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# Module 2, Lecture 7

EECS 16A

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Last time:
- Capacitive Touchscreen Motiv.
- Intro to Capacitors
- Capacitor Equivalence

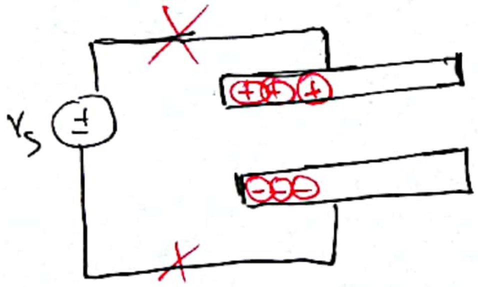
} Note 16

Today:
- Build Capacitive Touch Screen
- Charge Sharing

} Note 17 + supplemental algorithm.

## "16-A" Capacitor Physics

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


Why are these structure called capacitors?

$Q = C \cdot V$ → if $V\uparrow$ → $Q\uparrow$

→ if $C\uparrow$ → $Q\uparrow$

Capacitors are charge storage mechanisms "buckets" of charge

$$V_c = \frac{dE}{dq} \Rightarrow dE = V_c \cdot dq = V_c \cdot C \cdot dV_c$$

$$\overset{\int}{\Rightarrow} \boxed{E = \frac{1}{2} C V_c^2}$$

If I disconnect the voltage source, the charge will remain on the capacitor!!

**CHARGE IS CONSERVED!**

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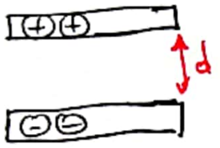
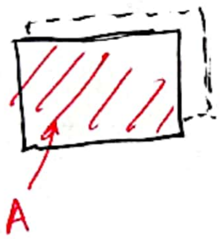
Capacitor value depends on:

1) Geometry of the conductor
2) Material properties of the insulator
   - ↳ $\varepsilon$: permittivity $\left[\frac{F}{m}\right]$
   - air ↳ $\varepsilon_0 = 8.85\ pF/m$ p: pico: $10^{-12}$

