EECS 16A

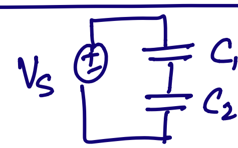
Logistics

- Midterm, Monday Nov 2nd.
- Clobber
- +2 points on MT1.

Today

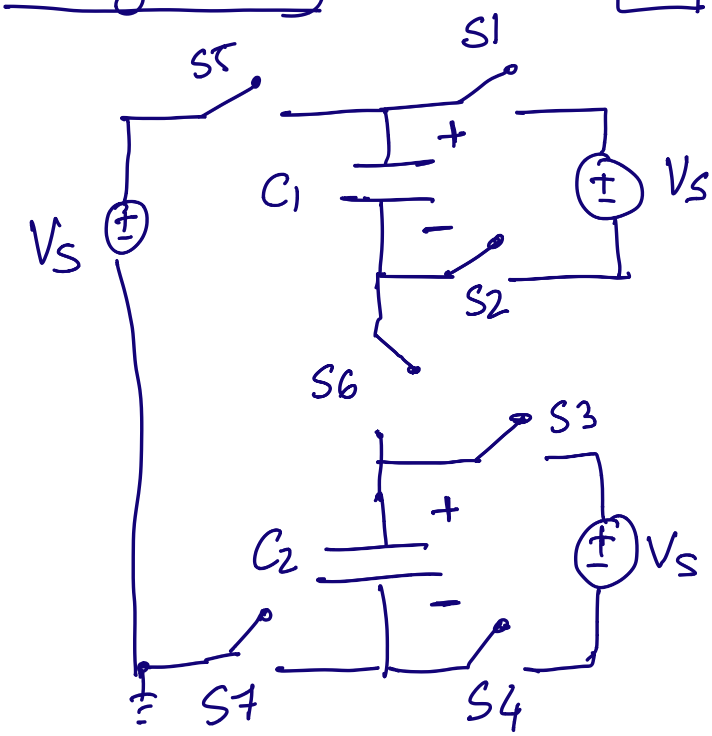
- More charge sharing
  "stuck in the middle with you"
- Comparators
- Op-amps.

Charge sharing



→ Initial charges 0. Last time.

Phases: 1, 2



Phase 1:

S1, S2, S3, S4 closed

S5, S6, S7 open

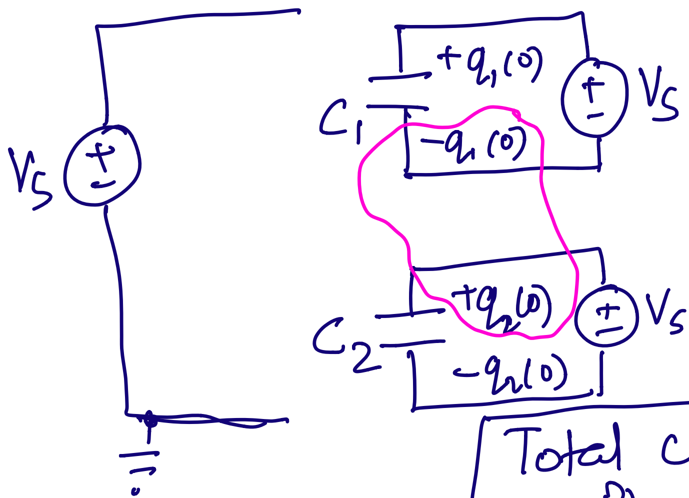
Phase 2:

S1–S4 open

S5–S7 are closed

Question: Steady state, after Phase 2, what is the charge q_1, q_2, V_1, V_2

Phase 1:

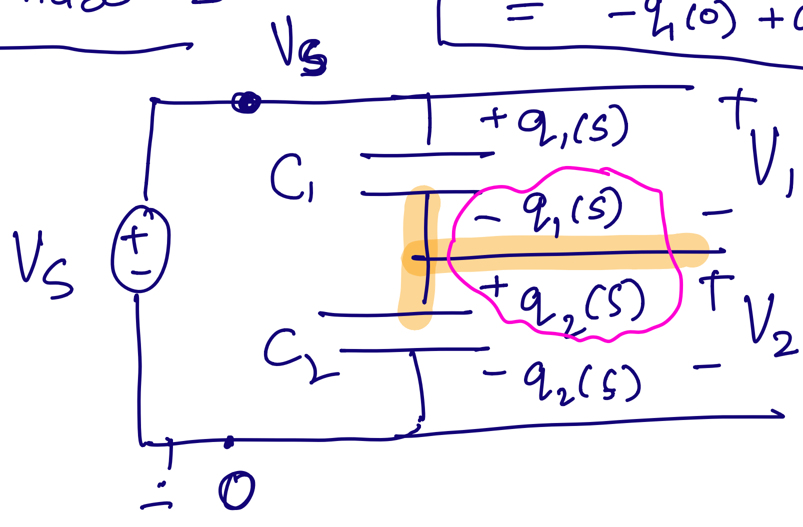


$$q_1(0) = V_S \cdot C_1$$

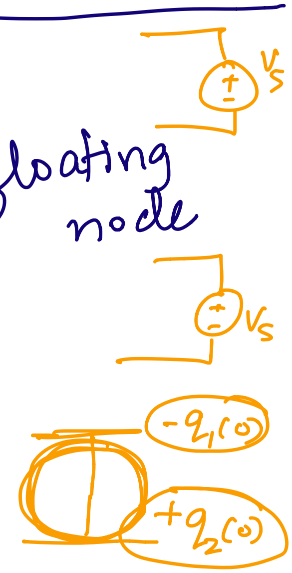
$$q_2(0) = V_S \cdot C_2$$

Total charge on "floating" node in Phase 1:
= charge on C_1 bottom plate + C_2 top plate
$= -q_1(0) + q_2(0)$

Phase 2:



floating node



Phase 2:

① $q_1(s) = C_1 V_1$

② $q_2(s) = C_2 \cdot V_2$

KVL: $V_1 + V_2 = V_s$ (3)

Goals:

$$\begin{bmatrix} q_1(s) \\ q_2(s) \\ V_1 \\ V_2 \end{bmatrix}$$

Charge on bottom plate of C_1: $-q_1(s)$

Charge on top plate of $C_2 = +q_2(s)$

Total charge on the floating node:

$$-q_1(s) + q_2(s)$$

Charge is conserved

$\Rightarrow$ $-q_1(s) + q_2(s) = -q_1(0) + q_2(0)$

$$\boxed{-q_1(s) + q_2(s) = -V_s C_1 + V_s C_2} \quad (4)$$

① $q_1(s) = C_1 V_1$

② $q_2(s) = C_2 \cdot V_2$

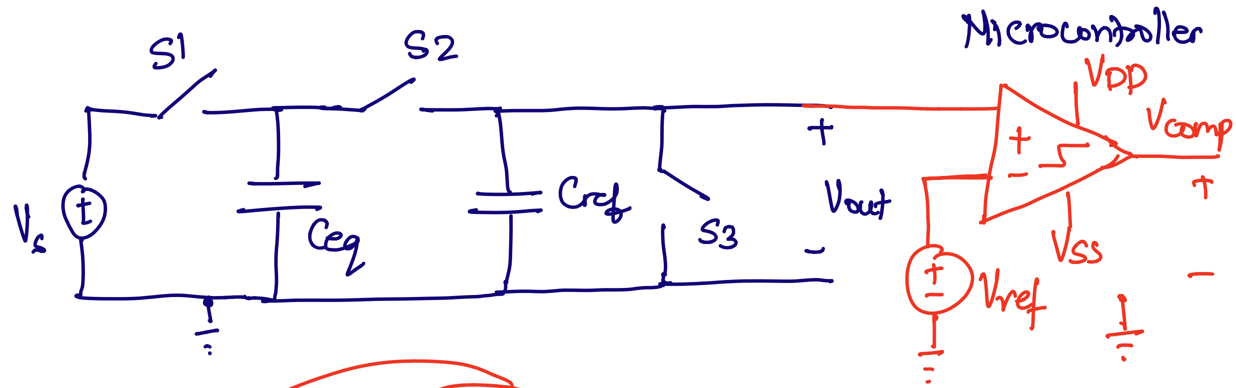
$V_1 + V_2 = V_s$ ③

$$\begin{bmatrix} 1 & 0 & -C_1 & 0 \\ 0 & 1 & 0 & -C_2 \\ 0 & 0 & 1 & 1 \\ -1 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} q_1(s) \\ q_2(s) \\ V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ V_s \\ -V_s C_1 + V_s C_2 \end{bmatrix}$$

Going back to the capacitive touch screen.

