

CENG4480

Lecture 02: Operational Amplifier – 1

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Overview

Introduction

Op-Amp Preliminaries

Op-Amp List



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Computer interfacing Introduction

To Learn:

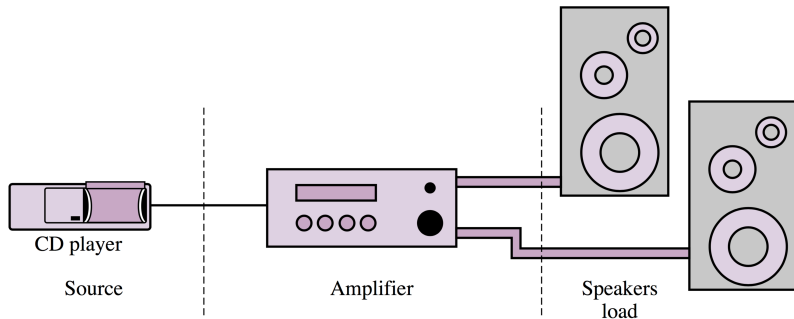
- ▶ how to connect the computer to various physical devices.
- ▶ Overall interfacing schemes
- ▶ Analog interface circuits, active filters

Some diagrams are taken from references:

- ▶ [1] S.E. Derenzo, "*Interfacing— A laboratory approach using the microcomputer for instrumentation, data analysis and control*", Prentice Hall, 1990.
- ▶ [2] Giorgio Rizzoni, "*Principles and Applications of Electrical Engineering*", McGraw-Hill, 2005.



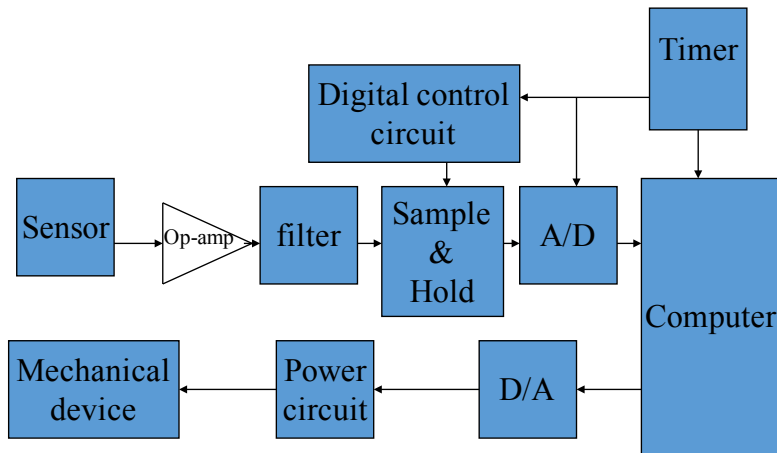
Amplifier in Audio System



Converting low-voltage sensor signal to a level suitable for driving speakers.



Typical Data Acquisition and Control System



Analog Interface Example 1

Audio recording systems

- ▶ Audio recording systems
- ▶ Audio signal is 20–20KHz
- ▶ Sampling at 40KHz, 16-bit is Hi-Fi
- ▶ Stereo ADC requires to sample at 80KHz.
- ▶ Calculate storage requirement for one hour?
- ▶ Audio recording standards: Audio CD; Mini-disk MD; MP3



Analog Interface Example 2

Analog hand held controller



(a) PS5



(b) Wii



(c) Driving wheel

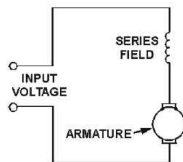
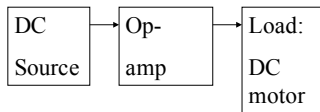
Operational Amplifier (Op-Amp)

- ▶ Why use op amp?
- ▶ What kinds of inputs/outputs do you want?
- ▶ What frequency responses do you want?



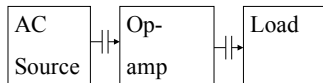
Direct Current (DC) amplifier

- ▶ Example: use power op amp (or transistor) to control the DC motor operation.
- ▶ Need to maintain the output voltage at a certain level for a long time.
- ▶ All DC (biased) levels must be designed accurately .
- ▶ Circuit design is more difficult.



Alternating Current (AC) amplifier

- ▶ **Example:** Microphone amplifier, signal is AC and is changing at a certain frequency range.
- ▶ Current is alternating not stable.
- ▶ Use capacitors to connect different stages
- ▶ So no need to consider biasing problems.