Side-View




Top-View

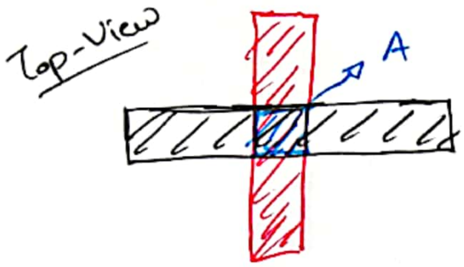


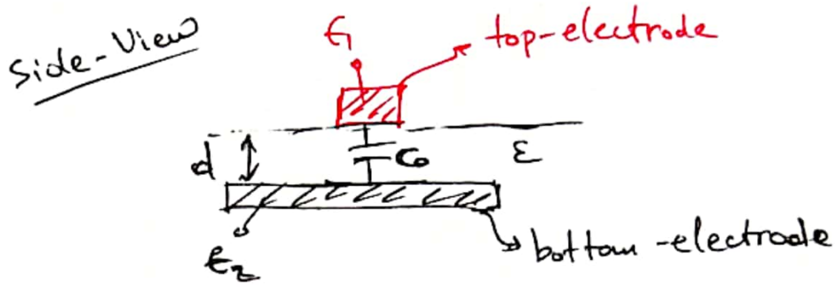

$$\boxed{C = \varepsilon \frac{A}{d}}$$

→ model capacitance in our touchscreen. as a "parallel plate" capacitance

# Let's get back to touchscreens:

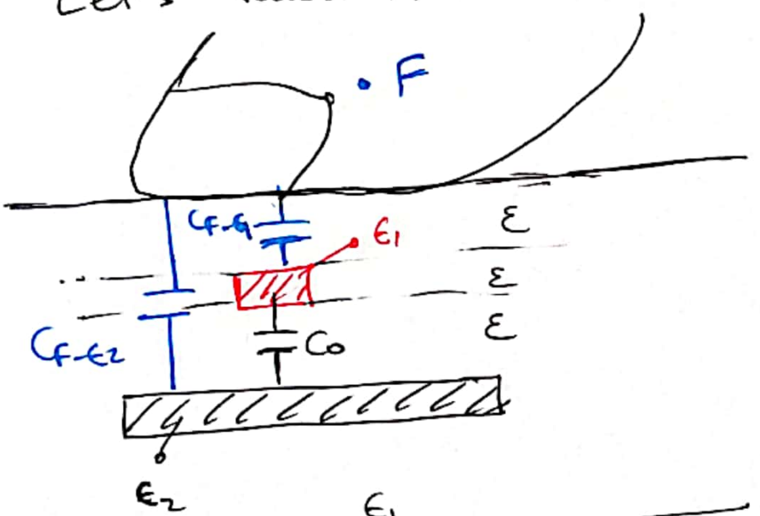
- Single pixel

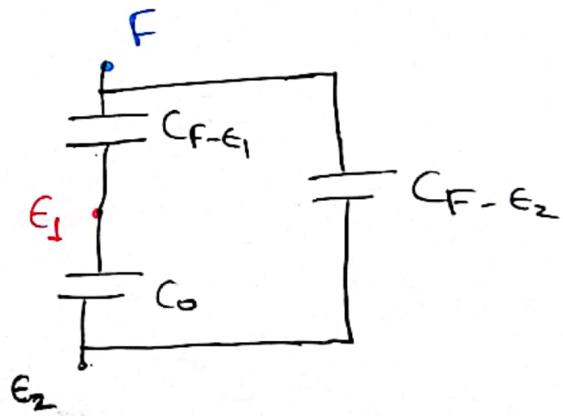


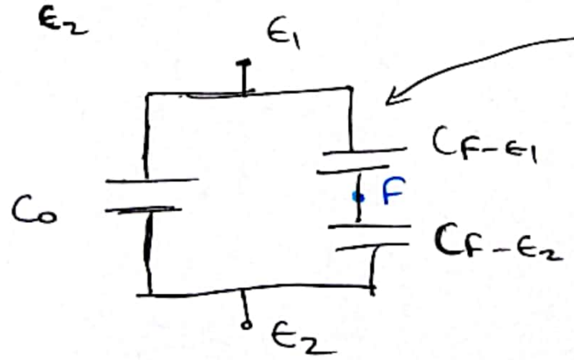




$$C_{eq,\,no\,touch} = C_0 = \varepsilon \frac{A}{d}$$

Let's touch it!



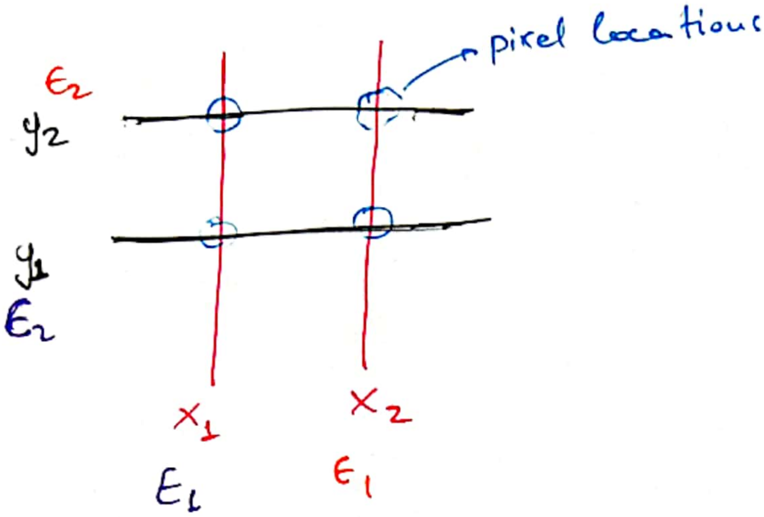




$\equiv$

$$C_{eq,touch} = C_0 + \underbrace{C_{FE_1} \parallel C_{FE_2}}_{\Delta C}$$
$$= C_0 + \Delta C > C_0$$

