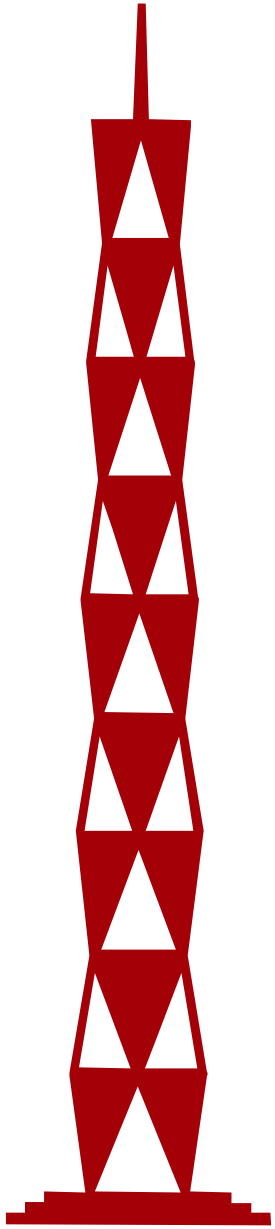


SI100B
Introduction to Information Science and Technology (Part 3: Electrical Engineering)

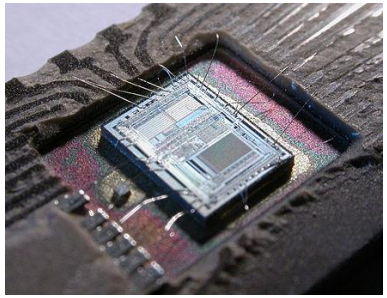
Lecture #6 Analog Circuits

Instructor: Haoyu Wang(王浩宇)

Apr 20th, 2023

The Theme Story

Devices (1)



Circuits (4/5)

Systems (1)

(Figures from Internet)

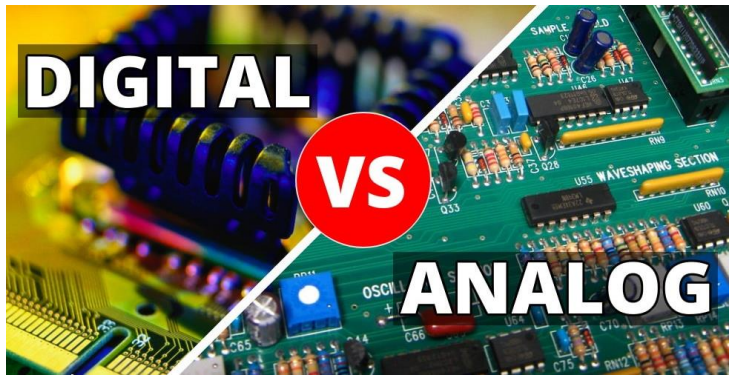
Study Purpose of Lecture #6

- 哲学三问
  - Who are you?
  - Where are you from?
  - Where are you going?

To answer those questions throughout your life

(Figures from Internet)

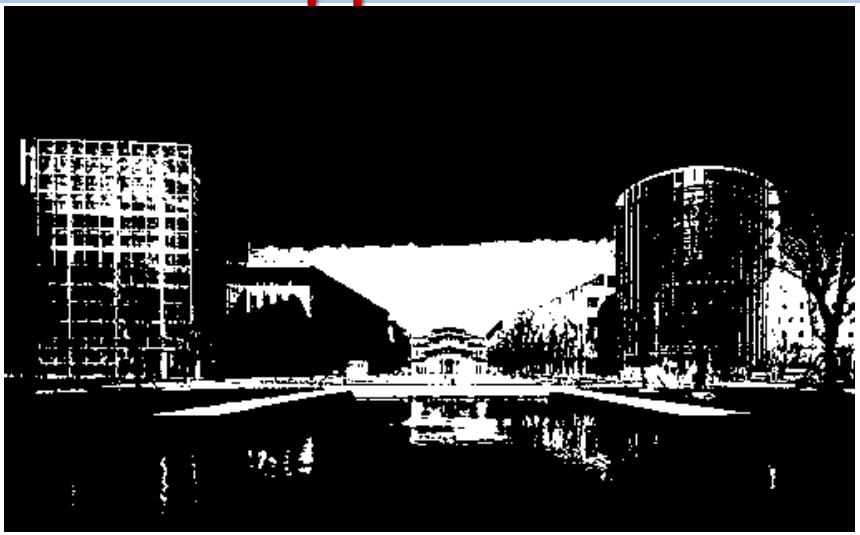
- In this lecture, we ask
  - How to connect a discrete digital machine to the physical world?
  - What are the purpose and basic principle of an analog circuit?
  - How to convert analog (continuous) signal into digital (discrete) signal?



Lecture Outline

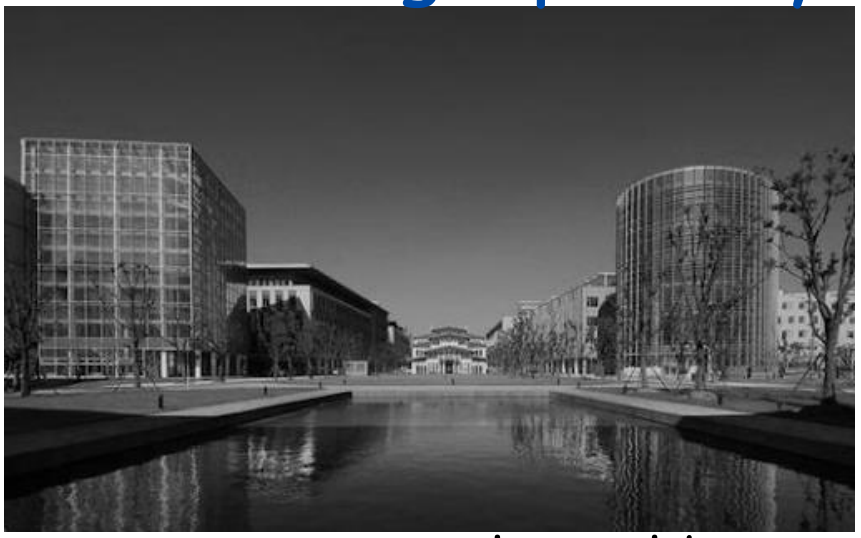
- The real world vs. a binary world
- Fundamentals of **analog (linear) circuit** Amplification
  - Operational amplifier
- Basic MOS **amplifier**
  - Voltage range
  - Frequency limitations
- Analog to digital conversion (ADC)
- Digital to analog conversion (DAC)

How to approximate the real world graphically?



A binary world

every pixel can only be either 1 (black) or 0 (white)



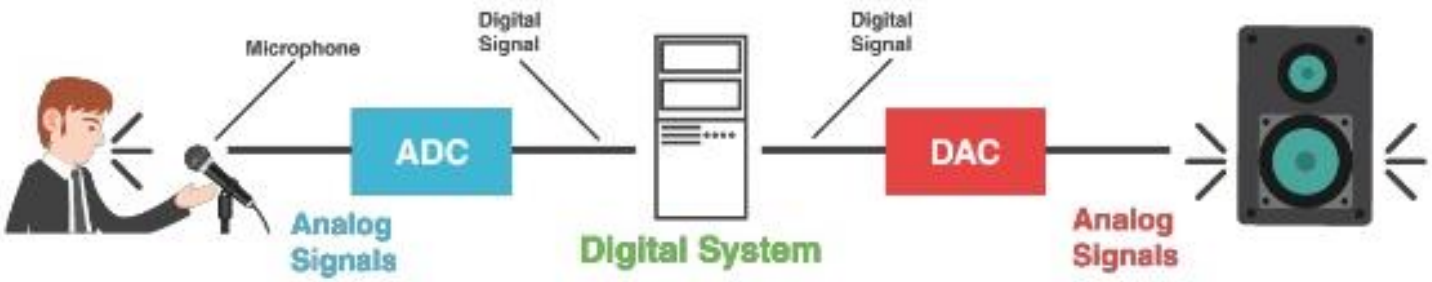
A gray scale world

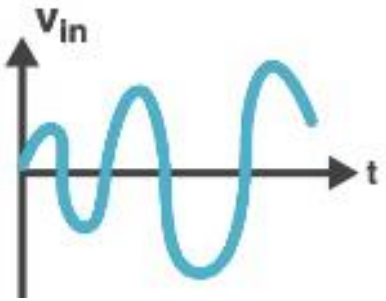
every pixel can only be a number between 1 (black) or 0 (white)

The colorful real world

How to approximate the real world vocally?