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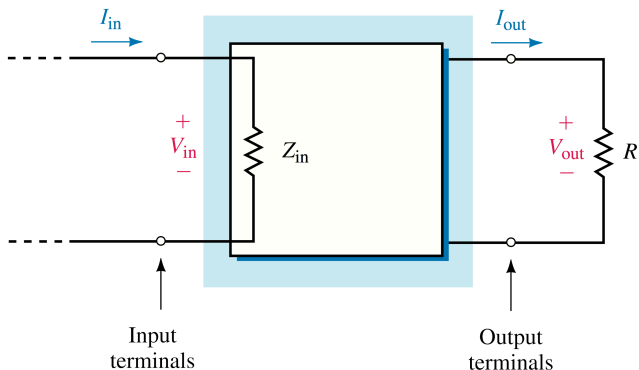
Amplifier

A circuit where the output signal power is greater than the input signal power.

Otherwise is referred as an **attenuator**.



Black-Box to Consider Circuit Effect



- ▶ Without examining actual operation (thousands of elements)
- ▶ Z_{in} : input impedance (a.k.a. R_{in})



Voltage gain A

$$A = \frac{V_{out}}{V_{in}}$$

- ▶ Usually voltage gain may be either very large or very small
- ▶ Inconvenient to express as a simple ratio
- ▶ Therefore, **decibel** (dB):

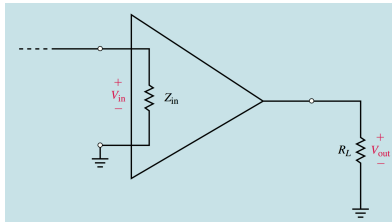
Voltage gain in **dB**

$$A = 20 \cdot \log_{10} \frac{V_{out}}{V_{in}}$$

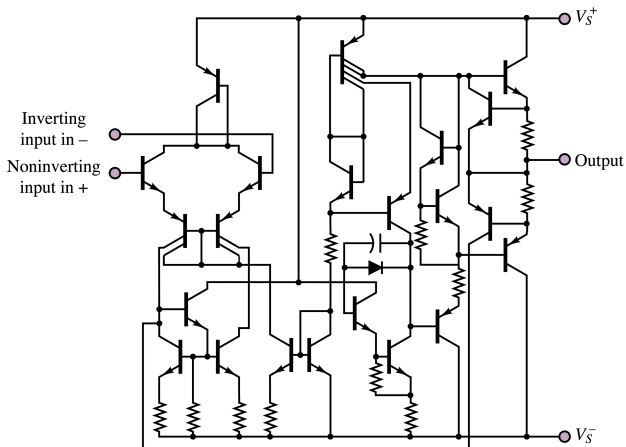


Question: Voltage Gain

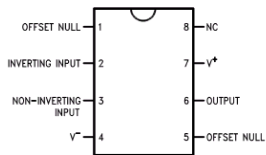
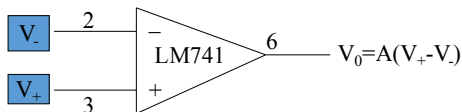
$V_{in} = 20\text{mV}$, $V_{out} = 500\text{mV}$. Calculate the voltage gain in dB.



Operational amplifier circuit diagram



Simplified circuit symbol

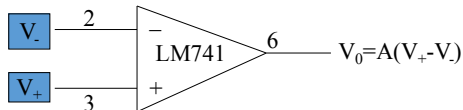


Order Number LM741J, LM741J/883,

- ▶ **Ideal** difference amplifier
- ▶ (+): **noninverting input**
- ▶ (-): **inverting input**
- ▶ **A**: **open-loop voltage gain** (order of 10^5 to 10^7)



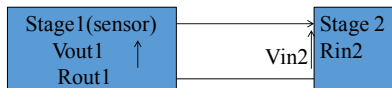
R_{in} & R_{out}



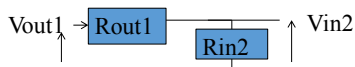
- ▶ R_{in} : input impedance (**High**)
- ▶ R_{out} : output impedance (**Low**)



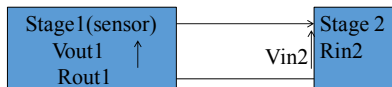
Why prefer High R_{in} , Low R_{out} ?



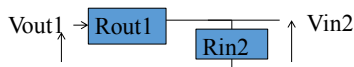
Is equivalent to:



Why prefer High R_{in} , Low R_{out} ?



Is equivalent to:



To maximize V_{in2}

$$V_{in2} = V_{out1} \cdot \frac{R_{in2}}{R_{out1} + R_{in2}}$$



Open-loop & Closed-loop

- ▶ Open-loop gain
- ▶ Closed-loop gain

Feedback connection

The effect of the feedback connection from output to **inverting input** is to force the voltage at the inverting input to be equal to that at the noninverting input.

