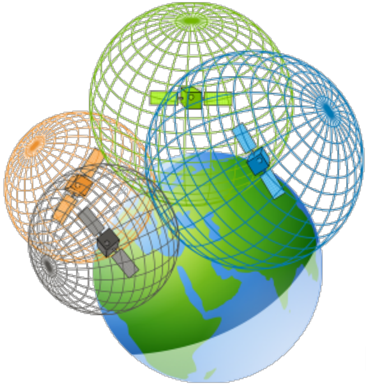
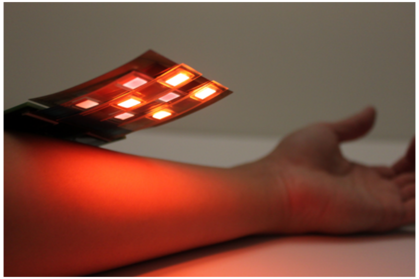




Welcome to EECS 16A!

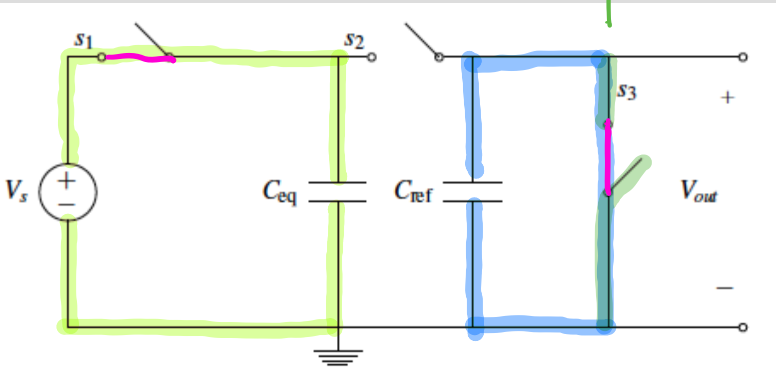
Designing Information Devices and Systems I

Ana Claudia Arias and Miki Lustig

Fall 2021

Module 2
Lecture 9
Operational Amplifier and Negative Feedback
(Note 18)

Measuring Capacitance Models – Attempt #3 – known initial condition



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

Phase 1: S_3 closed, S_1 closed, S_2 open

Creq discharges $V_{out} \to 0$

$q = C_{req} \cdot V_{out} = 0$ ✓

Ceq charges

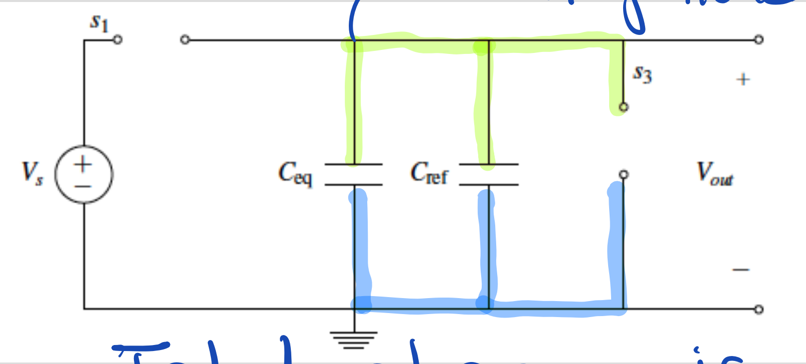
$q = C_{eq} \cdot V_s$

Phase 2: S_1 open, S_2 closed, S_3 open

Ceq - charged

Measuring Capacitance Models – Attempt #3 – known initial condition

floating node



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!

$$q(\text{phase } 1) = q(\text{phase } 2)$$

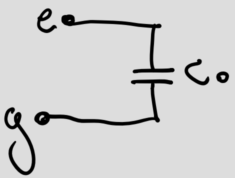
$$C_{eq} \cdot V_s = C_{eq} V_{out} + C_{ref} \cdot V_{out}$$

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

⇒ Vout changes when Ceq changes!!!

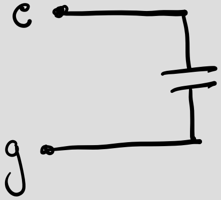
Effect of touch on total capacitance

when no touch:



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

with touch:

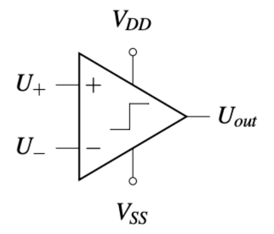


$$C_0 + \underbrace{\frac{C_1C_2}{C_1+C_2}}_{C_\Delta}$$

Extra Capacitance due to 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?