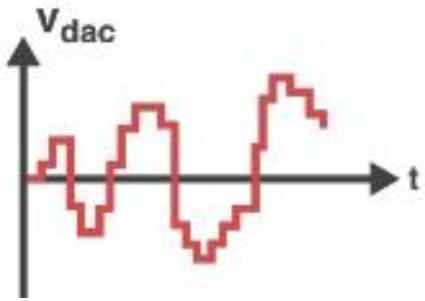
The real world vs. a binary world





Real-world signal

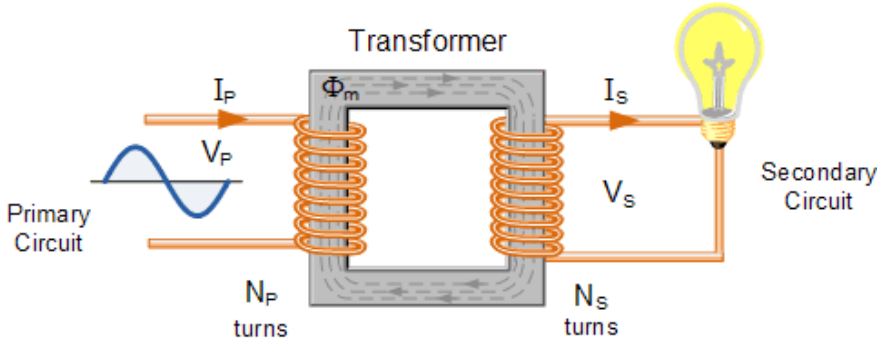
Digital data



Real-world approximation

The importance of amplification

- In the mechanical domain
  - What is amplified?
  - What is reduced?
- In the electrical domain
  - What is amplified?
  - What is reduced?



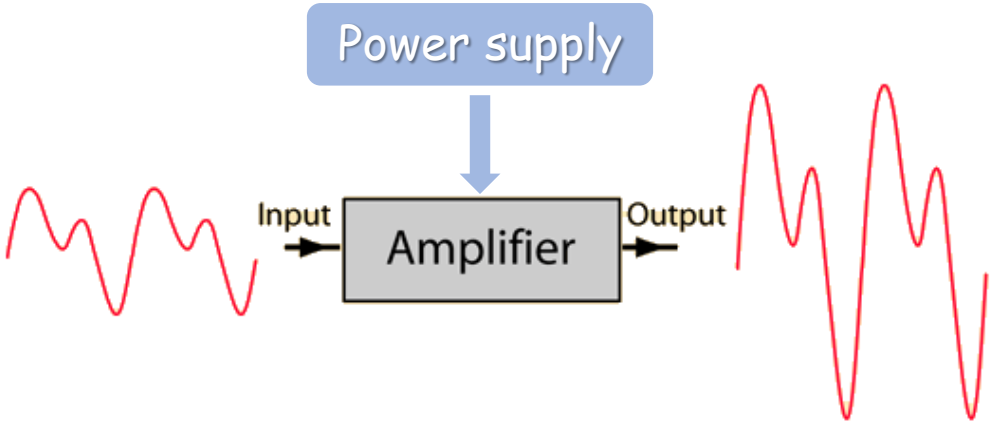
How about these?

- In the mechanical domain
  - What is amplified?
  - What is reduced?

- In the electrical domain
  - What is amplified?
  - What is reduced?

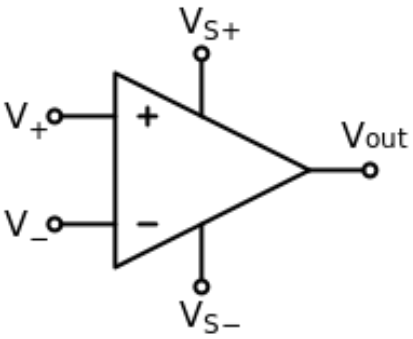
(Electronic) amplifier

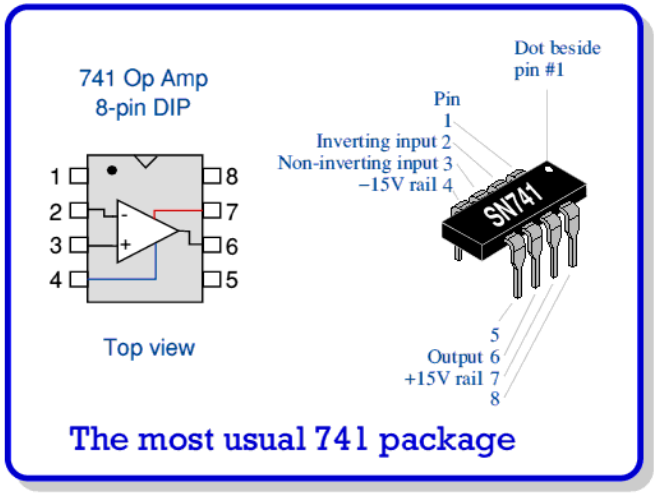
- An electronic device that increases the power of a signal
  - Taking energy from a power supply
  - Controlling the output to match the input signal shape but with a larger amplitude
  - The opposite of an attenuator
  - An amplifier provides gain, an attenuator provides loss



Operational amplifier (op amp)

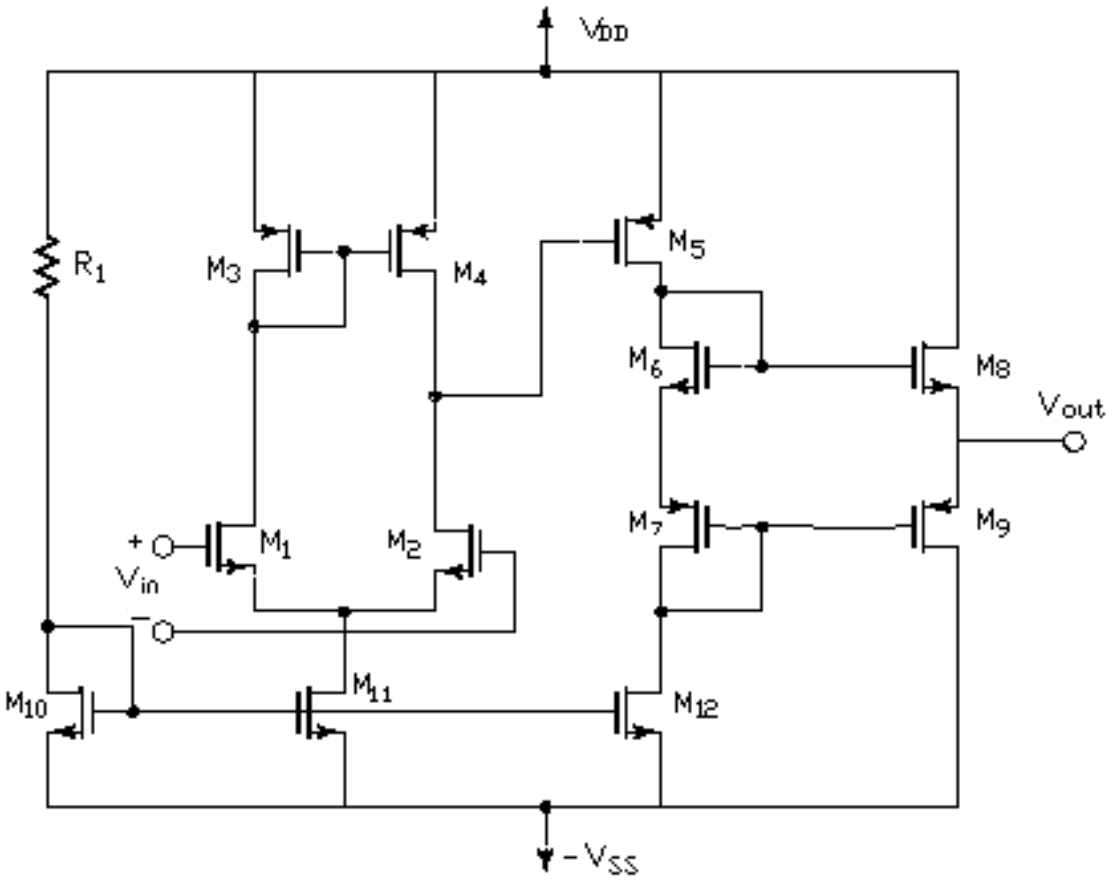
- One of the most widely used electronic devices
- Originally from analog computers for doing mathematical operations
- Characteristics
  - DC-coupled
  - Voltage amplifier
  - High gain ($A \to \infty$)
  - A differential input ($V_+ - V_-$)
  - A single-ended output (V_{out})





