ECE 203

Circuits I

Op-amps

Lecture 5-2

Chapter 4: Op Amps

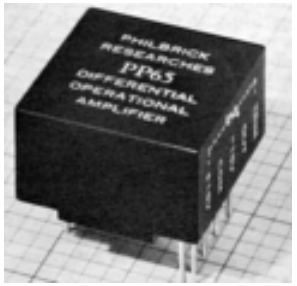
Op Amp = Operational Amplifier

A complex circuit, but for our purposes, can be analyzed using simplifying assumptions.

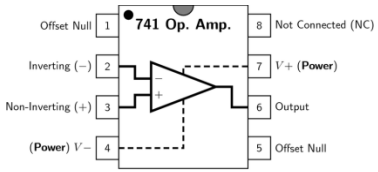
Operational Amplifiers (Op Amps)

1941 Bell Labs Patent

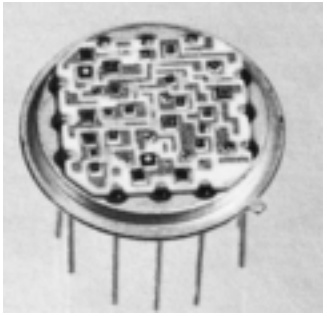
1961



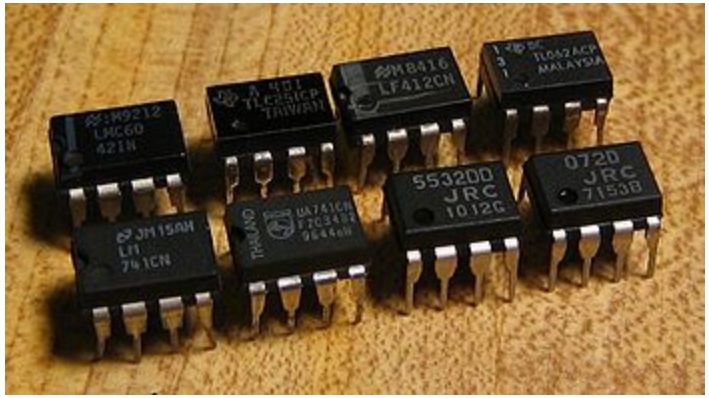
1962



1963



1979



Today

Introduction

❑ What is an Op-Amp?

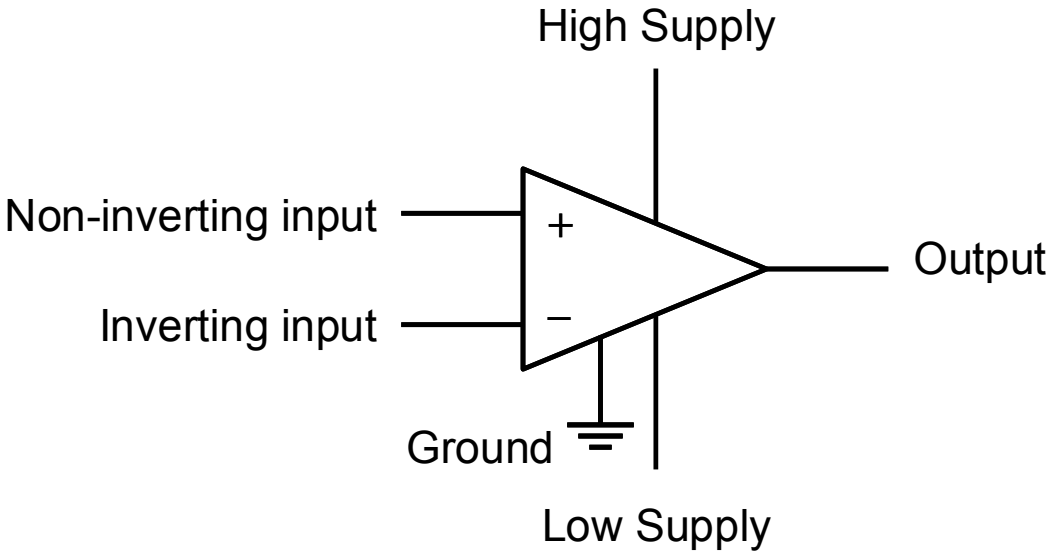
- **Op-Amp is short for "operational amplifier".**
- **It is an integrated circuit (IC) originally used to perform some *mathematical operations*, such as addition, subtraction, differentiation, and integration.**
- **That's why it is called an operational amplifier!**

❑ How Op-Amps are built?

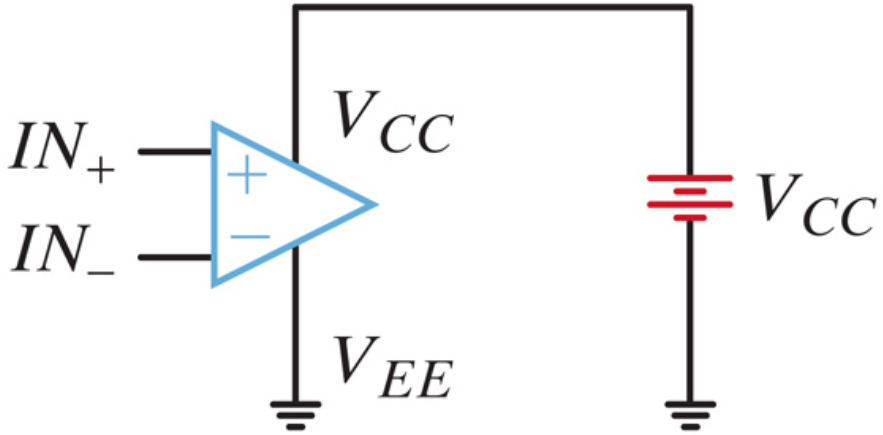
- **They are built using transistors in an integrated circuit.**

What is an Op-Amp?

