EECS 16A

Spring 2023 - Profs. Muller & Waller

Lecture 9A – Capacitive Touchscreen & Capacitance Modeling

Toolbox

KVL: Voltage drops around a loop sum to 0

KCL: All currents coming out of a node sum to 0

$$V = IR$$

$$P = IV$$

$$R = \frac{\rho L}{A}$$

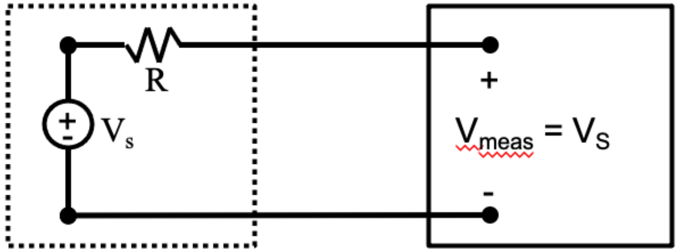
V_{source}(off) → short

I_{source}(off) → open

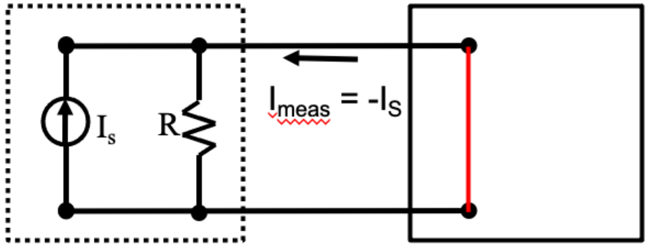
$$R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

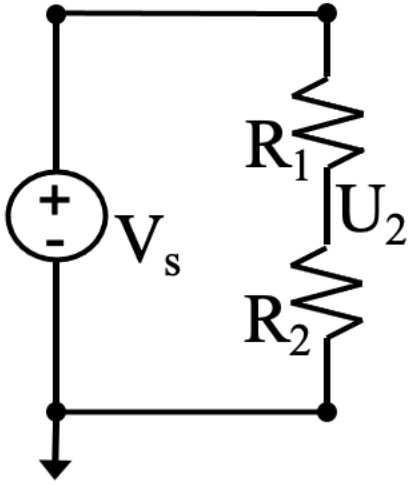
$$R_{Th} = V_{Th}/I_N$$

V Measurement Circuit



I Measurement Circuit

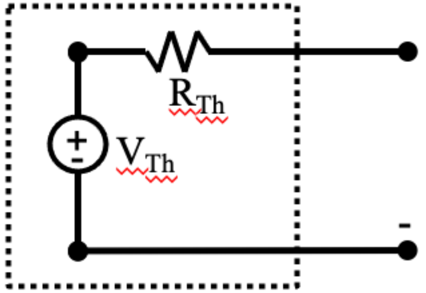




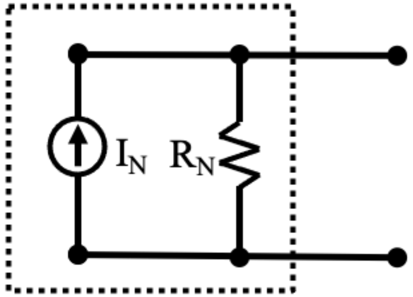
$$I = \frac{V_S}{R_1 + R_2}$$

$$U_2 = \frac{V_S R_2}{R_1 + R_2}$$

Thevenin Equivalent Circuit

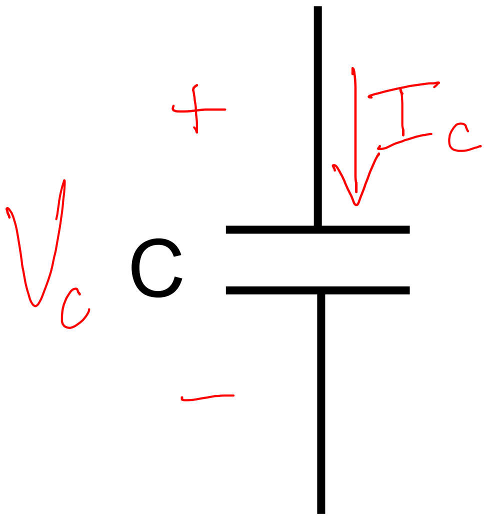


Norton Equivalent Circuit



Last Time - Capacitors!

Capacitance C in [Farads] or [F]



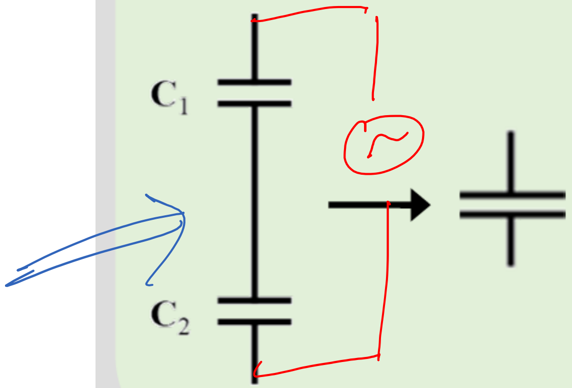
$$Q = CV$$ ①

$$I = C\frac{dV}{dt}$$ ②

$$\frac{\partial}{\partial t}$$

$$C = \frac{\epsilon A}{d}$$ ③

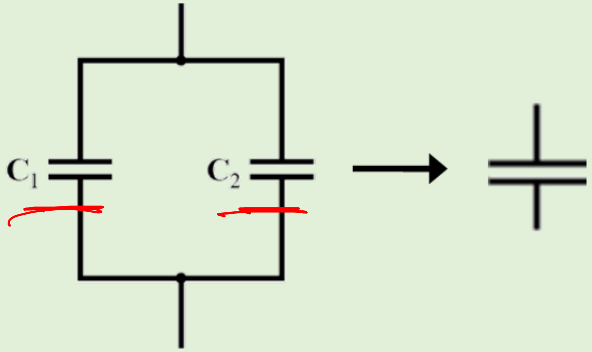
Capacitors in Series



$C_1 \| C_2$

$$C_{eq} = \frac{C_1C_2}{C_1+C_2}$$ ④

Capacitors in Parallel



$$C_{eq} = C_1 + C_2$$ ⑤

Last Time – Capacitors!

↑ $Q = CV$ ↑

$$* \boxed{I = C\frac{dV}{dt}}$$

Constant Voltage

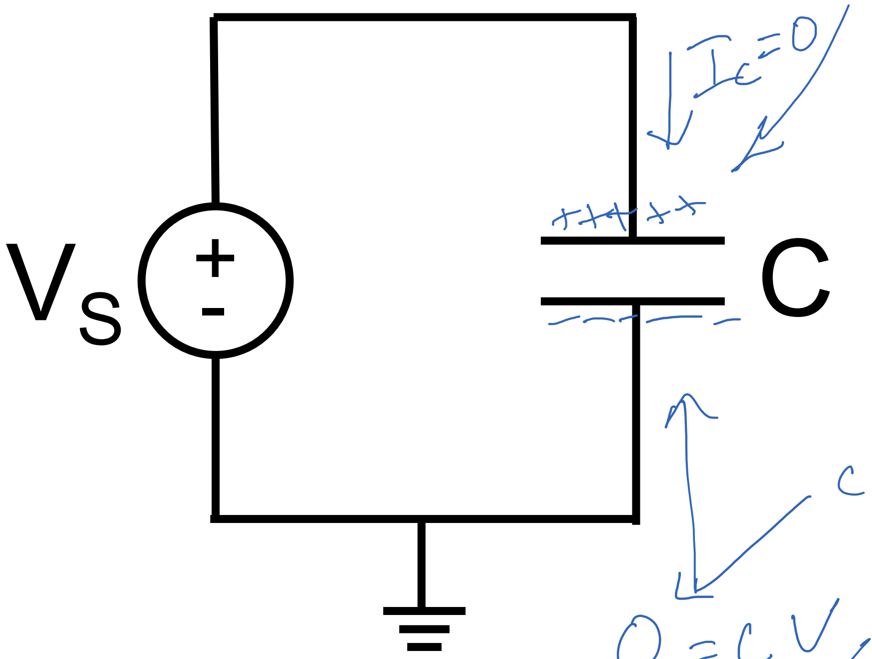
→ Charge doesn't change

No current flows!

Constant current

Cap charges (or discharges)

Voltage is a ramp!

