Fundamental Electronic 2

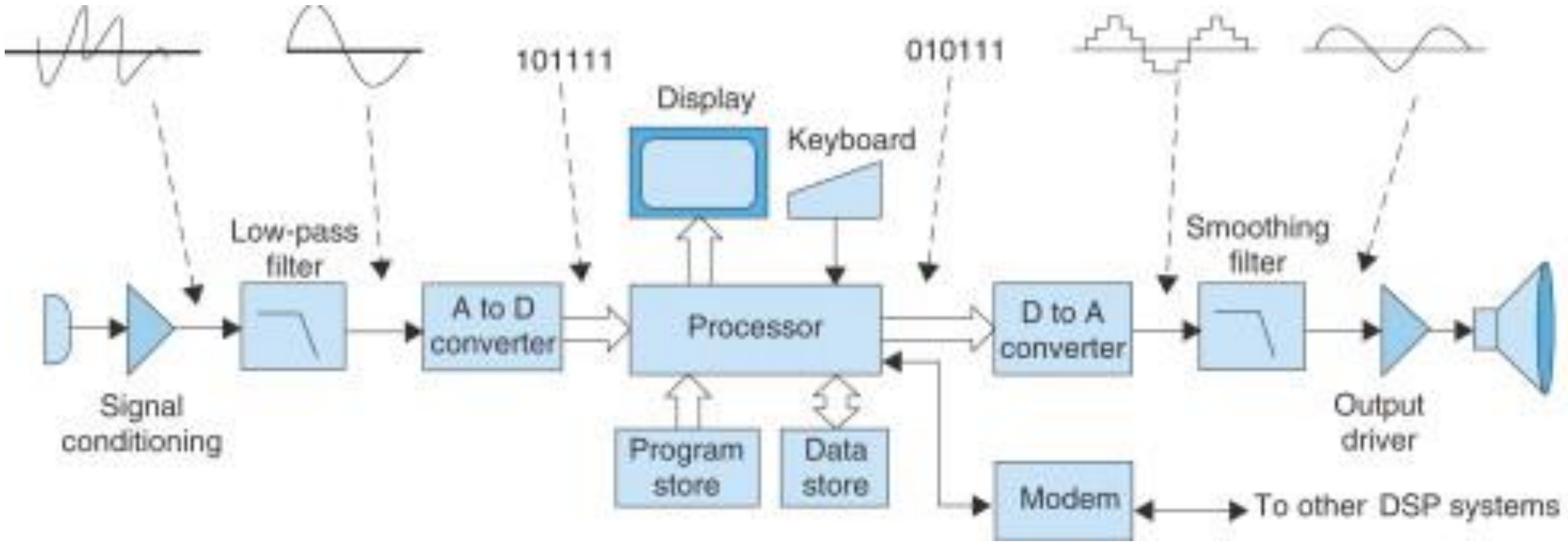
Presented by Dr. A. Djenadi

Motivation: Digital signal processing

Digital signal device

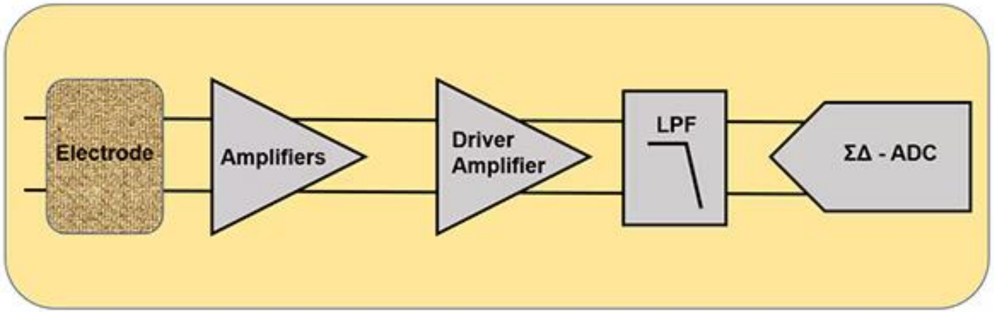
Digital signal processor

Motivation: Digital signal processing

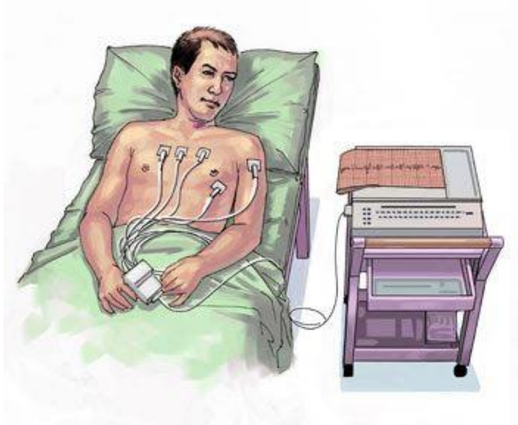


Digital signal basic process (audio signal)

Motivation: Electrocardiography (ECG)

