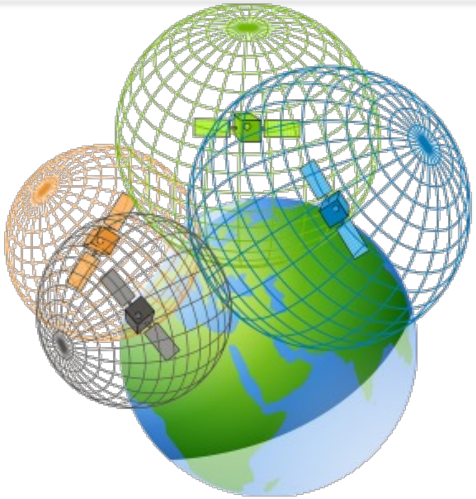

Welcome to EECS 16A!

Designing Information Devices and Systems I

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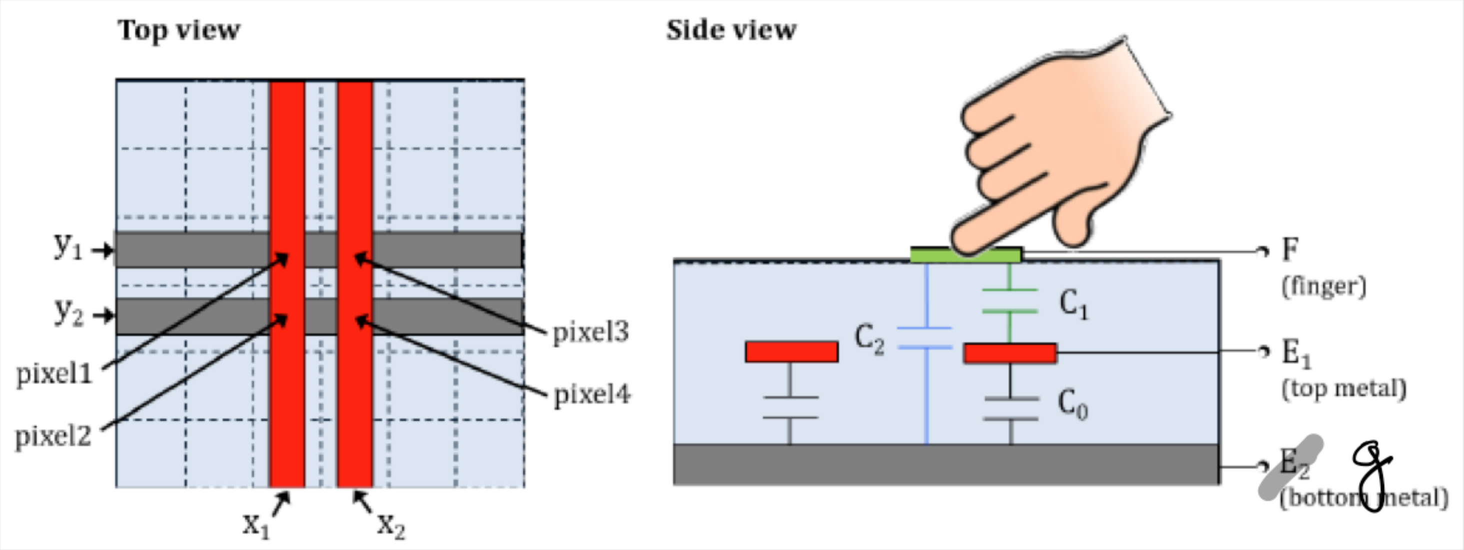
Fall 2022

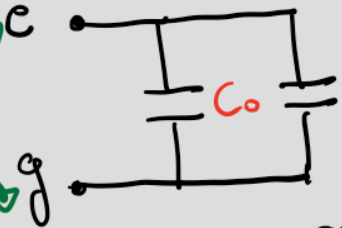
Module 2
Lecture 9
Capacitance Modeling and Comparator
(Note 18)

Last Class…



Problem: We don't have a capaci-meter!