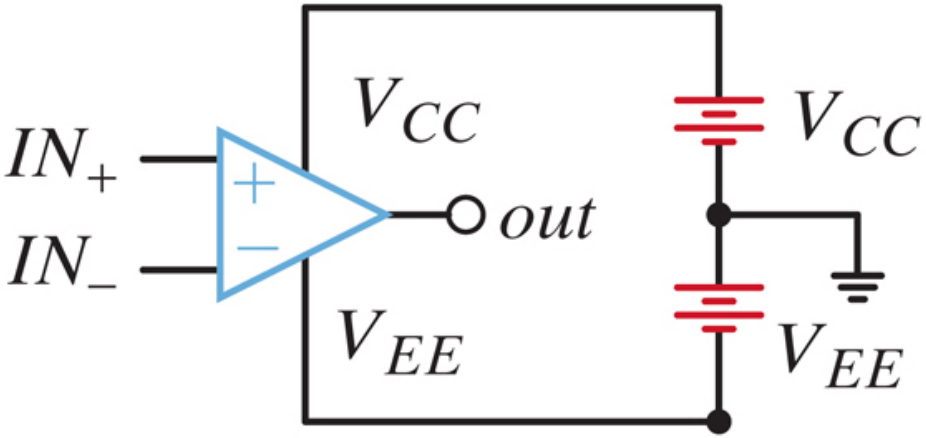
- **The Op-Amp is an "active" element with a high gain that is designed to be used with other circuit elements to perform signal processing operations.**
- **It requires power supplies, sometimes a single supply, sometimes positive and negative supplies.**
- **It has two inputs and a single output.**