$C_{eq} = C_0$ if no touch

$= C_0 + C_\Delta$ if touch.

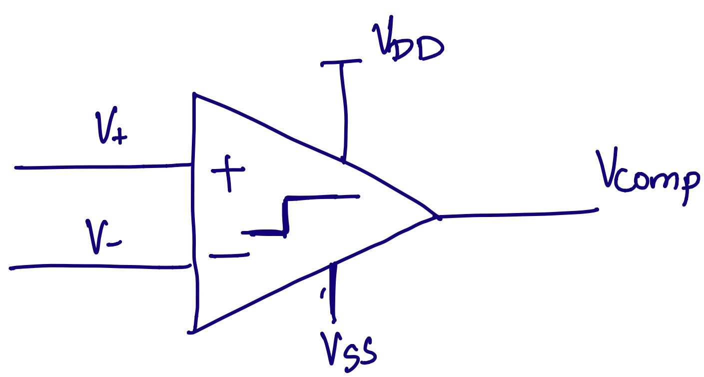


$$V_{out} = \begin{cases} \dfrac{(C_0+C_\Delta)V_s}{C_0+C_\Delta+C_{ref}} & \text{touch} \\[2ex] \dfrac{C_0 V_s}{C_0+C_{ref}} & \text{No touch} \end{cases}$$

→ V_{ref} (midpoint of touch + no touch)

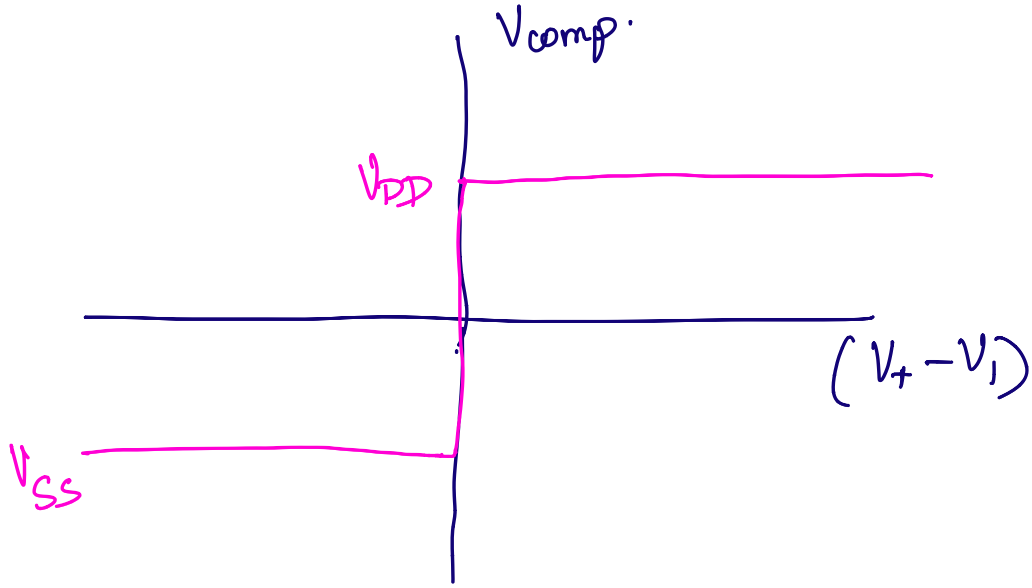
__Comparator:__ Compare two voltages.