“Note that closing the feedback loop turns a generally **useless** amplifier (the gain is too high!) into a very **useful** one (the gain is just right)!”



Ideal Op-Amp Rules

Rule 1

No current flows in or out of the inputs

Rule 2

The Op-Amp tries to keep the inputs the **same** voltage

* only for negative feedback op-amp



Ideal Op-Amp v.s. Real Op-Amp

Open-Loop Gain A

Ideal: Infinite, thus $V^+ = V^-$

Real: Typical range (20,000, 200,000), thus $V_{out} = A(V^+ - V^-)$

Input Impedance

Ideal: Infinite. Since $Z_{in} = \frac{V_{in}}{I_{in}}$, zero input current

Real: No such rule.

Bandwidth

Ideal: Infinite Bandwidth

Real: Gain-Bandwidth product (GB).



Overview

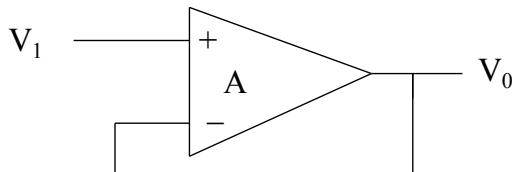
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Voltage follower



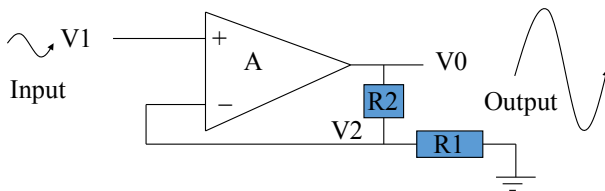
- ▶ Unit voltage gain
- ▶ Output $V_0 = V_1$
- ▶ high current gain, high input impedance

In real op-amp

$$V_0 = A(V_1 - V_0) \Rightarrow V_0 = \frac{V_1 A}{1 + A} \approx V_1$$



Non-inverting Amplifier



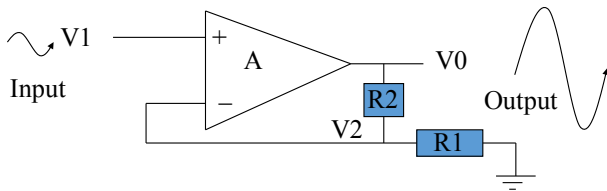
- R_{in} : High input impedance

In real op-amp

$$V_0 = A(V_1 - V_0) \text{ and } \frac{V_2}{V_0} = \frac{R_1}{R_1 + R_2}$$
$$\Rightarrow \frac{V_0}{V_1} = \frac{R_1 + R_2}{R_1 + (R_1 + R_2)/A} \approx \frac{R_1 + R_2}{R_1}$$



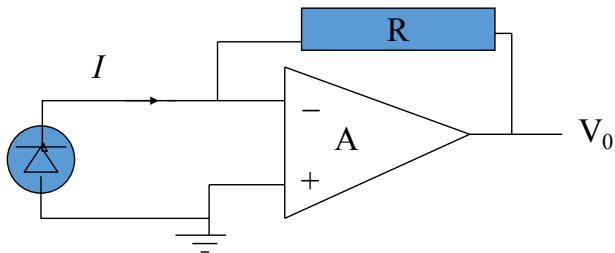
Question: Non-inverting Amplifier Gain



Calculate $\frac{V_0}{V_1} =$

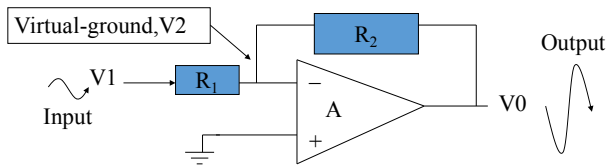


Current to Voltage Converter



$$V_0 = I \cdot R$$

Inverting Amplifier

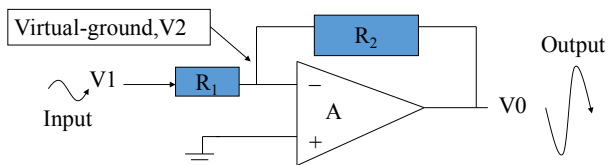


In real op-amp

$$V_0 = A(0 - V_2) \text{ and } \frac{V_0 - V_1}{R_1 + R_2} = \frac{V_2 - V_1}{R_1}$$
$$\Rightarrow \frac{V_0}{V_1} = \frac{R_2}{R_1} \cdot \frac{R_1 A}{R_1 A + R_1 + R_2} \approx -\frac{R_2}{R_1}$$