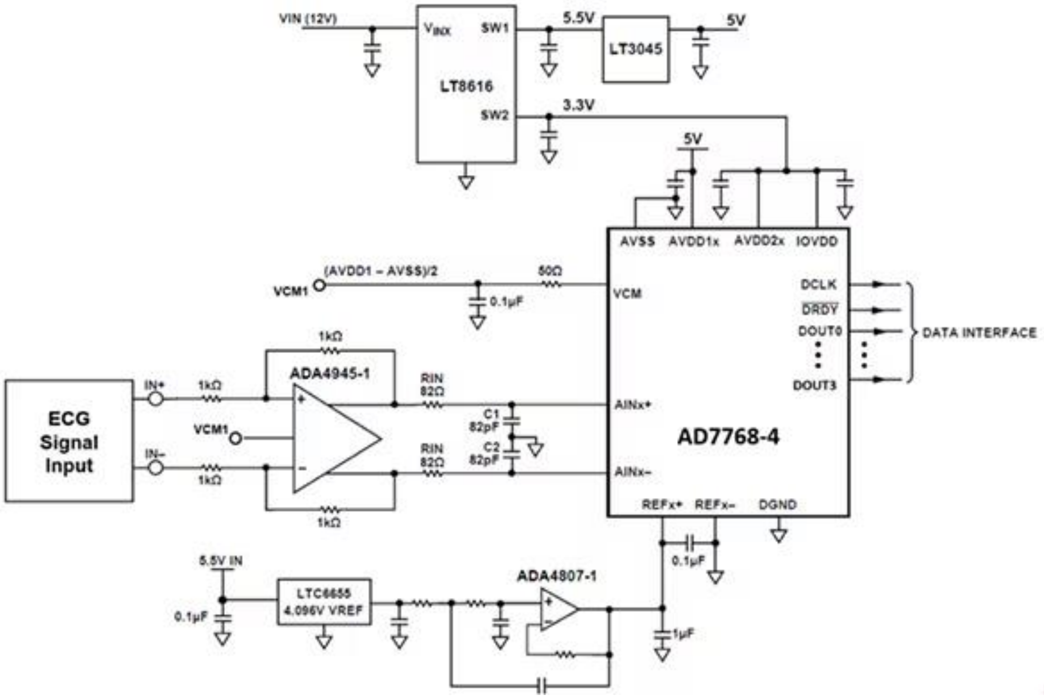


Block diagram of signal conditioning at the ECG input stage
(LPF: Low-Pass Filter, ADC: Analog to Digital converter)



Electrocardiography (ECG)

Motivation: Electrocardiography (ECG)



ECG Circuit: Converting Heart Analog Signals into Digital Data

Module objectives

After completing this course, you should be able to

- Design and analyze circuits centered around the **operational amplifier**.
- Generate **analog and digital signals**.
- Understand the different operating principles of **A/D and D/A converters**.
- Grasp the operation of basic setups in a **data acquisition system** (sample and hold circuits, converters, amplifiers, clock).
- Master an **analog modulation technique**.

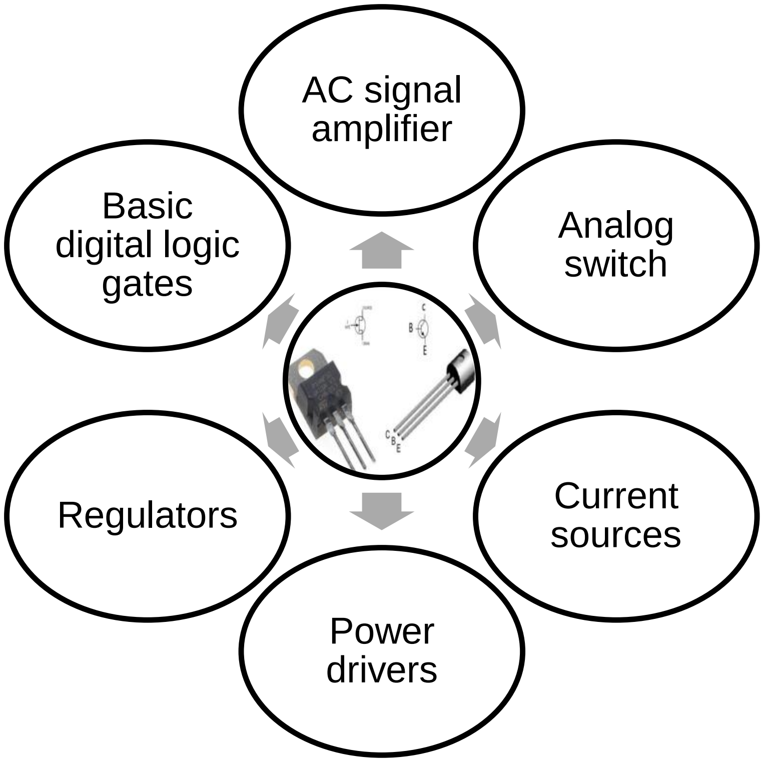
CHAPTER 1: OPERATIONAL AMPLIFIER

Chapter 1: Operational Amplifier

PART 1: INTRODUCTION TO OPERATION AMPLIFIER

Introduction: context

In fundamental Electronic 1, we learned about circuit design with active “discrete devices” including: transistors (BJT, FET) and diodes, along with passive devices including resistors and capacitors used to set bias, couple and block signals and more.



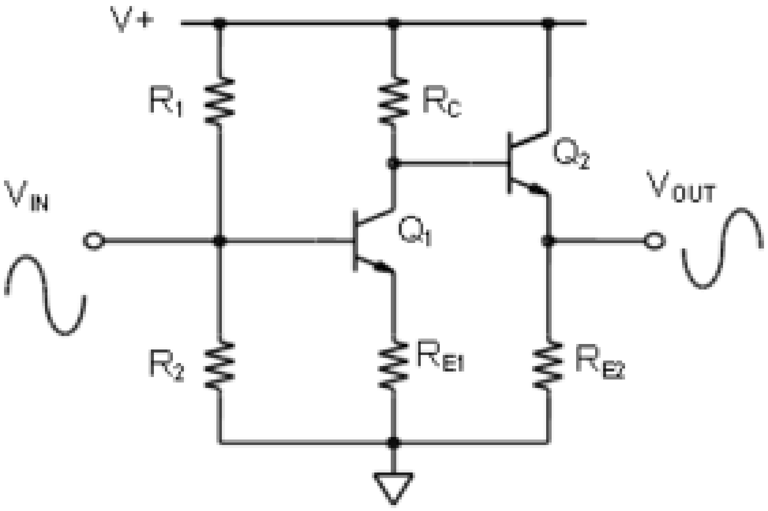
Introduction: context

However, those circuits showcases complexities or imperfections including:

- Low voltage gain.
- Lack for the ability to amplify DC signals
- Nonlinearity (Because its equations are exponential and its parameters vary).
- Variability in voltage V_{BE} and β with the change in the temperature.