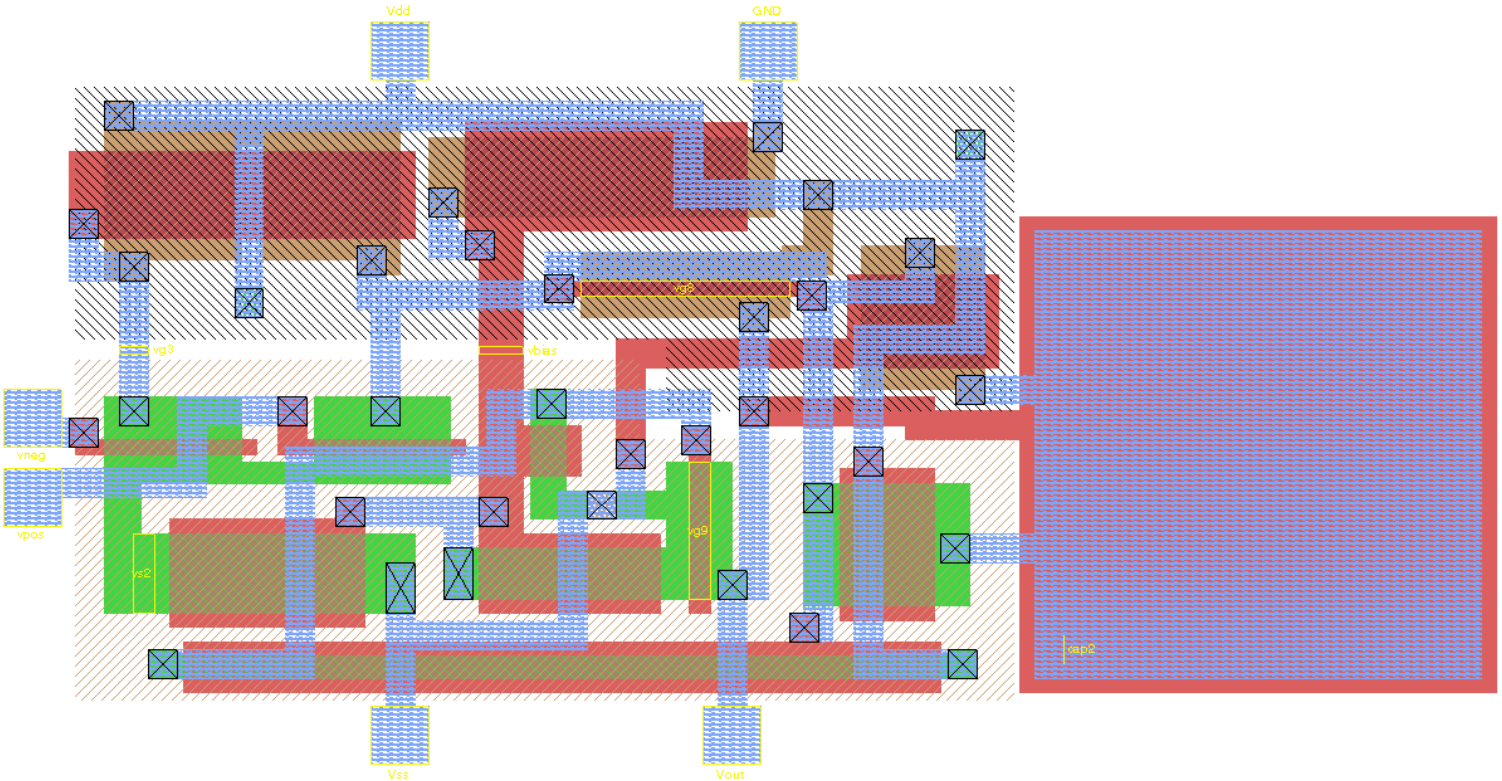
Realization

- CMOS Technology



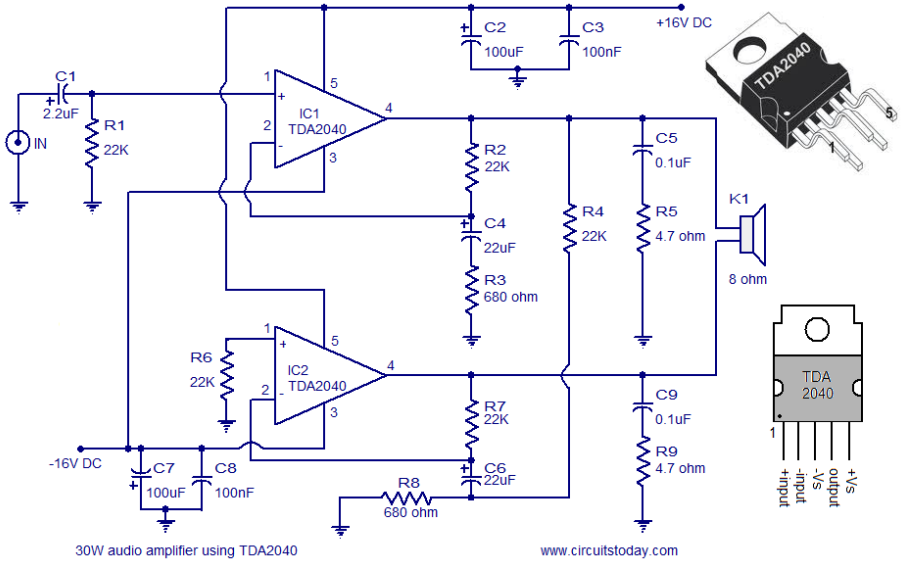
Realization

- Layout view of a simple CMOS operational amplifier

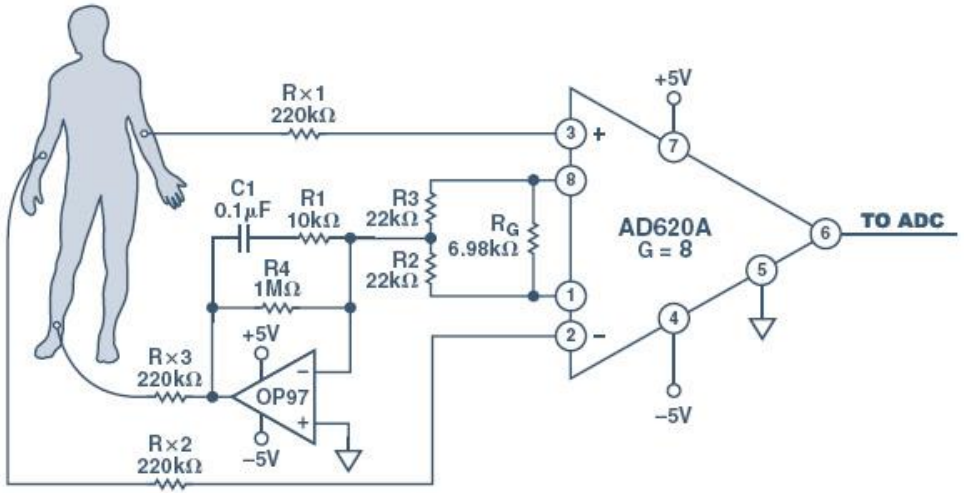


Applications

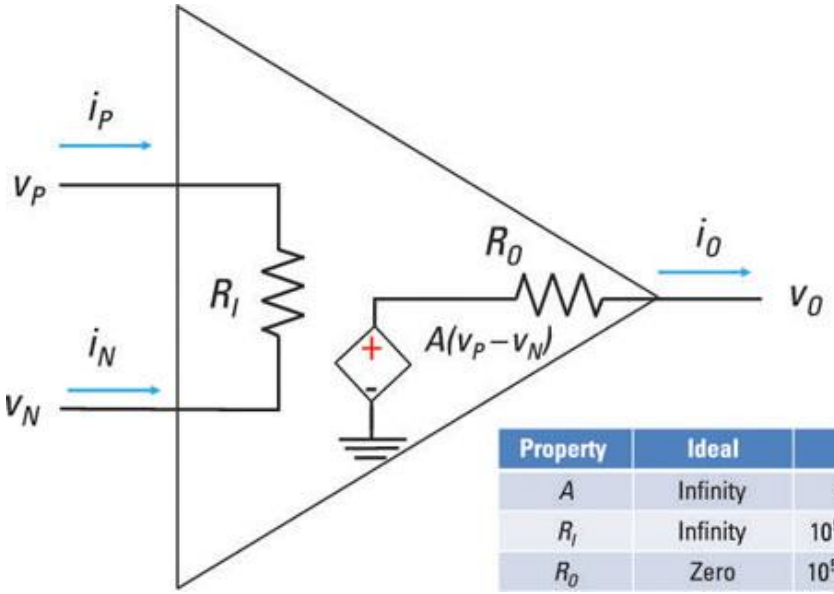
- Audio system



- Bio-electric signal



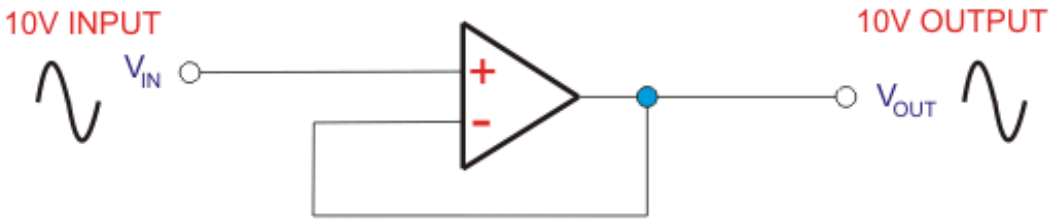
Ideal op amp



Property	Ideal	Typical
A	Infinity	$10^5 < A < 10^8$
R_I	Infinity	$10^5\,\Omega < R_I < 10^8\,\Omega$
R_O	Zero	$10^5\,\Omega < R_O < 10^8\,\Omega$