__Op-Amps__ (Operational amplifers)



If $V_+ > V_-$ then $V_{comp} = V_{DD}$

If $V_- > V_+$ then $V_{comp} = V_{SS}$



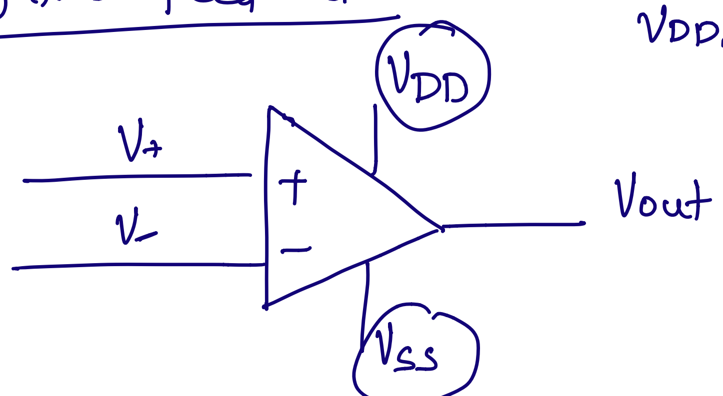
Operational Amplifiers

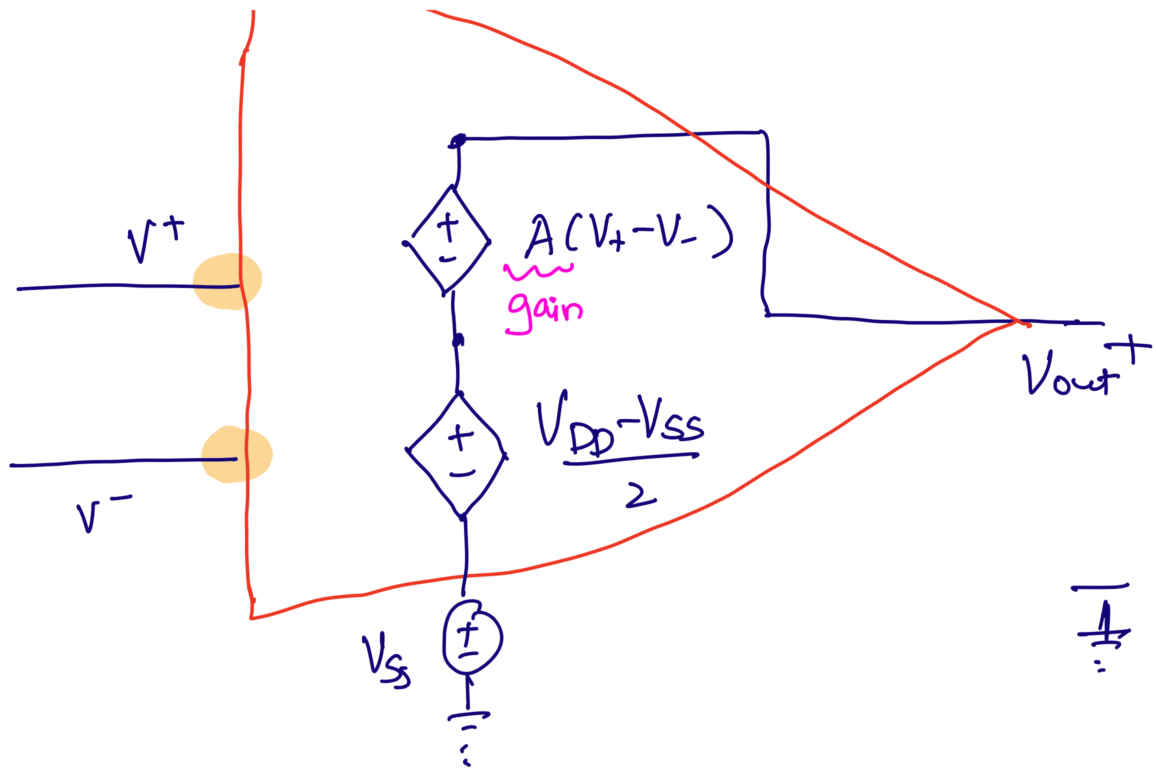
"Amplify signals"

"Isolate circuits" to avoid "loading effect"

Negative feedback.

References:
VDD, VSS
Midpoint: $\frac{V_{DD}+V_{SS}}{2}$





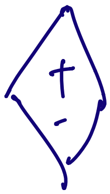
$$V_{out} = V_{SS} + \frac{V_{DD}-V_{SS}}{2} + A(V_+ - V_-)$$

$$= \frac{2V_{SS} + V_{DD} - V_{SS}}{2} + A(V_+ - V_-)$$

$$V_{out} = \frac{V_{DD}+V_{SS}}{2} + A(V_+ - V_-)$$

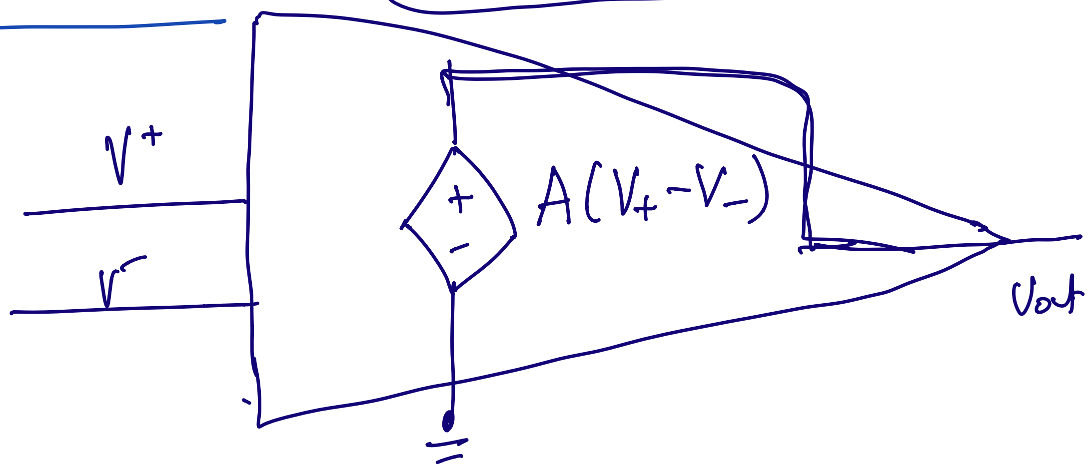
Caveat: Max value of $V_{out} = V_{DD}$

Min value of $V_{out} = V_{SS}$



: Voltage Dependant Voltage soure.

In our class: $V_{DD} = -V_{SS}$



$$V_{out} = \frac{V_{DD} + V_{SS}}{2} + A(V_+ - V_-)$$

$$= 0 + A(V_+ - V_-)$$

(A: scalar)

$$V_{out} = A(V_+ - V_-)$$

(A: scalar)

$V_{DD} = -V_{SS}$

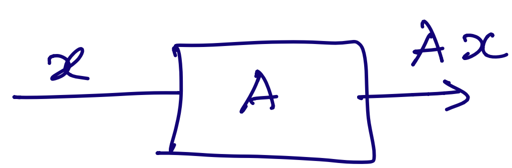
What happens as $A \to \infty$?

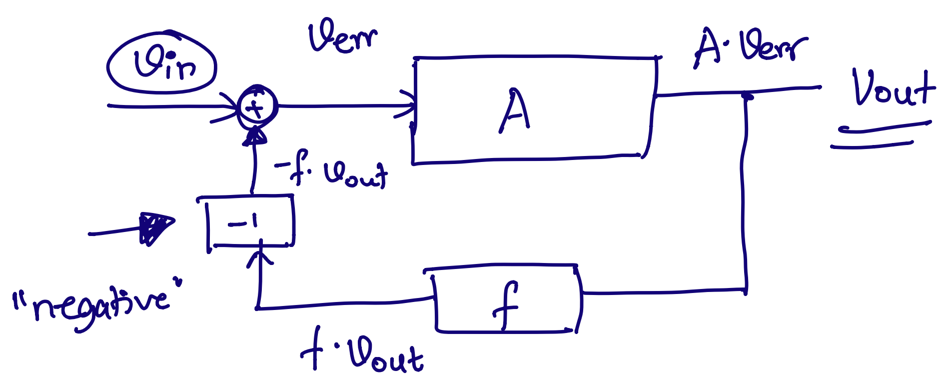
$$V_{out} = \begin{cases} V_{DD} & \text{if } V_+ > V_- \\ V_{SS} & \text{if } V_- > V_+ \end{cases}$$

Capacitive touchscreen completed with comparator.

Negative feedback

Block diagram:





$\rightarrow \quad V_{out} = A \cdot V_{err}$

$\rightarrow \quad V_{err} = V_{in} - f \cdot V_{out}$

$\Rightarrow \quad V_{out} = A \left(V_{in} - f \cdot V_{out} \right)$

$\Rightarrow \quad V_{out} + A \cdot f \cdot V_{out} = A \cdot V_{in}$

$$\Rightarrow \quad \boxed{V_{out} = \frac{A}{1+Af} \cdot V_{in}}$$

$A \rightarrow$ very large. $\quad A \rightarrow \infty$

$$\frac{A}{1+Af} = \frac{A/A}{\frac{1+Af}{A}} = \frac{1}{\frac{1}{A} + f}$$

$$\lim_{A \rightarrow \infty} \frac{1}{\frac{1}{A} + f} = \frac{1}{f}$$