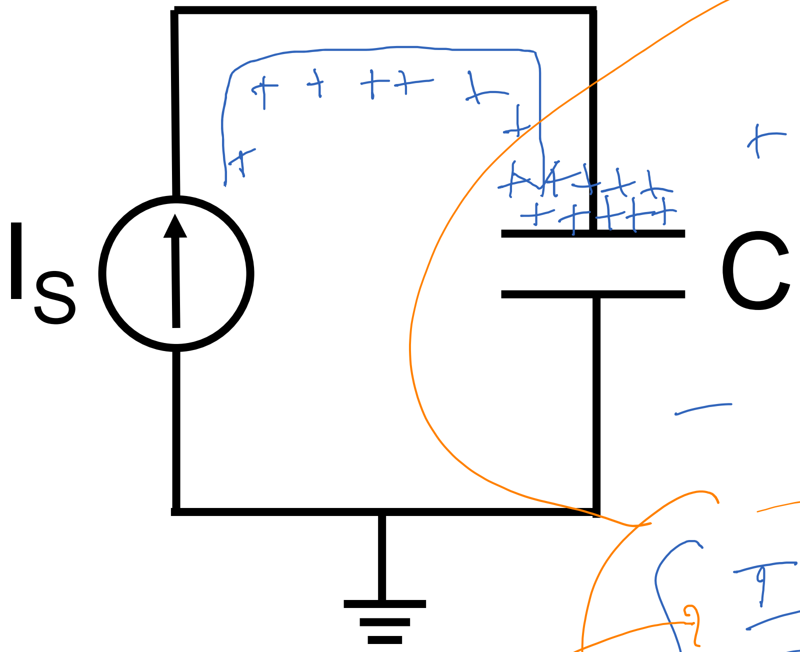


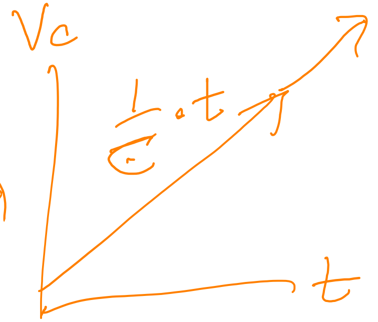
$I_c = 0$

constant

$Q = CV \to 0$

$I = C\cancel{dV/dt} = 0$





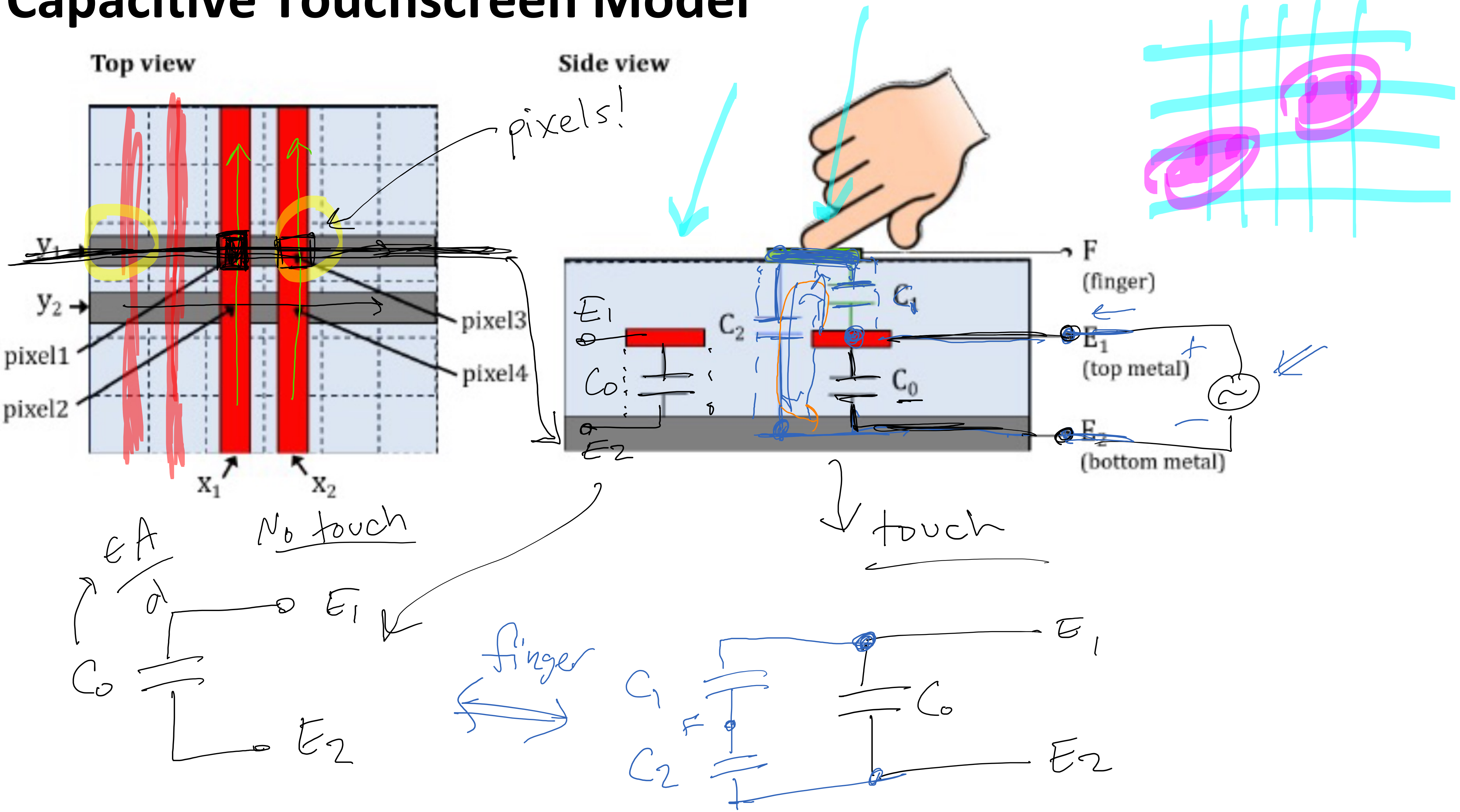
$V_c \to$ ramp

$I = C\,dV/dt$

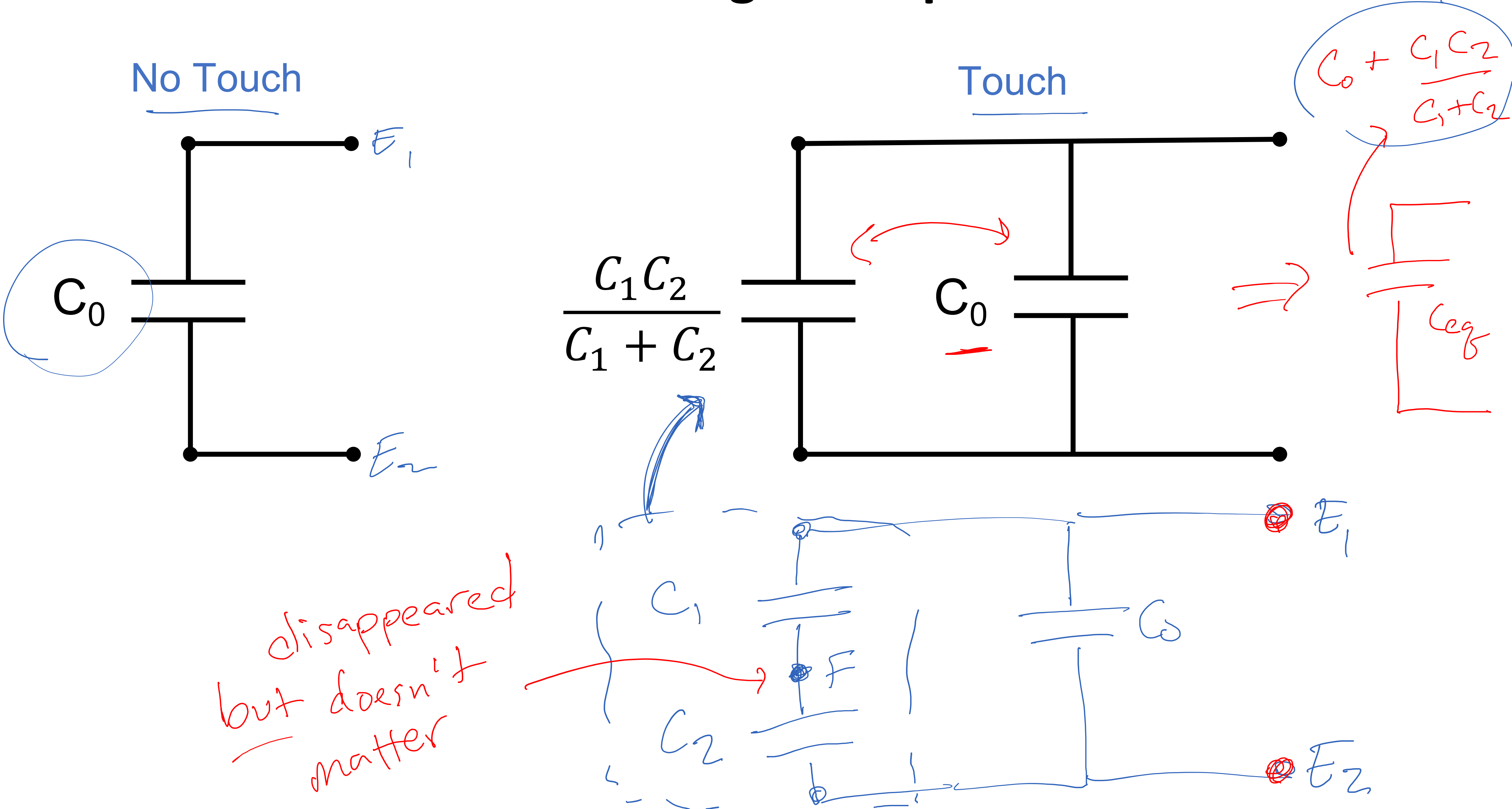
$\int \frac{I}{C}\,dt = \int dV$

constant

Capacitive Touchscreen Model

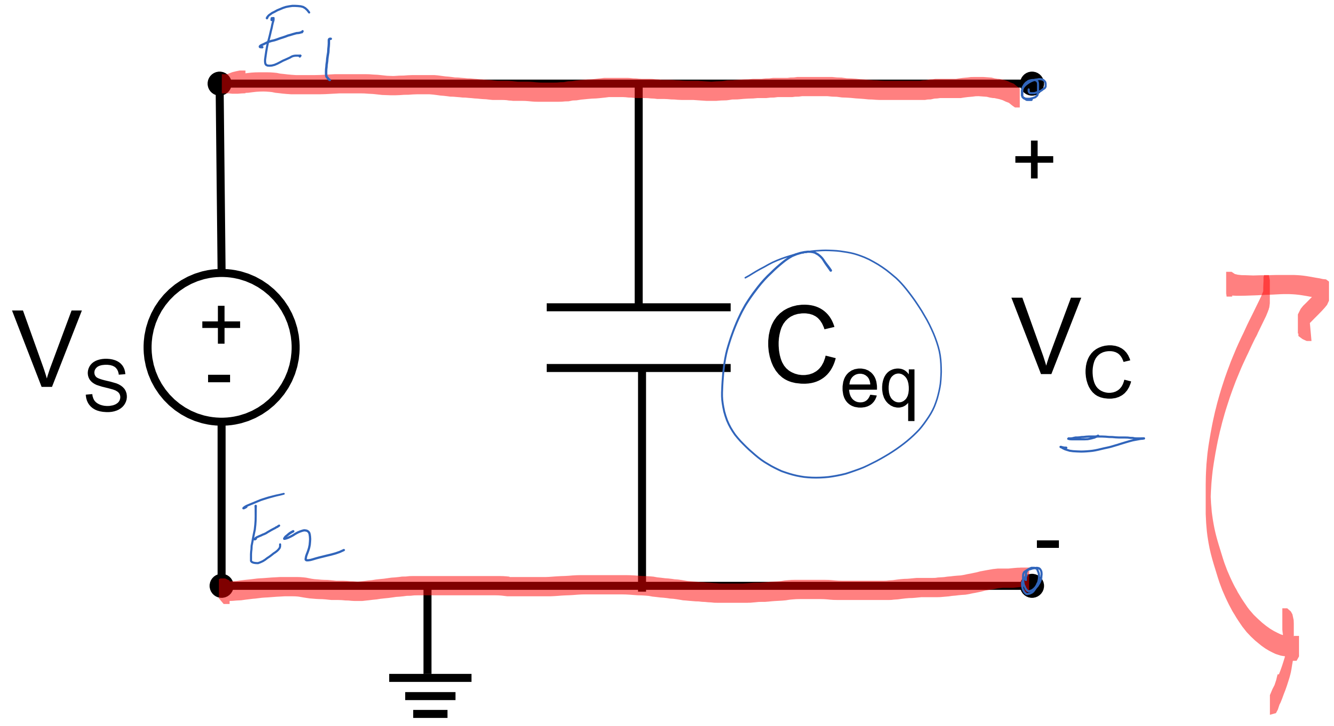


How Do We Read Out the Change in Capacitance?



Attempt #1

Not a good idea



Without touch: $C_{eq} = C_0$

$V_C =$ V_S

With touch: $C_{eq} = C_0 + \frac{C_1 C_2}{C_1 + C_2}$

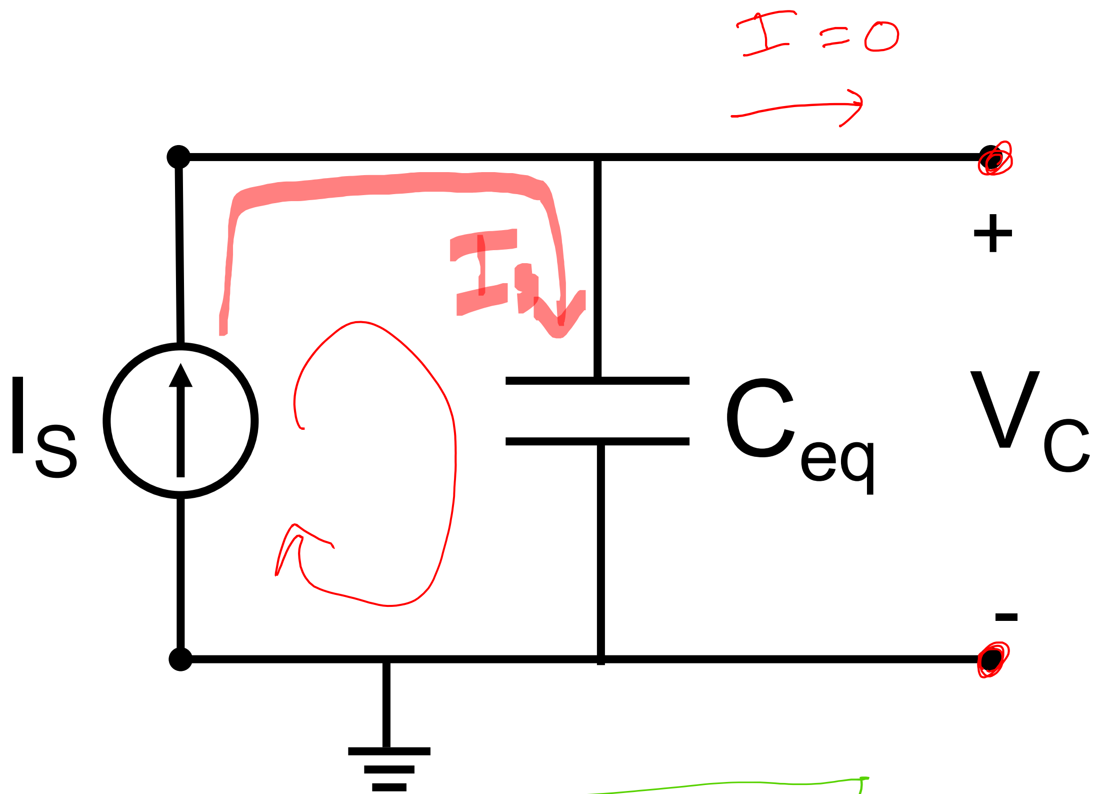
$V_C =$ V_S

constant V_S across C

$$I = C\frac{\cancel{dV}^{\to 0}}{dt} = 0$$

