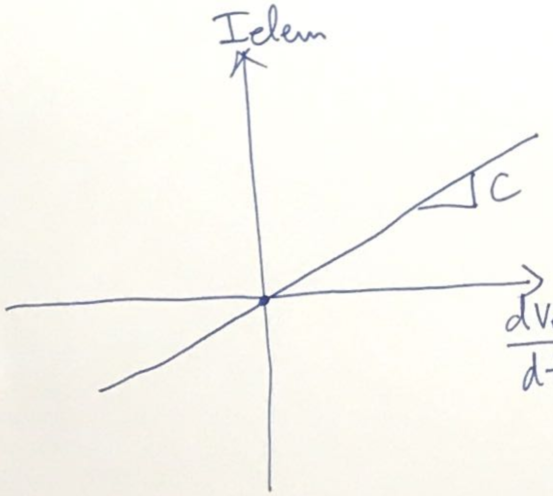
Capacitor (symbol)



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

$[C]$ $[F]$ $[V]$

Farad



know: $I_{elem} = \frac{dQ_{elem}}{dt} = C \cdot \frac{dV_{elem}}{dt}$

C = const over time

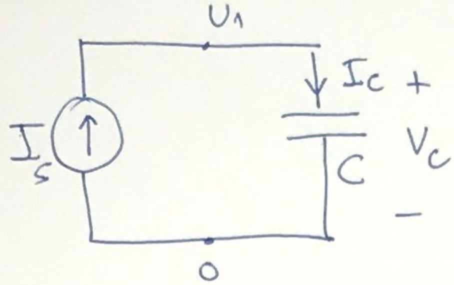
$$\boxed{I_{elem} = C \cdot \frac{dV_{elem}}{dt}}$$

"Ohm's law" for a capacitor.

Can use the same 7-step ckt analysis.

2

Simple circuit # 1:



KCL: $I_s = I_c$

element def for C: $I_c = C \cdot \frac{dV_c}{dt}$

voltage def: $U_1 - 0 = V_c$

$$\Downarrow$$

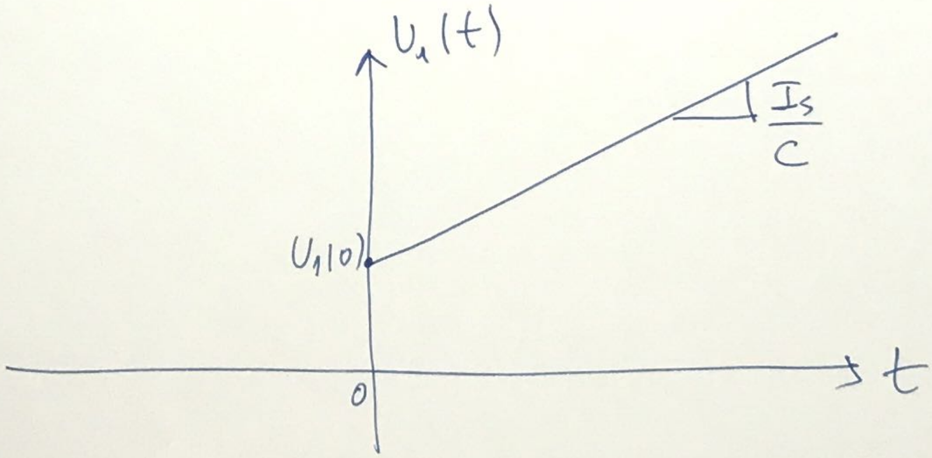
$$I_s = C \frac{dU_1}{dt}$$

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

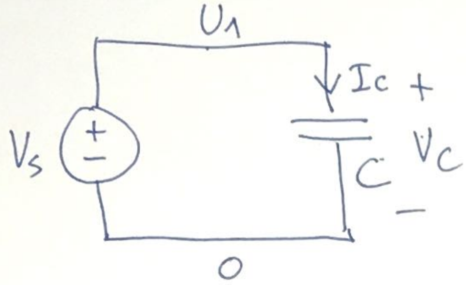
$$\int_0^t I_s\, dt = \int_{U_1(0)}^{U_1(t)} C\, dU_1$$

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

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



Simple circuit #2:

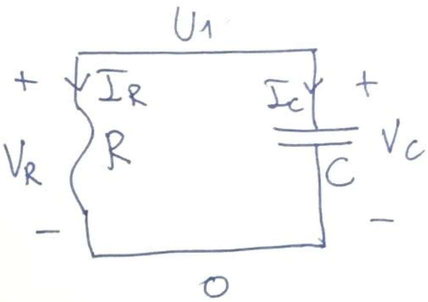


$$V_S = V_C \quad \begin{cases} U_1 = V_S & \text{(voltage elem def)} \\ U_1 = V_C & \text{(voltage def)} \end{cases}$$

$$I_C = C\frac{dV_C}{dt} \quad \text{(capacitive elem. def)}$$

$$I_C = C\frac{dV_C}{dt} = C\cdot\cancelto{0}{\frac{dV_S}{dt}} = 0$$

Simple circuit #3:



Looking for U_1 value when

V_C = const (steady-state)

⇓

$$I_C = C\,\cancelto{0}{\frac{dV_C}{dt}} = 0$$

KCL: $\cancelto{0}{I_C} + I_R = 0$

⇓

$I_R = 0$

Ohm's law: $V_R = \cancelto{0}{I_R}\cdot R = 0$

voltage def: $U_1 - 0 = \cancelto{0}{V_R}$

⇓

$$\boxed{U_1 = 0}$$

steady-state means when voltages settle

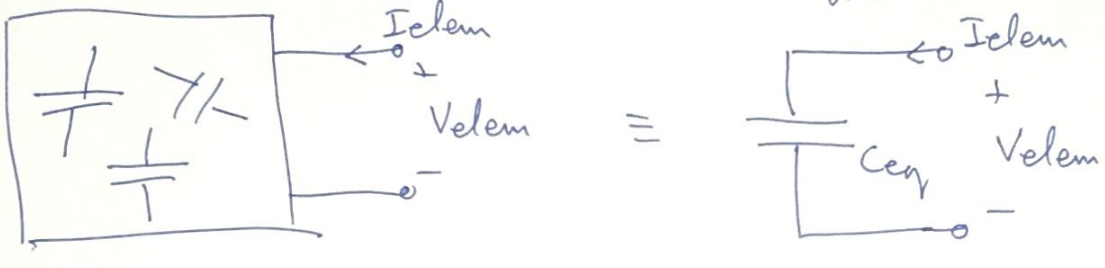
(e4)

Equivalent circuits with capacitors:

* Capacitor - only circuits

* ~~step 1 : find V_{th}~~ or I_{No} No source

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



(match $\frac{dV_{elem}}{dt}$)

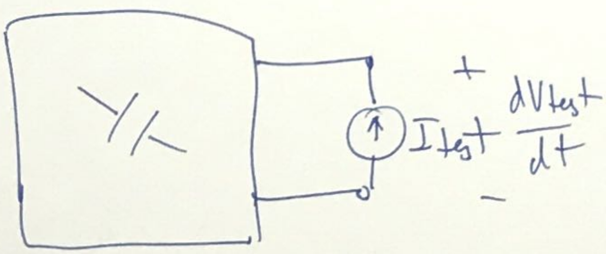
a) Apply I_{test} and measure $\frac{dV_{test}}{dt}$

or

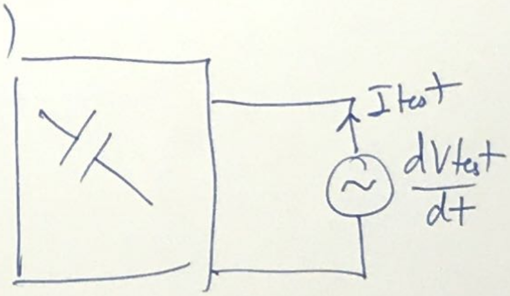
b) Apply $\frac{dV_{test}}{dt}$ and measure I_{test}

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

a)

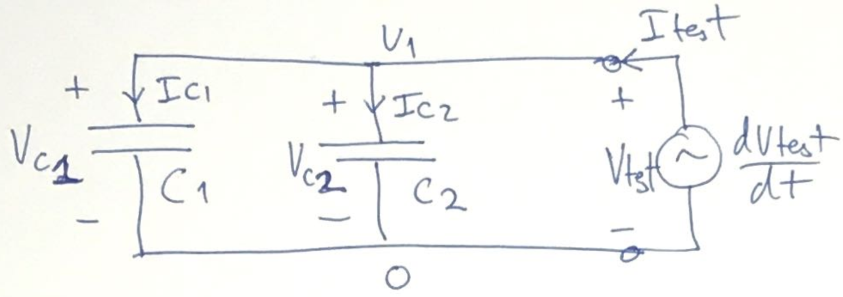


b)



(5)

Example 1:



$$V_{C1} = U_1 \;,\; V_{C2} = U_1 \quad \text{and} \quad U_1 = V_{test} \Rightarrow \frac{dU_1}{dt} = \frac{dV_{test}}{dt}$$

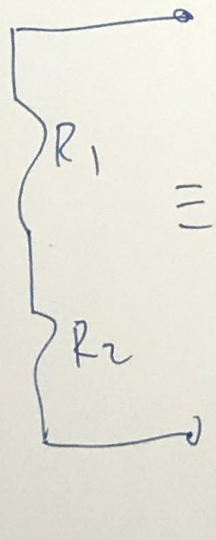
elem. df: $I_{C1} = C_1 \frac{dV_{C1}}{dt} = C_1 \frac{dU_1}{dt} = C_1 \frac{dV_{test}}{dt}$

elem. df: $I_{C2} = C_2 \frac{dV_{C2}}{dt} = C_2 \frac{dU_1}{dt} = C_2 \frac{dV_{test}}{dt}$

KCL: $I_{test} = I_{C1} + I_{C2} = C_1 \frac{dV_{test}}{dt} + C_2 \frac{dV_{test}}{dt}$

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

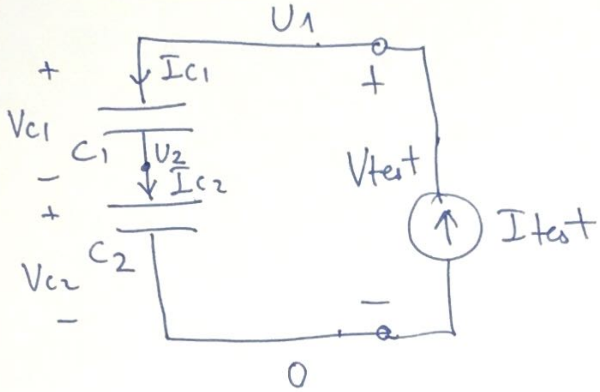
$$C_{eq} = \frac{I_{test}}{\frac{dV_{test}}{dt}} = C_1 + C_2$$



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

(6)

Example 2: "Capacitors in series"



KCL: $I_{c_1} = I_{c2} = \underline{I_{test}}$

elements: $I_{c2} = C_2 \frac{d V_{c2}}{dt}$

$I_{c1} = C_1 \frac{d V_{c1}}{dt}$

voltage def:

$V_{c2} = U_2 - 0 = U_2$

$V_{c1} = U_1 - U_2$

$V_{test} = U_1 - 0$

$$\underbrace{I_{test} = C_2 \frac{d U_2}{dt}}$$

$$\frac{dV_{c1}}{dt} = \frac{dU_1 - dU_2}{dt} = \frac{I_{test}}{C_1}$$

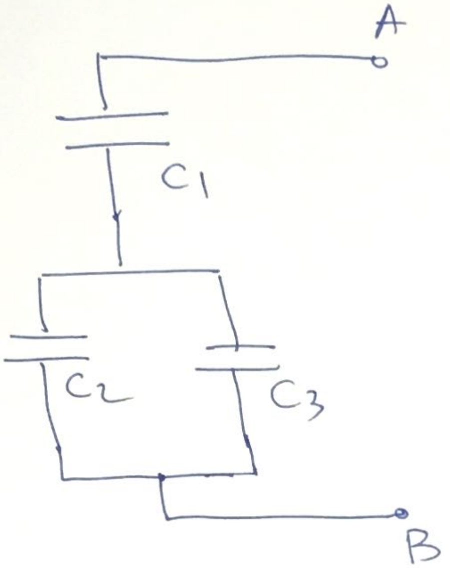
$$\frac{dU_1}{dt} = \frac{dU_2}{dt} + \frac{I_{test}}{C_1} = \frac{I_{test}}{C_2} + \frac{I_{test}}{C_1}$$