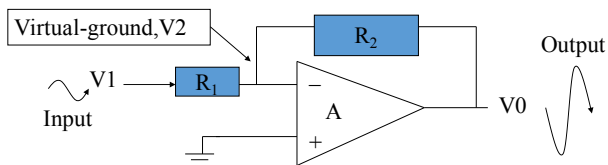


Inverting Amplifier



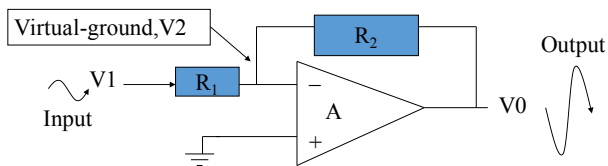
- ▶ $R_{in} = R_1$
- ▶ Gain (G) =

Inverting Amplifier



- ▶ $R_{in} = R_1$
- ▶ Gain (G) = $-\frac{R_2}{R_1}$

Inverting Amplifier



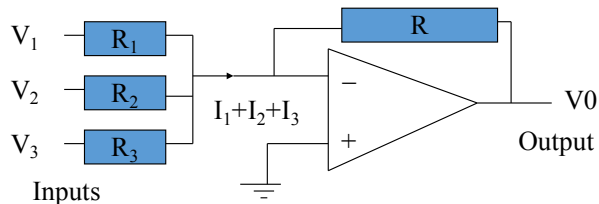
▶ $R_{in} = R_1$

▶ Gain (G) = $-\frac{R_2}{R_1}$

Question: How to increase input impedance?



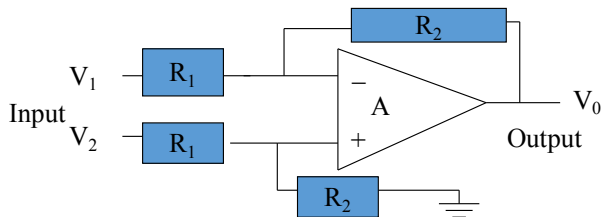
Summing Amplifier



$$V_0 = -R \cdot \left\{ \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right\}$$



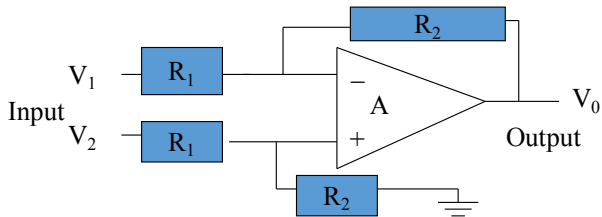
Differential Amplifier



- ▶ Calculate the difference between V_1 and V_2
- ▶ Can control gain



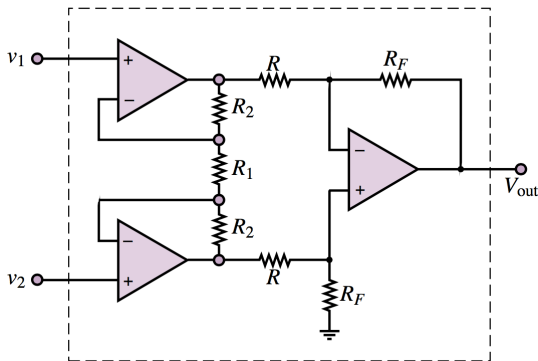
Question: Differential Amplifier Gain



Calculate $V_0 =$



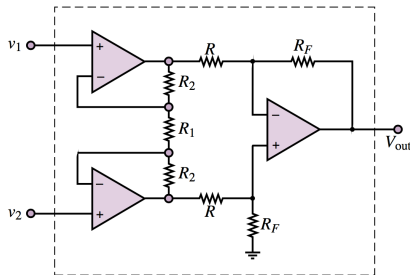
Instrumental Amplifier



- ▶ To make a **better** DC amplifier from op-amps
- ▶ combine **2** noninverting amplifier & **1** differential amplifier



Instrumental Amplifier (cont.)



- ▶ For each non-inverting amplifier: $A = 1 + \frac{2R_2}{R_1}$
- ▶ Connecting to differential amplifier:

$$\begin{aligned} V_{out} &= \frac{R_F}{R} (A_{v1} - A_{v2}) \\ &= \frac{R_F}{R} \left(1 + \frac{2R_2}{R_1}\right) (v_1 - v_2) \end{aligned}$$



Comparing Amplifiers

	Op Amp	Inv. Amp	Noninv. Amp	Diff. Amp	Instr. Amp
High R_{in}	✓	X	✓	X	✓
Diff Input	✓	X	X	✓	✓
Define Gain	X	✓	✓	✓	✓