Introduction: context

A prominent solution is to consider cascading multiple amplifier stages. For instance, the **common emitter / common collector cascade amplifier.**



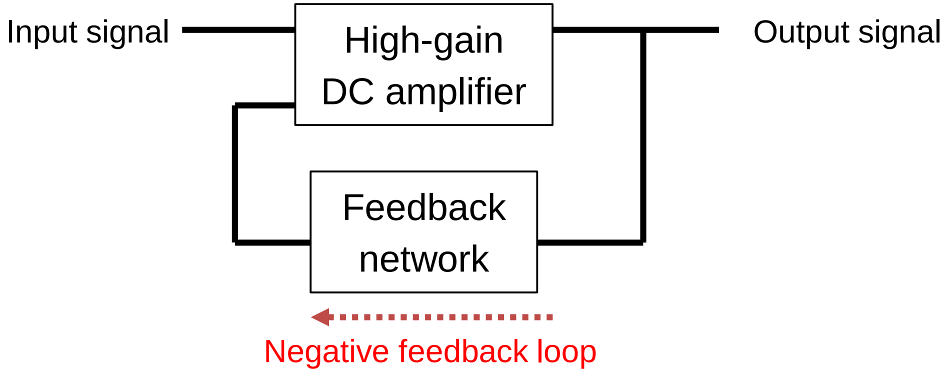
CE-CC cascade amplifier

Advantages:

- Increased gain
- Better amplification of signals

Introduction: context

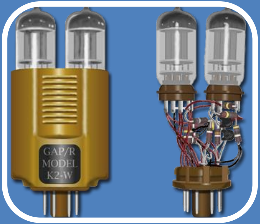
A better solution consists in **applying negative feedback** to a high-gain DC amplifier, which linearizes the circuit and provides an accurate gain determined solely by the **feedback network**.



$$Gain = \frac{Output\ signal}{Input\ signal}$$

Introduction: context

Following the same design, more complex circuits were developed for various purposes including the **operational amplifier (op-amp).**

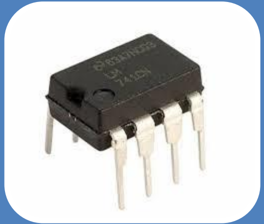


1941

- **A vacuum tube op amp**

1963

- **A monolithic IC op amp** (µA702)



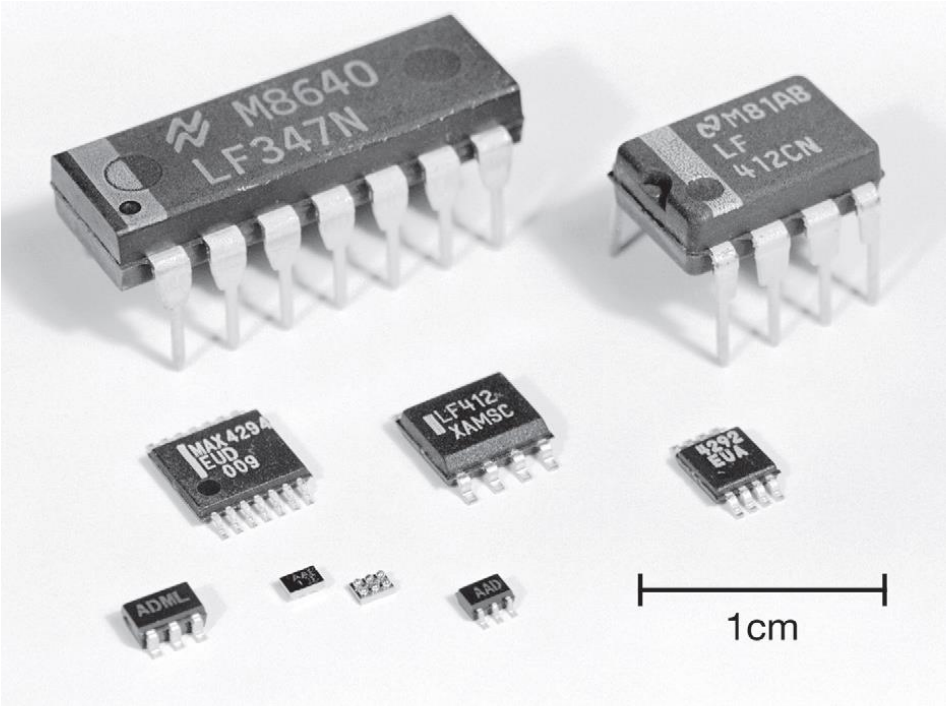
1968

- **µA741 chip**

Introduction: context

The **op-amps are widely used in the field of electronics**.