Op-Amp Power Supply Configurations



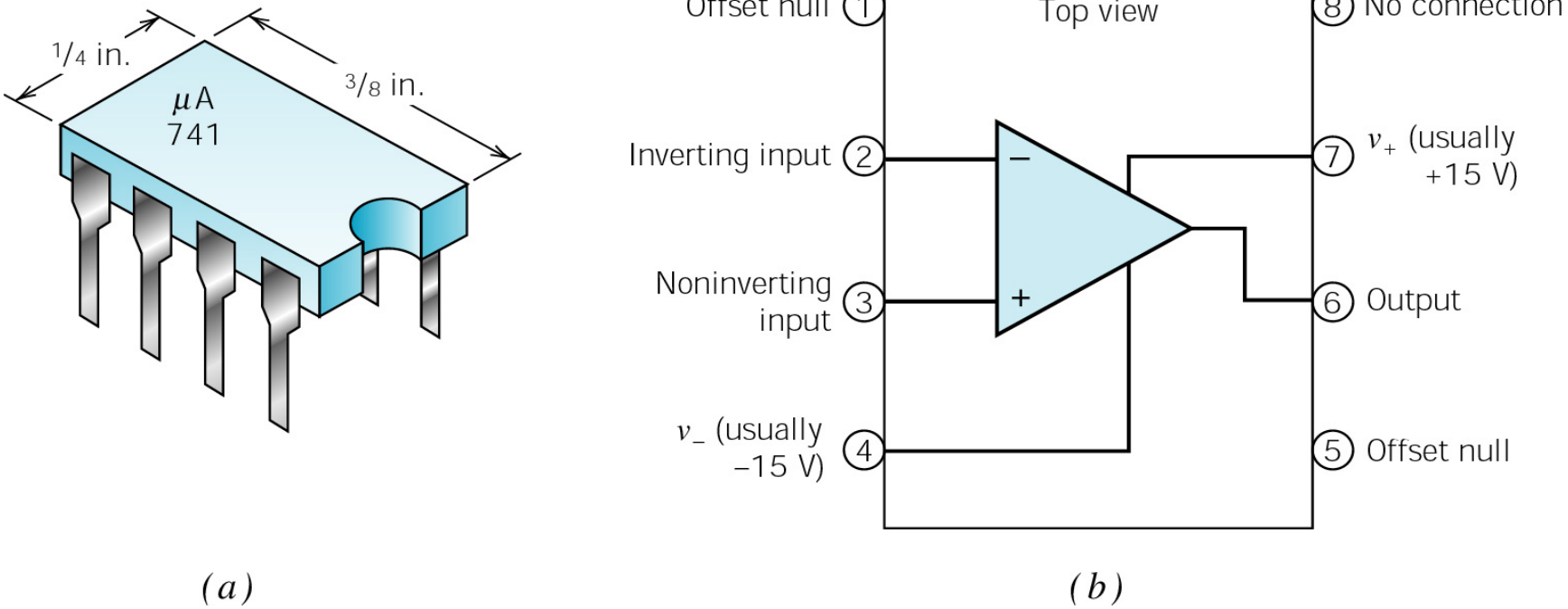
Single-supply implementation



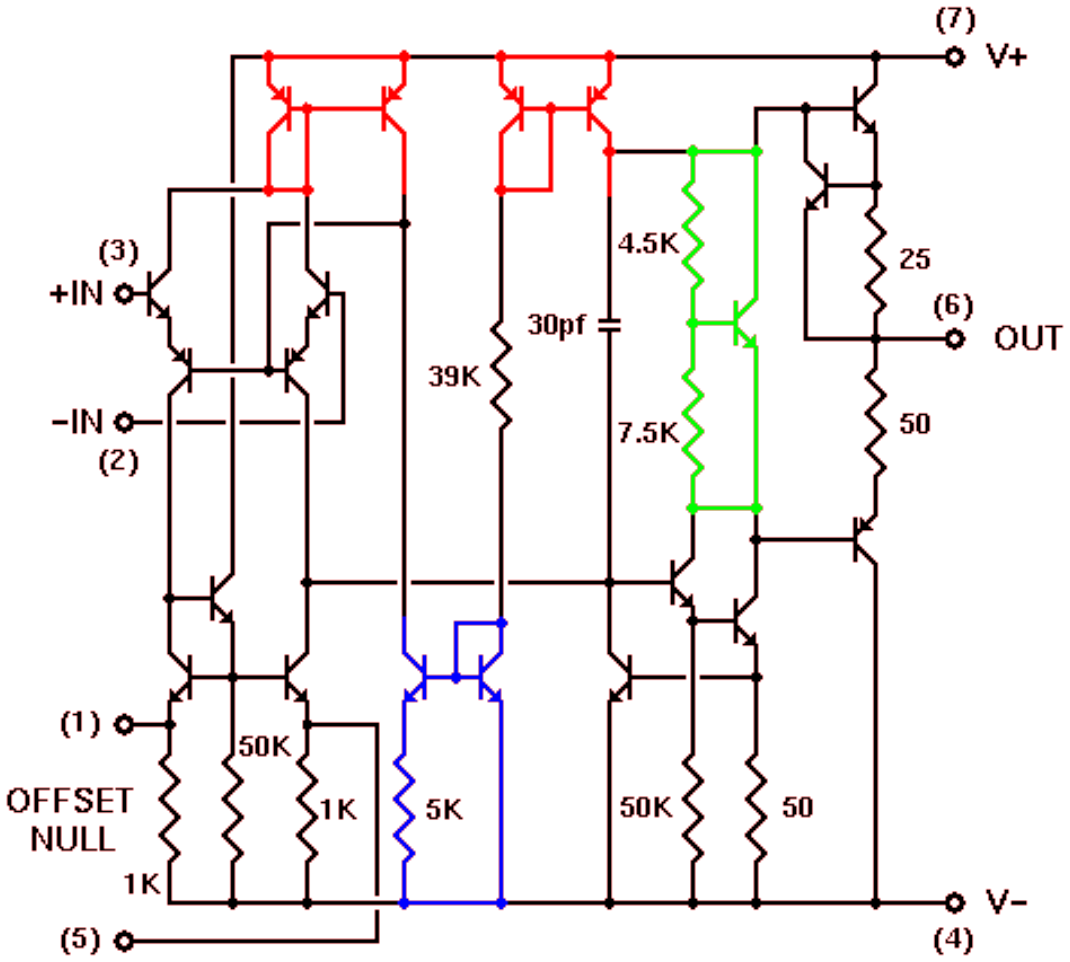
Dual-supply implementation

UA 741: A standard Off-The-Shelf Op-Amp

(*a*) A *μ*A741 integrated circuit has eight connecting pins. (*b*) The correspondence between the circles pin numbers of the integrated circuit and the nodes of the operational amplifier.



UA 741 Internal Circuit



How Can We Model Op-Amps?

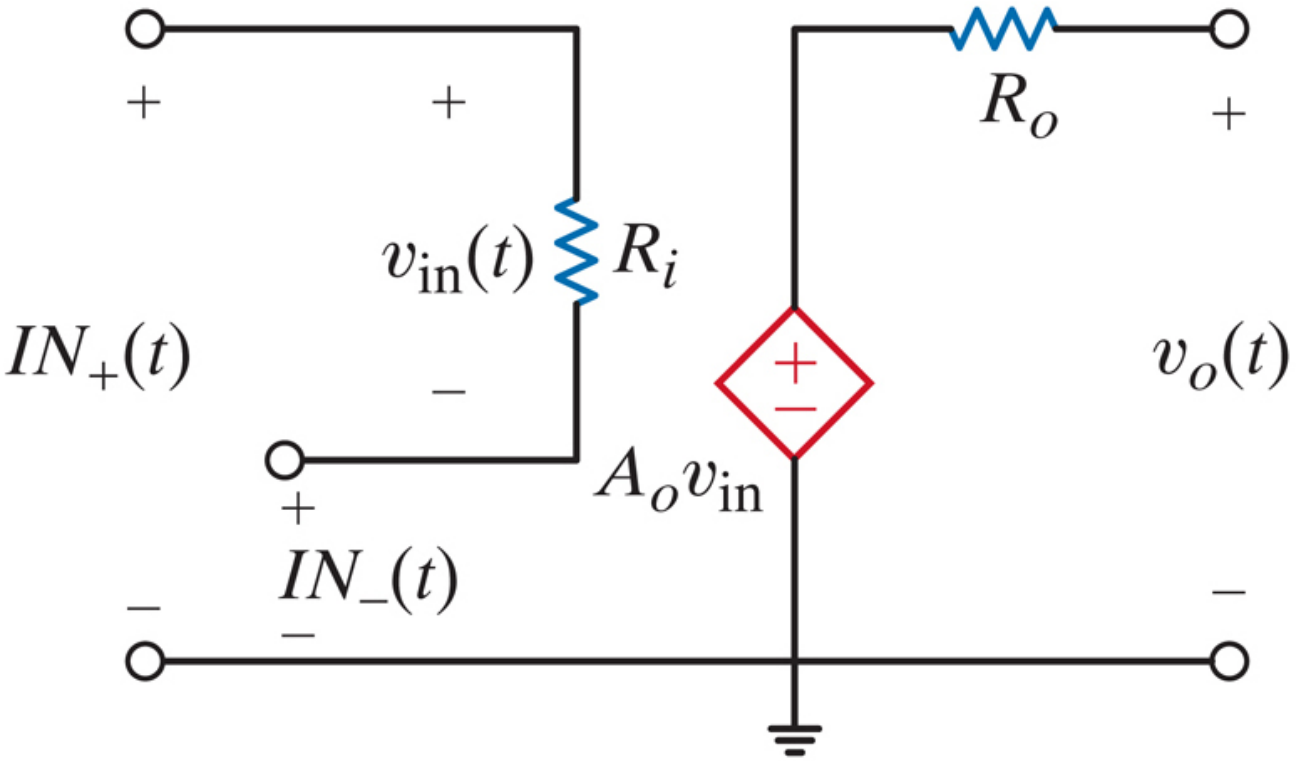
- Op-Amp is an Amplifier.
- So the output voltage is an amplified version of the inputs