Attempt #2 – Assume C_{eq} starts discharged

$$V_c(0) = 0$$



$$I_s = C\frac{dV}{\partial t} = C_{eq}\frac{dV_c}{\partial t}$$

$$\int_0^t \frac{I_s}{C_{eq}}\,dt = \int_{V_c(0)}^{V_c(t)} dV_c$$

$$t=0 \rightarrow t \qquad V_c(0) \rightarrow V_c(t)$$

$$\left.\frac{I_s}{C_{eq}}t\right|_0^t = \left.V_c\right|_{V_c(0)}^{V_c(t)}$$

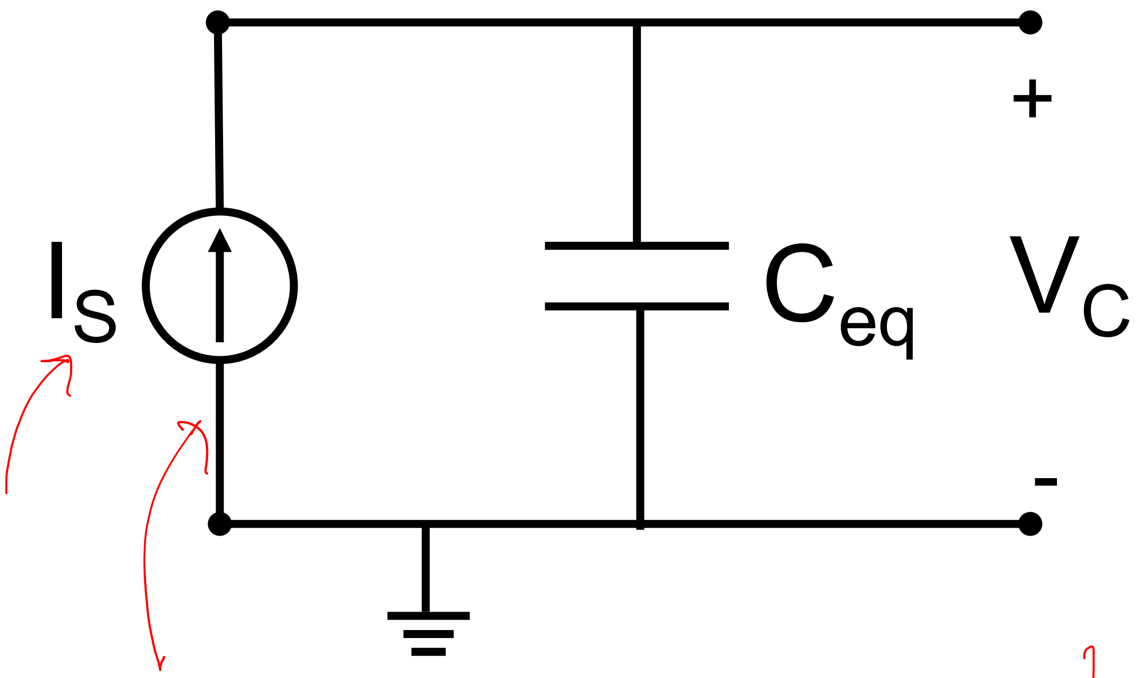
$$\frac{I_s}{C_{eq}}t - 0 = V_c(t) - \cancel{V_c(0)}^{0}$$

$$\boxed{V_c(t) = \underbrace{\frac{I_s}{C_{eq}}}_{\text{slope!}} \cdot t}$$

Attempt #2 – Assume C_{eq} starts discharged

$I_s = C_{eq} \frac{dV_c}{dt}$

$\frac{dV_c}{dt} = \frac{I_s}{C_{eq}}$



higher slope!

Without touch: $C_{eq} = C_0$

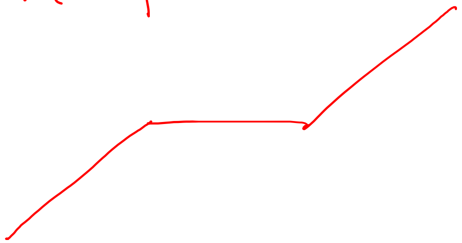
$dV_C/dt = \frac{I_s}{C_{eq}} = \frac{I_s}{C_0}$

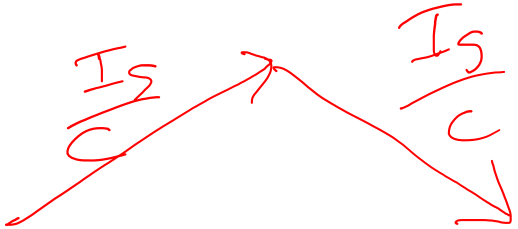
smaller → C_{eq}

With touch: $C_{eq} = C_0 + \frac{C_1 C_2}{C_1 + C_2}$

$dV_C/dt = \frac{I_s}{C_{eq}} = \frac{I_s}{C_0 + \underbrace{\frac{C_1 C_2}{C_1 + C_2}}_{\Delta C}}$

On forever? ⇒ explosions!

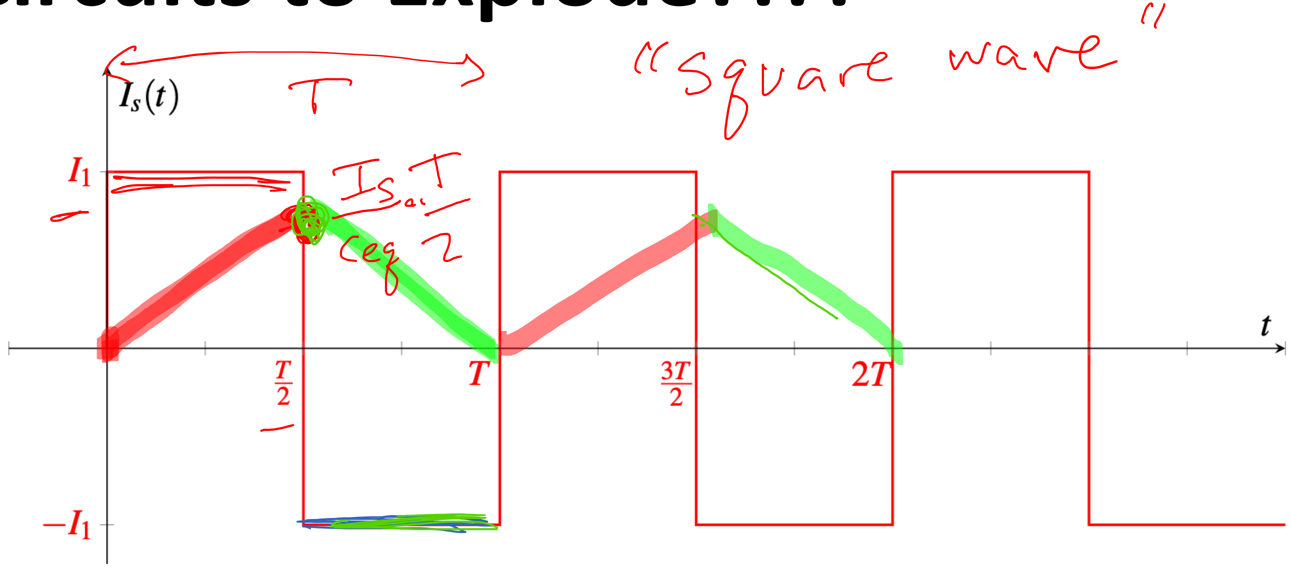


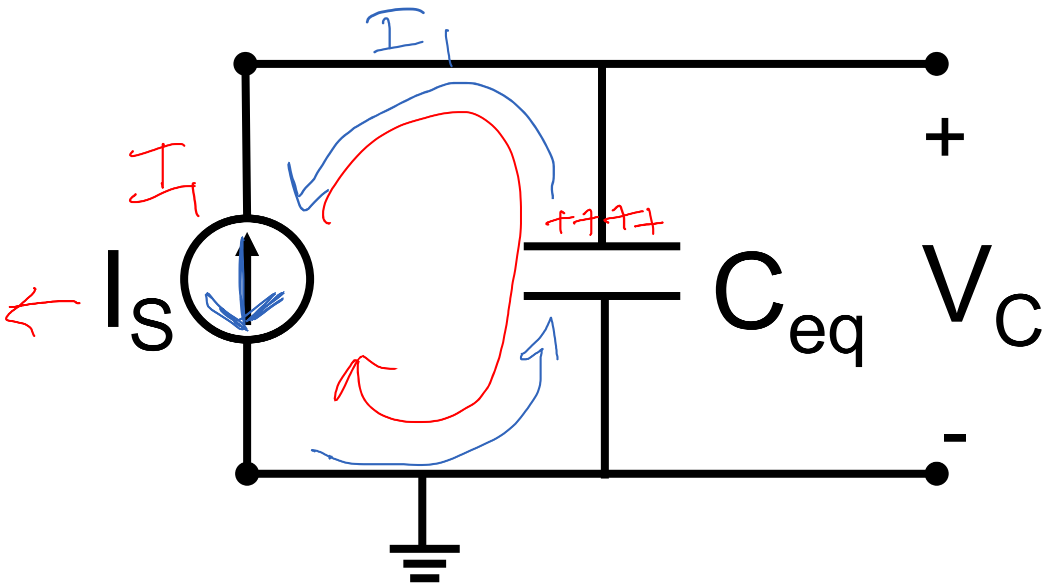


⟸ !good idea

Won't the Voltage Ramp Forever and Cause All of the Circuits to Explode?!?!

$I = \frac{dQ}{dt}$





$V_c(t) - V_c(0)$

same but $t \neq 0$

$$V_C(t) = \frac{I_s}{C_{eq}}(t - t_0) + V_C(t_0)$$

$$V(t) = \frac{I_1}{C}t \quad \text{when } 0 \le t \le \frac{T}{2}$$

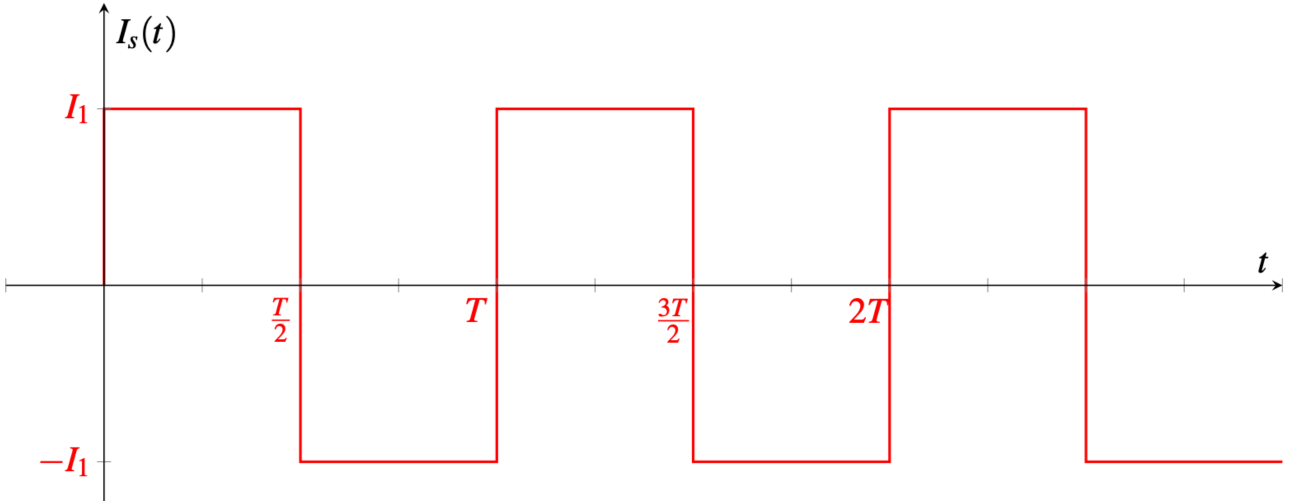
when $\frac{T}{2} < t \le T$

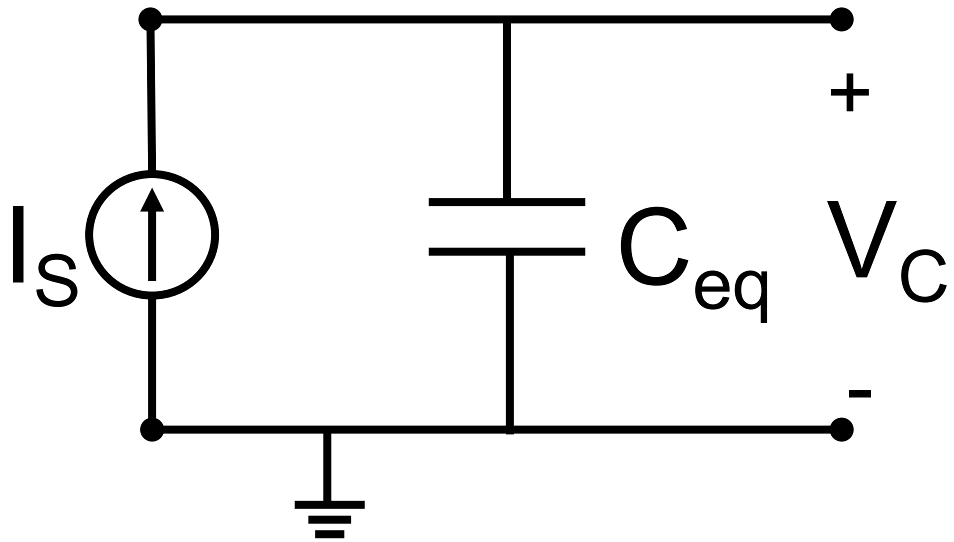
Initial condition

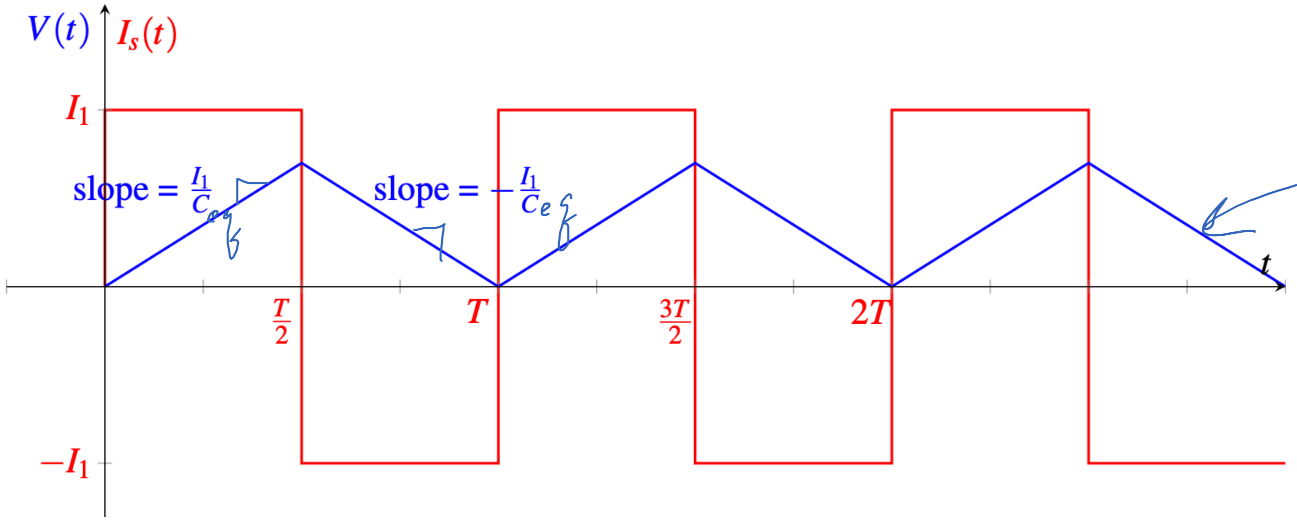
$$V(t) = \frac{-I_1}{C_{eq}}\left(t - \frac{T}{2}\right) + V\left(\frac{T}{2}\right)$$

$$V(t) = \frac{-I_1}{C}\left(t - \frac{T}{2}\right) + \frac{I_1 T}{2C}$$

Attempt #3 – Alternating Current (AC!)



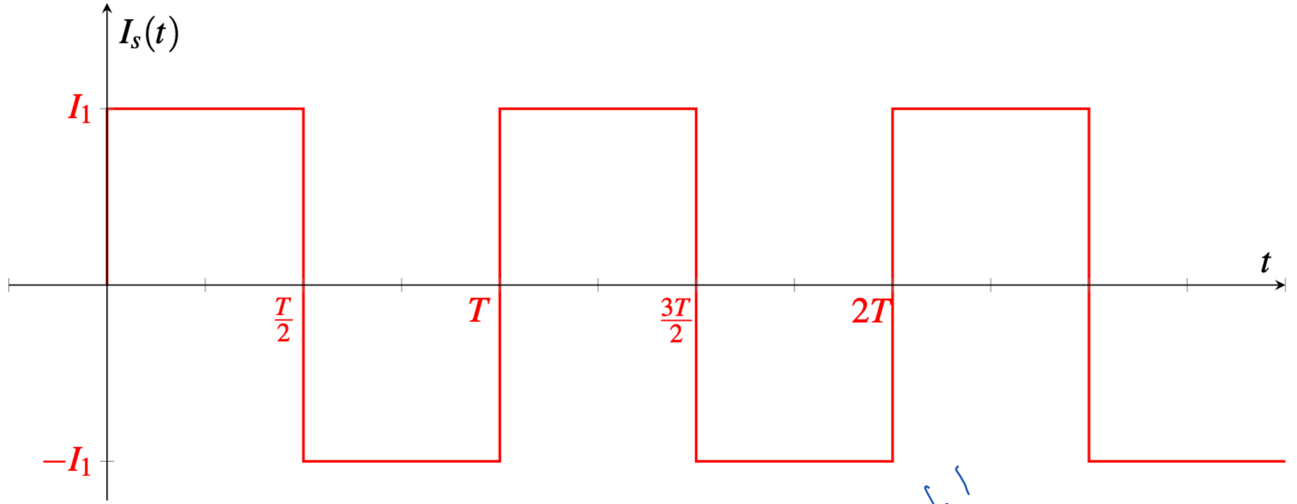


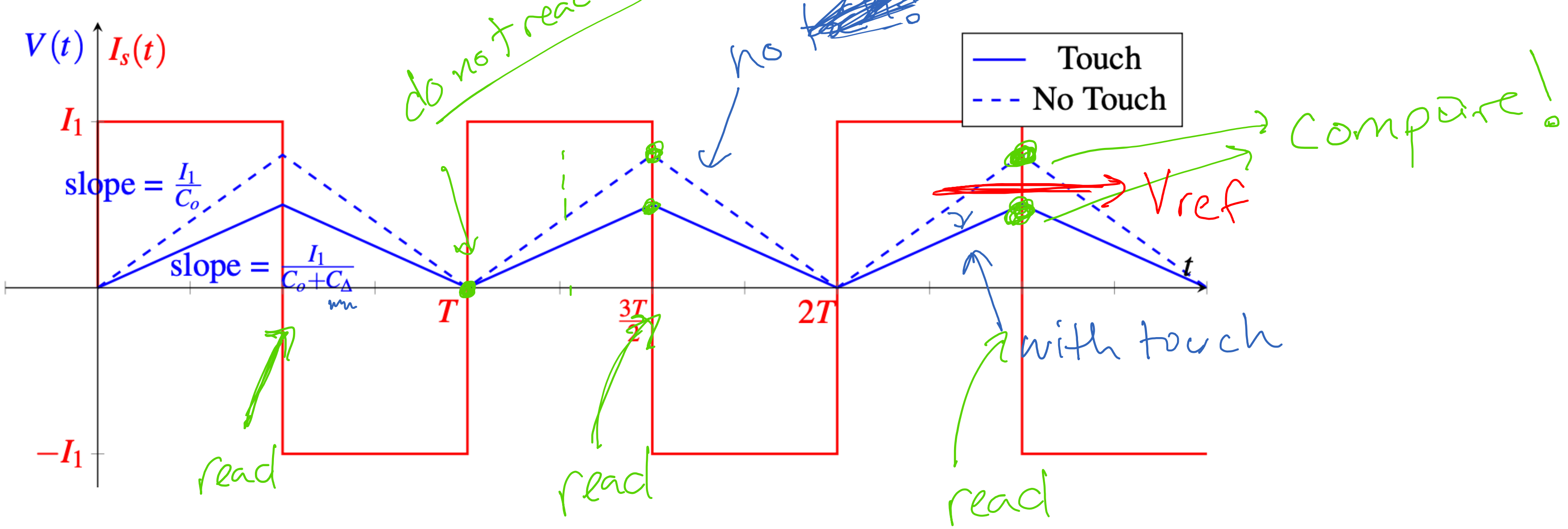


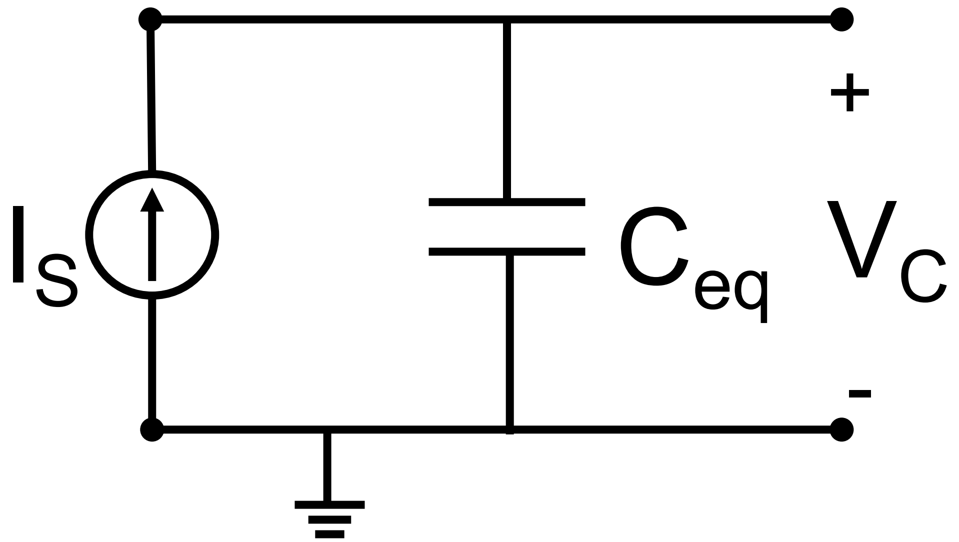
$C_{eq} = C_0$ (no touch)

$\rightarrow C_{eq} = C_0 + \frac{C_1 C_2}{C_1 + C_2}$

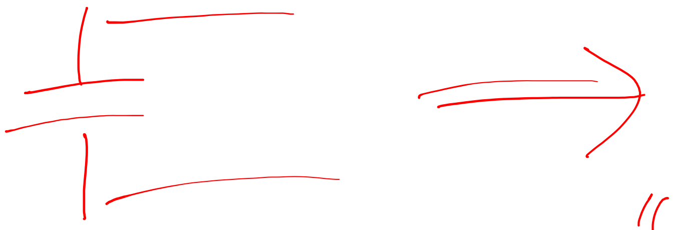
Attempt #3 – Alternating Current (AC!)







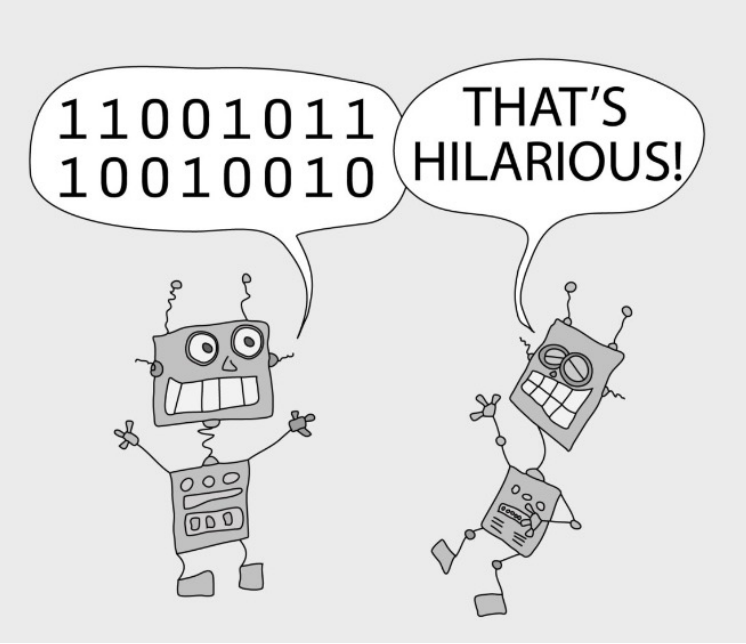
How to But Touch or No-Touch is Binary!

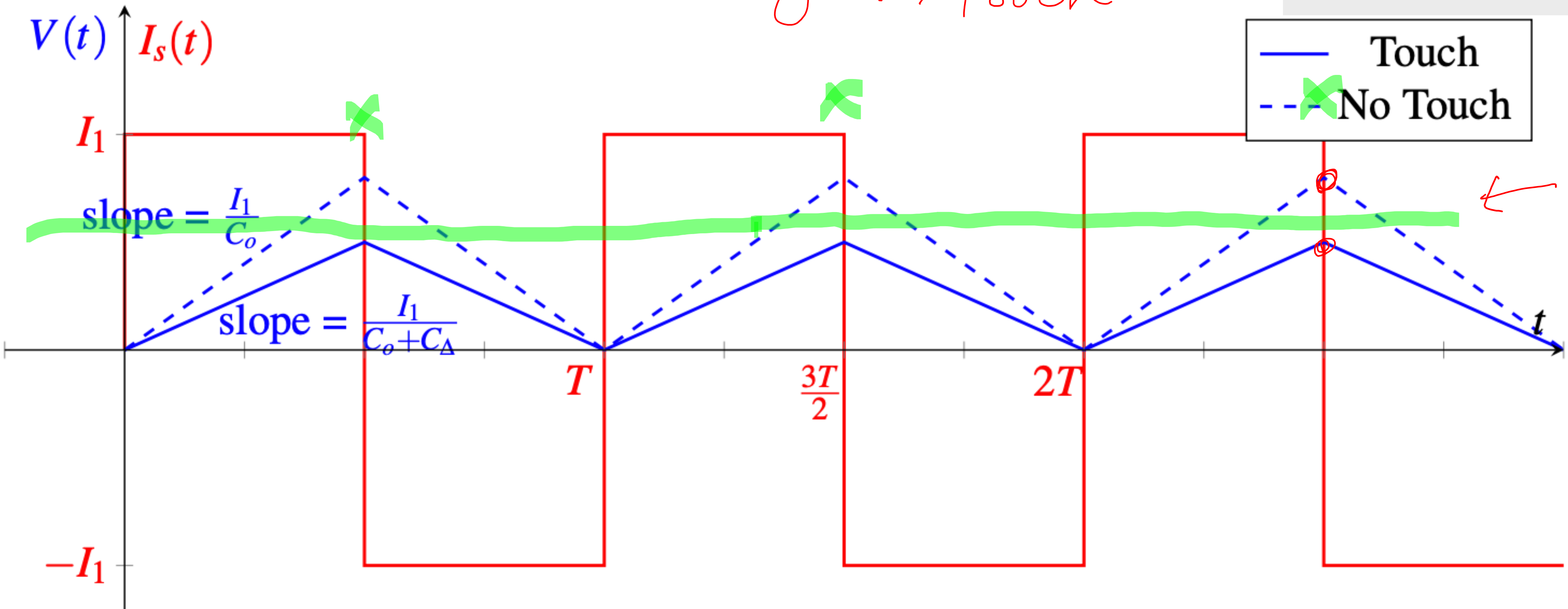


“0” or “1”

“1” → no touch

“0” → touch

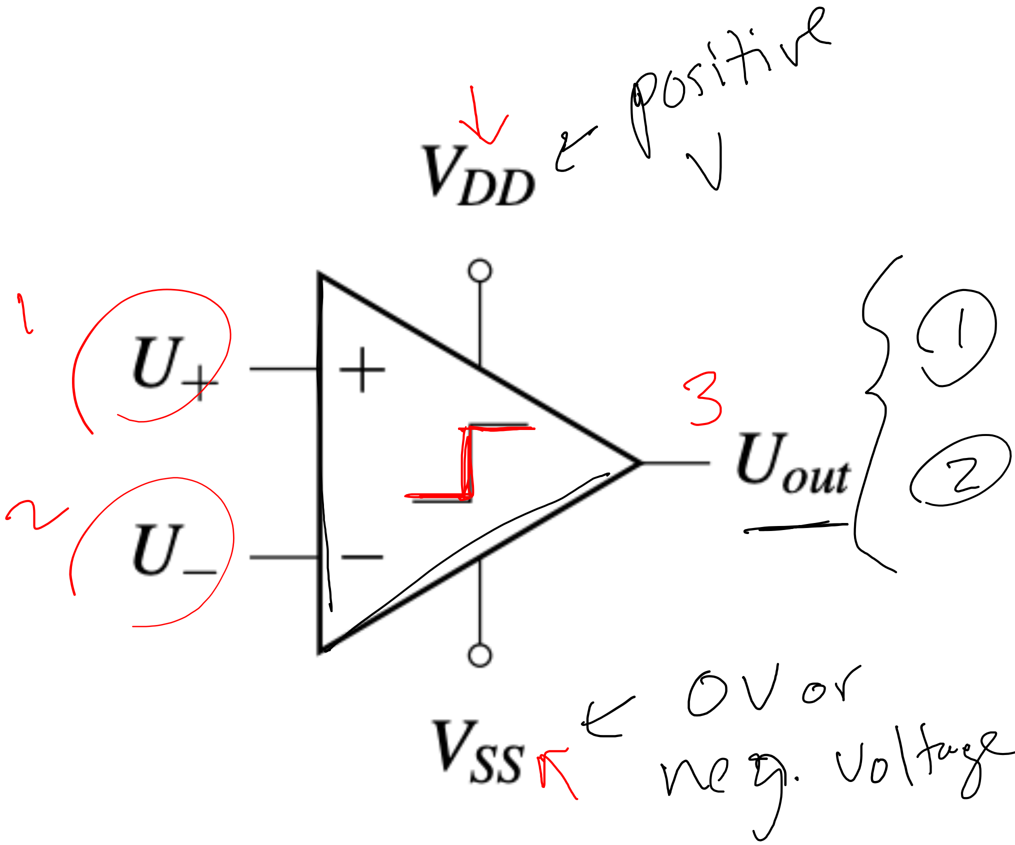




← How do we compare?

How do we Compare Two Values?

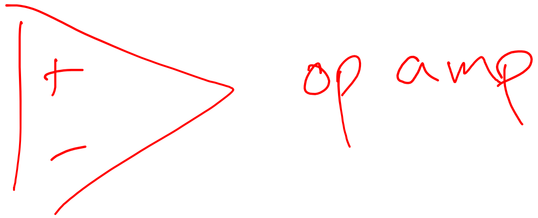
new element

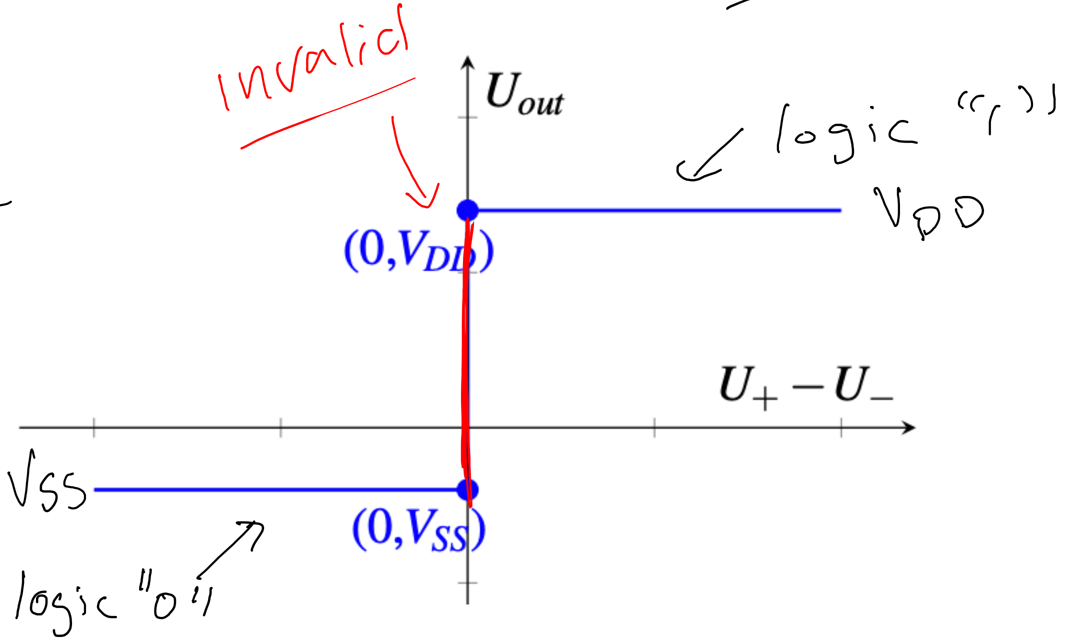


Comparators compare two values (inputs):