We want to measure Capacitance here



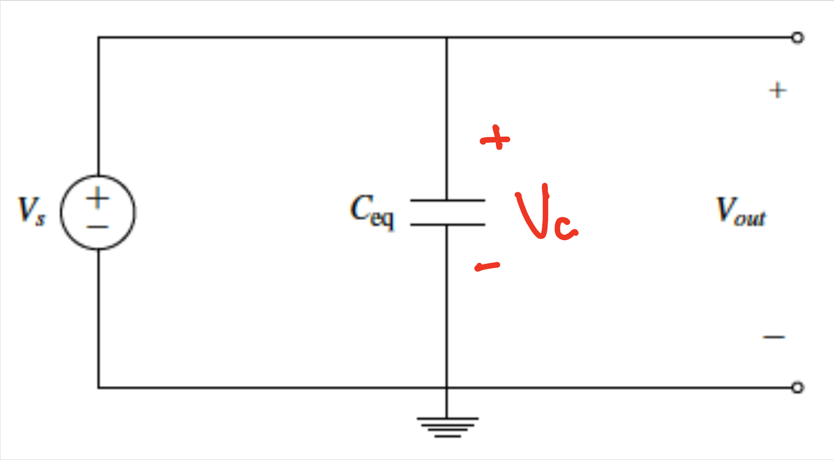
$$\frac{C_1 C_2}{C_1 + C_2} = C_\Delta$$

(change)

This capacitor goes away with no touch

We will try ideas to get to a final model.

Measuring Capacitance Models – Attempt #1 ∴ Add power sources

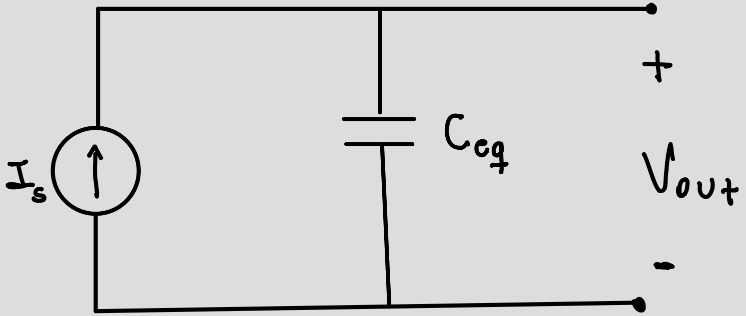


If there is touch: $V_c = V_s$

If there is no-touch: $V_c = V_s$

V_{out} does not change!

Need a better idea...



We will learn how to design current sources in EE140

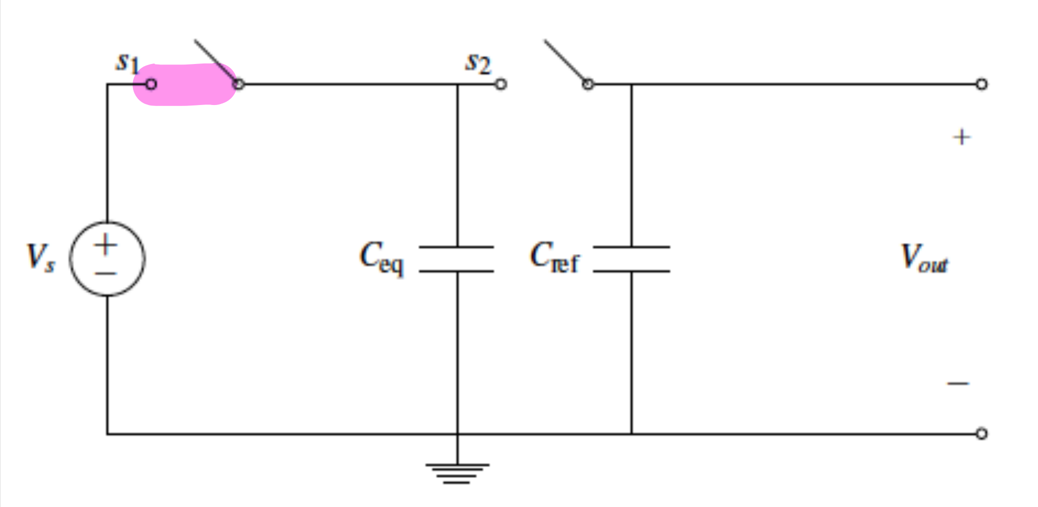
Assume C_{eq} starts out discharged

$$V_{out}(t=0) = 0$$

$$I_s = C_{eq} \frac{dV_{out}(t)}{dt} \rightarrow V_{out}(t) = \int_0^t \frac{I_s}{C_{eq}} dt$$

$$V_{out} = \frac{I_s \cdot t}{C_{eq}} \Rightarrow C_{eq} = \frac{I_s \cdot t}{V_{out}}$$

Measuring Capacitance Models – Attempt #2 – add switches and a reference capacitor



If S_1 and S_2 are both closed – we have attempt #1

We want to charge C_{ref} and measure V_{out} as C_{ref} discharges.