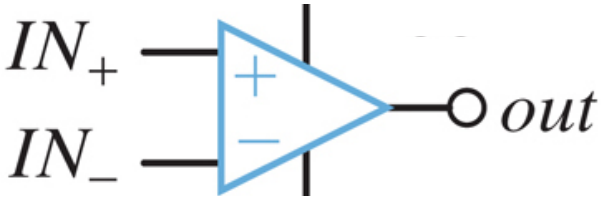
$$V_o = A_o(IN_+ - IN_-)$$

In this equation, A_o is the amplification (or gain), IN_+ is the voltage at the non-inverting input and IN_- is the voltage at the inverting input.

- V_o can be easily modeled with a "dependent voltage source"

A Circuit Model for Op-Amp

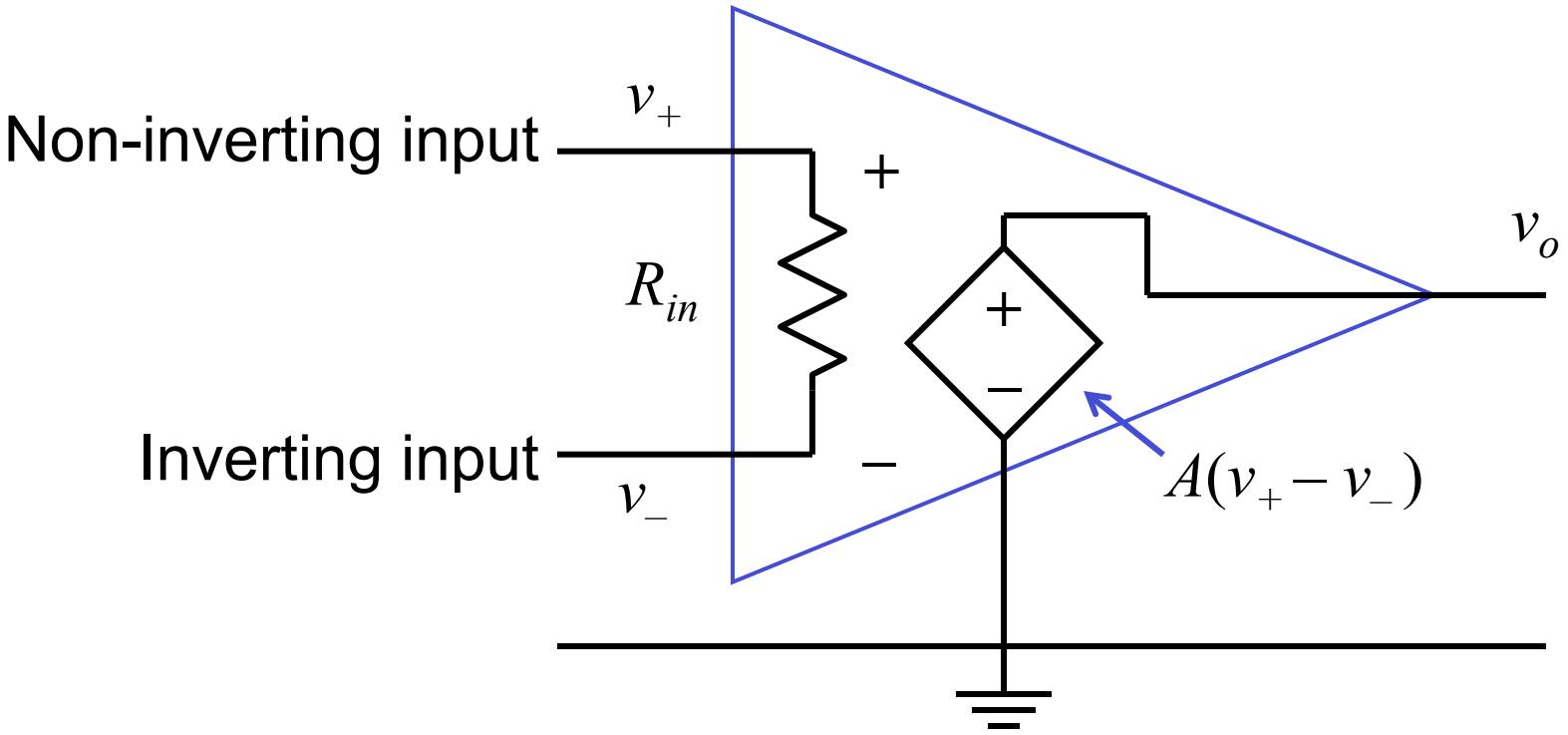




$$V_o = A_o(IN_+ - IN\_)$$

Another Circuit Model for Op-Amp

- An operational amplifier is modeled as a voltage-controlled voltage source.



Typical versus Ideal Op-Amp

Typical Op Amp:

1. The input resistance (impedance) R_{in} is very large (practically infinite).
2. The voltage gain A is very large (practically infinite).
3. Output resistance is a few tens of Ohms.

Ideal Op Amp:

1. The input resistance is infinite.
2. The gain is infinite.
3. The output resistance is zero.

Consequences of the Ideal Op-Amp

- Infinite input resistance means the current into the inputs is zero:

$$i_- = 0;\ i_+ = 0$$

- Infinite gain means the difference between v_+ and v_- is zero:

$$v_o = A_o\,(v_+ - v_-)$$

$$v_+ - v_- = v_o/A_o$$

If A_o = infinity, then:

$$v_+ - v_- = 0$$

This means $v_+ = v_-$

- Zero output resistance: $R_{out} = 0$

Ideal versus Practical Op-Amp

characteristic	ideal	practical	sample
Bias current	0	> 0	0.012 - 80 nA
Input resistance	infinite	finite	2 - 10^6 MΩ
Output resistance	0	> 0	60 – 1 kΩ
Differential gain	infinite	finite	100-5000V/mV
Current saturation	infinite	finite	2 – 30 mA

Practical Op-Amp Datasheet

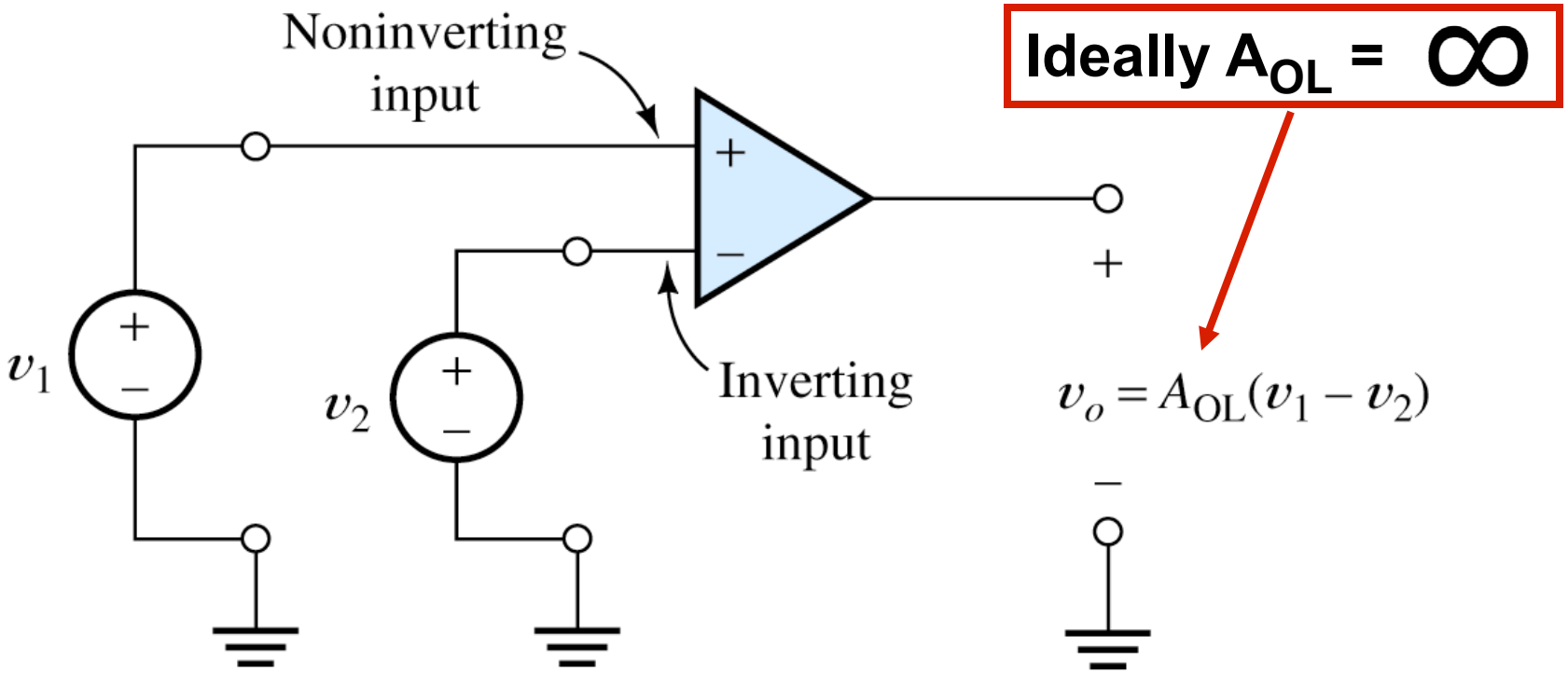
TABLE 4.1 A list of commercial op-amps and their model values

MANUFACTURER	PART NO.	A_o (V/V)	R_i (MΩ)	R_o (Ω)	COMMENTS
National	LM324	100,000	1.0	20	General purpose, up to ± 16 V supplies, very inexpensive
National	LMC6492	50,000	10^7	150	Low voltage, rail-to-rail inputs and outputs†
Maxim	MAX4240	20,000	45	160	Micro-power (1.8 V supply @ 10 μA), rail-to-rail inputs and outputs
Apex	PA03	125,000	10^5	2	High-voltage, ± 75 V and high-output current capability, 30 A. That's 2 kW!

†Rail-to-rail is a trademark of Motorola Corporation. This feature is discussed further in the following paragraphs.

*Op-amps are available that have input and/or output voltage ranges beyond the supply rails. However, these devices constitute a very small percentage of the op-amp market and will not be discussed here.

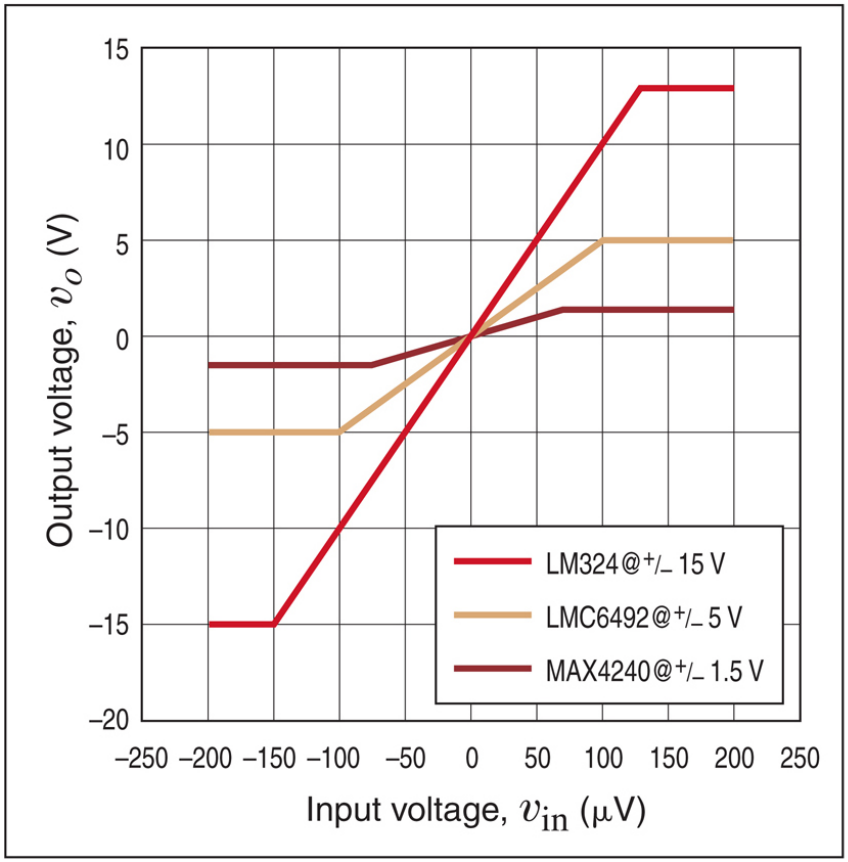
These are some of the newer op amps

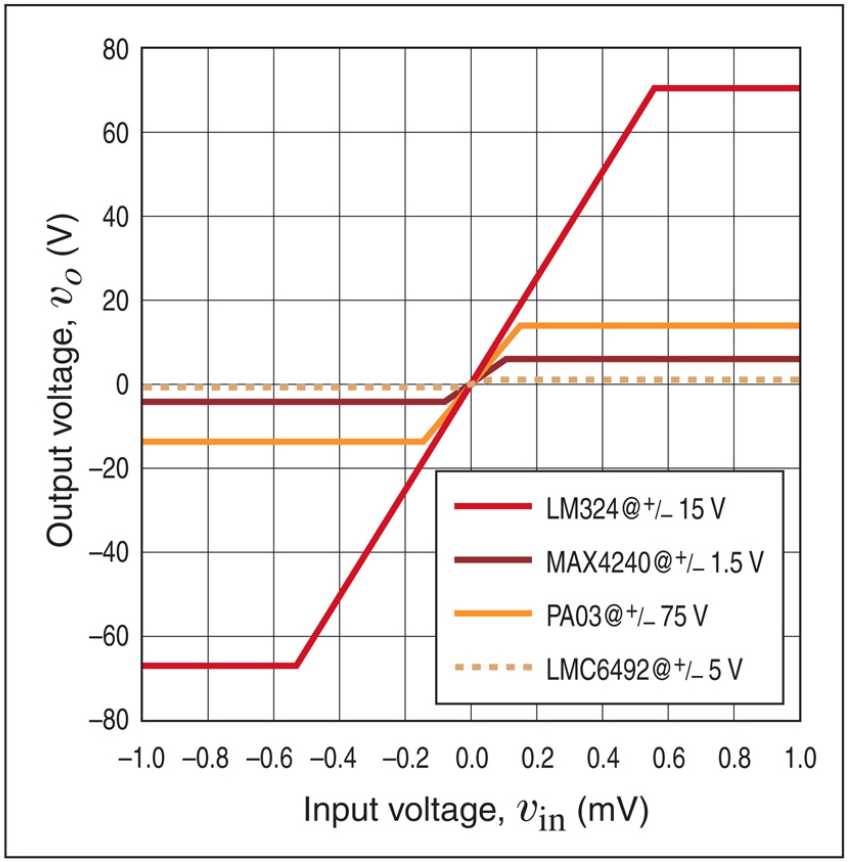


Circuit symbol for the op amp.

Non-Ideal Effects in Op-Amps

- For proper operation, all the inputs and output voltages are limited within the power supply range!





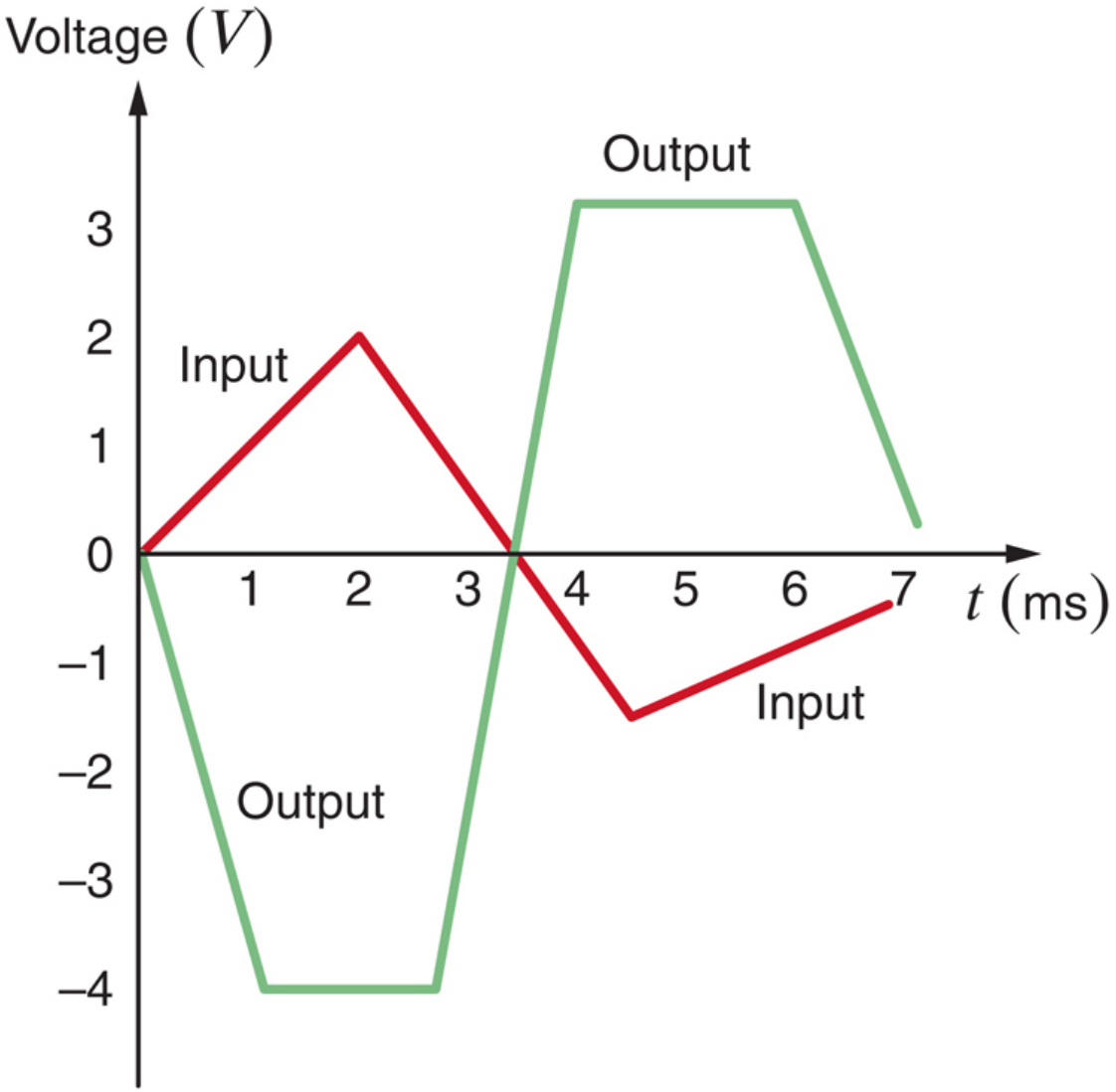
What is Clipping?

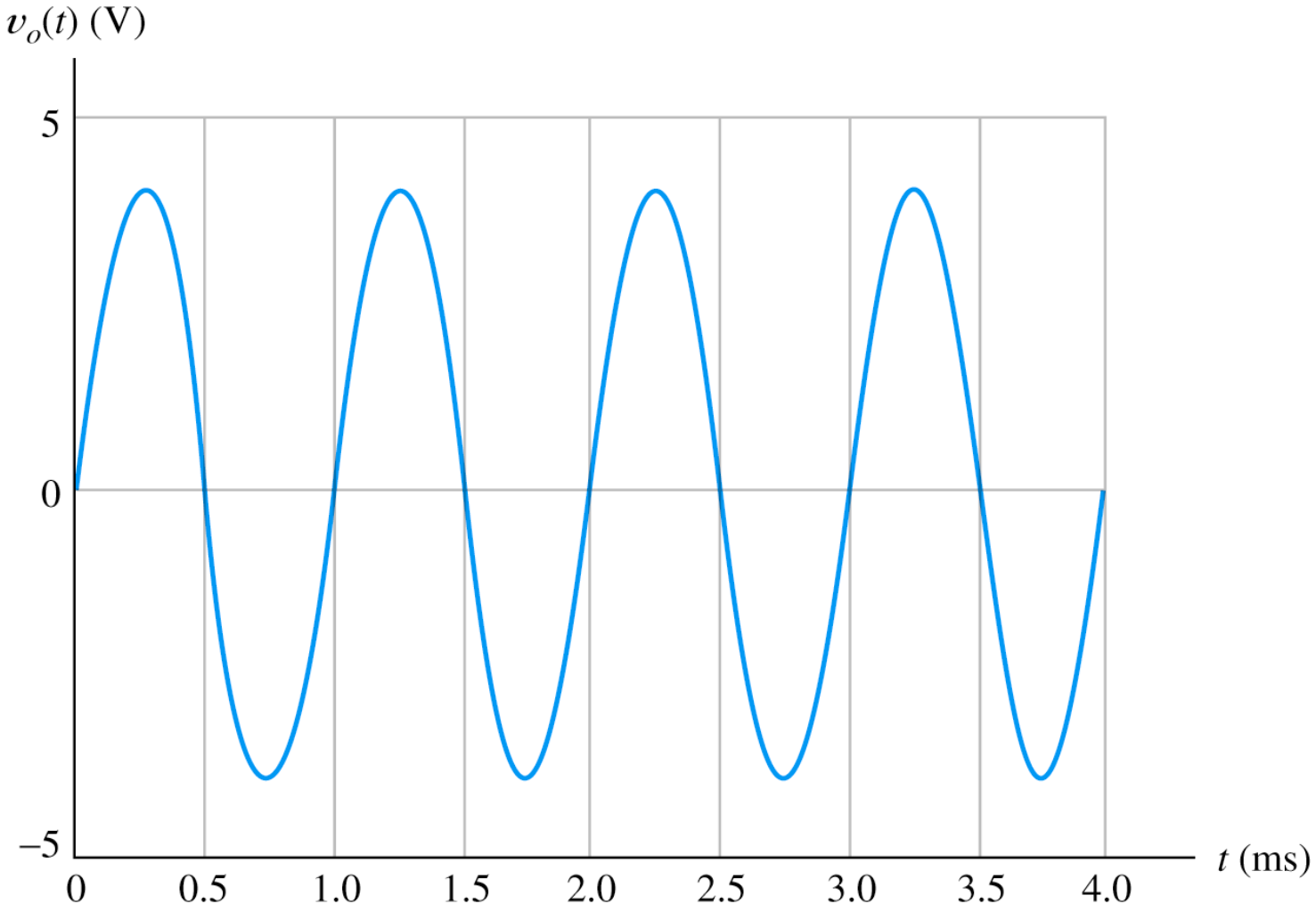
The output voltage of a real Op-Amp is limited to the range between certain limits that depend on the internal design of the Op-Amp. When the output voltage tries to exceed these limits, clipping occurs.

Similarly, the output current must stay within a specific range to prevent clipping at the output of Op-Amp.

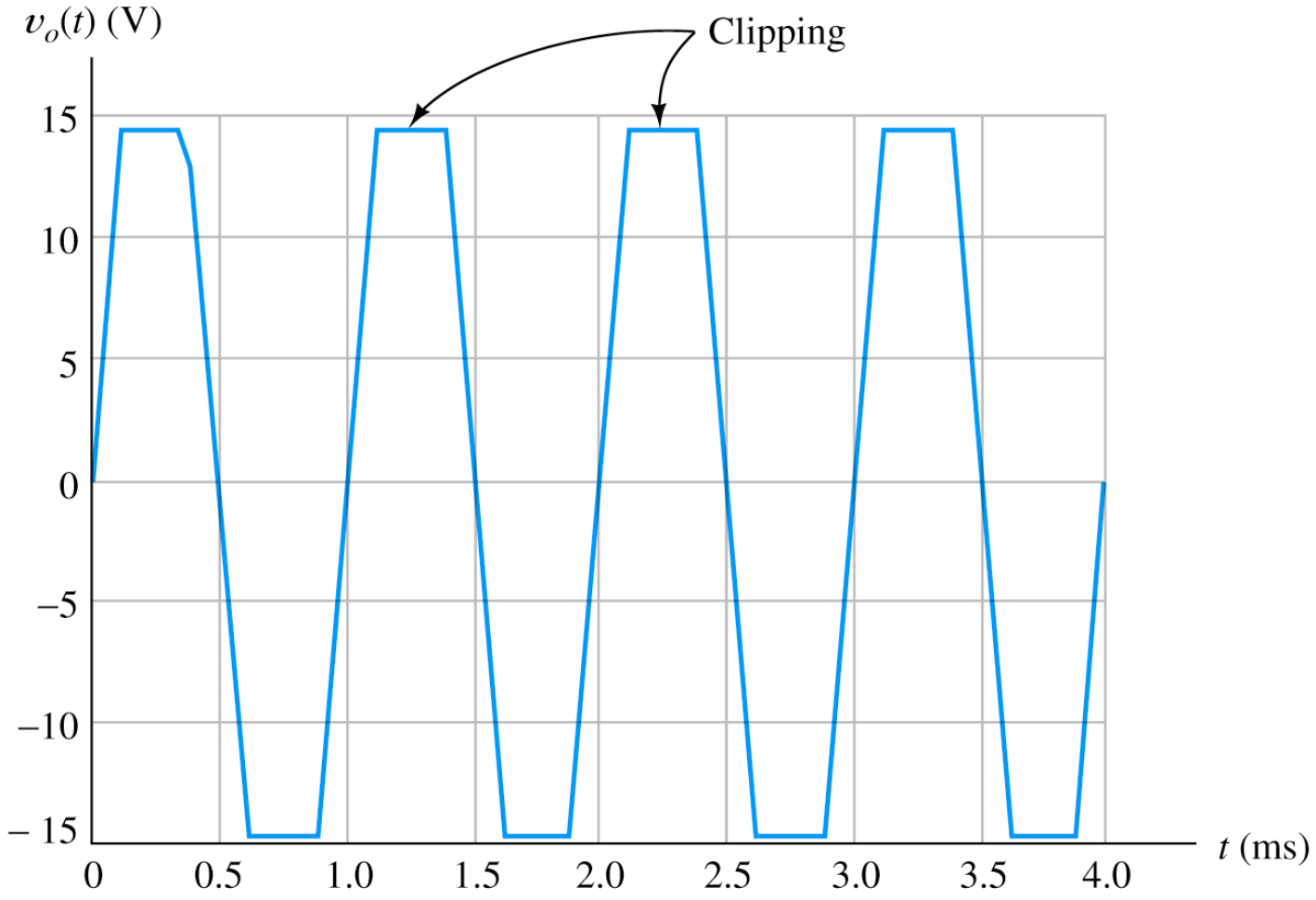
An Example of Output Clipping

Note: this is set up as an inverting amplifier





Output of a circuit operating in the "linear range" --- note the sinusoidal output is following a sinusoidal input signal.



Output of a circuit where the sinusoidal input signal is too large, driving the unit into the saturation region … note the clipping at top and bottom!

Op-Amp Circuit Analysis

Basic Assumptions:

1) No current flowing into the V^+ or V^- inputs
2) Since gain is infinite, V^+ and V^- are approximately equal
3) Output resistance is zero

Op-Amp Examples

- Go to op-amp circuit examples, found in Examples 5-2.1 thru 5-2.3