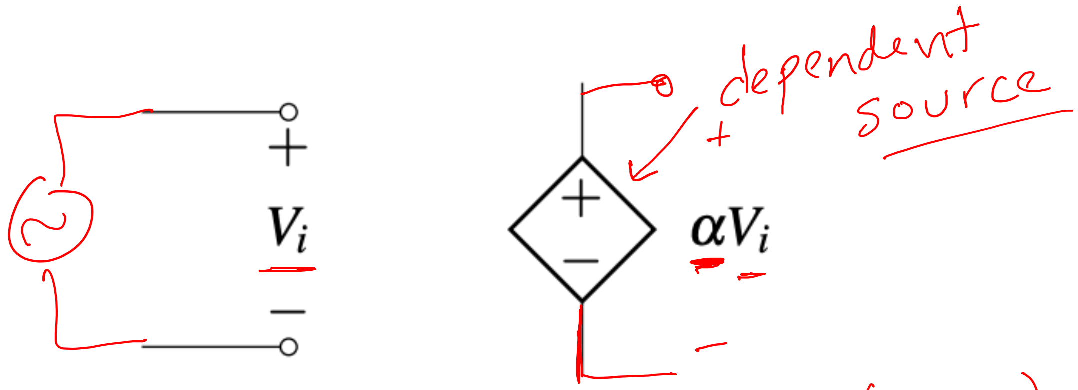
① $U_+ > U_- \rightarrow U_{out} = "1" = V_{DD}$

② $U_+ < U_- \rightarrow U_{out} = "0" = V_{SS}$

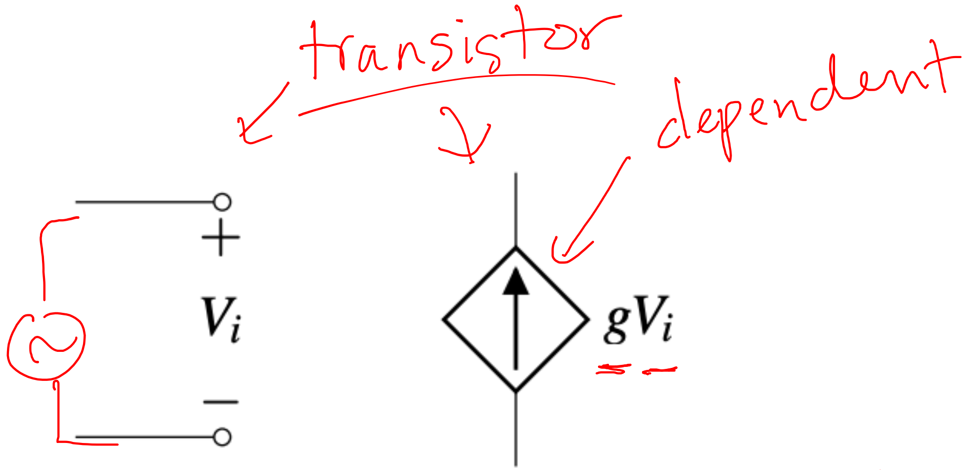




To Understand How it Works, We Must Introduce New Elements!

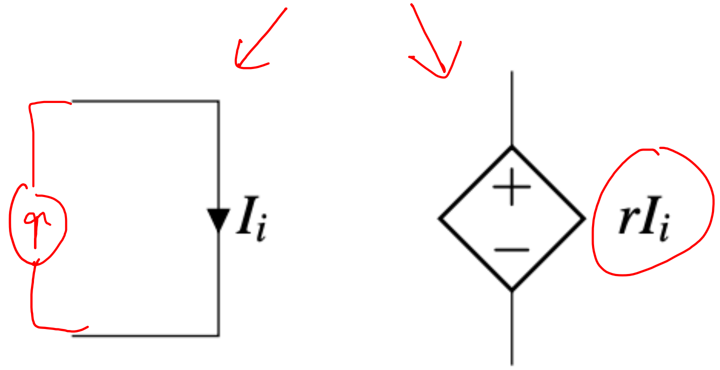


① Voltage-controlled voltage source (VCVS)



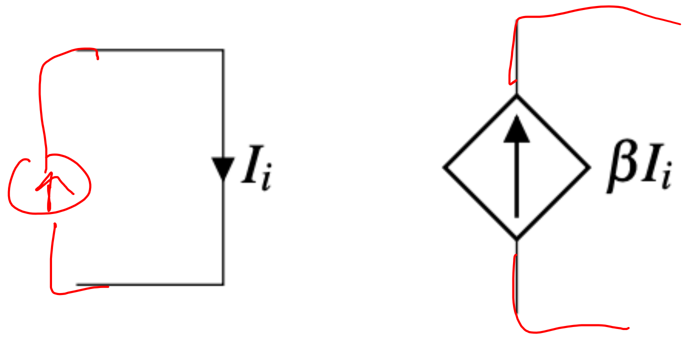
② Voltage-controlled current source (VCCS)

also transistors



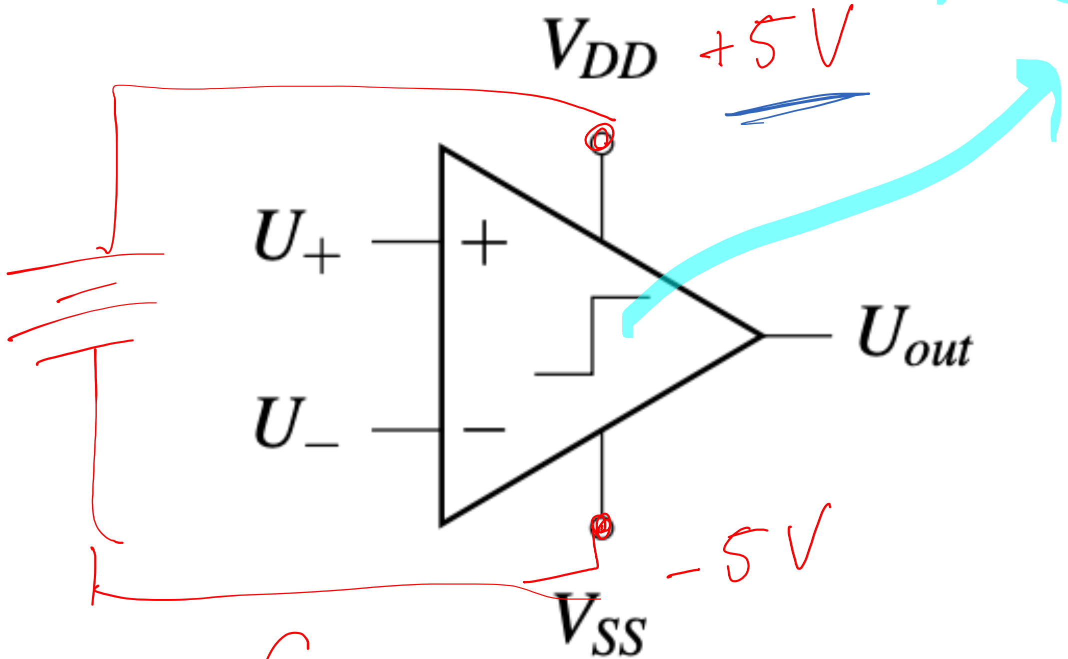
③ Current-controlled voltage source

(CCVS)



④ Current-controlled current source (CCCS)