They are available in a wide range of package types

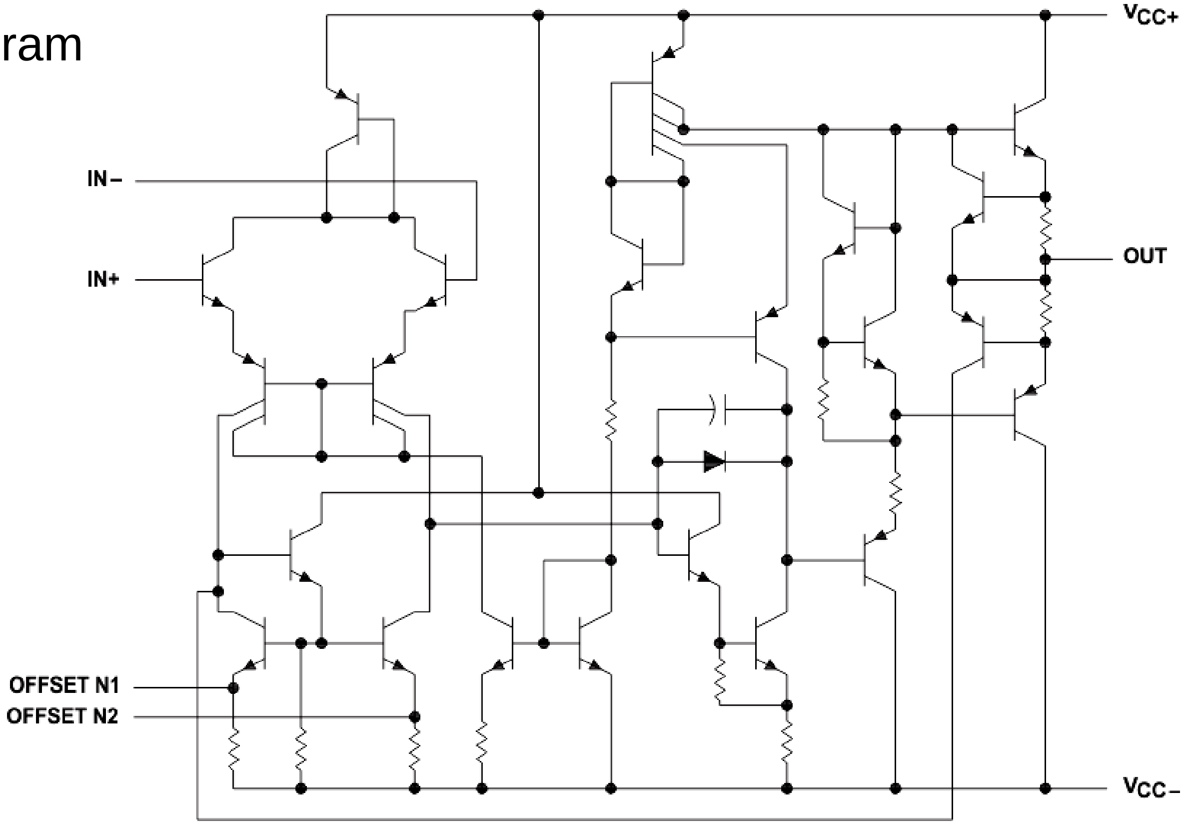


Introduction: context

Op-amps applications

- Voltage amplifiers (Ex. audio amplifiers),
- Mathematical operations like addition, subtraction.
- used in measurement and data acquisition systems.
- Signal Conditioning.
- Signal Modulation and Demodulation

μA741 Functional Block Diagram



Component Count	
Transistors	22
Resistors	11
Diode	1
Capacitor	1

Note:

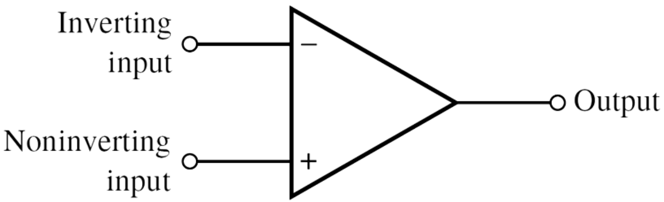
In our study, we consider the entire circuit as a unified device, focusing our attention on the inputs and output.

Introduction

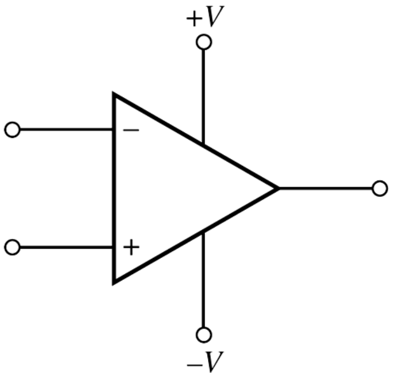
Definition

An operational amplifier (op-amp) is a **high-gain** **differential amplifier** characterized by **high** **input impedance** and **low** **output impedance**.

Terminals and Symbols



(a) Symbol

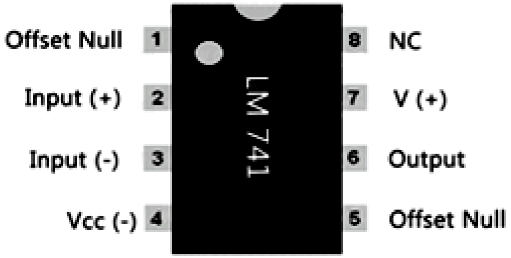


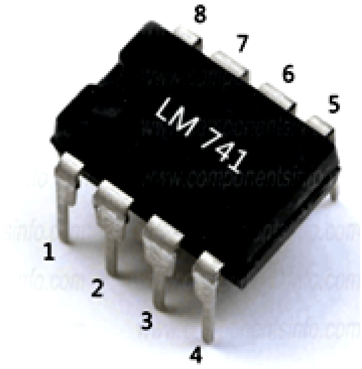
(b) Symbol with dc supply connections

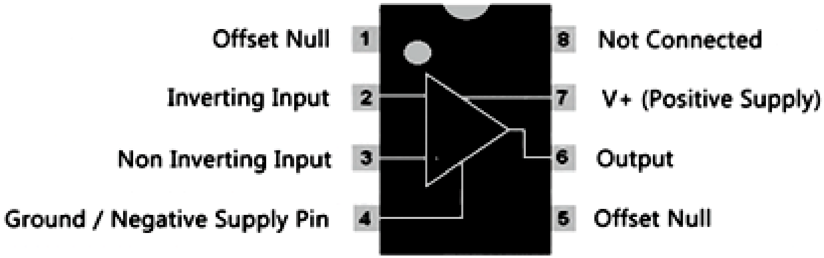
Introduction

Terminals and Symbols

LM741 terminals description

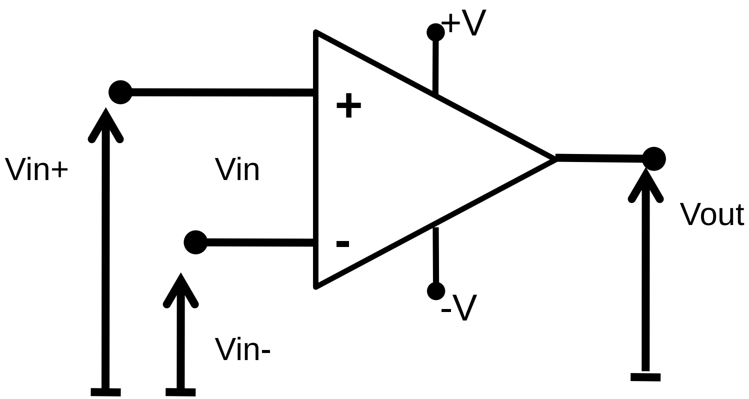






Introduction

Output voltage :



