EECS 16A

Logistics
- MT2 coming
- Power outage + fires
- Circuit review - moved to Friday
- 16B

Today:
- Capacitive touchscreen
- Charge-sharing

Top view:
- Conducting strip
- Pixel of my touchscreen
- Conducting strip

Side view:
- $C_{EF}$
- $C_{E2F}$
- Insulator
- Conductor
Capacitor between $E_1$ and $E_2$: we call $C_0$

\[ C_{E_2F} \]

When finger is touching:

\[ C_{E_2F} \]

Circuit Notouch:

\[ C_{E_2} \]

No finger touching

Reliably: $E_1$, $E_2$ will always be there

Redraw circuit looking in from $E_1$, $E_2$.
If no finger, no pink path!

⇒ Equivalent capacitance between $E_1 - E_2$ changes based on if we touch!
\[ C_\Delta = C_{E1-F} \parallel C_{E2-F} \]

\[ = \frac{C_{E1F} \cdot C_{E2F'}}{C_{E1F} + C_{E2F'}} \]

Redraw:

If No touch:
\[ C_{eq} = C_0 \]

If touch:
\[ C_{eq} = C_0 + C_\Delta \]
Summary: Touch changes equivalent capacitance between $E_1 - E_2$.

Question: How to detect this change?

Attempt I: Use a current source

$\text{I}_s = \text{C}_\text{eq} \frac{dV_c}{dt}$, $V_c = \int_0^t \frac{\text{I}_s}{\text{C}_\text{eq}} \, dt = \frac{\text{I}_s \cdot t}{\text{C}_\text{eq}}$

Assuming $V_{out}(0) = 0$
Attempt 2:

\[ V_{\text{in}} \quad \square \quad \frac{1}{C_{\text{eq}}} \quad \uparrow \quad V_{\text{out}} \]

\[ V_{\text{out (touch)}} = V_{\text{in}} \]

\[ V_{\text{out (no touch)}} = V_{\text{in}} \]

Fails because \( V_{\text{out}} \) does not change based on touch. \( V_{\text{in}} \) vs no touch.

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Attempt 3: Use a reference capacitor

\[ V_{\text{in}} \quad \square \quad C_{\text{eq}} \quad \square \quad C_{\text{ref}} \quad \uparrow \quad V_{\text{out}} \]
V_{out} (when switch is open) = 0
V_{out} (--- closed) = V_s

Attempt 4:

\[ \begin{align*}
V_s & \quad \text{S1} \quad \text{S2} \\
& \quad \text{C}_{eq} \quad \text{C}_{ref} \quad + \quad V_{out} \\
& \quad \text{+} \quad \text{--} \\
& \end{align*} \]

Question: is it helpful to close both S1 and S2 at the same time?

Ans: No: \( V_{out} = \Theta V_s \) in this case
Phase 1: Close $S_1$, $S_2$ is open.

$$q = C \cdot V = C_{eq} \cdot V_s$$

Phase 2: Close $S_2$, open $S_1$.

Issue: Don't know if initial charge on $C_{ref} = 0$

Attempt $S$: 

\[ \square \]
Phase 1: S3 ON, S1 ON, S2 OFF

Voltage across $C_{ef}$: 0
Charge on $C_{ef}$: $q = C_{ef} \cdot V = 0$
Voltage across $C_{eq}$: $V_s$
Charge on $C_{eq}$: $q = C_{eq} \cdot V_s$
Phase 2: S1 off, S3 off, S2 on

Voltage across $C_{eq}$: $V_{out}$
Voltage across $C_{eq'}$: $V_{out}$
Charge across $C_{eq}$: $C_{eq} \cdot V_{out}$
Charge across $C_{eq'}$: $C_{eq'} \cdot V_{out}$

Total charge is conserved at yellow node.
Phase 1 charge: \( C_{eq} \cdot V_s \)

Phase 2 charge: \( C_{eq} \cdot V_{out} + C_{ref} \cdot V_{out} \)

\[ C_{eq} \cdot V_s = C_{eq} \cdot V_{out} + C_{ref} \cdot V_{out} \]

\[ V_{out} = \frac{C_{eq} \cdot V_s}{C_{ref} + C_{eq}} \]

If touch:
\[ V_{out} = \frac{(C_0 + C_{\Delta}) \cdot V_s}{C_{ref} + C_0 + C_{\Delta}} \]

If no touch:
\[ V_{out} = \frac{C_0 \cdot V_s}{C_{ref} + C_0} \]
Capacitor trick 1:

\[ V_1(0) = 0 \]
\[ V_2(0) = 0 \]

\[ V_s \]
\[ +q \]
\[ -q \]
\[ C_{eq} = C_1 \parallel C_2 \]
\[ q = C_{eq} \cdot V_s \]

\[ q = C_{eq} \cdot V_s \]
\[ q = V_1 C_1 \]

\[ \Rightarrow V_1 C_1 = V_S \cdot C_{eq} \]

\[ \Rightarrow V_1 = \frac{C_{eq}}{C_1} \cdot V_S \]

Similarly:

\[ V_2 = \frac{C_{eq}}{C_2} \cdot V_S \]
\[ C_{eq} \frac{dV_{out}}{dt} = I_s \Rightarrow \frac{dV_{out}}{dt} = \frac{I_s}{C_{eq}} \]

\[ I_1 = I_s \frac{C_1}{C_{eq}} \]

\[ I_1 = \frac{I_s}{C_{eq}} \cdot C_1 = \frac{I_s}{C_1 + C_2} \]
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\[ V_{\text{out}} = I \cdot R_2 \]

\[ = \frac{V_s}{R_{\text{req}}} \cdot R_2 = \frac{V_s \cdot R_2}{R_1 + R_2} \]

\[ I_{\text{req}} = V_s \]