Key Result: $\boxed{C_{eq,touch} > C_{eq,\,no\,touch}}$

## 2D - View

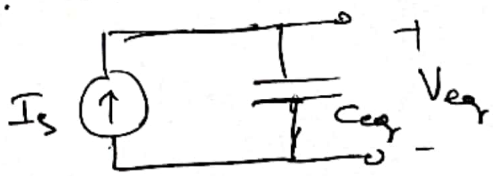


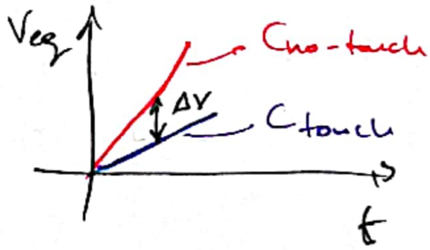

bottom-left corner:
connect $E_1, E_2$ to $(x_1, y_1)$

top-right corner:
connect $E_1, E_2$ to $(x_2, y_2)$

## How to measure capacitance (change in capacitance)

**Proposal 1**: Use a current source



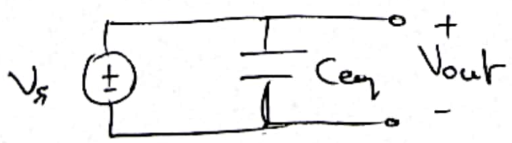




Problem: Current Sources are really hard to build!

**Proposal 2**: Use a voltage source

Key Idea: $Q = C \cdot V$ (apply a fixed voltage and measure $dQ$ due to $dC$)

**Attempt #1**:




$V_{out} = V_s$ set by the voltage source
$\neq f(C_{eq})$

:(

My goal was to ~~th~~ detect a change in $C_{eq}$!

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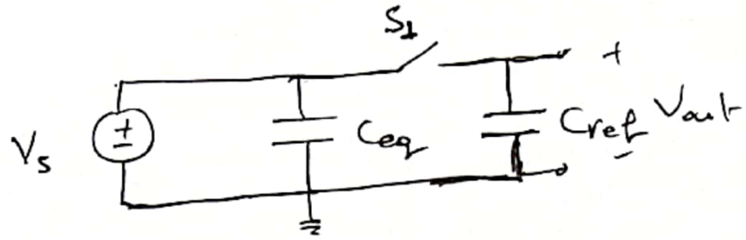
## Attempt #2