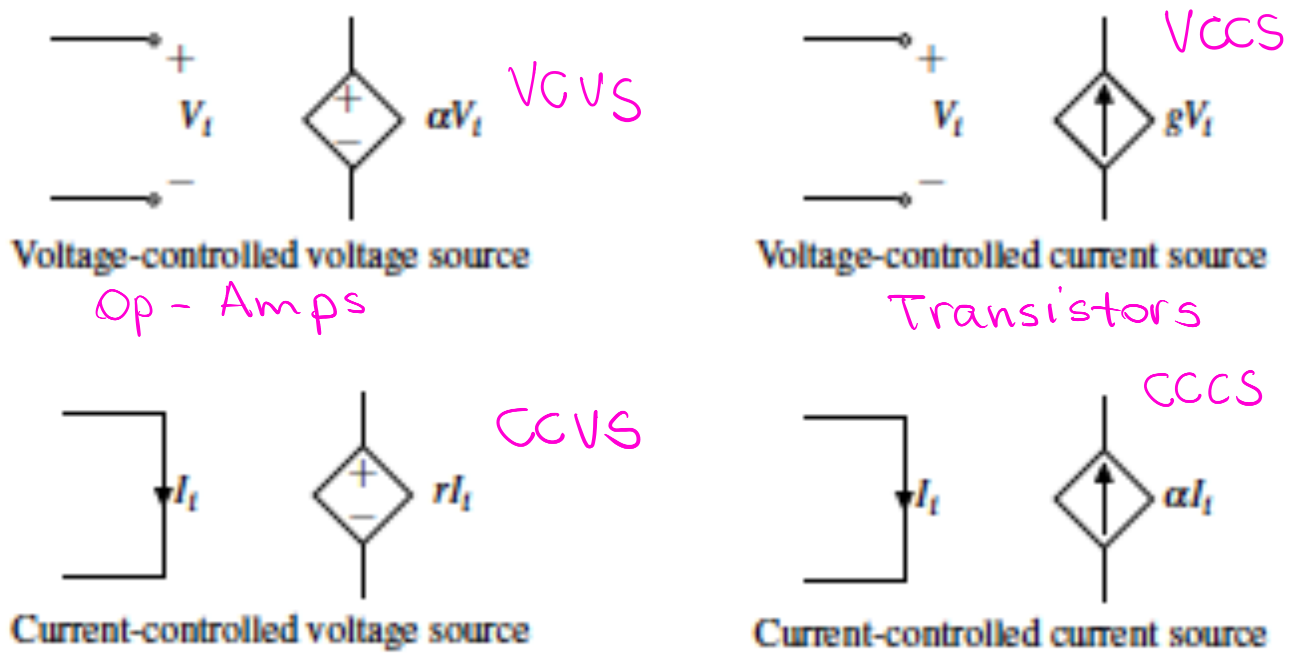


- We need to choose a Voltage that we call : Threshold Voltage (V_{th})
- Above V_{th} ∴ 1 (touch)
- Below V_{th} ∴ 0 (no- touch)