$$\boxed{V_{out} = A_v(V_{in}^{+} - V_{in}^{-}) + V_0}$$

$$\begin{cases} V_{in} = V_{in}^{+} - V_{in}^{-} \\ V_0 = A_{cm}\left(\dfrac{V_{in}^{+} + V_{in}^{-}}{2}\right) \\ V_{sat}^{-} < V_{out} < V_{sat}^{+} \end{cases}$$

- V_{out}: Output voltage
- V_{in}^{+}: non-inverting input
- V_{in}^{-}: inverting input
- +V, -V: Supply voltages

- A_v: Differential gain
- V_0: Common-mode output voltage
- A_{cm}: Common-mode gain
- V_{sat}: saturation threshold

Introduction

Output voltage :

We define: $CMRR = \frac{A_v}{A_{cm}}$ as the common-mode rejection ratio

We have:

$$V_{out} = A_v(V_{in}^+ - V_{in}^-) + V_0 = A_v(V_{in}^+ - V_{in}^-) + A_{cm}\left(\frac{V_{in}^+ + V_{in}^-}{2}\right) = A_v(V_{in}^+ - V_{in}^-) + \frac{A_v}{CMRR} \cdot \frac{V_{in}^+ + V_{in}^-}{2}$$

$$\boxed{V_{out} = A_v\left[\left(1 + \frac{1}{2CMRR}\right)V_{in}^+ - \left(1 - \frac{1}{2CMRR}\right)V_{in}^-\right]}$$

<u>Note:</u> This equation makes the model more accurate but also more complicated

Introduction

Output voltage :

The CMRR is parameter that is typically very large, For example, a typical LF351 operational amplifier has $A_V = 10^5$ and $CMRR = 10^5$. This means that:

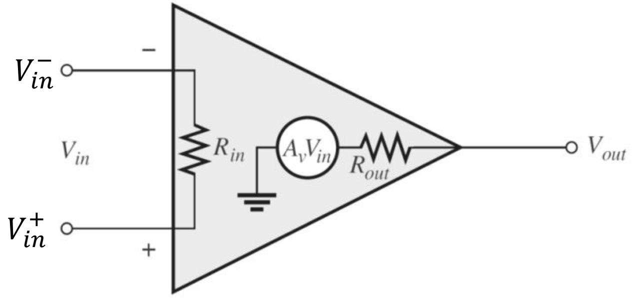
$$V_{out} = A_v\left[\left(1+\frac{1}{2CMRR}\right)V_{in}^{+} - \left(1-\frac{1}{2CMRR}\right)V_{in}^{-}\right] = 100000{,}5\cdot V_{in}^{+} - 99999{,}5\cdot V_{in}^{-}$$

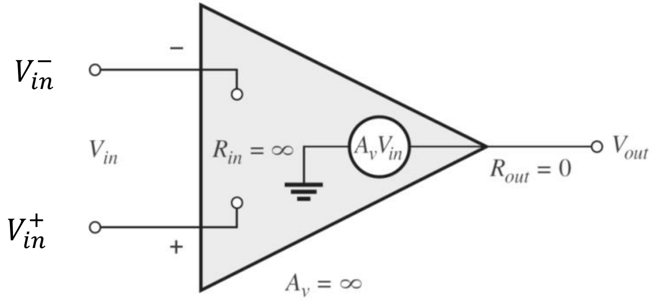
$$\boxed{V_{out} \approx 100000\cdot V_{in}^{+} - 100000\cdot V_{in}^{-} \approx A_v(V_{in}^{+} - V_{in}^{-})}$$

Conclusion: In most cases, negligible error is caused by ignoring the CMRR of the operational amplifier. The CMRR does not need to be considered unless accurate measurements of very small differential voltages must be made in the presence of very large common mode voltages.

Introduction

Ideal vs. practical op-amp model





Practical op-amp model

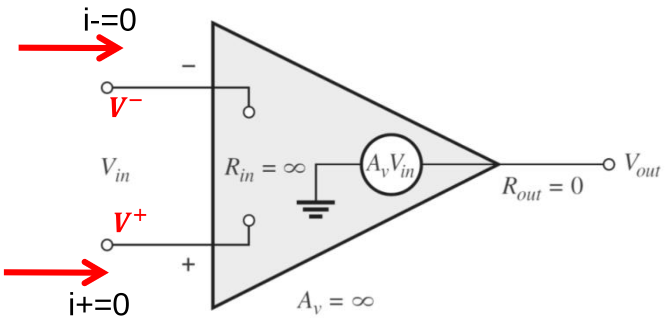
- High differential gain A_v $(10^5 \sim 10^9)$
- High input impedance R_{in} $(10^6 \sim 10^{12}\Omega)$
- Low output impedance R_{out} $(100 \sim 1000\ \Omega)$
- Low common-mode output voltage V_0 $(\sim 10^{-5}\ volt)$

Ideal op-amp model

- Infinite differential gain $A_v = +\infty$
- Infinite input impedance $R_{in} = \infty$
- Null output impedance $R_{out} = 0$
- Null common-mode output voltage $V_0 = 0$

Introduction

Ideal op-amp model importance



Ideal op-amp model

- Infinite differential gain $A_v = \infty$
- Infinite input impedance $R_{in} = \infty$
- Null output impedance $R_{out} = 0$
- Null common-mode output voltage $V_0 = 0$

