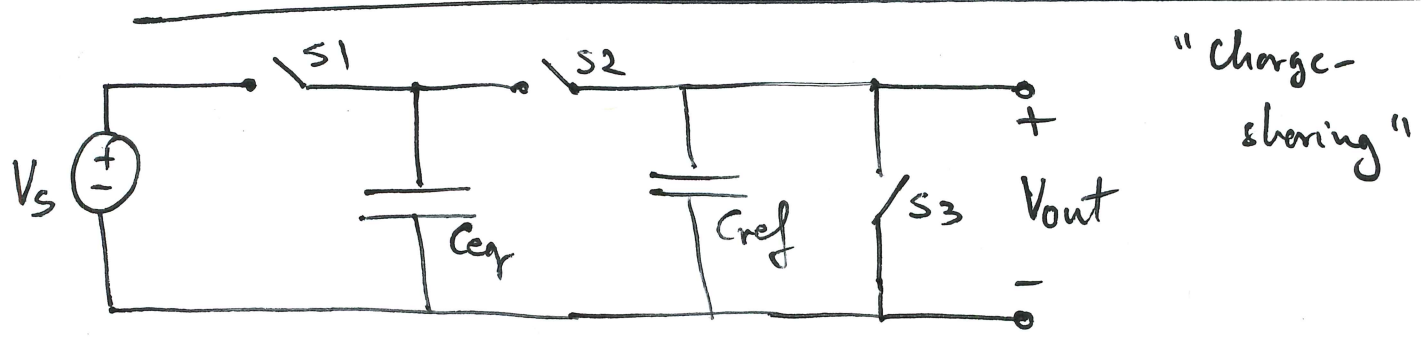


# EE16A Module 2 - Lecture 7

\* Measuring capacitance - recap / 2D touch

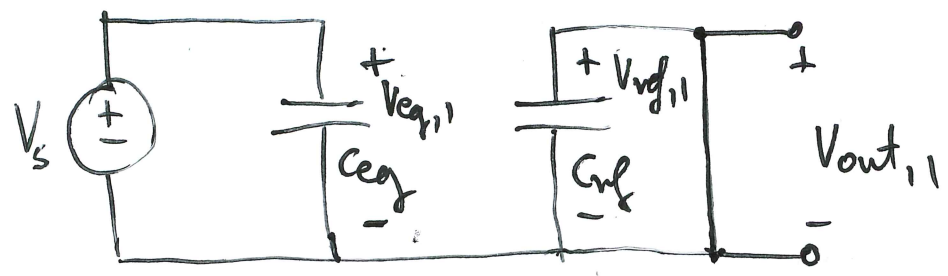
\* Comparator (op-amp)



Task: Turn the value of  $C_{eq}$  into  $V_{out}$

Assumption:  $C_{eq}$  is constant during the measurement

Phase 1: ( $S1$  on,  $S2$  off,  $S3$  on)



$$V_{eq,1} = V_s$$

$$V_{ref,1} = 0 = V_{out,1}$$

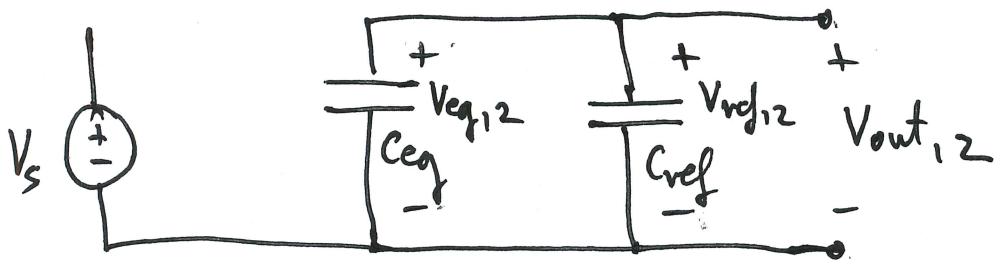
$$Q_{Ceq,1} = C_{eq} \cdot V_{eq,1}$$

$$= C_{eq} \cdot V_s$$

$$Q_{ref,1} = C_{ref} \cdot V_{ref,1} = 0$$

$$Q_{tot, phase1} = Q_{Ceq,1} + Q_{ref,1} = C_{eq} \cdot V_s$$

(2) Phase 2 of the measurement ( $S_1$  off,  $S_2$  on,  $S_3$  off):