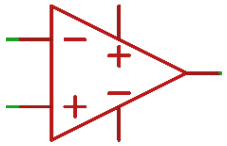
Voltage follower

- A voltage follower is a op-amp circuit which has a voltage gain of 1

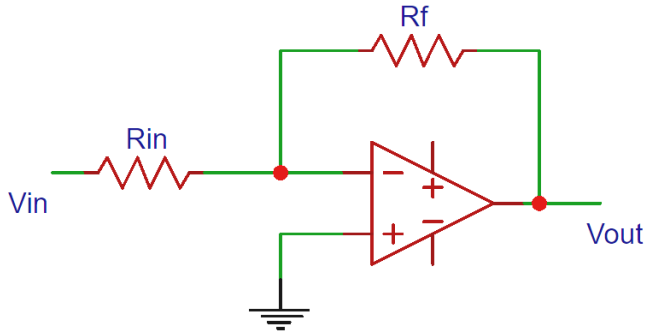


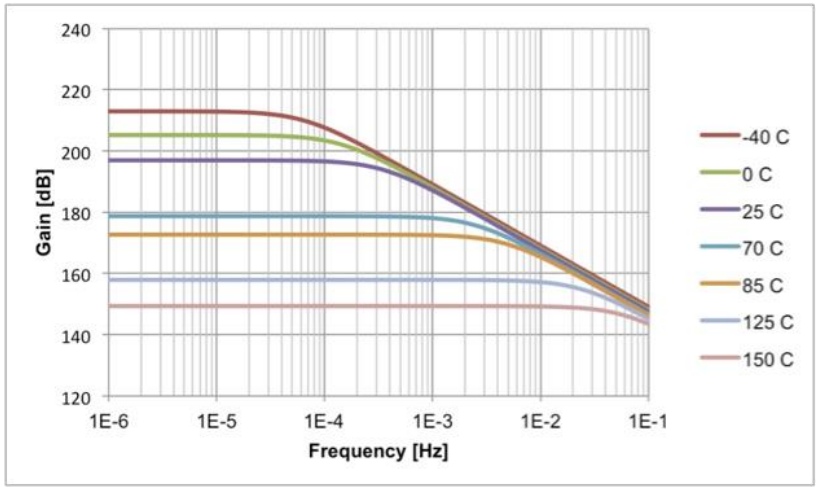
Open-loop and closed-loop gain

- Open-loop gain
  - Large but finite
  - Instable subjected to the manufacturing process, temperature, etc.

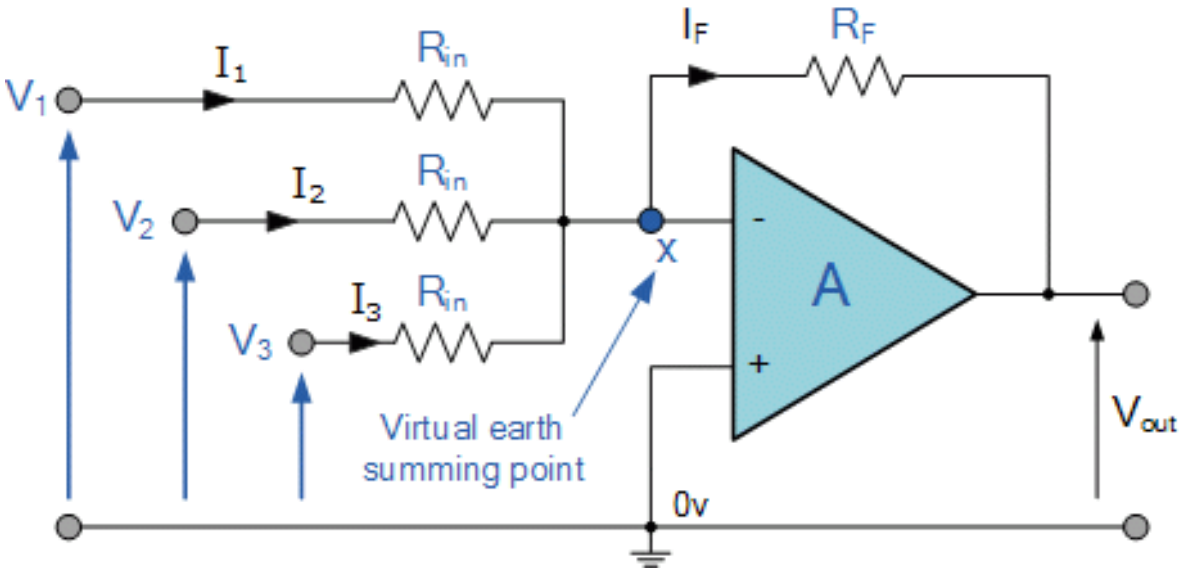


- Closed-loop gain





Summing amplifier circuit



Linear Range vs. Saturation Range

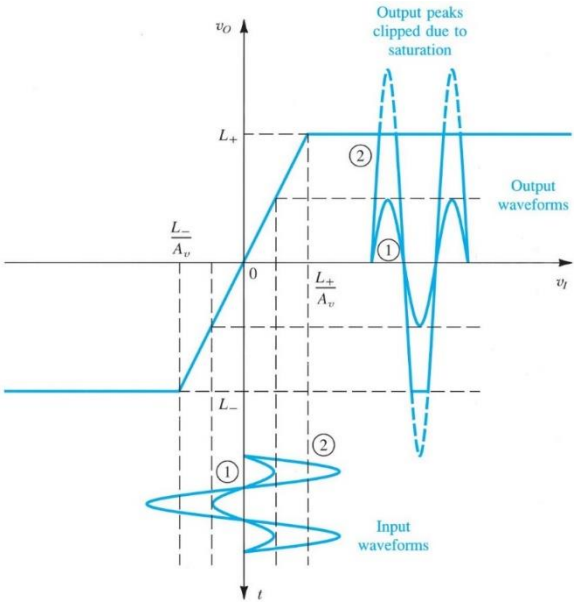
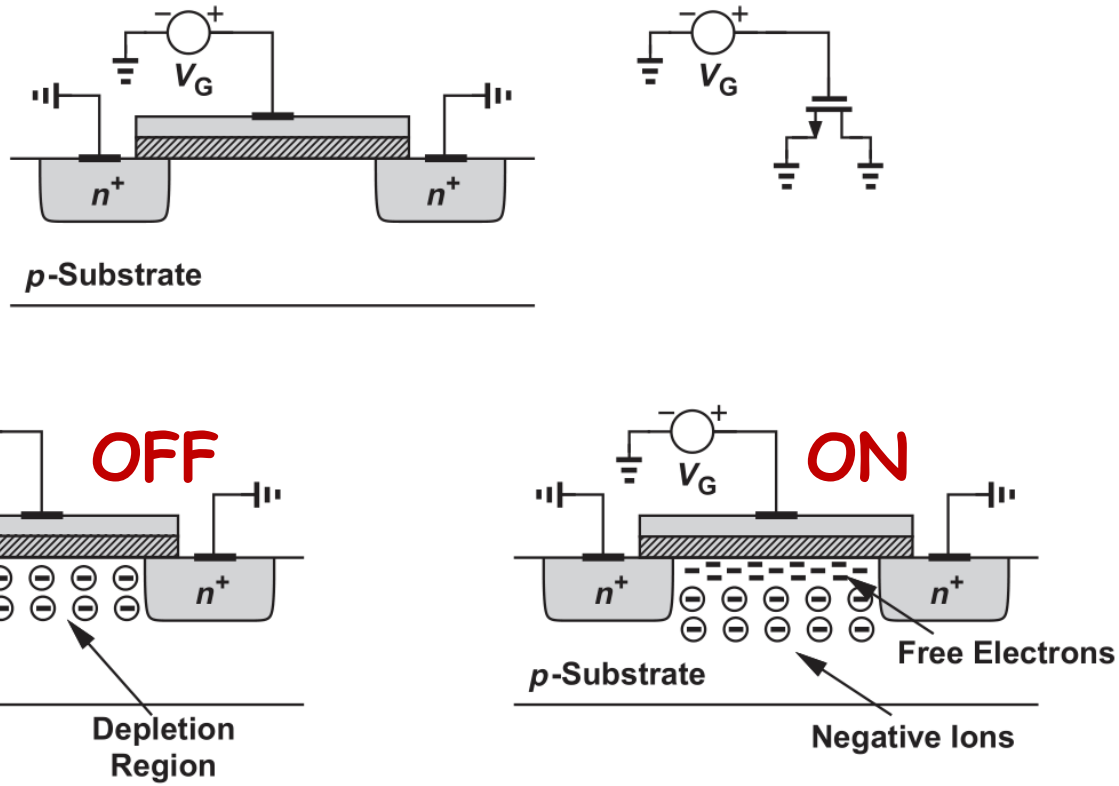


Figure 1.14 An amplifier transfer characteristic that is linear except for output saturation.