➡ Input currents are null: $i^+ = i^- = 0$

➡ Inverting and non-inverting voltages are equal: $V^+ = V^-$

Remark: The ideal model simplifies the mathematics involved in deriving gain expressions

Introduction

Practical op-amp transfer characteristic

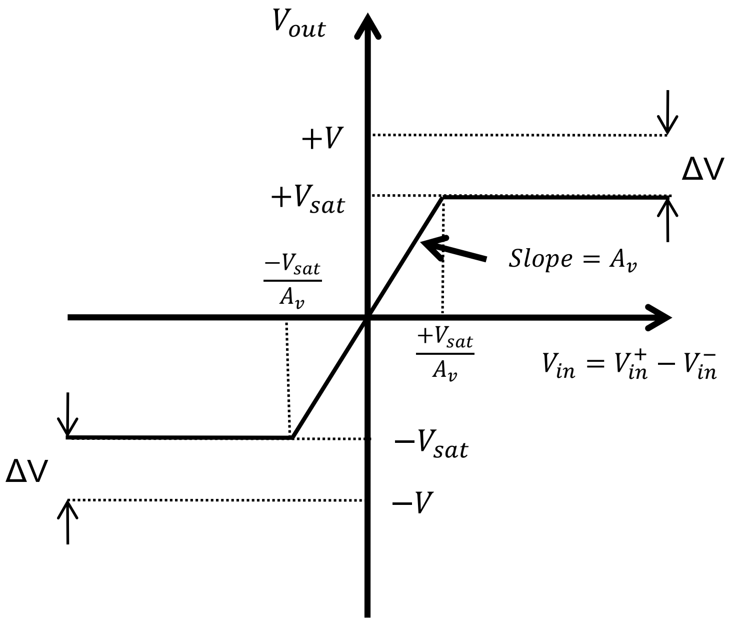
There are two operating zones depending on the input voltage values:

- **Saturation**, in case: $\begin{cases} V_{in} < \frac{-V_{sat}}{A_v} \rightarrow V_{out} = -V_{sat} \\ \quad or \\ V_{in} > \frac{+V_{sat}}{A_v} \rightarrow V_{out} = +V_{sat} \end{cases}$

- **Linear**, in case: $\frac{-V_{sat}}{A_v} \leq V_{in} \leq \frac{+V_{sat}}{A_v} \rightarrow V_{out} = A_v(V_{in}^{+} - V_{in}^{-})$

With:

$$-V + \Delta V < V_{out} < +V - \Delta V$$



Practical op-amp characteristic

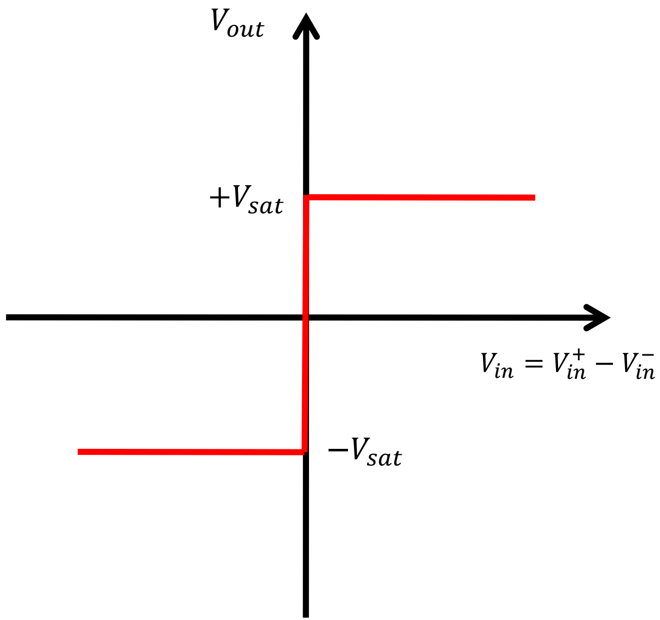
Introduction

Ideal op-amp transfer characteristic

There are two operating zones depending on the input voltage values:

- **Saturation**, in case: $\begin{cases} V_{in}^{+} - V_{in}^{-} < 0 \;\rightarrow\; V_{out} = -V_{sat} \\ \qquad\qquad or \\ V_{in}^{+} - V_{in}^{-} > 0 \rightarrow\; V_{out} = +V_{sat} \end{cases}$

- **Linear**, in case: $\mathrm{V_{in}^{+}} - \mathrm{V_{in}^{-}} = 0 \;\rightarrow \mathrm{V_{in}^{+}} = \mathrm{V_{in}^{-}} \rightarrow$ $\mathbf{V_{out}} = ???$



Ideal op-amp characteristic

Problem: What is the value of V_{out} in the linear zone?

Solution: Negative feedback!