$$V_{eq,1,2} = V_{out,1,2} = V_{ref,1,2}$$

$$Q_{eq,1,2} = C_{eq} \cdot V_{eq,1,2} = C_{eq} \cdot V_{out,1,2}$$

$$Q_{ref,1,2} = C_{ref} \cdot V_{ref,1,2} = C_{ref} \cdot V_{out,1,2}$$

$$Q_{ref,1,2} = C_{ref} \cdot V_{ref,1,2} = C_{ref} \cdot V_{out,1,2}$$

$$Q_{total, \text{ phase 2}} = Q_{eq,1,2} + Q_{ref,1,2}$$

$$= C_{eq} \cdot V_{out,1,2} + C_{ref} \cdot V_{out,1,2}$$

$$= (C_{eq} + C_{ref}) V_{out,1,2}$$

Charge-conservation:  $Q_{total, \text{ phase 1}} = Q_{total, \text{ phase 2}}$

$$C_{eq} \cdot V_s = (C_{eq} + C_{ref}) \cdot V_{out,1,2}$$

$$V_{out,1,2} = \frac{C_{eq}}{C_{eq} + C_{ref}} \cdot V_s$$

$$= \frac{1}{1 + \frac{C_{ref}}{C_{eq}}} \cdot V_s$$

(13)

# 2D touch:

no-touch state :  $C_{eq} = C_0$

$$V_{out,2} |_{no-touch} = \frac{1}{1 + \frac{C_{ref}}{C_0}} V_S$$

touch state :  $C_{eq} = C_0 + \Delta C$  ,  $\Delta C > 0$

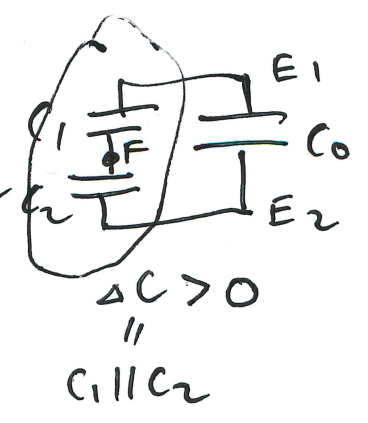
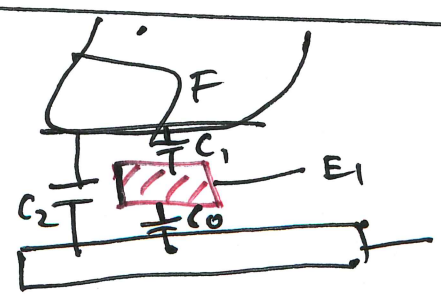
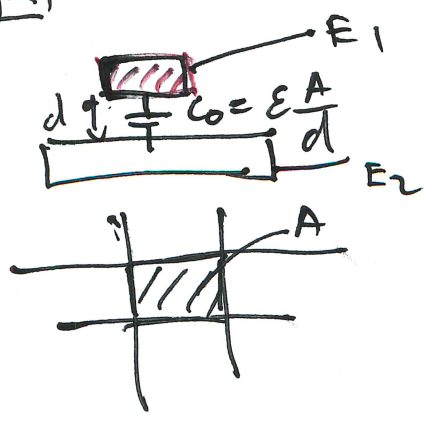
$$V_{out,2} |_{touch} = \frac{1}{1 + \frac{C_{ref}}{C_0 + \Delta C}} V_S$$

$V_{out,2} |_{touch} > V_{out,2} |_{no-touch}$

Need something to distinguish (i.e compare) these two values to figure-out if there was a "touch" or not.

recap!