- Within linear range, the output voltage (or current) is proportional to the input voltage (or current)

- Beyond linear range, the output voltage (or current) waveforms saturates, resulting in distortions
  - Lose fidelity in stereo system
  - Cause interference in wireless system

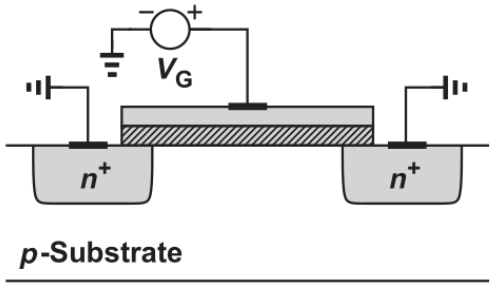
MOSFET in digital applications: a review



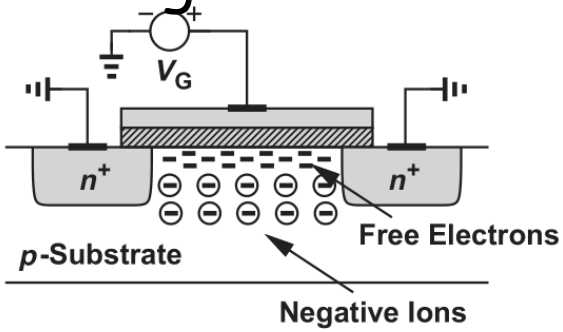
(Razavi, Fundamentals of Microelectronics)

Beyond the on/off states

- For digital electronics
  - Cut off

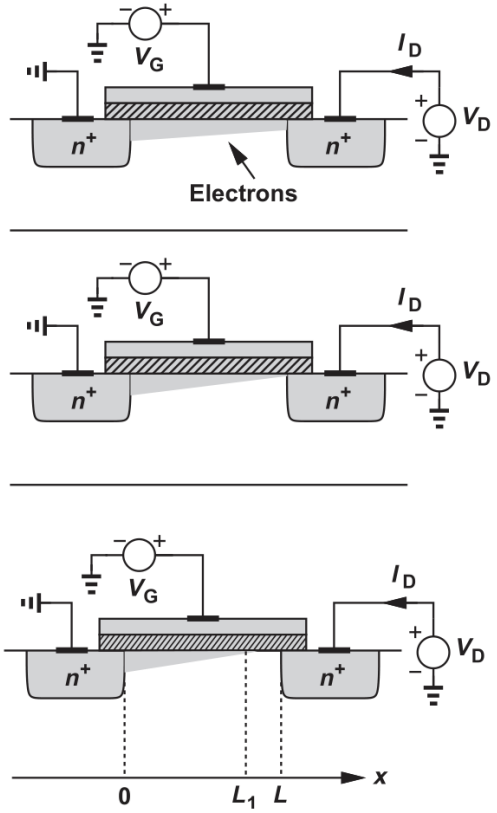


  - Conducting

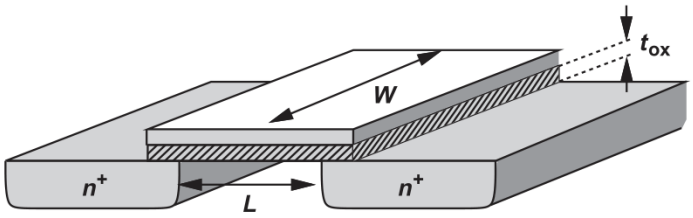


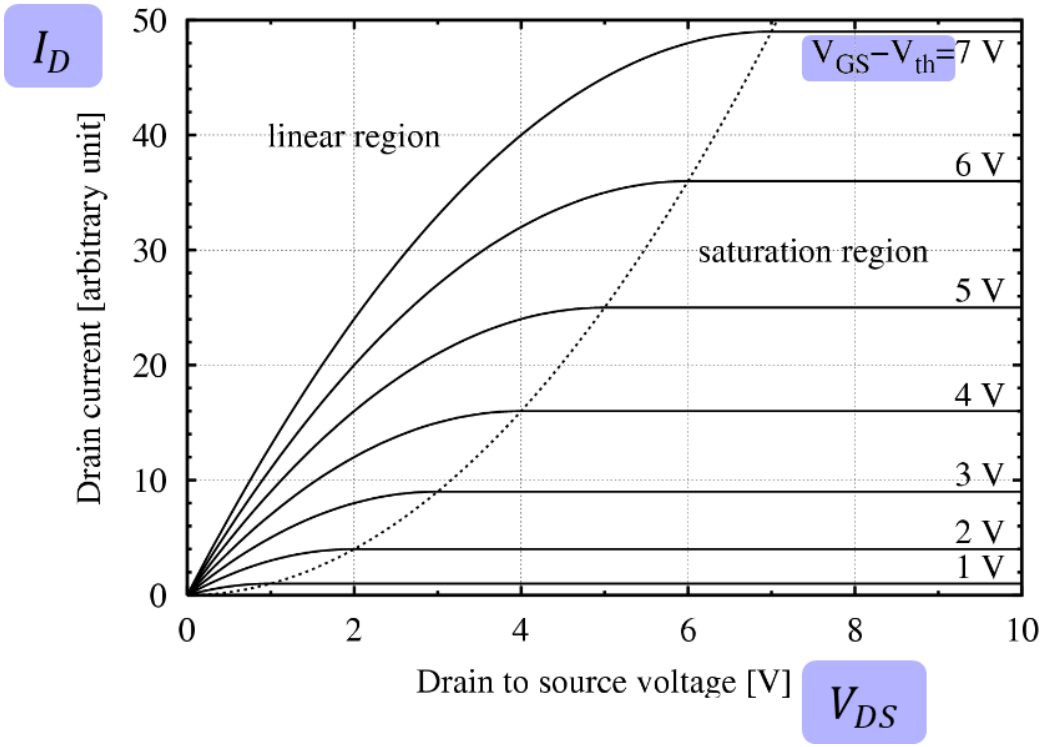
(Razavi, Fundamentals of Microelectronics)

- For analog electronics



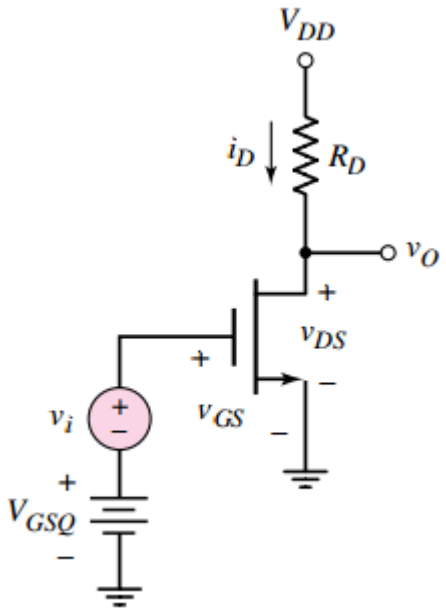
I/V characteristics

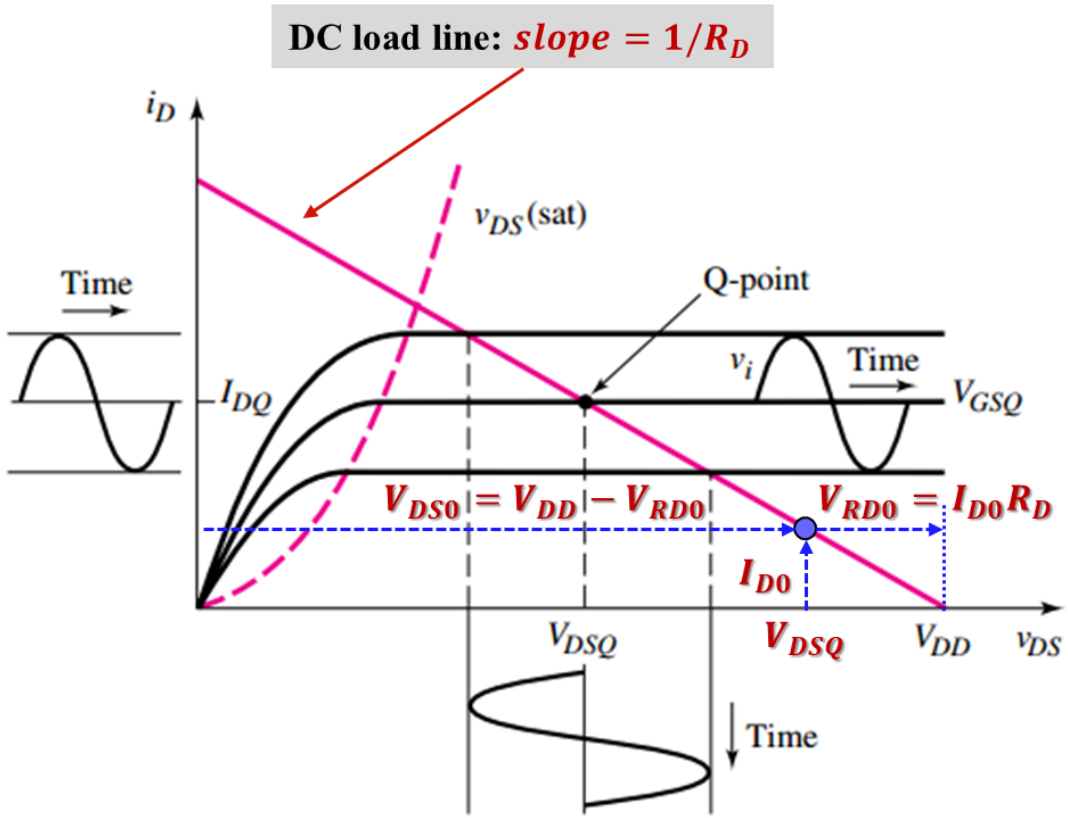




(Razavi, Fundamentals of Microelectronics)

Basic MOS amplifier

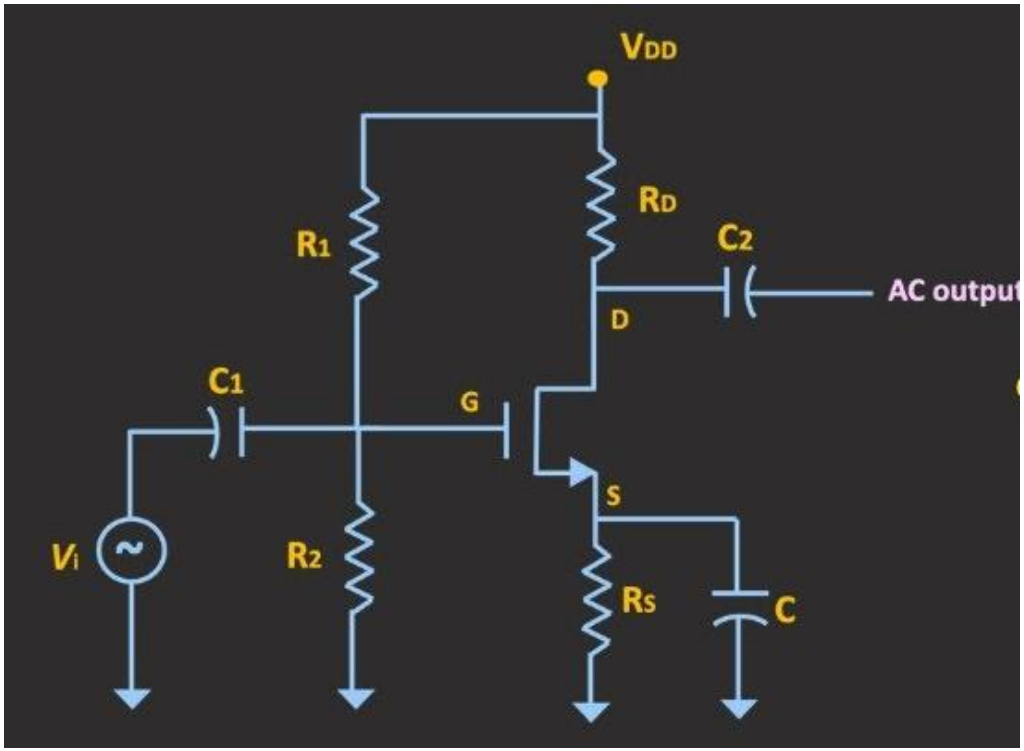




(Neamen, Electronic Circuit Analysis and Design)