Introduction

Remarks

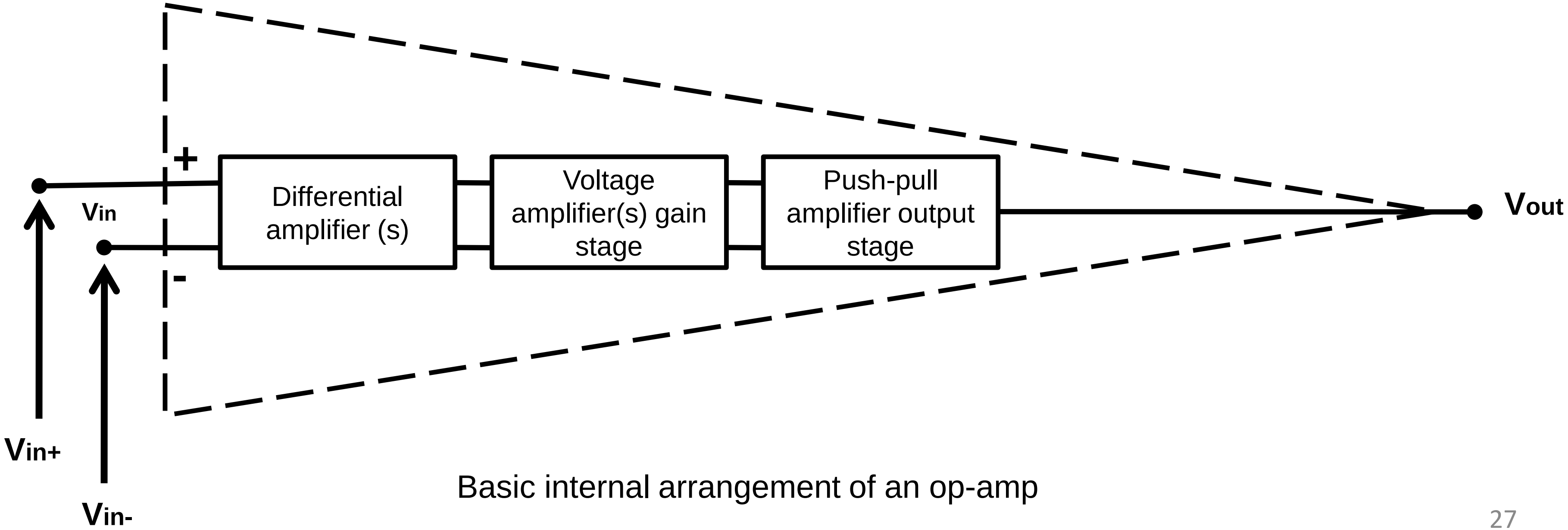
The op-amp based circuits use two major features:

1. The Differential amplifier as an inside component,
2. The negative feedback

Differential amplifier

Op-amp composition

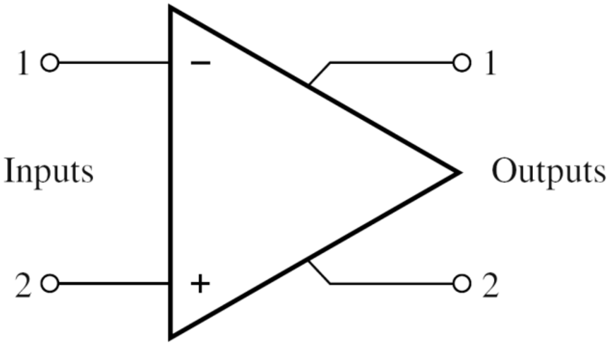
The op-amp is based on a differential amplifier as shown in the following diagram



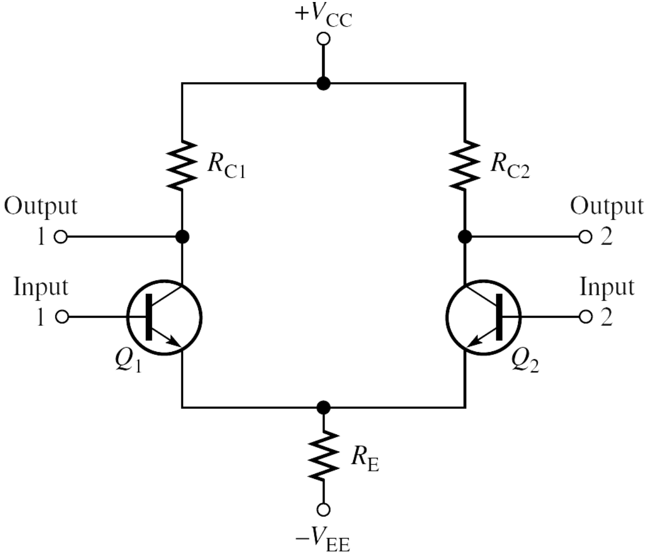
Basic internal arrangement of an op-amp

Differential amplifier

Symbol and basic circuit



Symbol of a diff-amp



Basic diff-amp circuit based on BJT

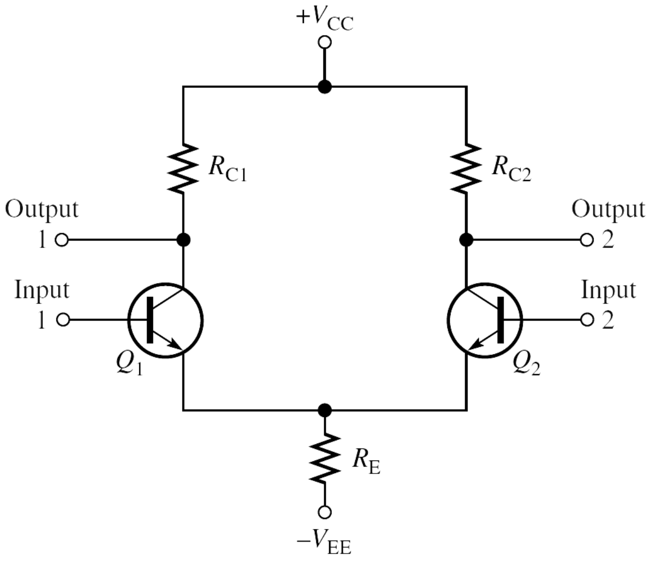
Differential amplifier

Differential amplifier: different modes

The possible **input signal** combination are classified as follows:

- Differential amplifier
  - Single-Ended mode
  - Differential mode
    - Differential input
    - Common-Mode input

Note: According to the outputs, 2 combinations are possible differential and single-ended