Comparator Model



for comparators

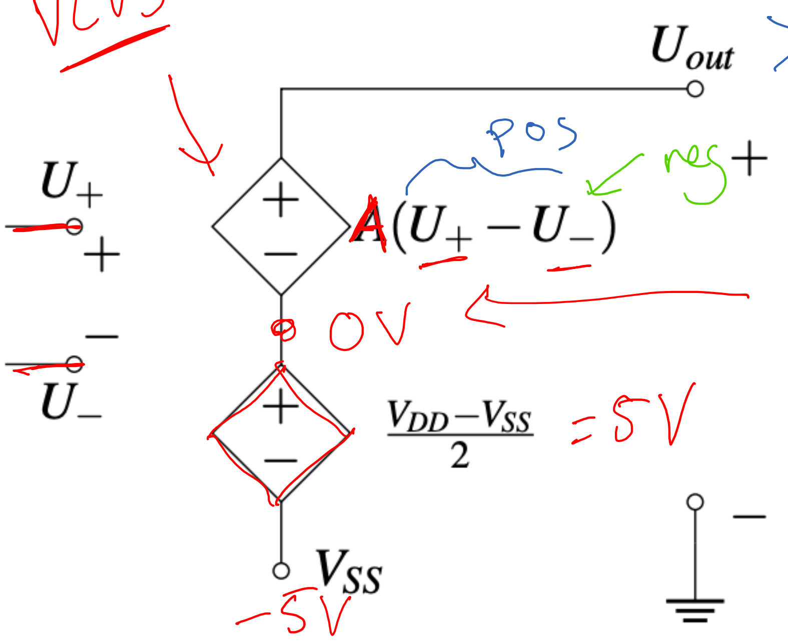
A ⇒ huge huuuge

fast

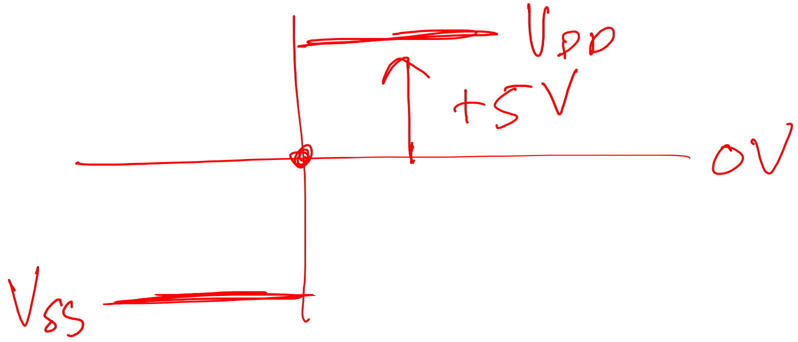
if $U_+ > U_-$

if $U_+ < U_-$

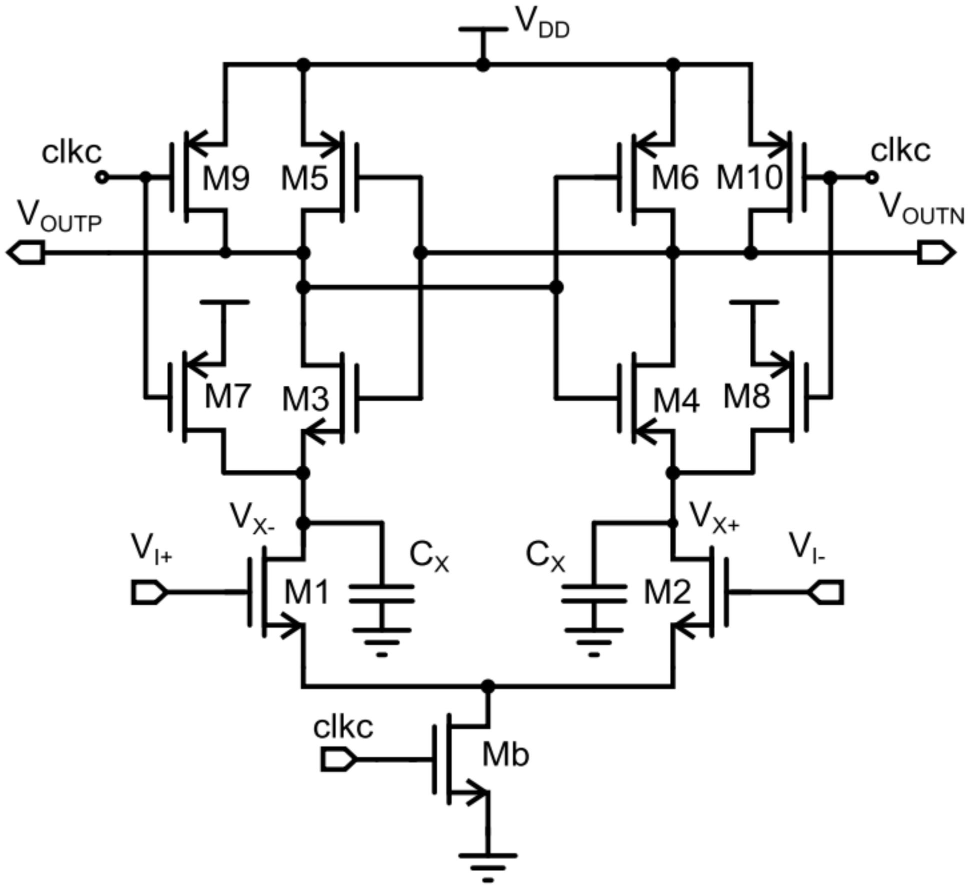
VCVS



start half way between V_{DD}, V_{SS}

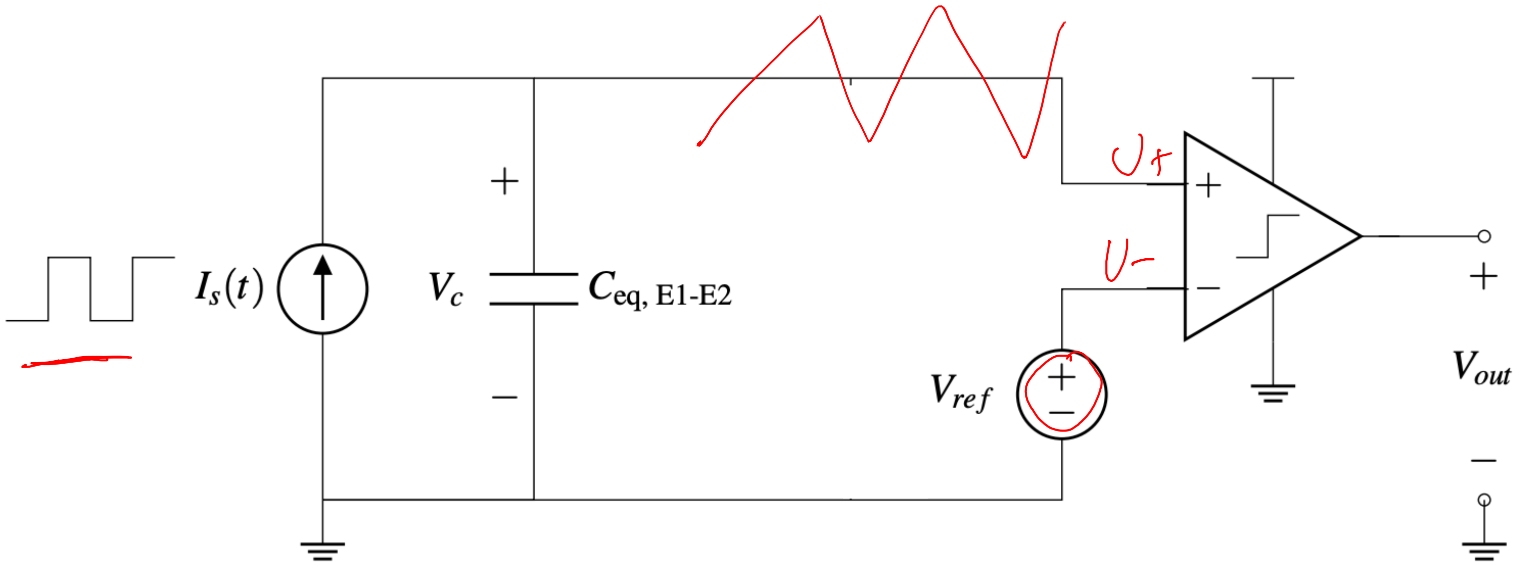


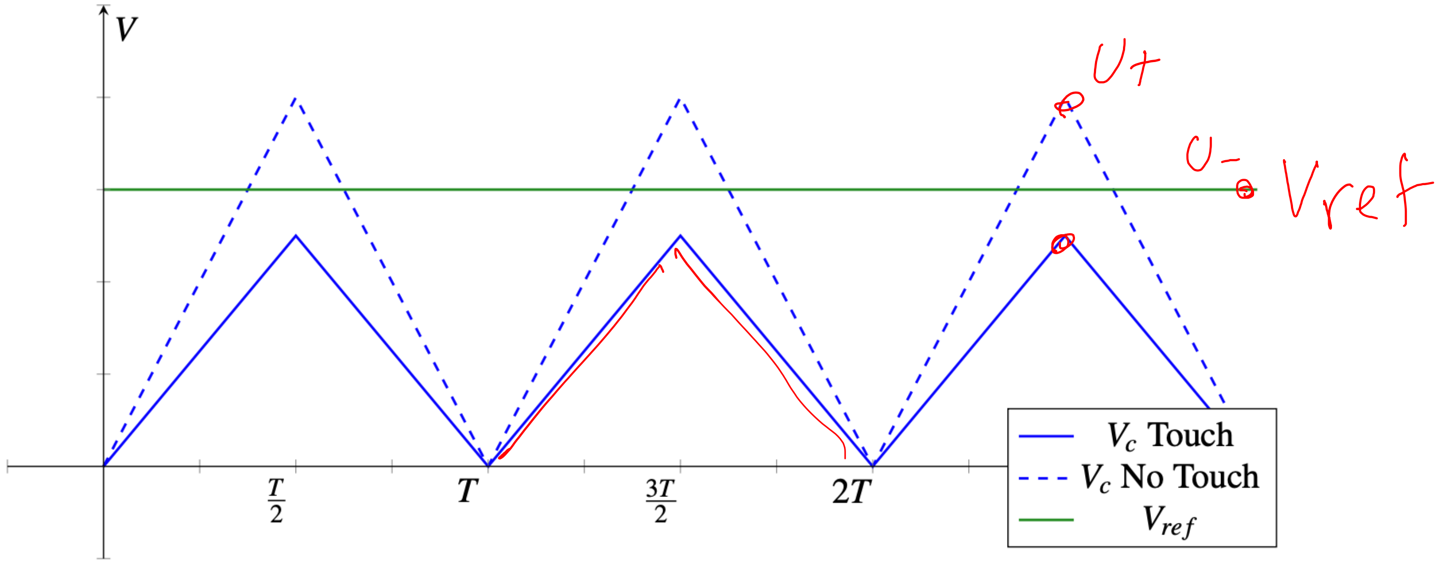
A Real Comparator!



Learn more in EE 105 & EE 140!

How to Read Out Touch





How to Read Out Touch