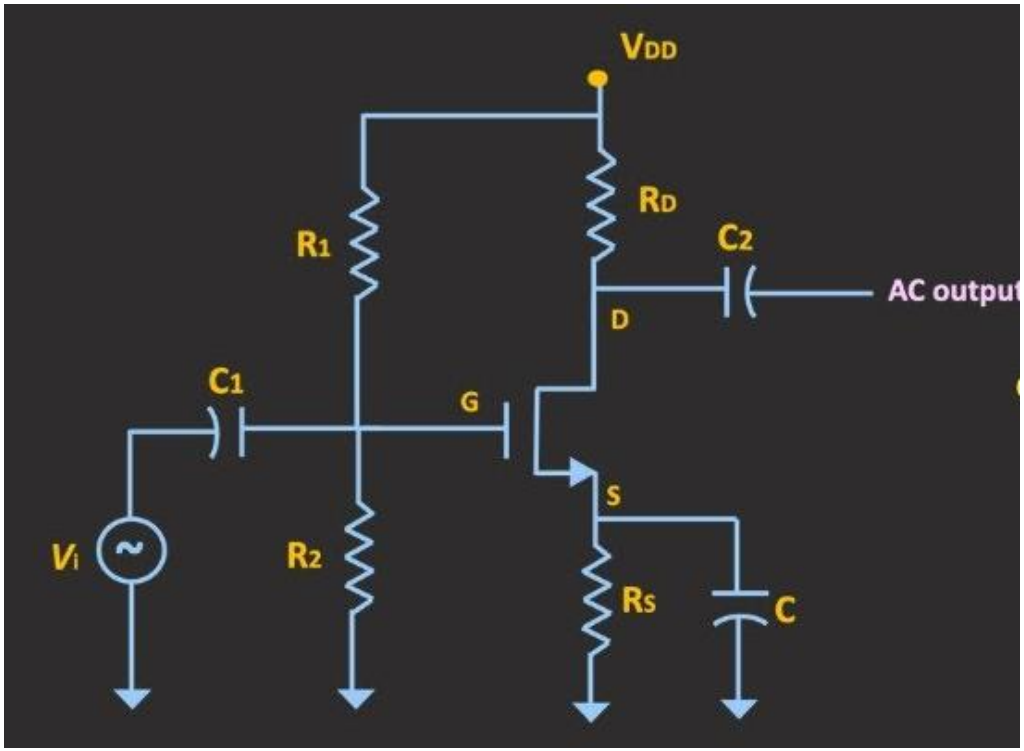
Voltage range limitations

- In a real transistor circuit

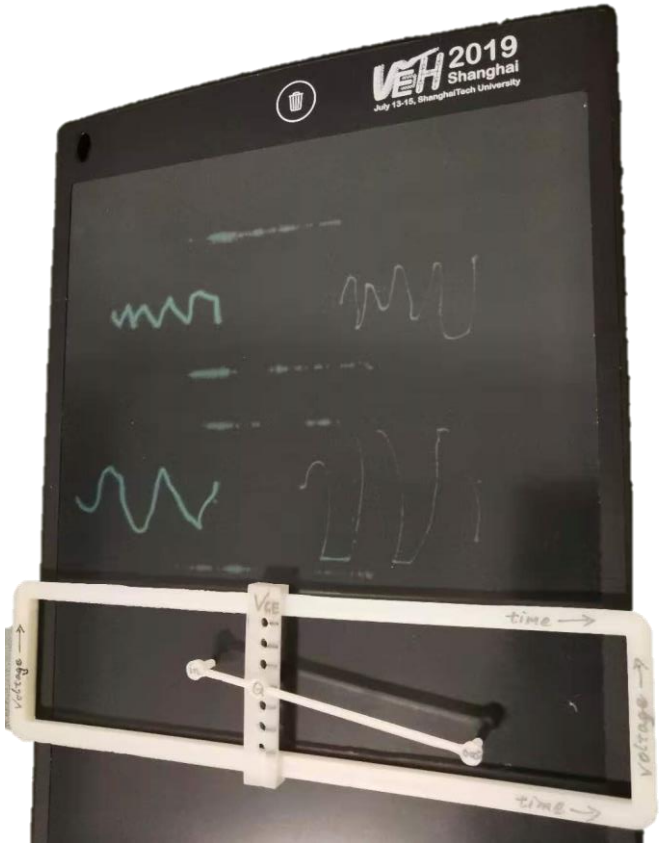


Voltage range limitations

- In a real transistor circuit

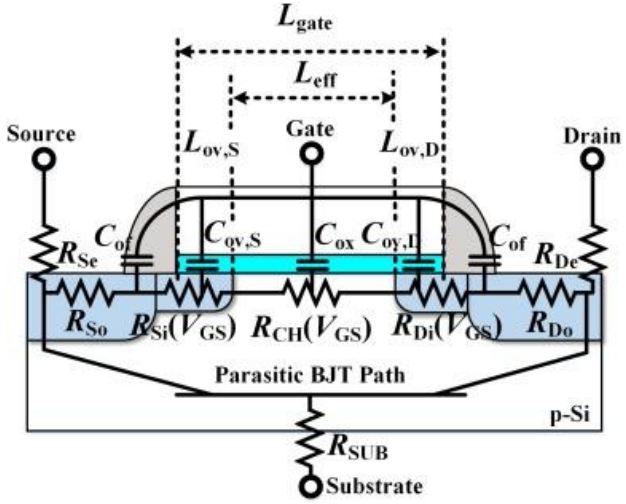


- A lever example

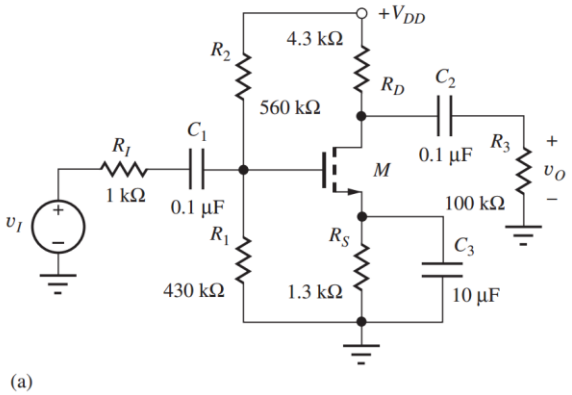


Frequency limitations

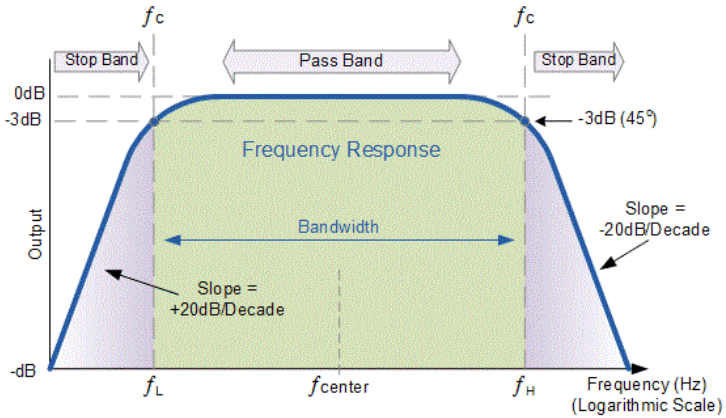
- Parasitic components of a MOSFET



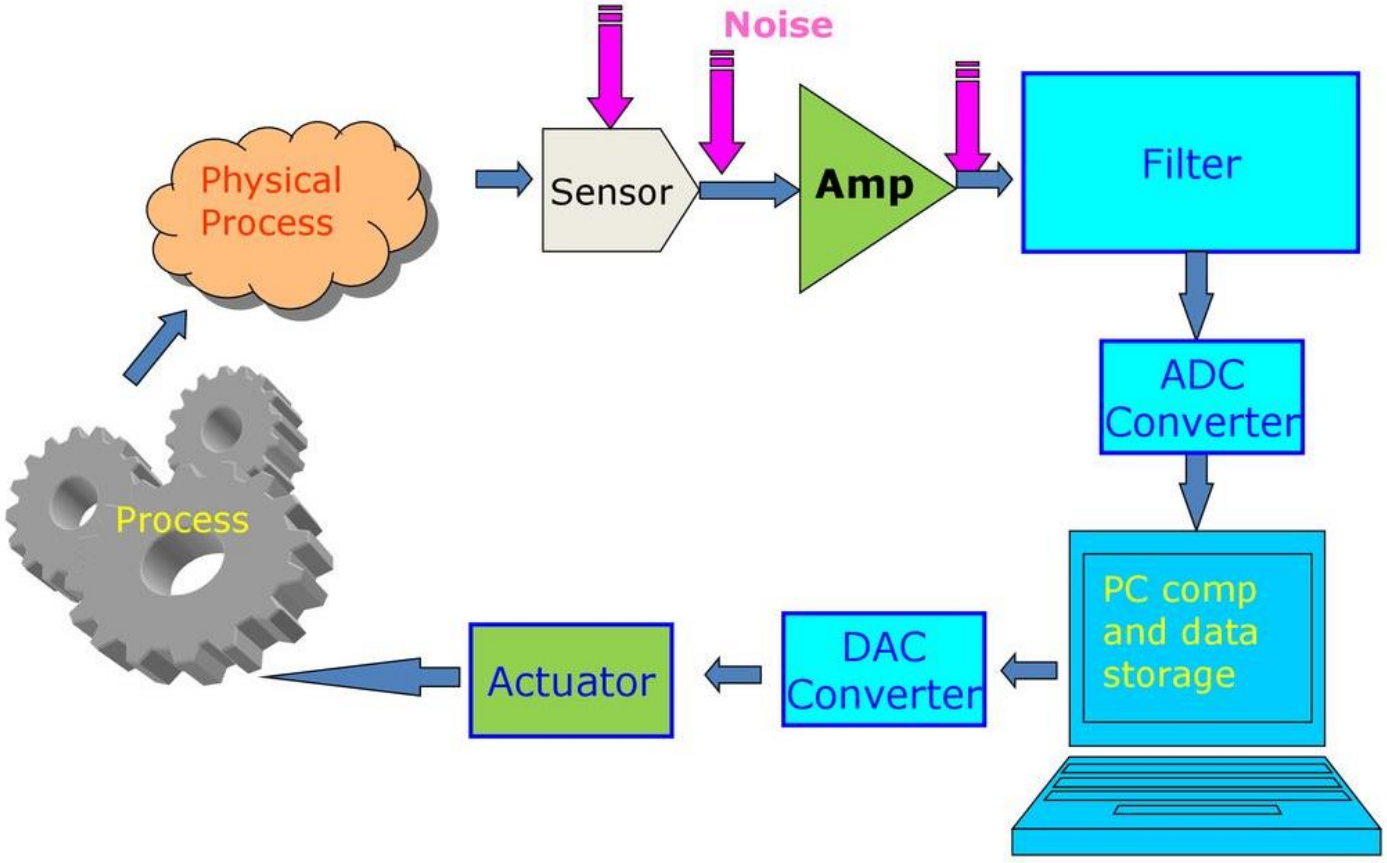
- Coupling capacitance



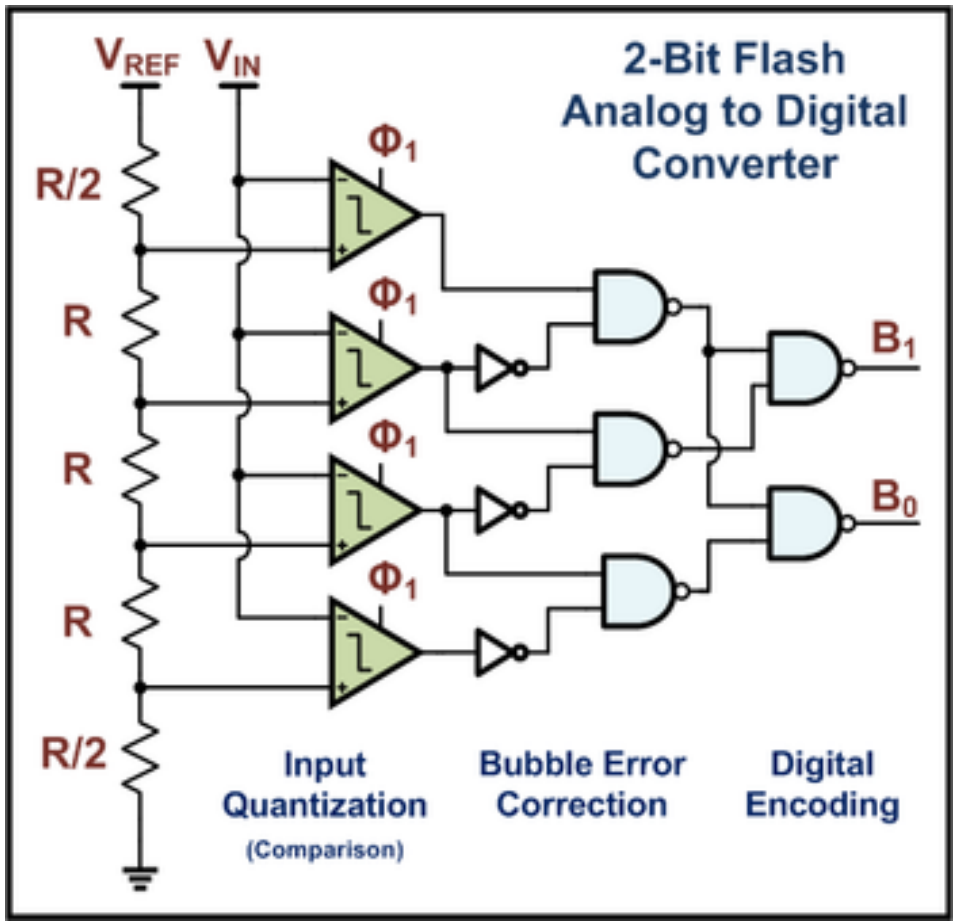
- Frequency response



ADC & DAC

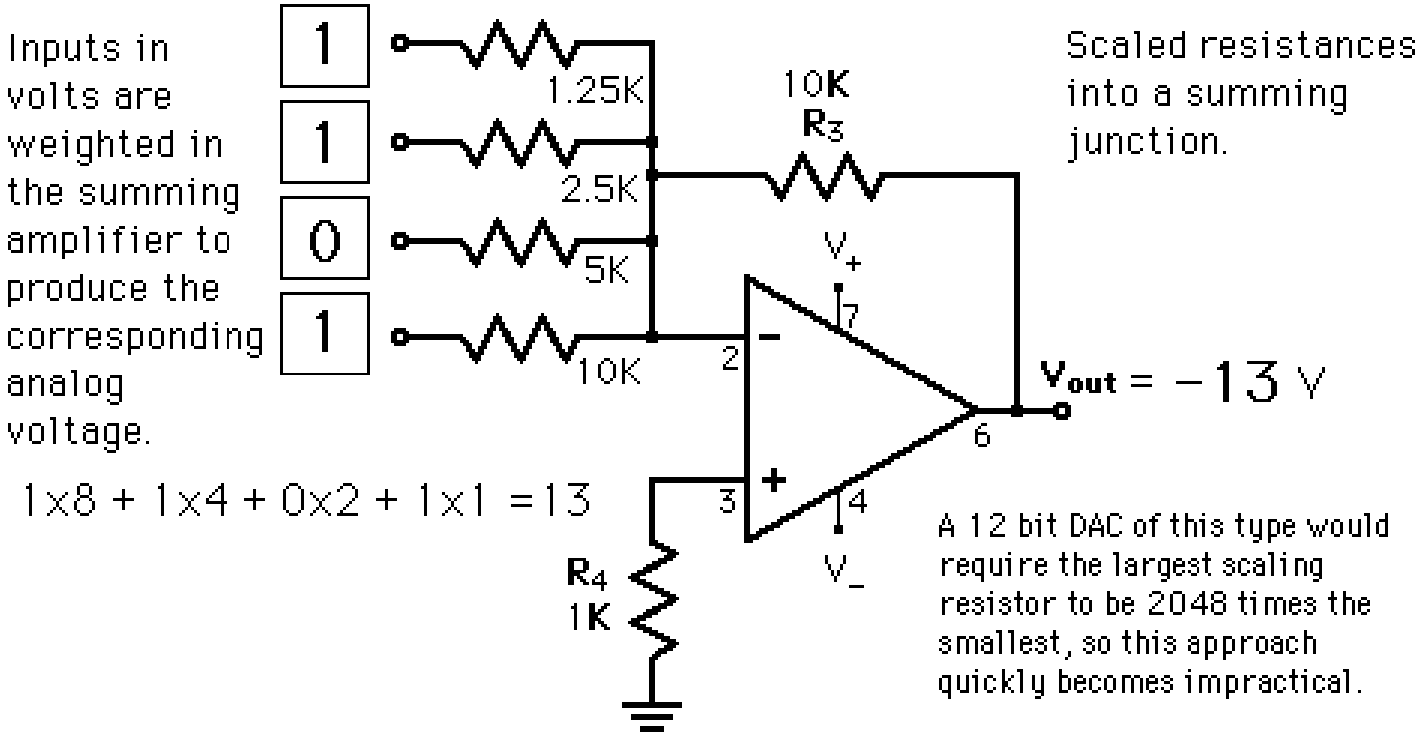

Noise
Physical Process
Sensor
Amp
Filter
ADC Converter
Process
PC comp and data storage
Actuator
DAC Converter

ADC example: Flash ADC (direct-conversion ADC)



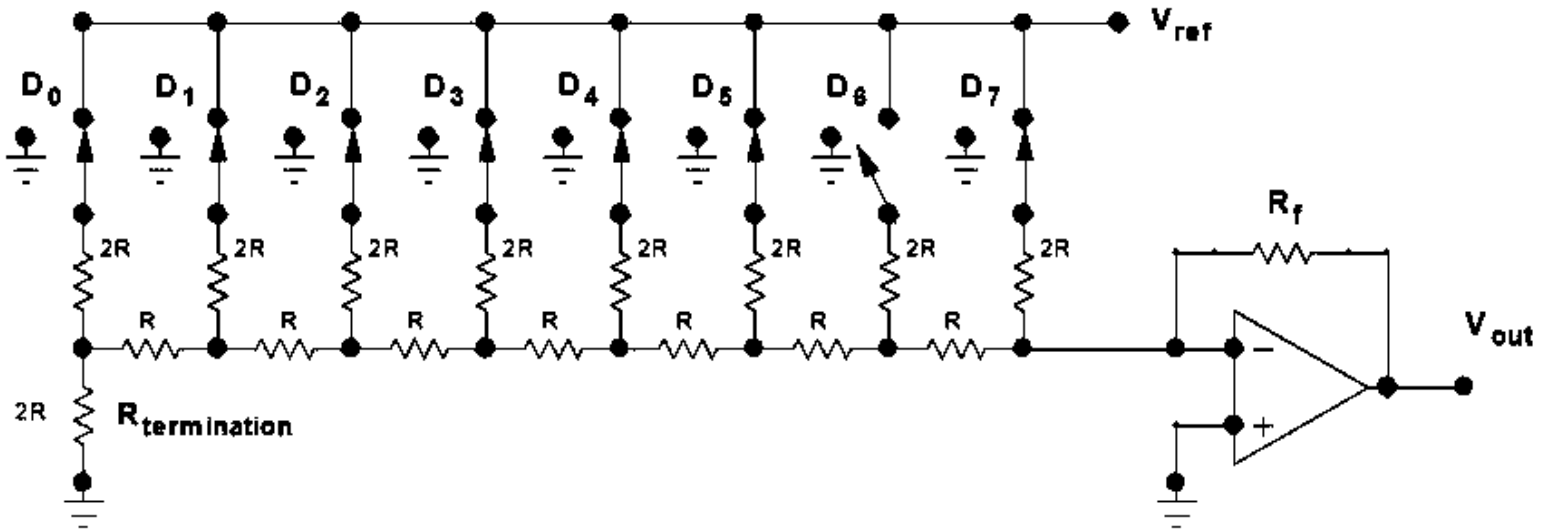
Digital-to-analog converter (DAC)

- The simplest form



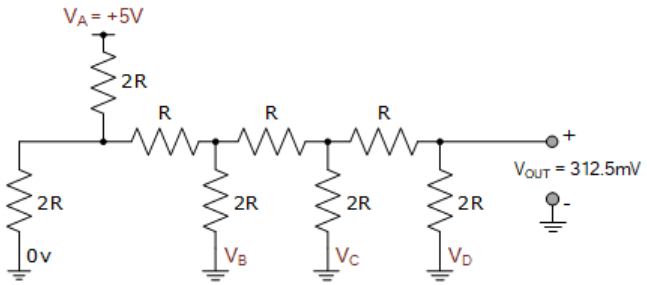
Digital-to-analog converter (DAC)

- The R-2R ladder

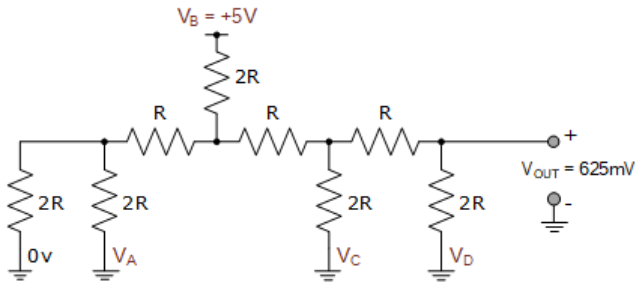


The R-2R ladder DAC

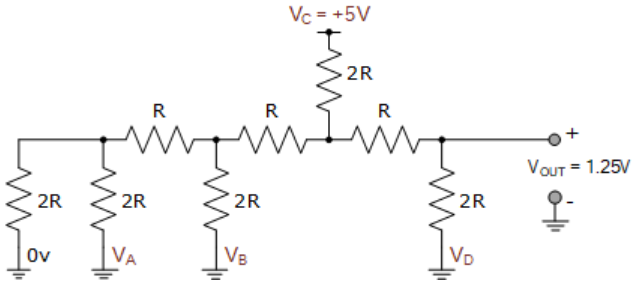
R-2R DAC with Input V_A



R-2R DAC with Input V_B



R-2R DAC with Input V_C



R-2R DAC with Input V_D