controlled by launchpad

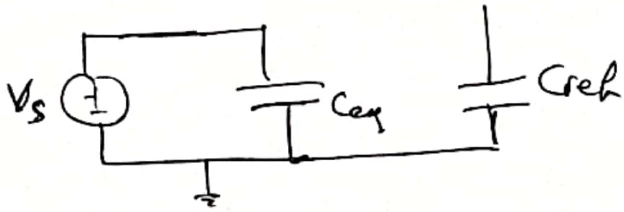



$S_1$ : ON — wire

$S_2$ : off — open-ckt

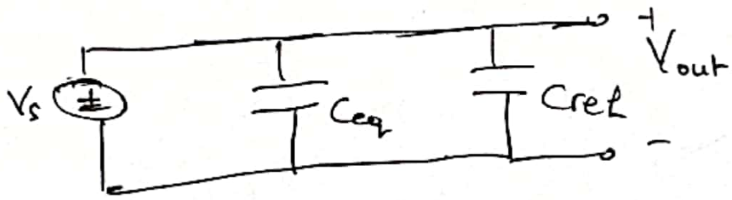
## Phase 1

$S_1$ : OFF




## Phase 2

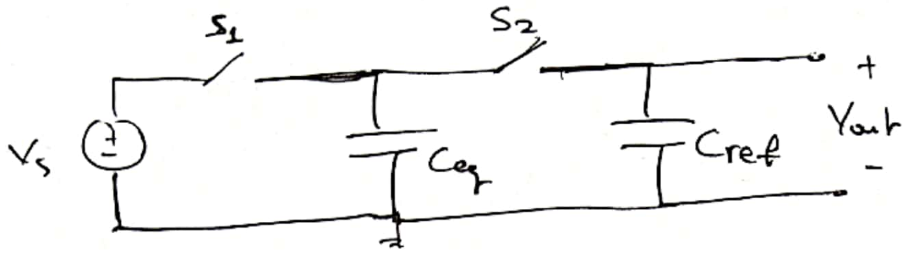
$S_1$ : ON




Same problem : $V_{out} = V_s \neq f(C_{eq})$

Scanned with CamScanner

## Attempt #3 :




Phase 1

$S_1$ : ON

$S_2$ : OFF


$V_{ref}(0) = ?$

$V_{out}(0) = ?$

↓

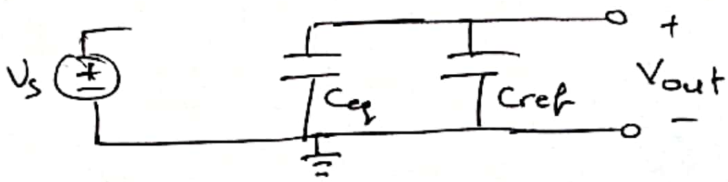
Cannot calculate $V_{out}$ at phase 2! (see ~~again~~ attempt #4)

:(

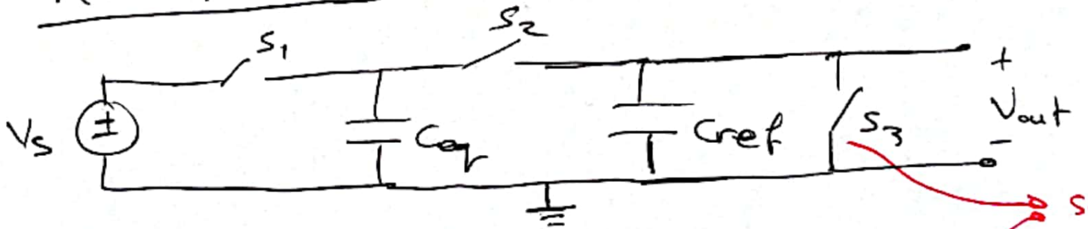
Phase 2

$S_1$ : OFF

$S_2$ : ON




## Attempt #4 :




set $V_{ref}(0) = 0$

Phase 1

$S_1$ : ON

$S_2$ : OFF

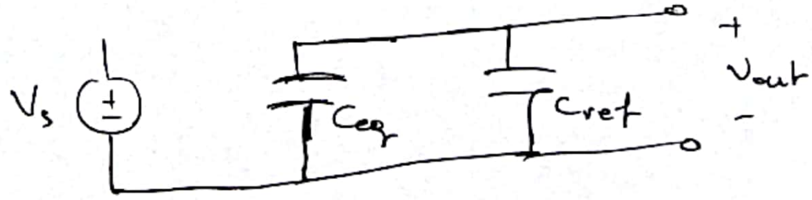
$S_3$ : ON


Phase 2

$S_1$ : OFF

$S_2$ : ON

$S_3$ : OFF



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Total Charge in Phase 1:

$$Q_{tot,1} = Q_{ceq_1} + Q_{cref_1} = C_{eq} \cdot V_s + 0 \quad (1)$$

$C_{ref} \cdot V_{ref}(0)$
→ in attempt #3 I did not know $V_{ref}(0)$

Total Charge in Phase 2:

$$Q_{tot,2} = (C_{eq} + C_{ref}) \cdot V_{out} \quad (2)$$

Charge Conservation: $Q_{tot_1} = Q_{tot_2}$

$$\Rightarrow C_{eq} \cdot V_s = (C_{eq} + C_{ref}) \cdot V_{out}$$

$$\Rightarrow V_{out} = \frac{C_{eq}}{C_{eq} + C_{ref}} \cdot V_s = f(C_{eq})$$

Charge Sharing

Let's Recap:

Goal: Build a new touchscreen

1) Look into capacitors
2) Modeled finger touching screen as a $C_{eq}$
3) Charge Sharing ckt to measure $\Delta C_{eq}$

Op-amp (used as a comparator)

Symbol: