Lecture 01
Operational Amplifiers
Op-Amps
Introduction

Chapter 9
Ideal Operational Amplifiers and Op-Amp Circuits

Donald A. Neamen (2009). ***Microelectronics****: Circuit Analysis and Design, 4th Edition, Mc-Graw-Hill*

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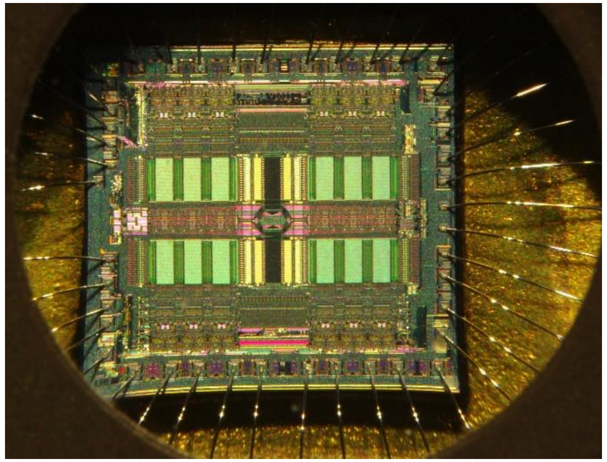
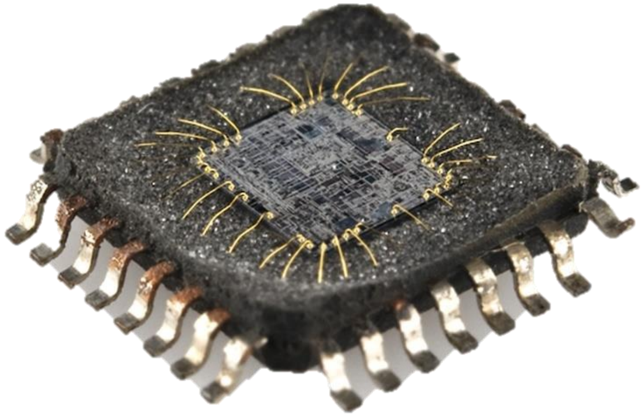
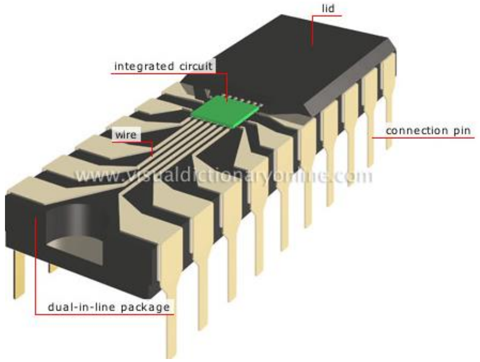
Integrated Circuit

- An **integrated circuit** (more often called an **IC**, microchip, silicon chip, computer chip, or chip) is a piece of specially prepared silicon (or another semiconductor) into which a very complex electronic **circuit** is etched using photographic techniques.





Integrated Circuit (IC Chip)

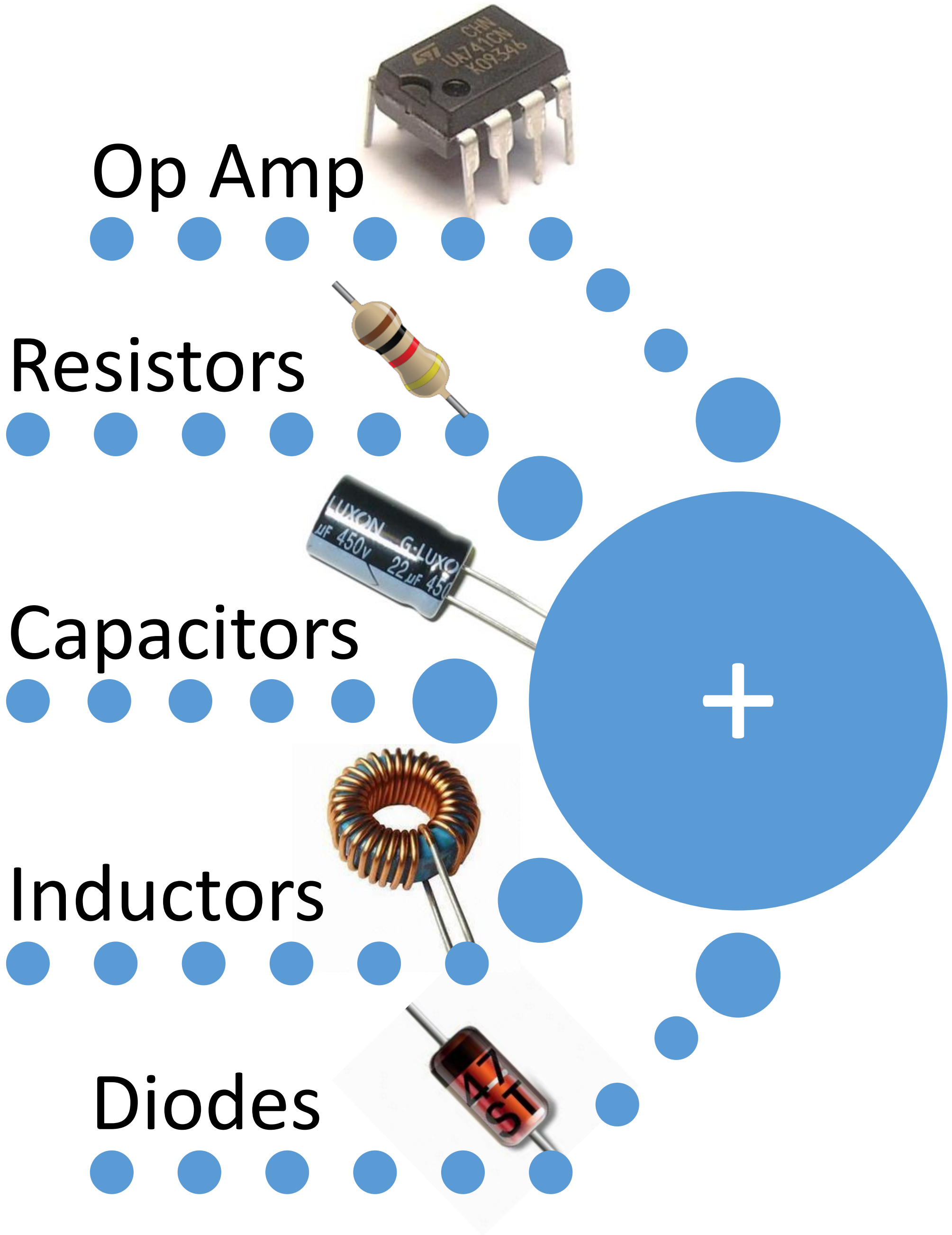


Introduction

- An **operational amplifier** (op-amp) is an integrated circuit that:
  - Amplifies the difference between two input voltages and
  - Produces a single output.
- The op-amp is dominant in analog electronics, and can be thought of as another electronic device, in much the same way as the BJT or MOSFET.

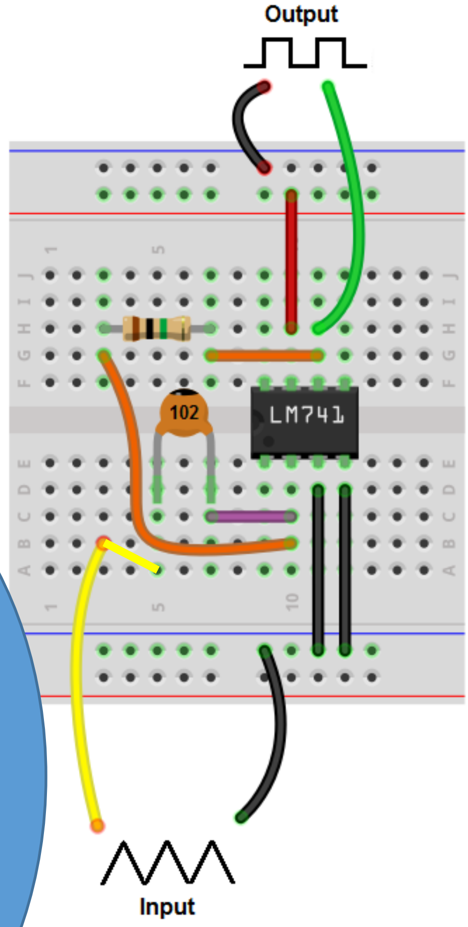
Introduction

- The term operational amplifier comes from the original applications of the device in the early 1960s.
  - Op-amps, in conjunction with resistors and capacitors, were used in analog computers to perform mathematical operations to solve:
    - Differential equations and
    - Integral equations.
  - The applications of op-amps have expanded significantly since those early days.



Arithmetic Operations:

- Addition
- Subtraction
- Integration
- Differentiation
- ..... etc.

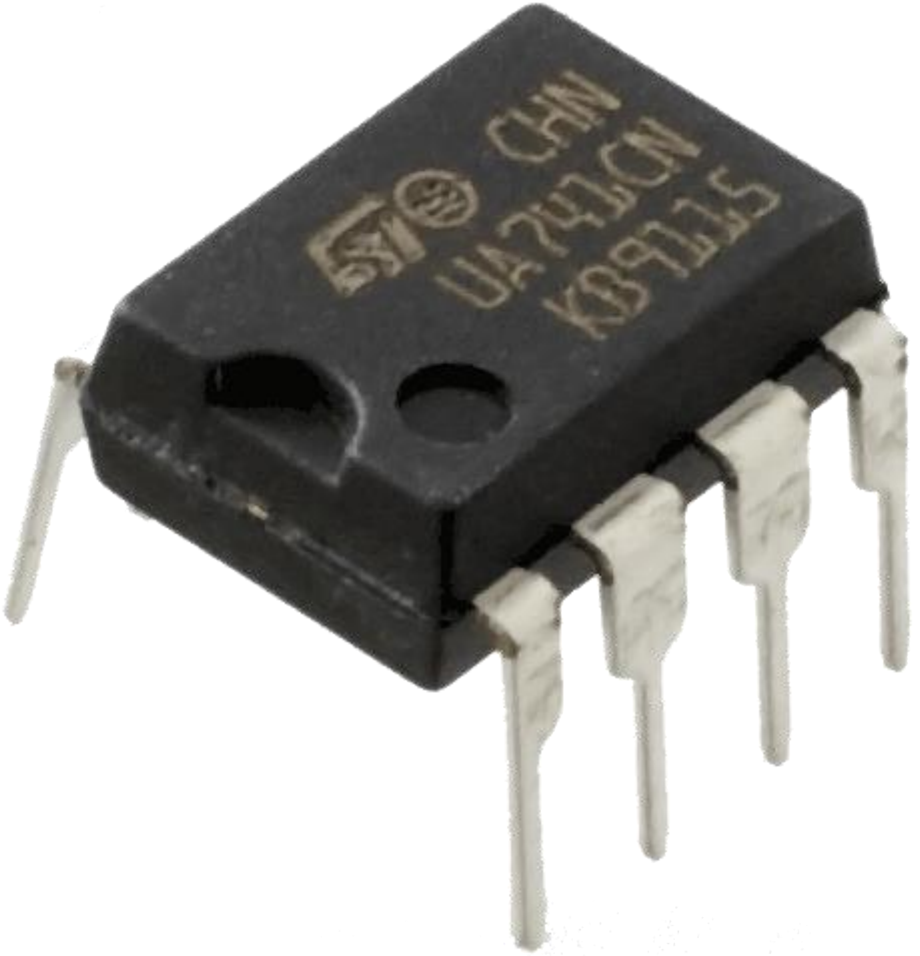


Introduction

- Our aim is to develop the ideal characteristics of the op-amps.
- You can then be more comfortable applying these ideal characteristics in the design of op-amp circuits.
- We will develop a basic op-amp equivalent circuit with:
  - A dependent source that represents the device gain that can be used to determine some of the nonideal properties of op-amp circuits.

9.1 The Operational Amplifier

- The classic μA-741, by Fairchild, was introduced in the late 1960s.
- Since then, a vast array of op-amps with improved characteristics, using both bipolar and MOS technologies, have been designed.
- Most op-amps are very inexpensive (less than a $dollar$).



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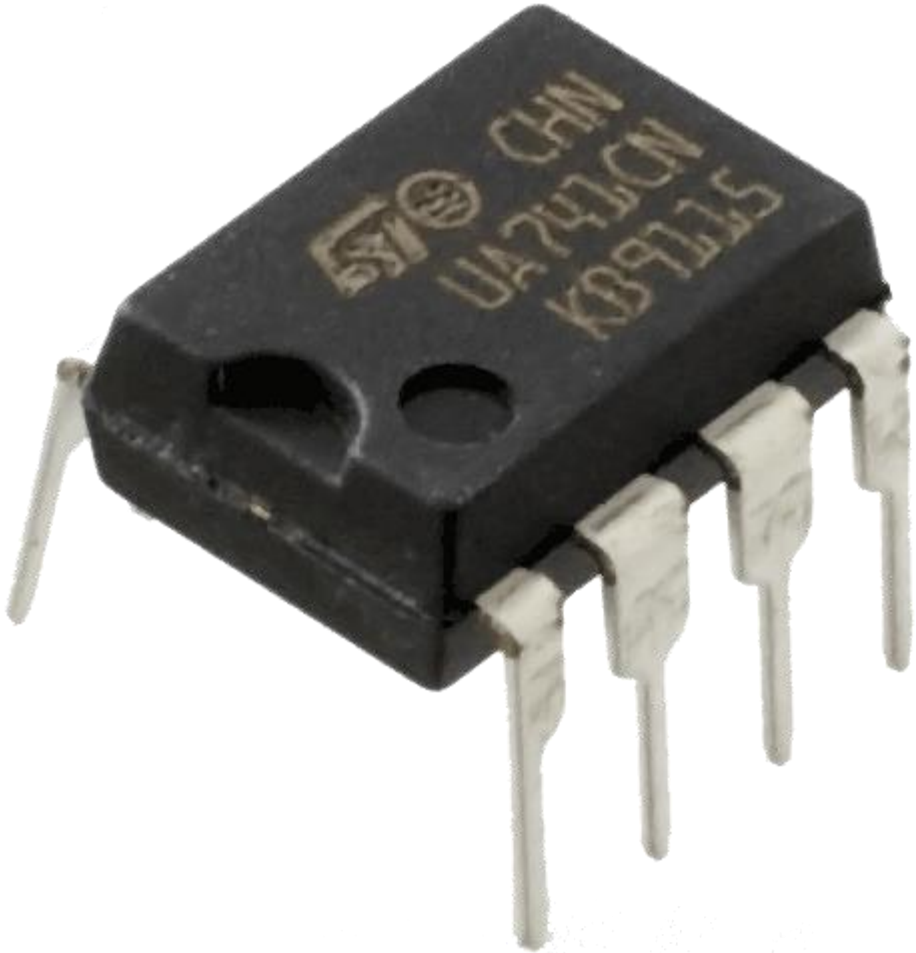
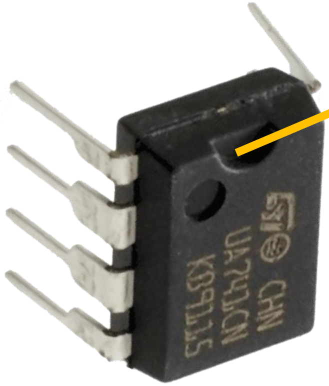
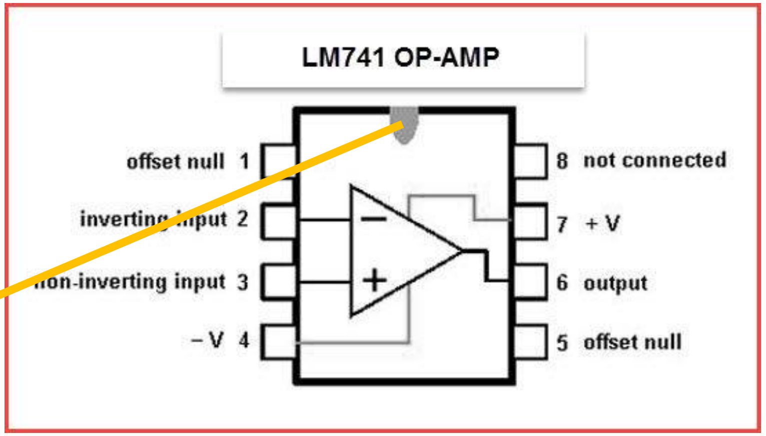
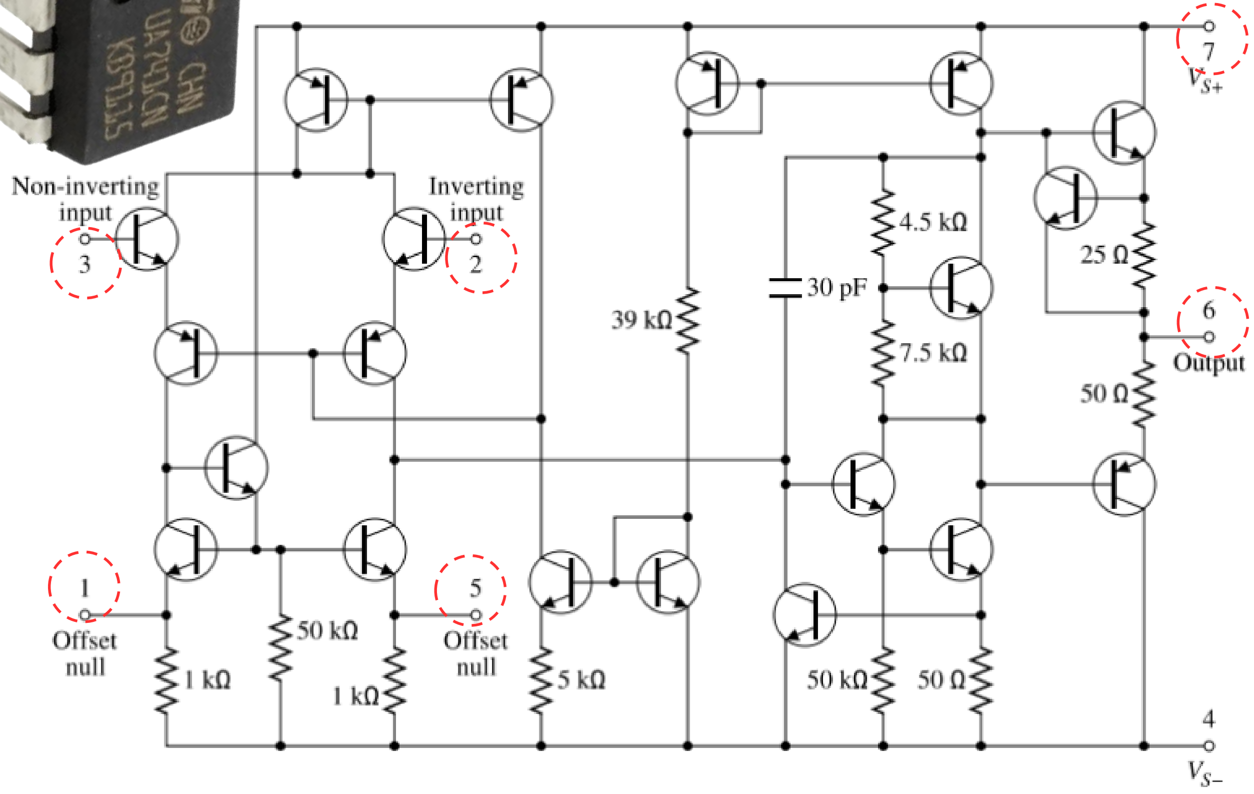
9.1 The Operational Amplifier



9.1 The Operational Amplifier







9.1 The Operational Amplifier

- From a signal point of view, the op-amp has:
  - Two input terminals and
  - One output terminal.

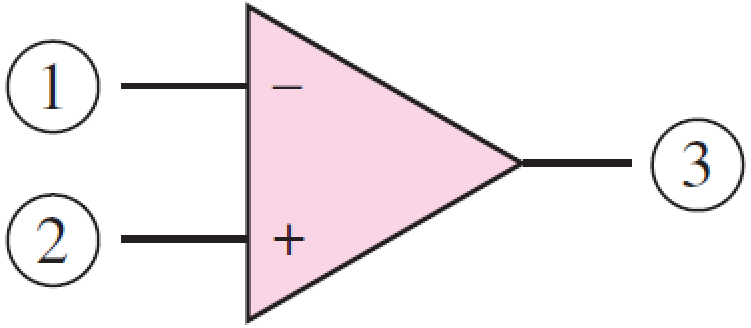


Figure 9.1(a)

9.1 The Operational Amplifier

- The op-amp also requires DC power so that the transistors are biased in the active region.
  - Op-amp is an active device.
- Most op-amps are biased with both:
  - A positive voltage supply V^+ and
  - A negative voltage supply V^-.

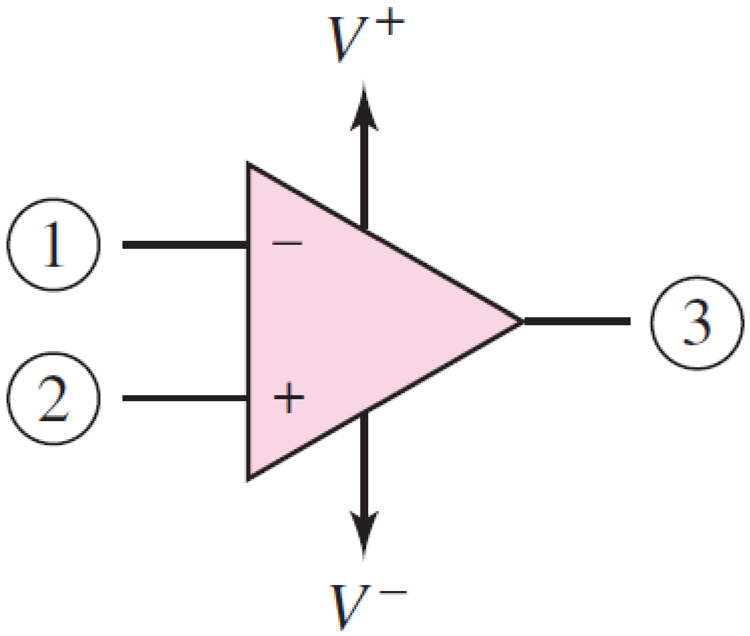
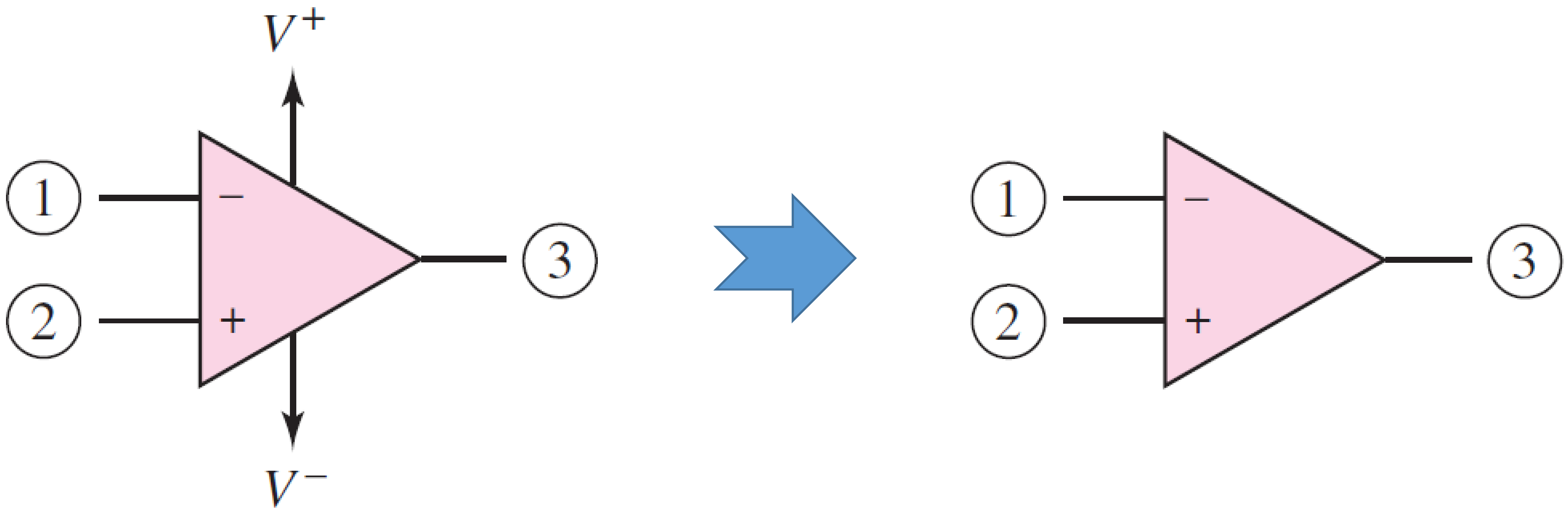


Figure 9.1(b)

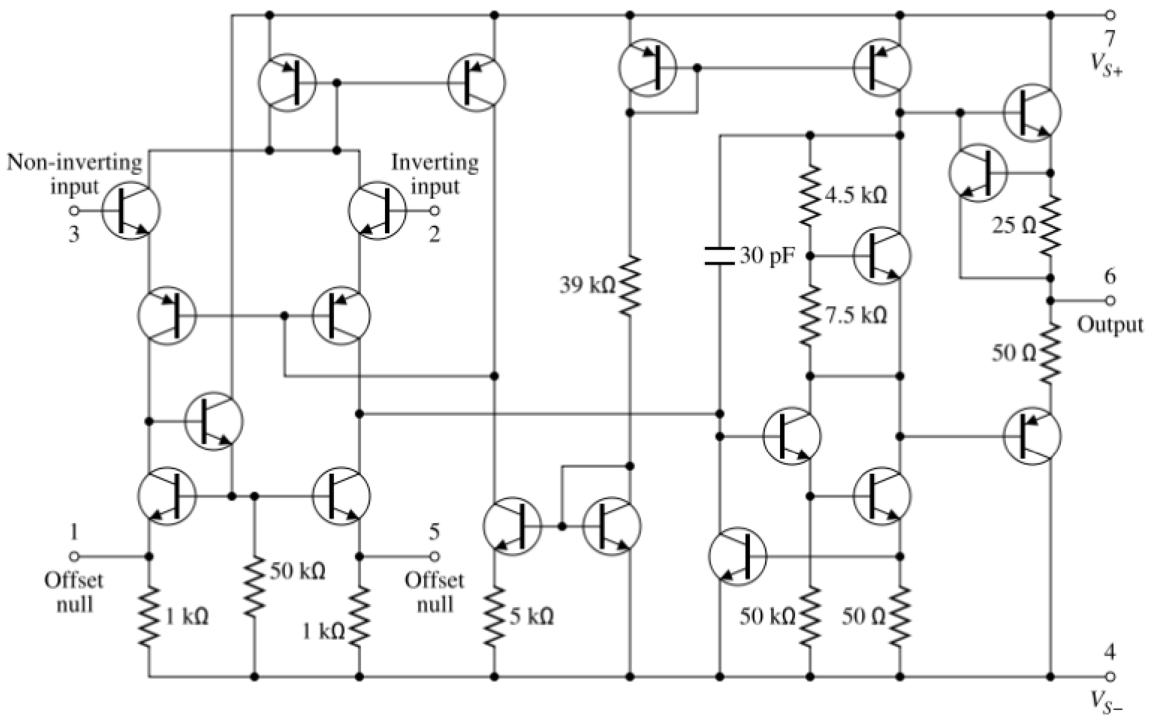
9.1 The Operational Amplifier



- <u>No need</u> to draw the voltage supplies: V^+ and V^-

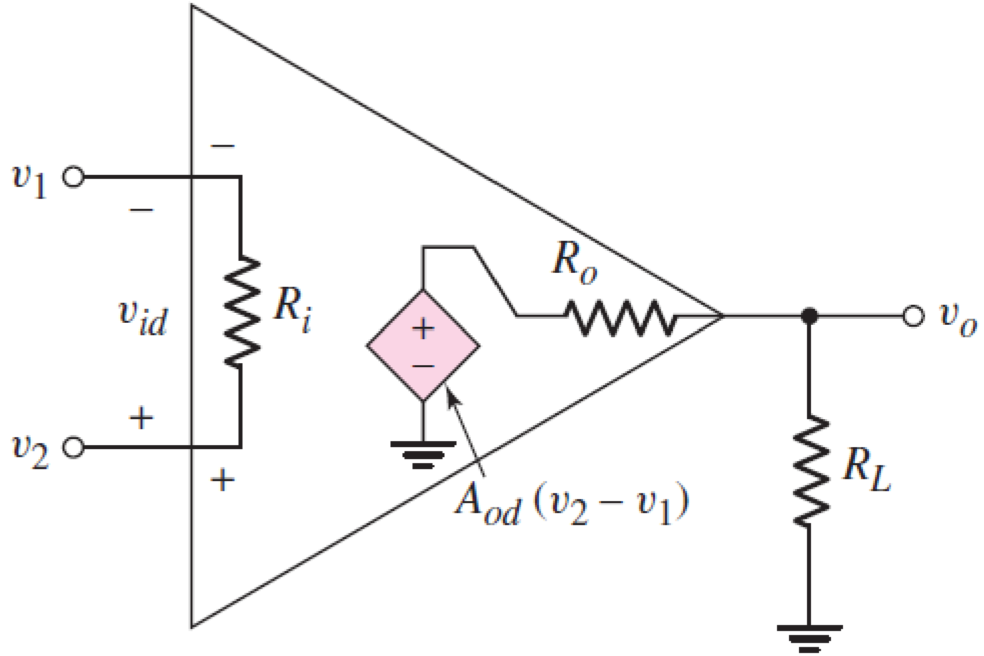
9.1 The Operational Amplifier

- There are normally 20 to 30 transistors that make up an op-amp circuit.
- The typical IC op-amp has parameters that approach the "ideal characteristics."
  - For this reason, we can treat the op-amp as a "simple" electronic device.
    - It is quite easy to design a wide range of circuits using the IC op-amp.



9.1 The Operational Amplifier

- In this chapter:
  - We develop the ideal set of op-amp parameters.
  - We consider the analysis and design of a wide variety of op-amp circuits.
  - In this Chapter, we generally assume, that the op-amp is ideal.



9.1.1 Ideal Parameters

- What is the basic operation principle of op-amp?
  - The ideal op-amp senses the difference between two input signals, i.e. v_1 and v_2, and amplifies this difference to produce an output signal v_O.
- What is the "terminal voltage"?
  - It is the voltage at a terminal measured with respect to ground.
- The ideal op-amp equivalent circuit is shown in Figure 9.2.

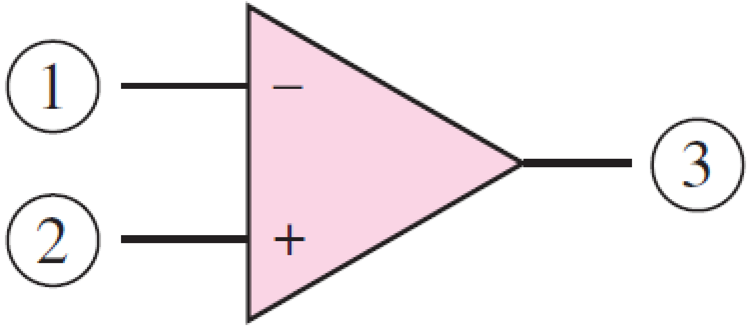


Figure 9.1(a)

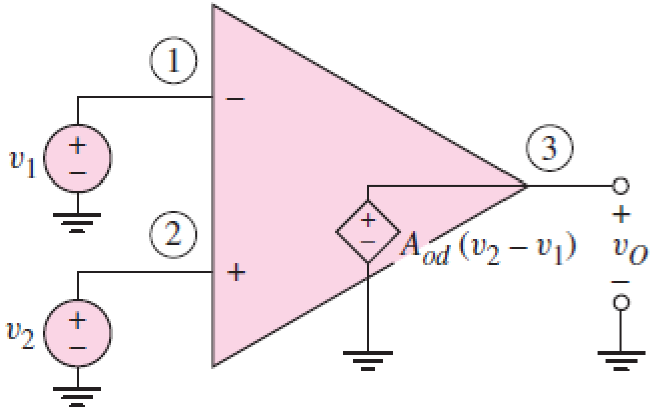


Figure 9.2

9.1.1 Ideal Parameters

Input Resistance R_i

- Ideally, the input resistance R_i between terminals 1 and 2 is infinite

$$R_i \to \infty:$$

  - Which means that the input current at each terminal is zero.

$$i_1 = i_2 = 0$$

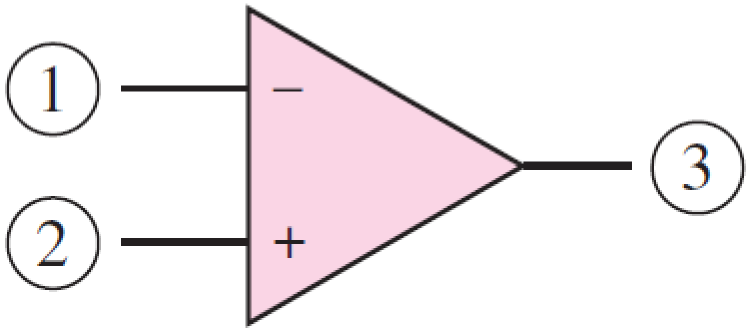


Figure 9.1(a)

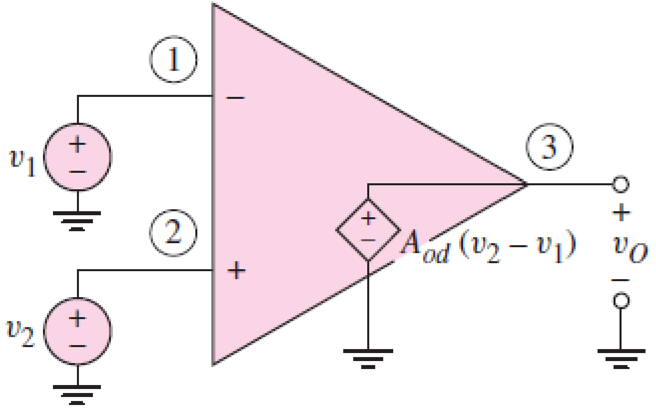


Figure 9.2

9.1.1 Ideal Parameters
Output Resistance R_o

- The output terminal of the ideal op-amp acts as the output of an ideal voltage source:
  - Meaning that the small-signal output resistance R_o is zero.

$$R_o \to 0$$

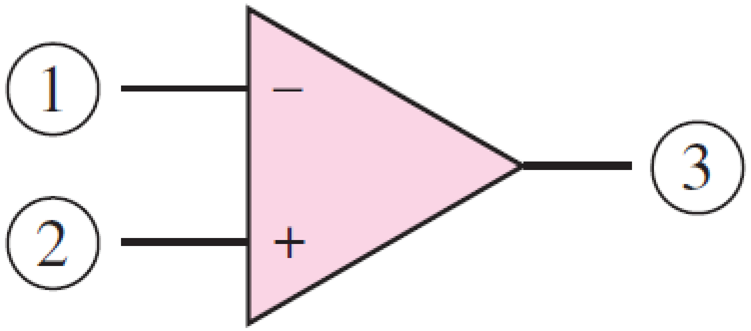


Figure 9.1(a)

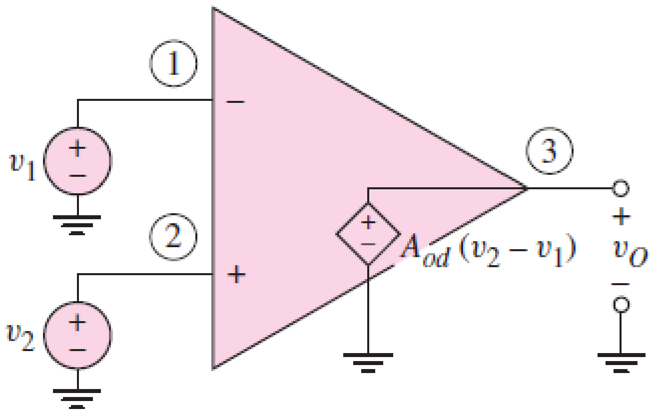


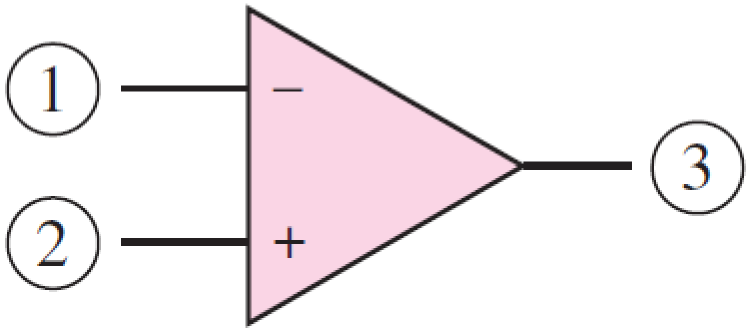
Figure 9.2

9.1.1 Ideal Parameters

Differential Voltage Gain A_{od}

- The parameter A_{od} shown in the equivalent circuit is the open-loop **differential voltage gain** of the op-amp.
- In the ideal op-amp, the **open-loop gain** A_{od} is very large and approaches infinity.

$$A_{od} \rightarrow \infty$$



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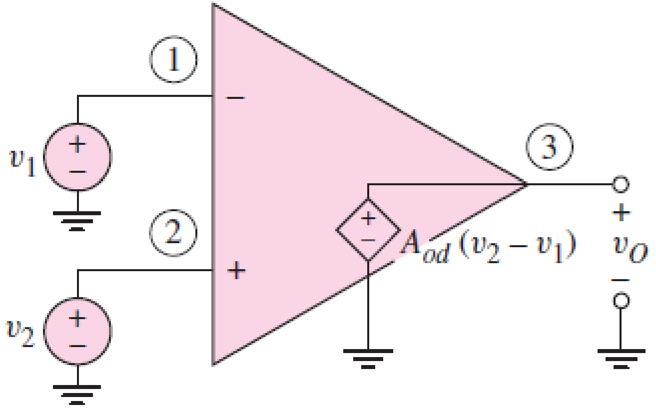
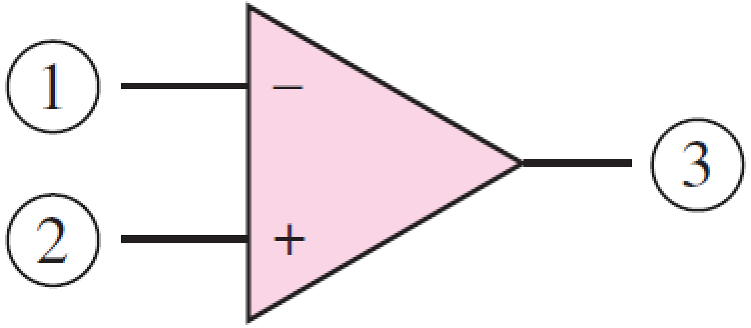


Figure 9.2

9.1.1 Ideal Parameters
Inverting/Noninverting Input Terminal v_1 & v_2

- Terminal (1):
  - Is the **inverting input terminal,** designated by the "−" notation.
- Terminal (2):
  - Is the **noninverting input terminal,** designated by the " +" notation.
- The output is:
  - Out of phase with respect to v_1 and
  - In phase with respect to v_2.
  - Why?



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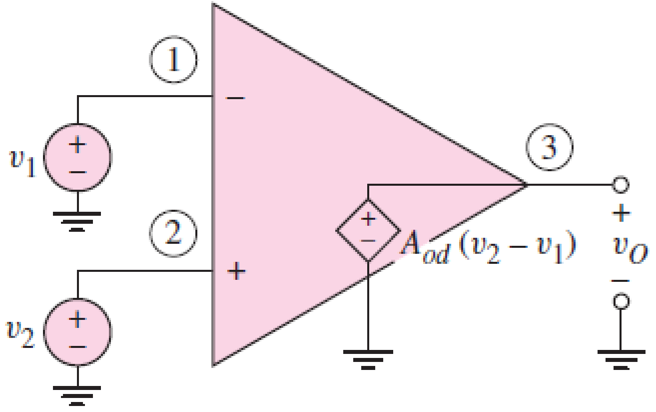


Figure 9.2

9.1.1 Ideal Parameters

Inverting/Noninverting Input Terminal v_1 & v_2

- The ideal op-amp responds only to the difference between the two input signals v_1 and v_2:
  - The ideal op-amp maintains a zero output signal for $v_1 = v_2$.

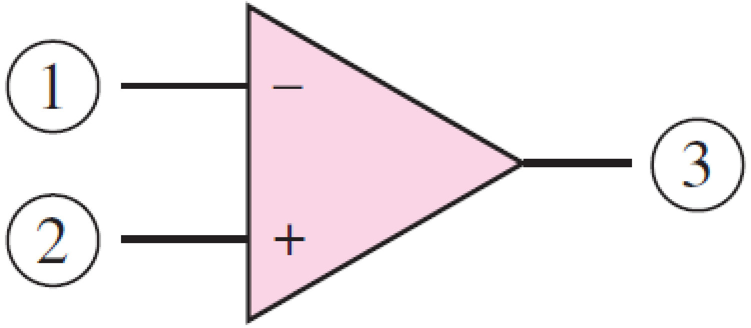


Figure 9.1(a)

- When $v_1 = v_2 = 0$:
  - It is called a **common-mode input signal.**
  - For the ideal op-amp, the common-mode output signal is $v_O = zero$.
    - This characteristic is referred to as **common-mode rejection.**

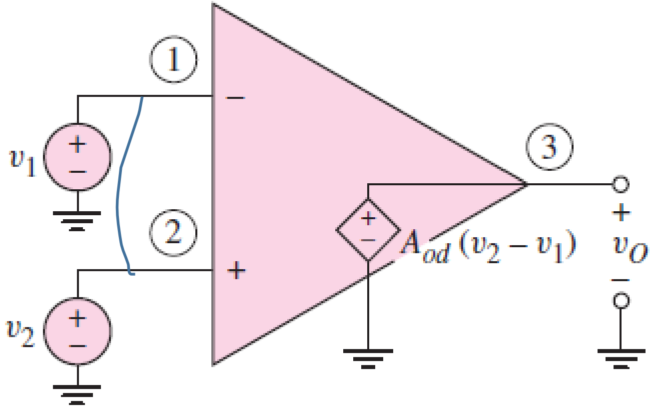
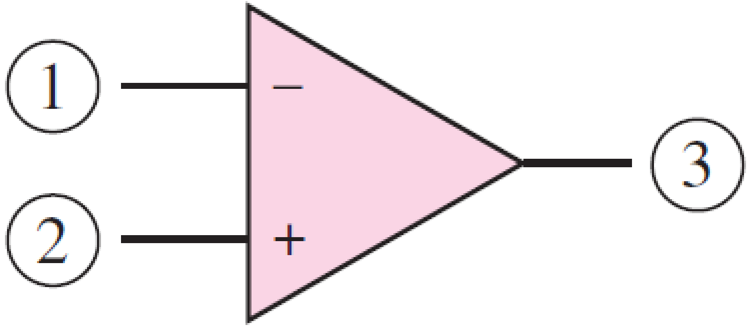


Figure 9.2

9.1.1 Ideal Parameters
Inverting/Noninverting Input Terminal v_1 & v_2

- Because the device is biased with both positive and negative power supplies, most op-amps are direct-coupled devices.
  - No coupling capacitors are used on the input.
  - Therefore, the input voltages v_1 and v_2 shown in Figure 9.2 can be DC voltages, which will produce a DC output voltage v_O.



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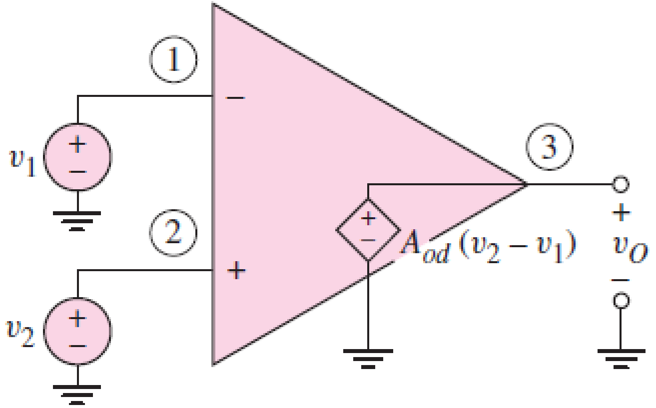
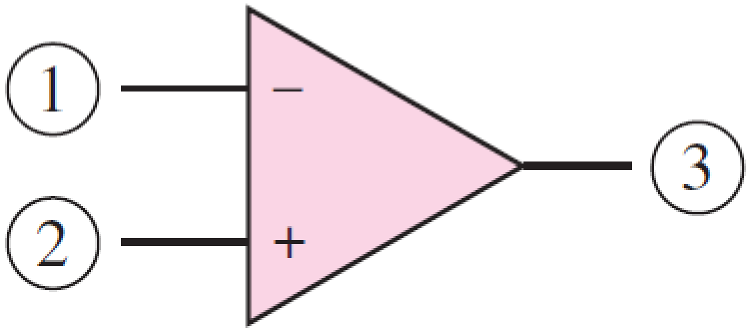


Figure 9.2

9.1.1 Ideal Parameters
Bandwidth

- Another characteristic of the op-amp that must be considered in any design is:
  - the **bandwidth** or frequency response.
- In the ideal op-amp, this parameter is neglected, $i.e. BW \to \infty$.



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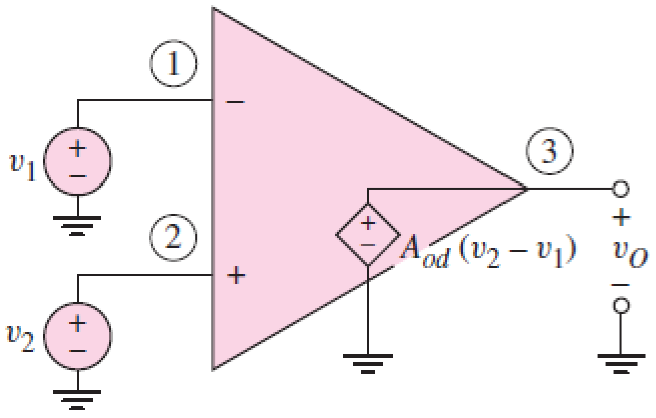

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