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



Voltage-controlled voltage source

VCVS

Op-Amps

Voltage-controlled current source

VCCS

Transistors

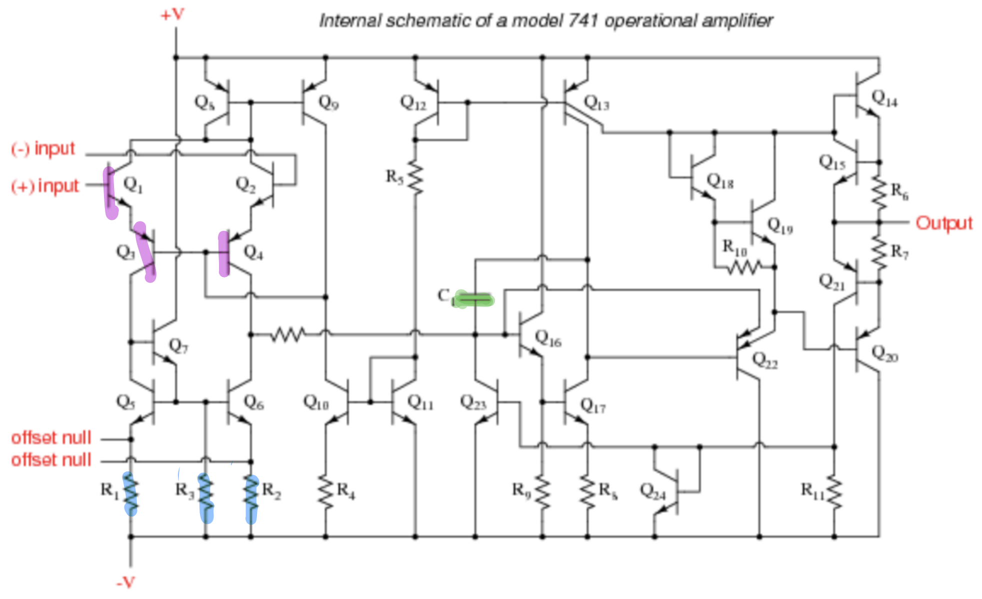
Current-controlled voltage source

CCVS

Current-controlled current source

CCCS

An example of an Op-amp circuit diagram

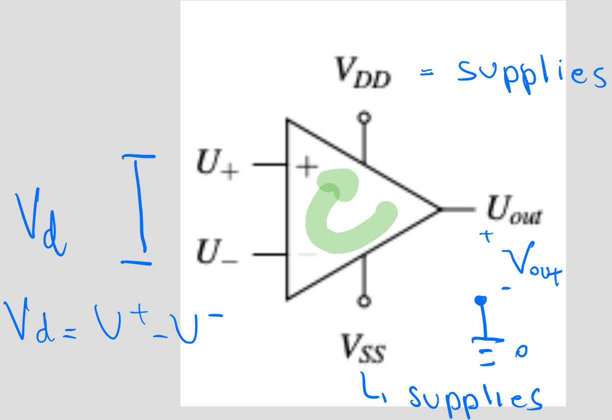


Schematic diagram of a model 741 op-amp.

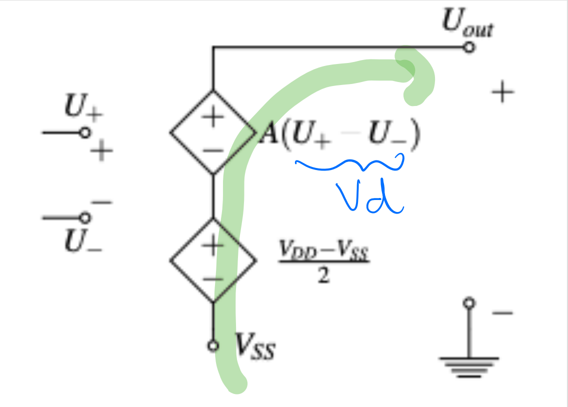
Operational Amplifier

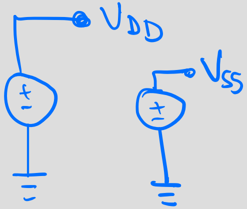
An op-amp (operational amplifier) is a device that transforms a small voltage difference into a very large voltage difference.