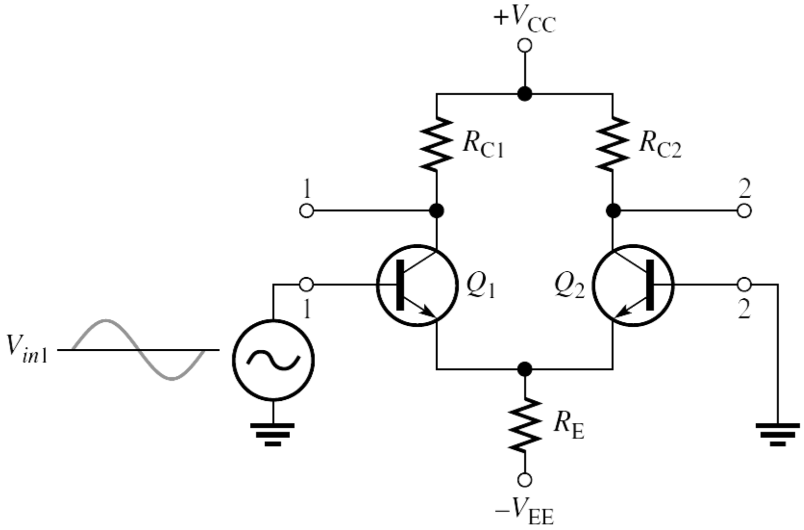
Basic diff-amp circuit based on BJT

Differential amplifier

Single-Ended mode

Definition

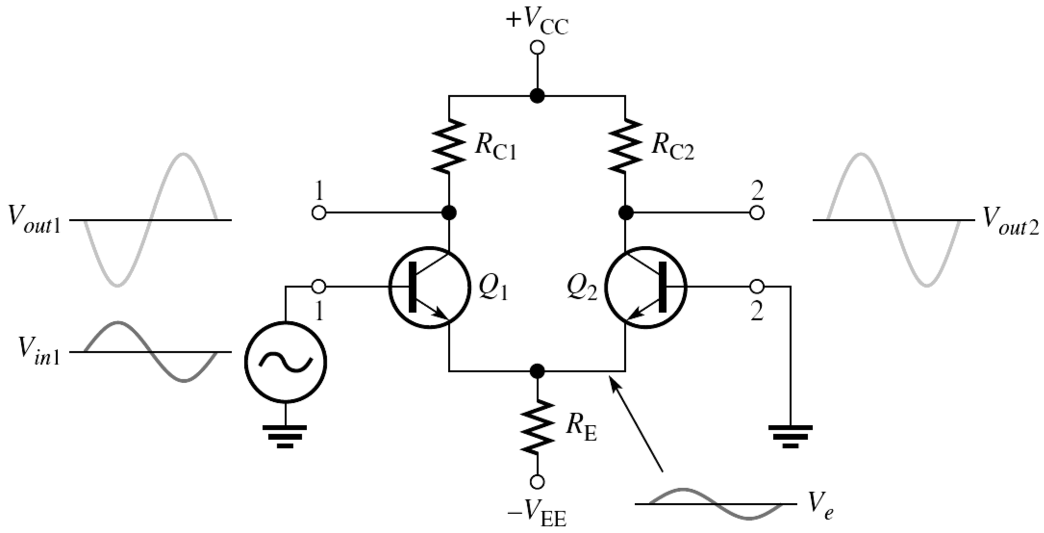
An input signal is applied to either input with the other input connected to ground, the operation is referred to as “single-ended.”



Differential amplifier

Single-Ended mode

- The signal V_{in1} is applied to input 1 and input 2 is grounded.
- Q1 is configured as common-emitter, thus, an **inverted amplified** signal appears in the output V_{out1}.
- Q1 and Q2 emitters are common, therefore, the Q1 emitter signal is the input signal of Q2
- Q2 is configured as common-base, thus, an **non-inverted amplified** signal appears in the output V_{out2}.

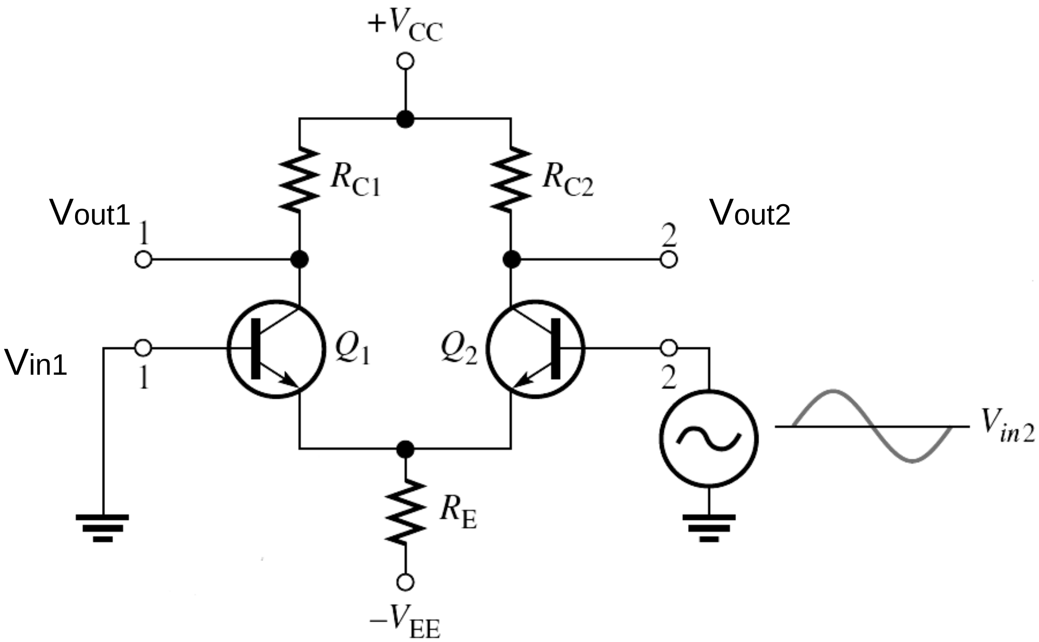


Differential amplifier

Single-Ended mode

Question

What will happen if a signal V_{in2} is applied to input 2 and input 1 is grounded?



Differential amplifier

Differential mode: Differential input

Definition

In the **differential mode (double ended)**, two signals of **opposite polarity** are applied to the inputs. Each input affects the outputs.