no-touch

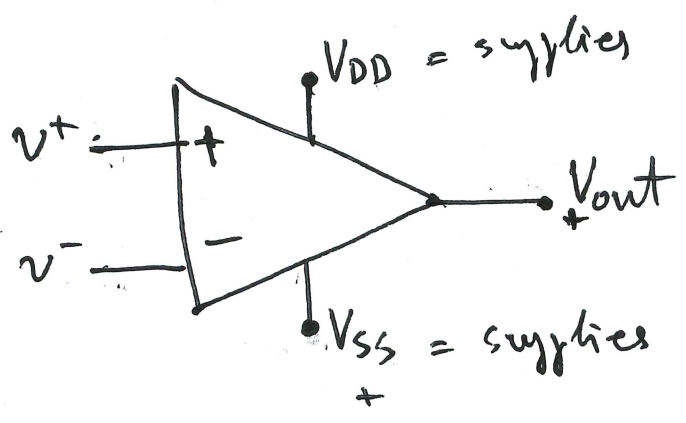


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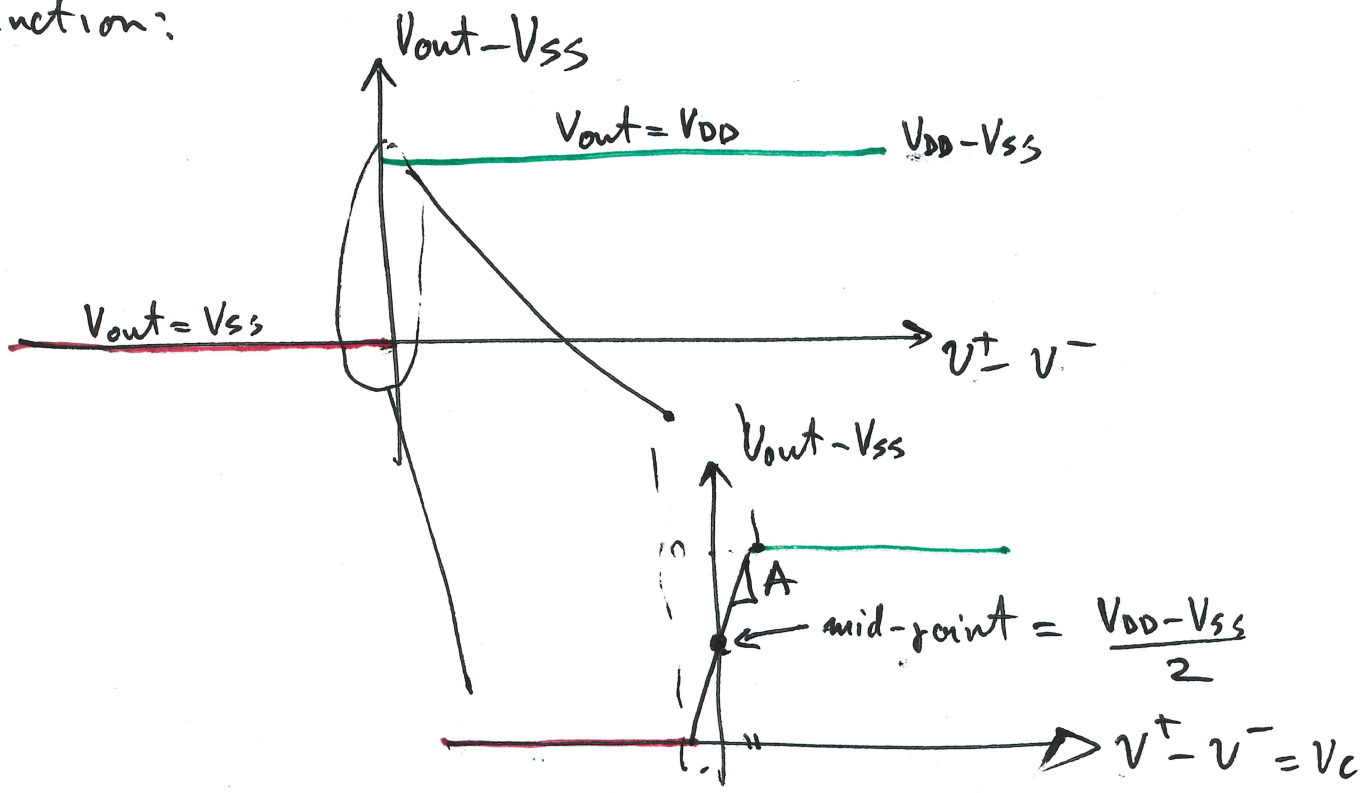
Need a new component (op-amp)

Op-amp

Symbol



Function:

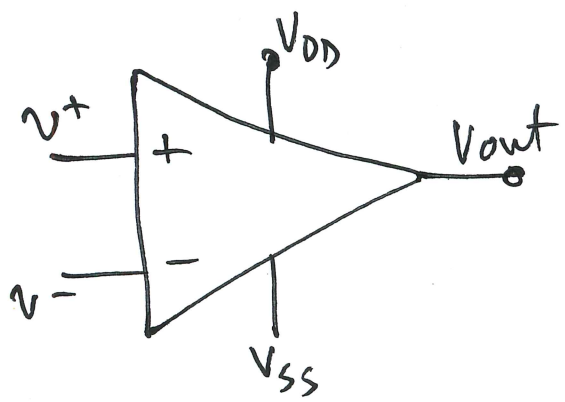


A - gain of the op-amps

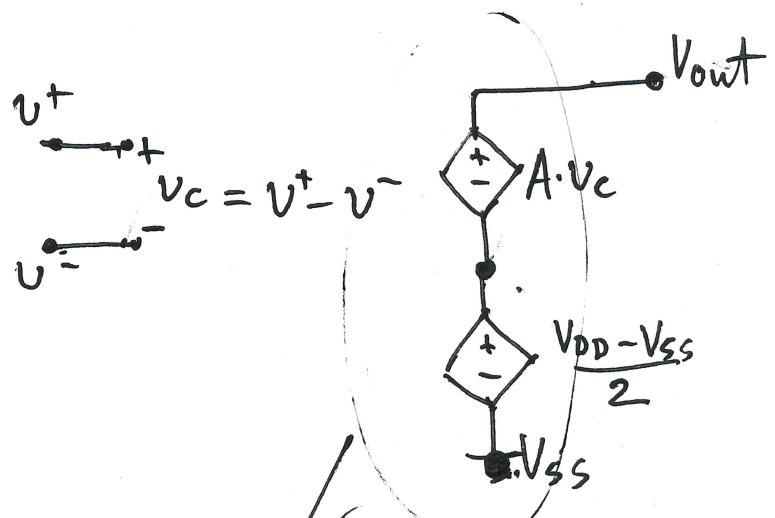
10 k - 10 M

CS

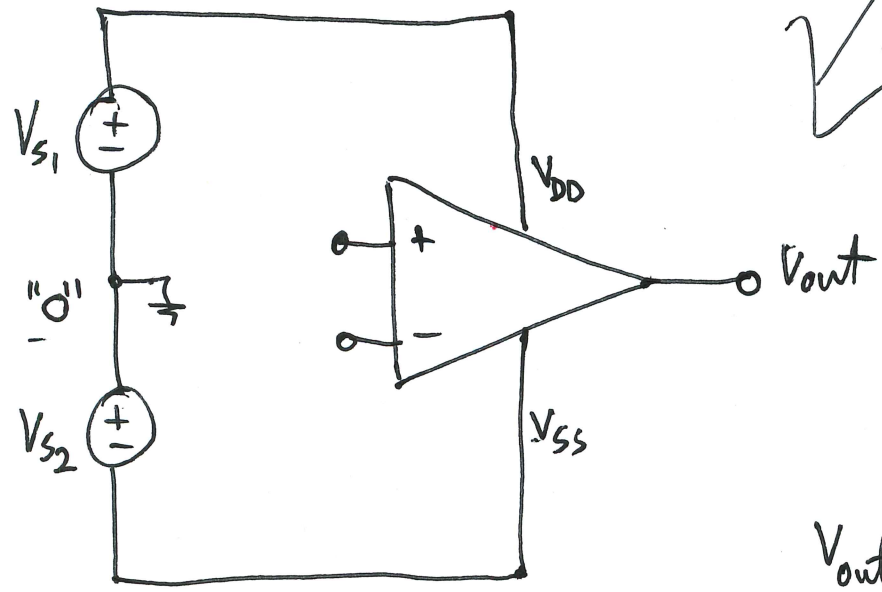
# Model :



=>



## example biasing of op-amps :



$$V_{DD} = V_{s1}$$

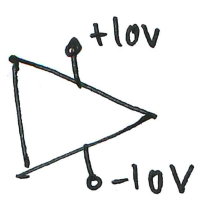
$$V_{SS} = -V_{s2}$$

$$V_{out} = V_{SS} + \underbrace{\frac{V_{DD} - V_{SS}}{2}}_{\text{mid-point}} + A \cdot v_c$$

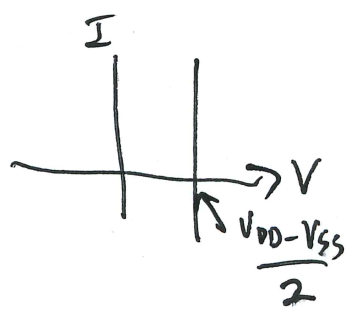
$$V_{out} = -V_{s2} + \frac{V_{s1} + V_{s2}}{2} + A \cdot v_c$$

$$= \underbrace{\frac{V_{s1} - V_{s2}}{2}}_{\text{mid-point of } V_{out}} + A \cdot v_c$$