Model



$V_d = U^+ - U^-$



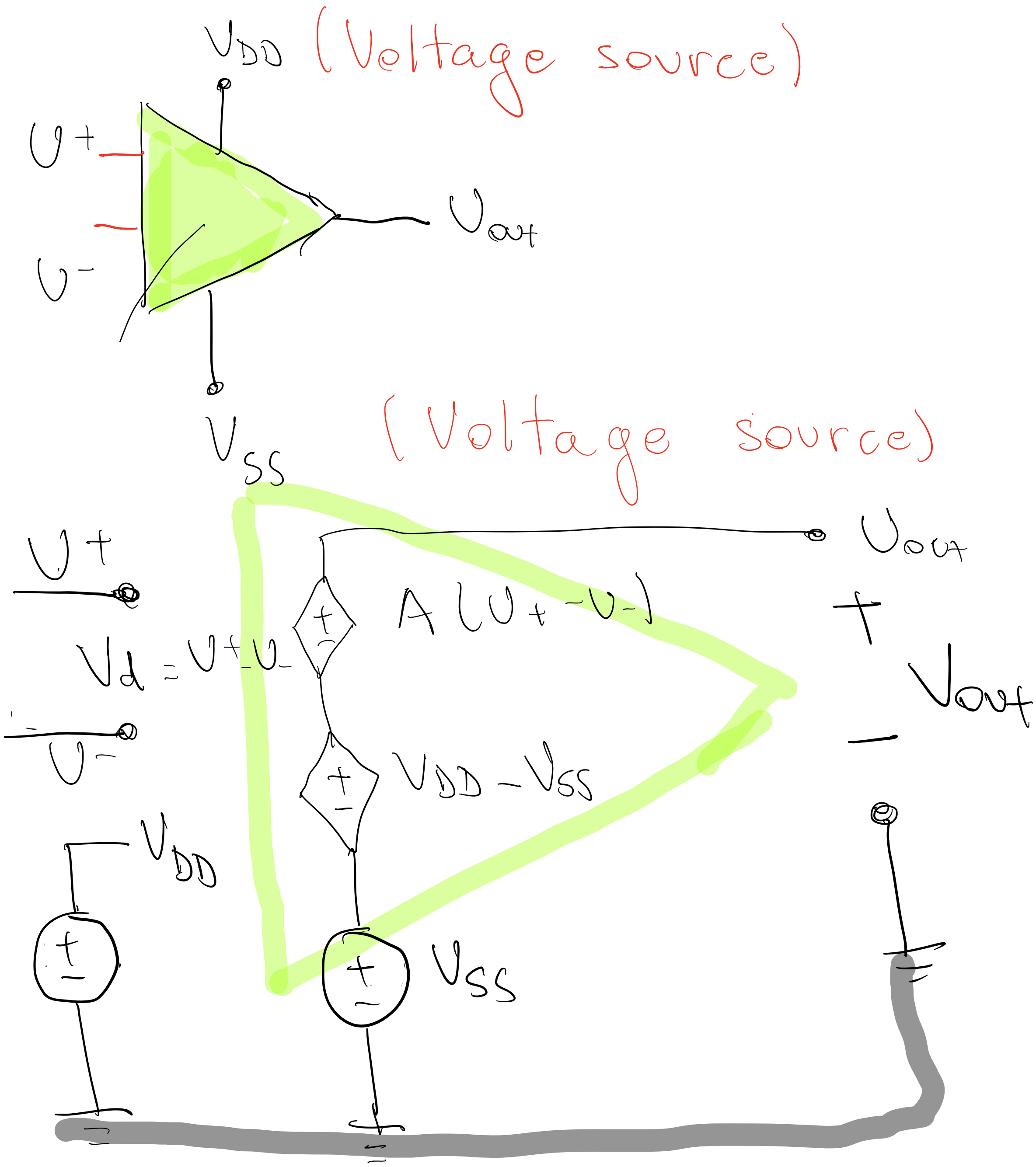


An op-amp has two input terminals marked (+) and (−) with potentials U+ and U−, two power supply terminals called VDD and VSS, and one output terminal with potential Uout.