Phase 1

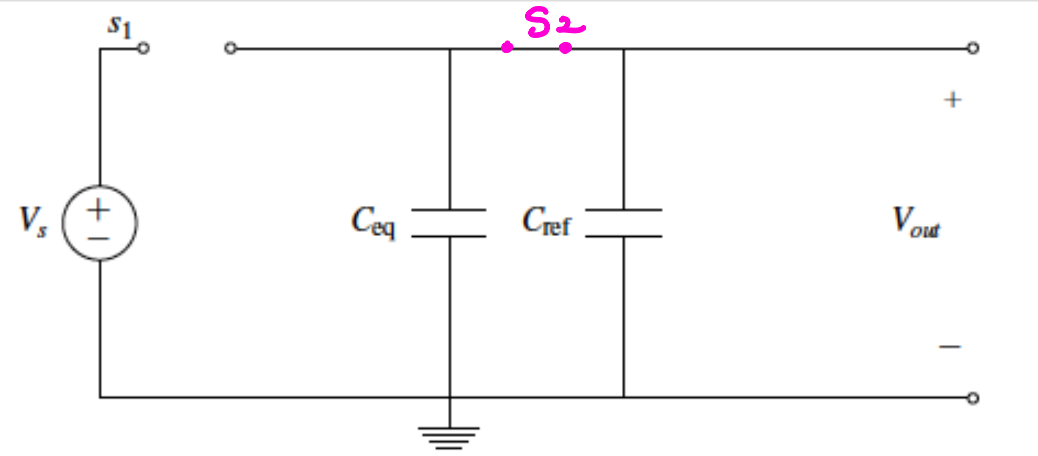
Close S_1 ; Open S_2

C_{eq} charges

$q = C_{eq} \cdot V_s$

(charge accumulates on capacitor plates)

Measuring Capacitance Models – Attempt #2 – add switches and a reference capacitor



Phase 2

Close S_2 ; open S_1

- There is a path for charge to move.
- Ceq provides the energy needed for current.

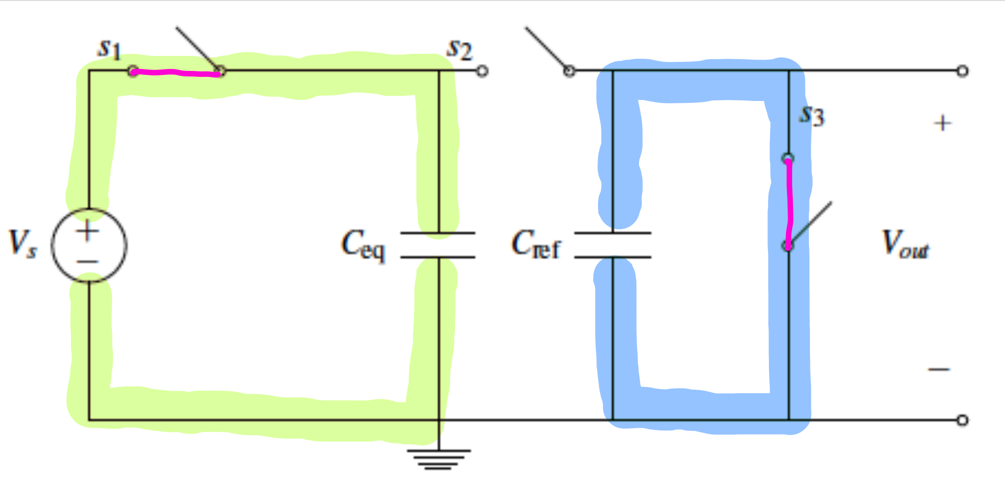
Charge will be shared between Ceq and Cref ∴ charge sharing

Very close!

But ... we don't know the initial value of Cref

Measuring Capacitance Models – Attempt #3 – known initial condition

Use S_3 to discharge C_{ref} so we know $C_{ref} = 0$



Phase 1

S_1 closed, S_2 open, S_3 closed

C_{ref} discharges $V_{out} \rightarrow 0$

$q = C_{req} \cdot V_{out} = 0$ ✓

C_{eq} charges

$q = C_{eq} \cdot V_s$

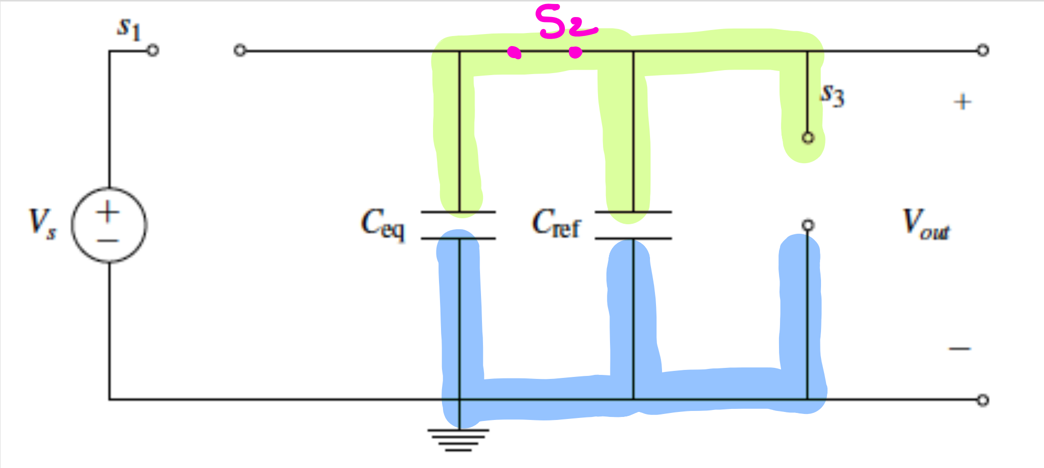
Phase 2

S_1 open, S_2 closed, S_3 open

C_{eq} : charged

C_{ref} : discharged

Measuring Capacitance Models – Attempt #3 – known initial condition



Voltage across Ceq : Vout

Voltage across Cref : Vout

Charge in Ceq : $q_1 = C_{eq} \cdot V_{out}$

Charge in Cref : $q_2 = C_{ref} \cdot V_{out}$

Total charge is conserved!

$$q(\text{phase1}) = q(\text{phase2})$$

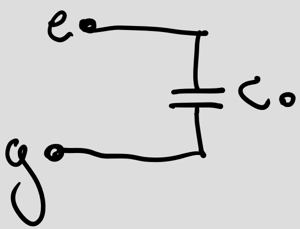
$$C_{eq} \cdot V_s = C_{eq} \cdot V_{out} + C_{ref} \cdot V_{out}$$

$$V_{out} = \frac{C_{eq} V_s}{C_{e\_} + C_{re\_}} \Rightarrow$$

Vout changes when Ceq changes!

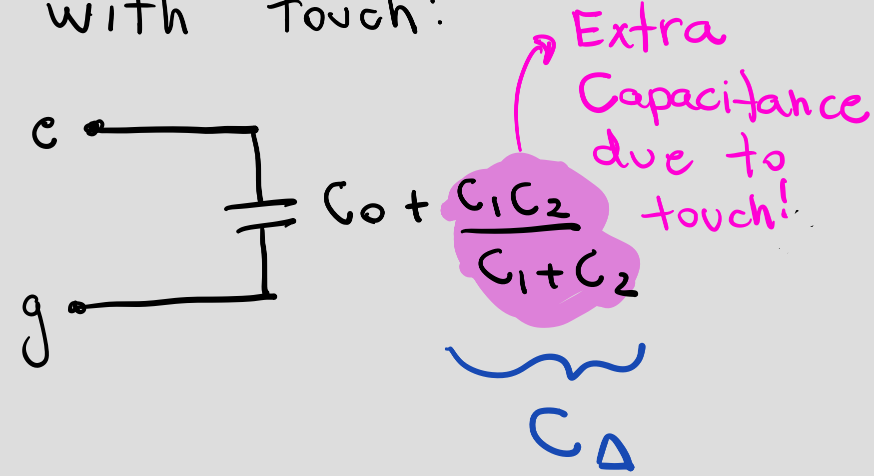
Effect of touch on total capacitance

when no touch:



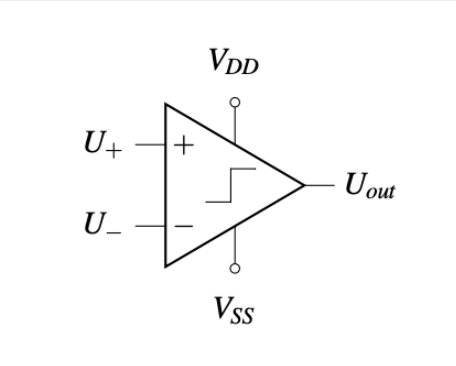
$$\Rightarrow \quad V_{OUT} = \frac{C_0}{C_0 + C_{ref}} \cdot V_S$$

with touch:



$$\Rightarrow \quad V_{OUT} = \frac{(C_0 + C_\Delta)}{C_0 + C_\Delta + C_{ref}} \cdot V_S$$

How can we go from voltage measurement to binary answer: touch or no touch?



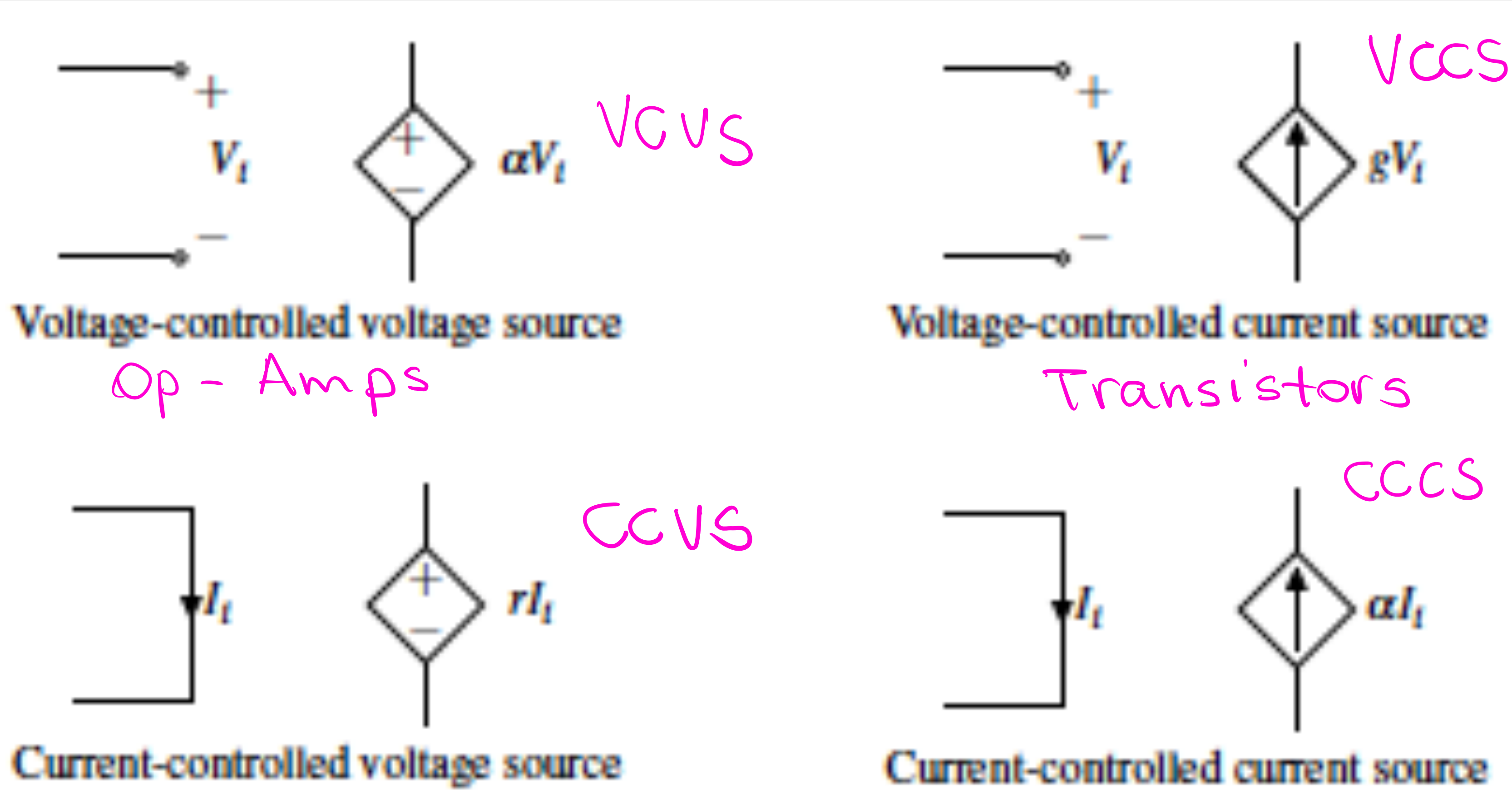
- We need to choose a Voltage that we call : Threshold Voltage (V_{th})

- Above V_{th} ∴ 1 (touch)
- Below V_{th} ∴ 0 (no-touch)

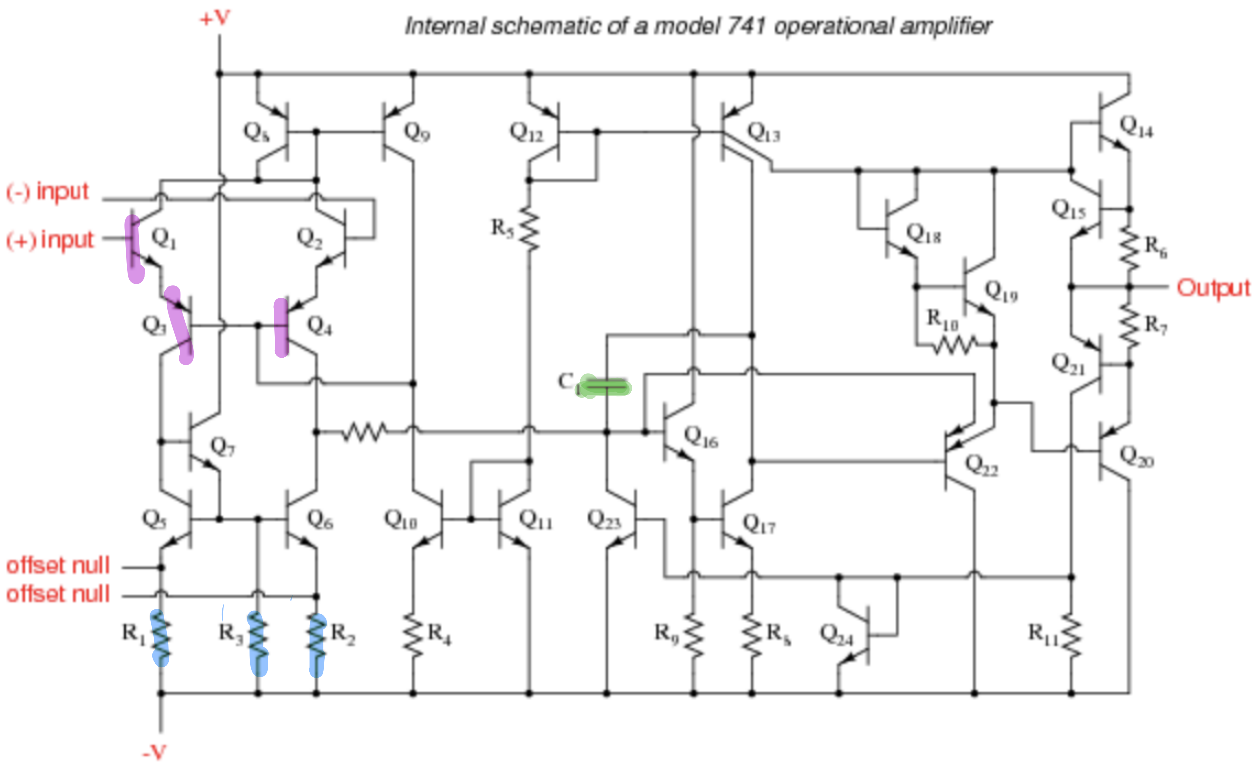
We need to compare Voltages to determine if 1 or 0

How can we go from voltage measurement to binary answer: touch or no touch?

- New tools are needed – new circuit elements



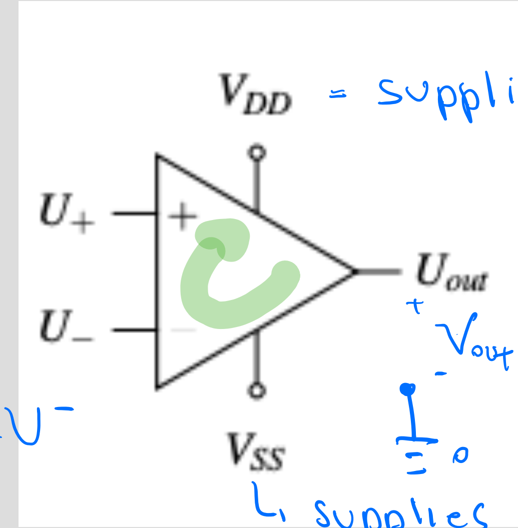
An example of an Op-amp circuit diagram



Schematic diagram of a model 741 op-amp.

Operational Amplifier

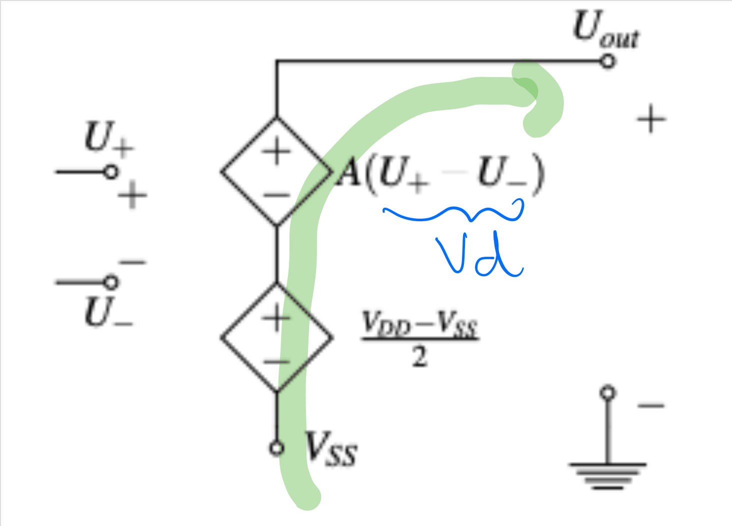
An op-amp (operational amplifier) is a device that transforms a small voltage difference into a very large voltage difference.

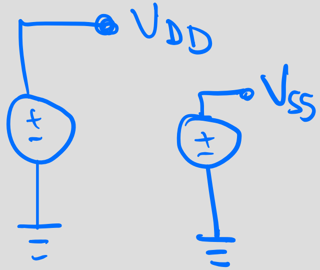


$V_d = U^+ - U^-$

An op-amp has two input terminals marked (+) and (−) with potentials U+ and U−, two power supply terminals called VDD and VSS, and one output terminal with potential Uout.

Model





$$V_{out} = V_{SS} + \frac{V_{DD}-V_{SS}}{2} + A \cdot V_d$$

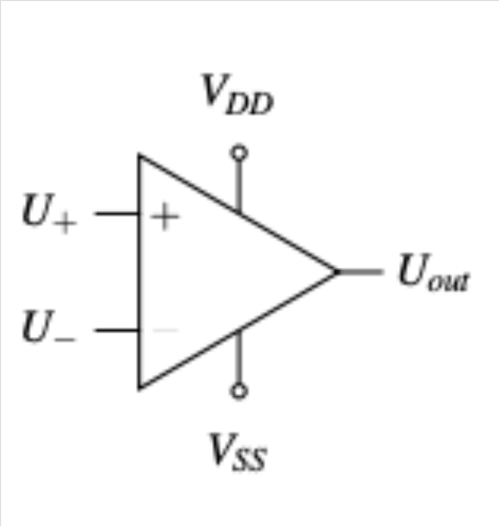
when

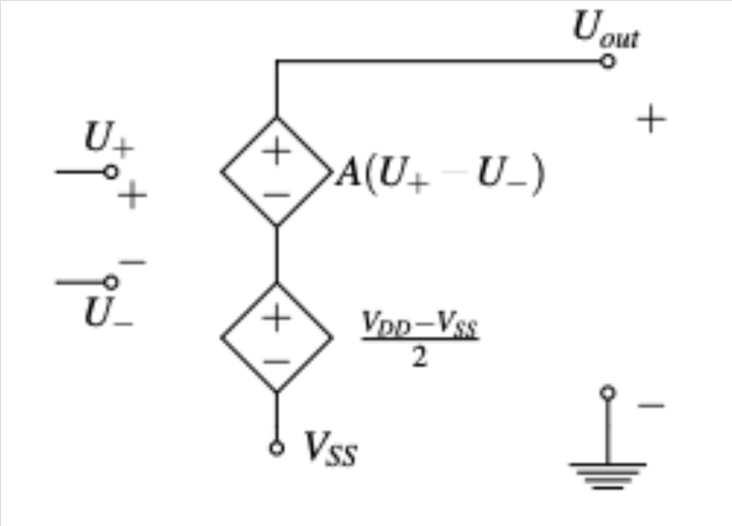
$$V_{SS} \leq \frac{V_{DD}-V_{SS}}{2} + A V_d \leq V_{DD}$$

Operational Amplifier

$\frac{V_{DD} - V_{SS}}{2} + A V_d$ V^*

An op-amp (operational amplifier) is a device that transforms a small voltage difference into a very large voltage difference.