if  $V_{s1} = V_{s2}$   
 $\Downarrow$   
 $V_{out \text{ mid-point}} = 0$

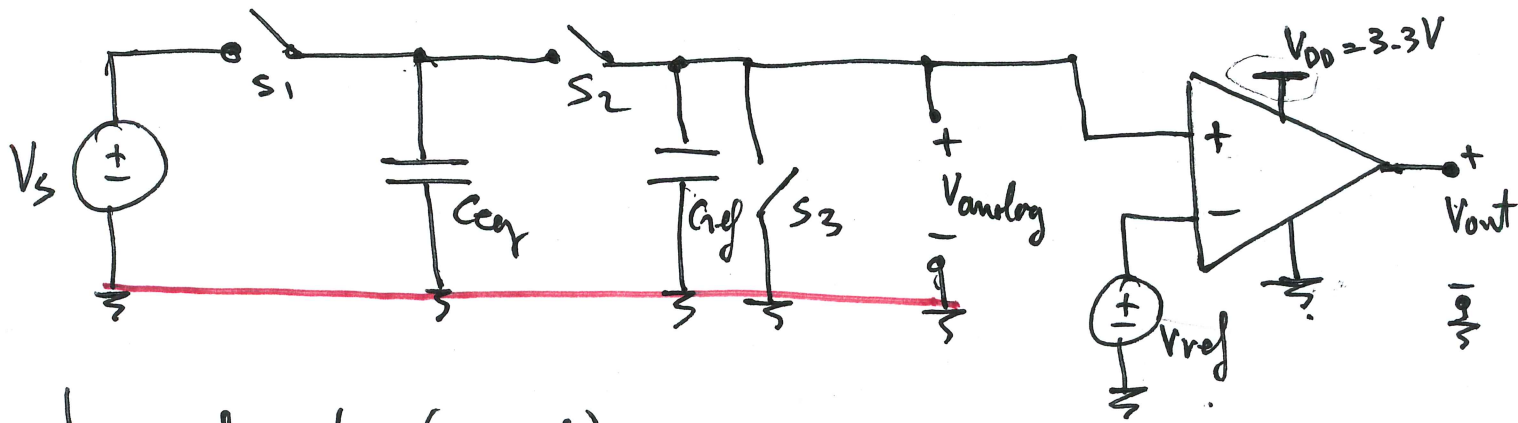
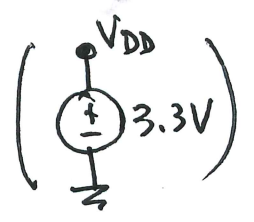


$\Downarrow$   
 $V_{out \text{ mid-point}} = 0$



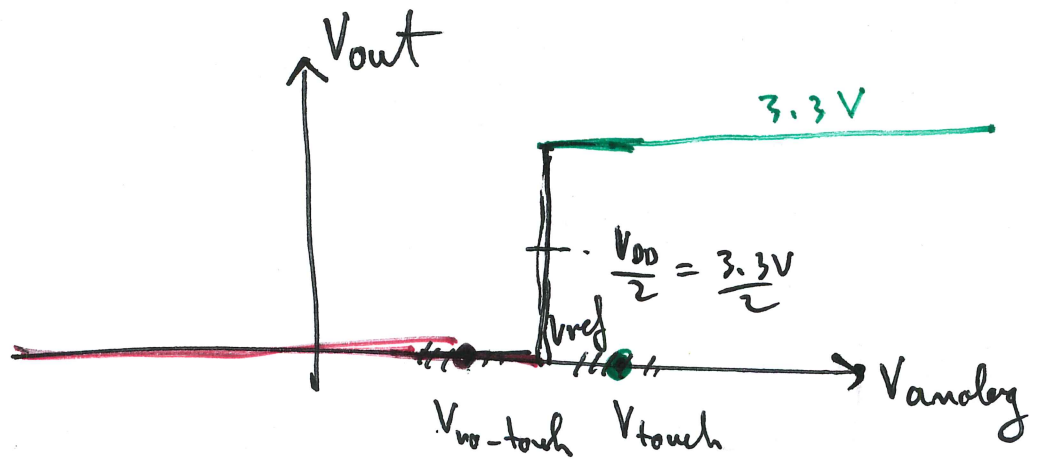
(26)

Use in 2D touch:



$\frac{1}{2} \equiv$  ref. node (ground)

"want"  $V_{out} = 3.3V$  when touch  
 $V_{out} = 0V$  when no-touch



$$V_{ref} = \frac{V_{analog, touch} + V_{analog, no-touch}}{2}$$

$$V_c = V_{analog} - V_{ref}$$