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

when

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



All connected to

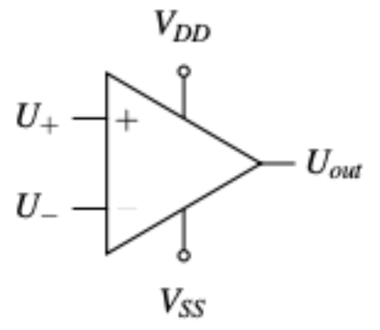
the same node : 0

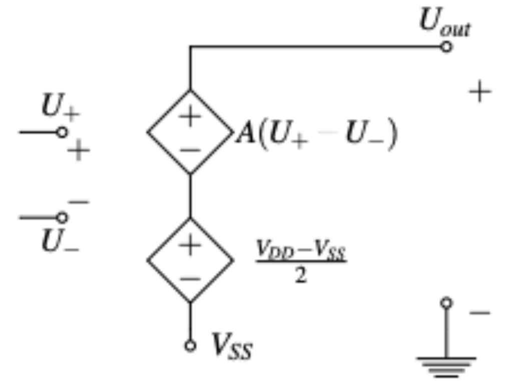
GROUND ⏚

Operational Amplifier

$\boxed{\frac{V_{DD}-V_{SS}}{2} + AV_d}$ V^*

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





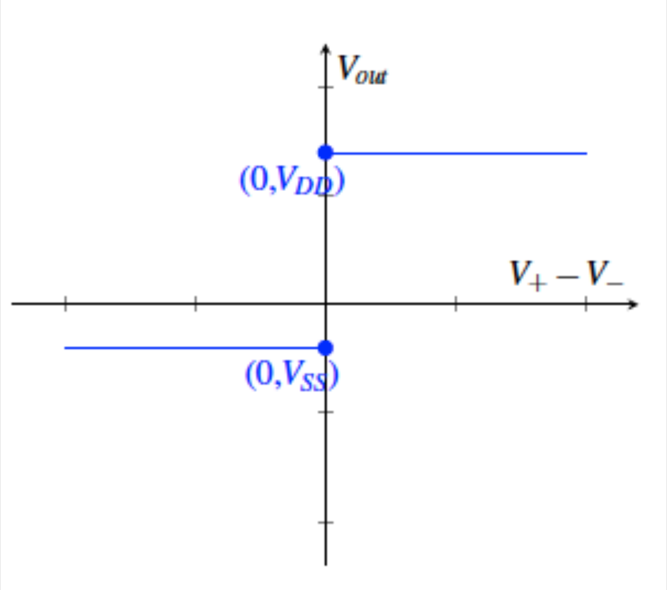
An op-amp has two input terminals marked (+) and (−) with potentials U+ and U−, two power supply terminals called VDD and VSS, and one output terminal with potential Uout.

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

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

Can be used to compare Voltage

Comparator – optimized for binary output

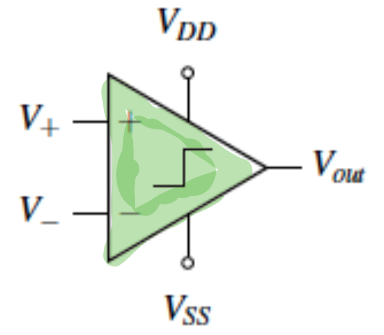


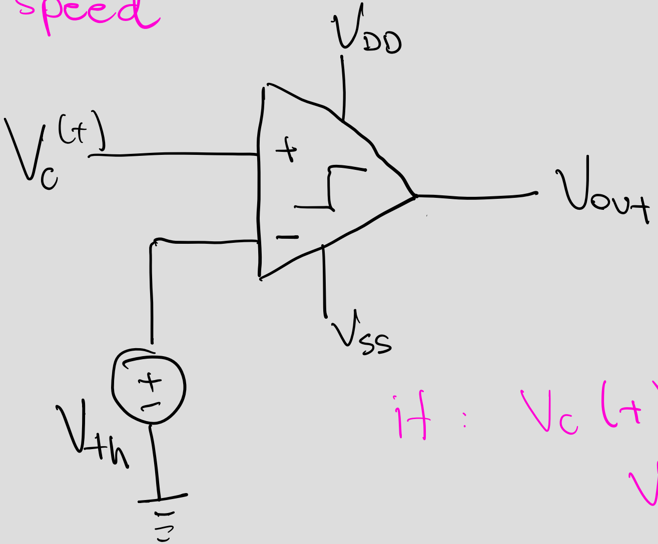
V_{DD} can be much higher than V_{SS}

∴ it amplifies the signal.

Comparator – optimized for binary output

Also optimized for speed





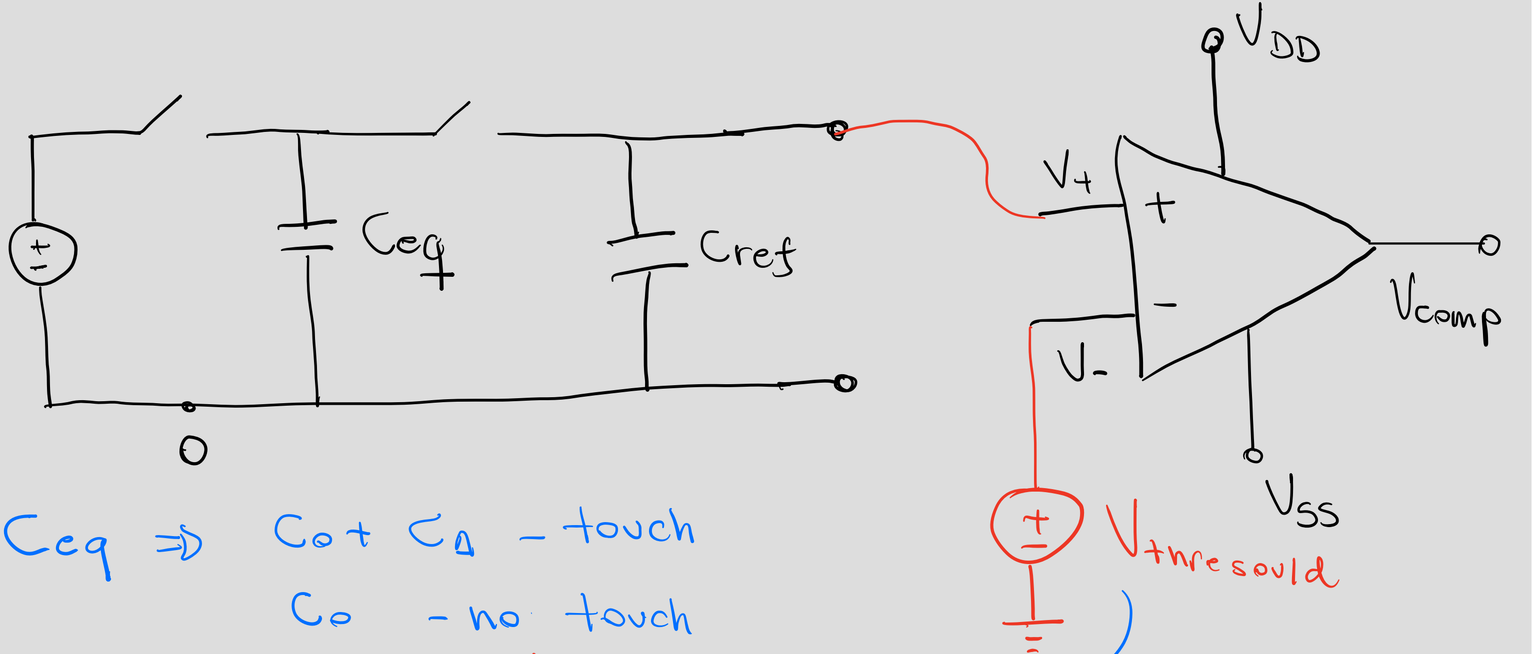
if : $V_c(t) > V_{th}$

$V_{out} = V_{DD}$

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

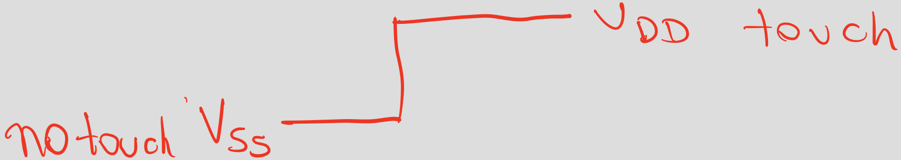
$V_{out} = V_{ss}$

Back to our Capacitive Touchscreen



$C_{eq} \Rightarrow C_0 + C_\Delta$ – touch

C_0 – no touch



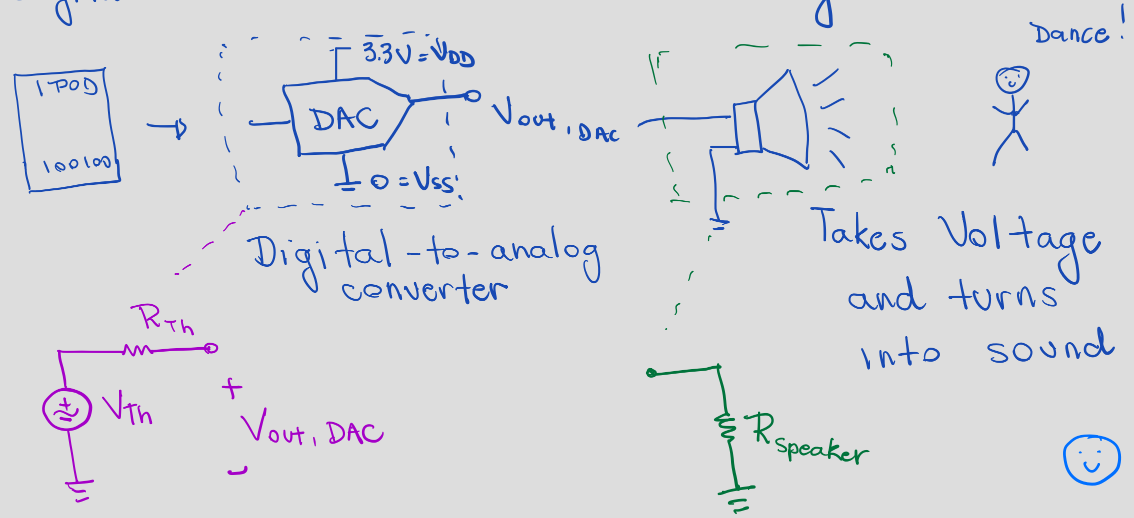
Should be half way between V_{touch} and $V_{notouch}$

New Design – Let's play music

* Want to play music LOUD

↳ Music is stored as digital signal

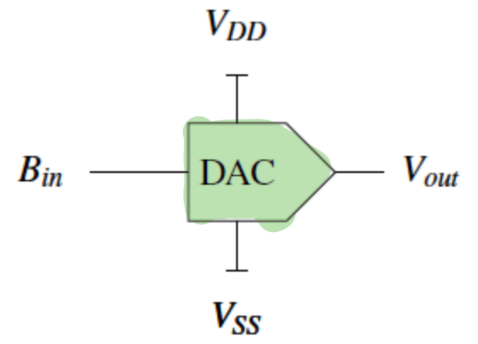
Digital → Analog

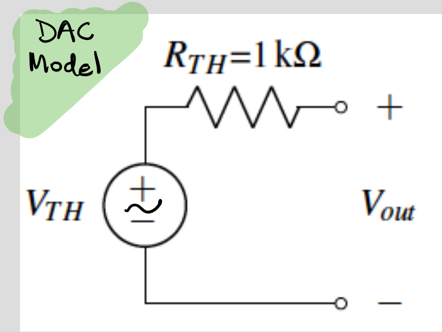


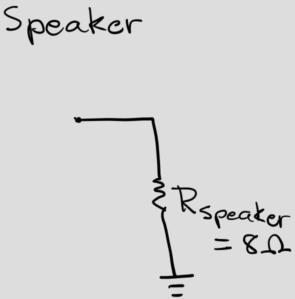
Digital-to-analog converter

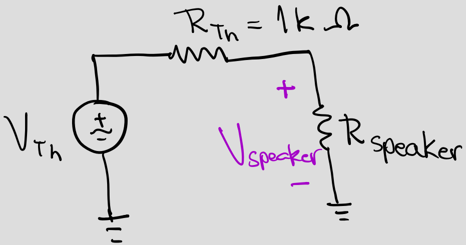
Takes Voltage and turns into sound

Digital to Analog Converter - DAC









Voltage Divider

$$V_{speaker} = \frac{\overset{8\Omega}{\cancel{R_{speaker}}}}{\overset{1000\Omega}{\cancel{R_{Th}}} + \overset{8\Omega}{\cancel{R_{speaker}}}} \cdot V_{Th}$$