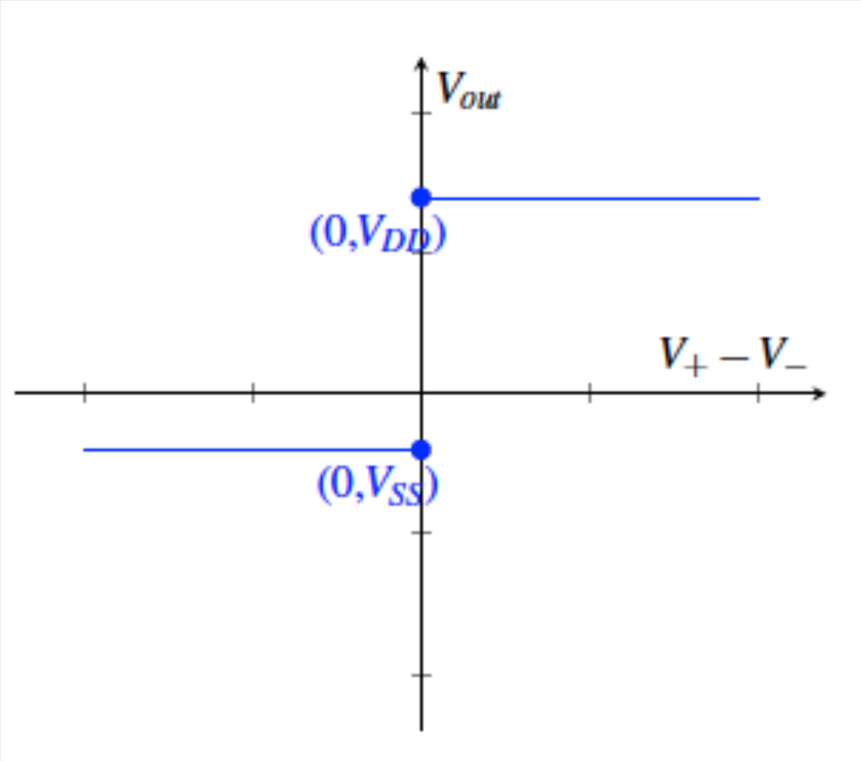
An op-amp has two input terminals marked (+) and (−) with potentials U+ and U−, two power supply terminals called VDD and VSS, and one output terminal with potential Uout.

$V_{out} = V_{DD}$ if $V^* > V_{DD}$

$V_{out} = V_{SS}$ if $V^* < V_{SS}$

Can be used to compare Voltage

Comparator – optimized for binary output

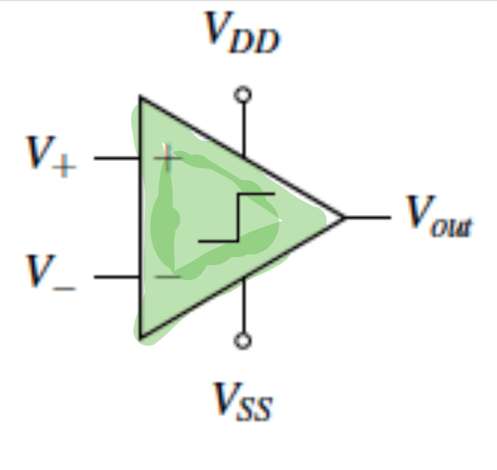


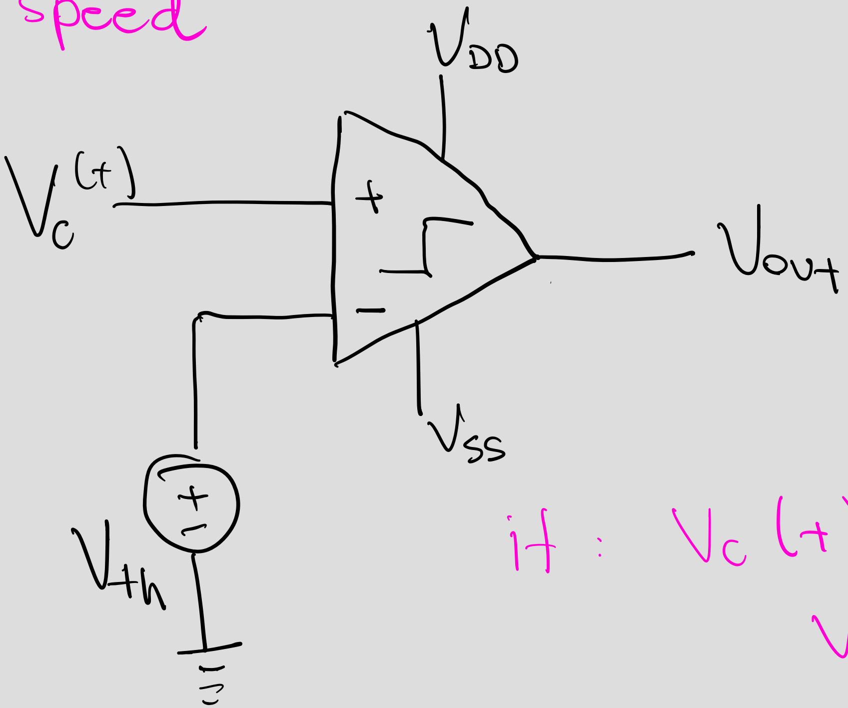
V_{DD} can be much higher than V_{SS}

∴ it amplifies the signal.

Comparator – optimized for binary output

Also optimized for speed





if : $V_c(t) > V_{th}$

$V_{out} = V_{DD}$

if : $V_c(t) \leq V_{Th}$

$V_{out} = V_{SS}$

Back to our Capacitive Touchscreen