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

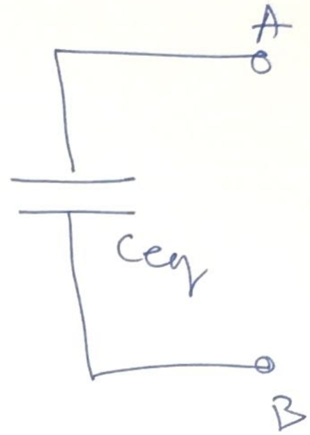
$$C_{eq} = \frac{I_{test}}{\frac{dV_{test}}{dt}} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}} = \frac{C_1 C_2}{C_1 + C_2} = \underline{C_1 || C_2}$$

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

Example #3 :

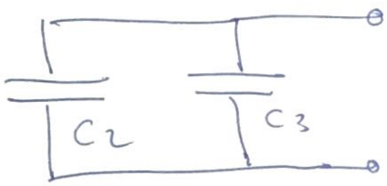


$=$

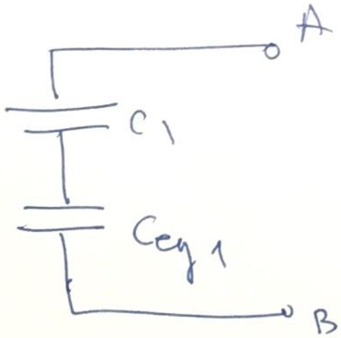


$$C_{eq} = ? = C_1 \,||\, (C_2 + C_3)$$

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

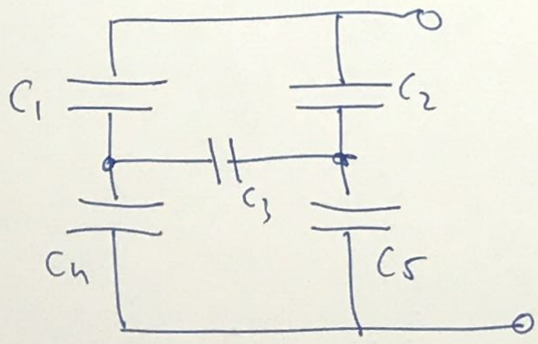


$\Rightarrow C_{eq1} = C_2 + C_3$



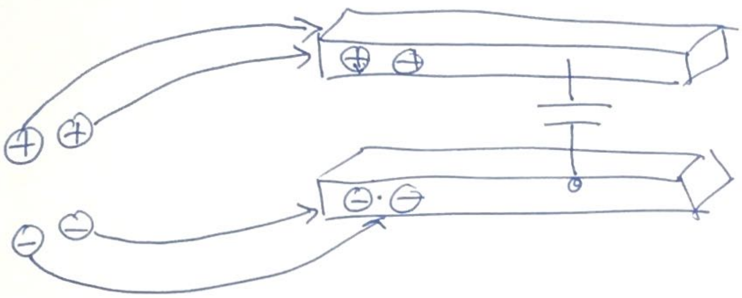
$$C_{eq} = C_1 \,||\, C_{eq1}$$

challenge ckt :



16A Capacitor physics

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



$\equiv$

$$\underline{\underline{Q = C \cdot V}}$$

$$\frac{dE}{dq} = V \quad \Rightarrow \quad E = \frac{1}{2} C V^2$$

Capacitor is a "bucket" for charge

Capacitor depends on:
1) geometry of the conductors
2) material properties of the insulator

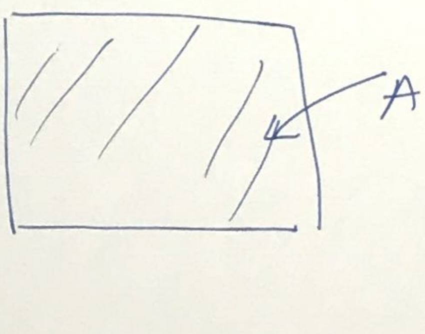
side view:

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

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

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

top view:



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