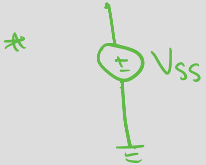
$$V_{speaker} = \frac{V_{th}}{126}$$

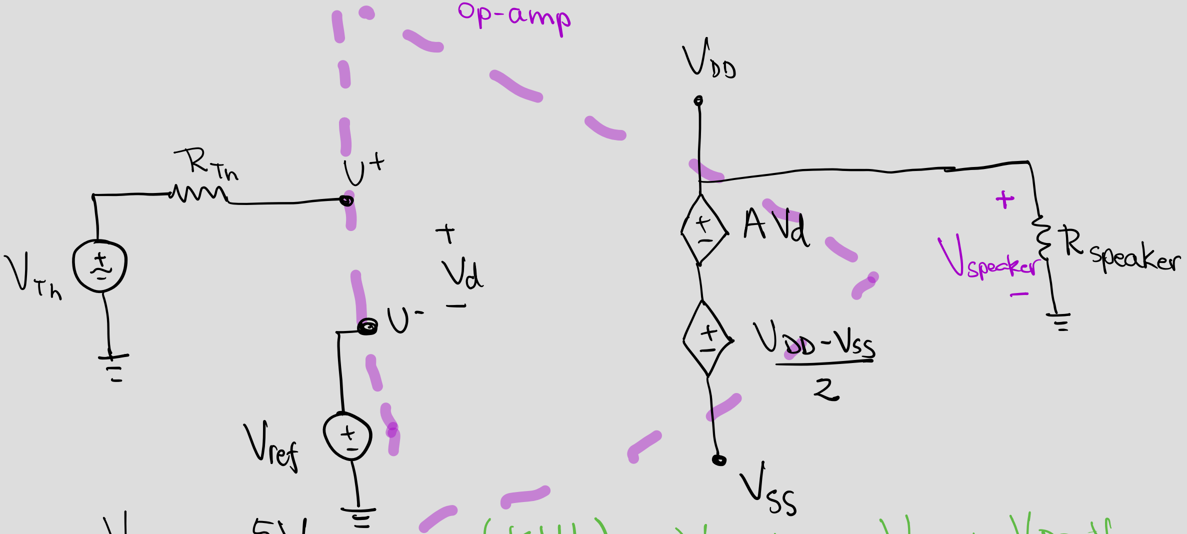
Not loud!

Too quiet!

Need to isolate DAC.

Digital to Analog Converter - DAC





$V_{DD} = -V_{SS} = 5V$

10V output

(Input)

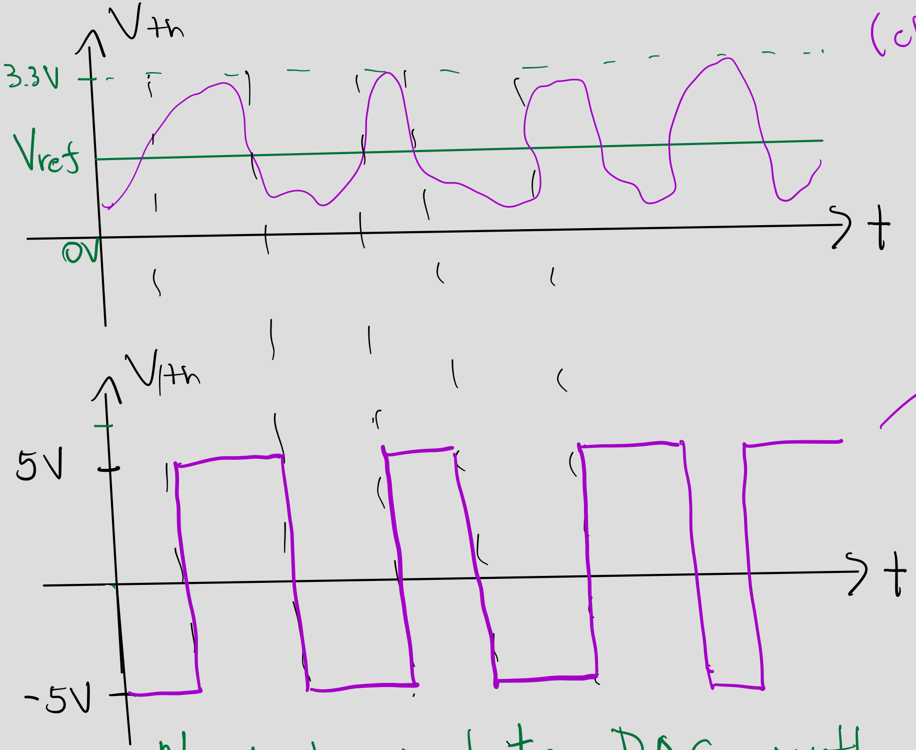
$$V_d = U^+ - U^- = V_{th} - V_{ref}$$

(KVL) $V_{speaker} = \underbrace{V_{SS} + \frac{V_{DD}-V_{SS}}{2}}_{\frac{V_{DD}+V_{SS}}{2} \to 0} + AV_d = AV_d$

when:

$V_{SS} < AV_d < V_{DD}$

Digital to Analog Converter - DAC



(classical music)

Metlalica

Need to isolate DAC with controlable gain!
e.g. 3x

✓