EE 254

Electronic Instrumentation

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Lecture Note #01

Content (Brief)

1. Operational Amplifiers

- Ideal Op-Amps
  - Open-loop gain
  - Input resistance
  - Output resistance
- Characteristics of Real Op-Amps
  - Open-loop transfer function
  - Voltage gains
  - Bandwidth
  - Slew rate
  - Power bandwidth
  - Clipping
  - Offset voltages and currents
  - Rejection ratio

Ideal Op-Amps

Ideal vs Non-Ideal

Ideal vs Non-Ideal :: Characteristics

Ideal Op-Amps

- Infinite open-loop gain
- Infinite input impedance
- Zero output impedance
- Infinite bandwidth
- Infinite common-mode rejection ratio (CMRR)

Non-Ideal Op-Amps

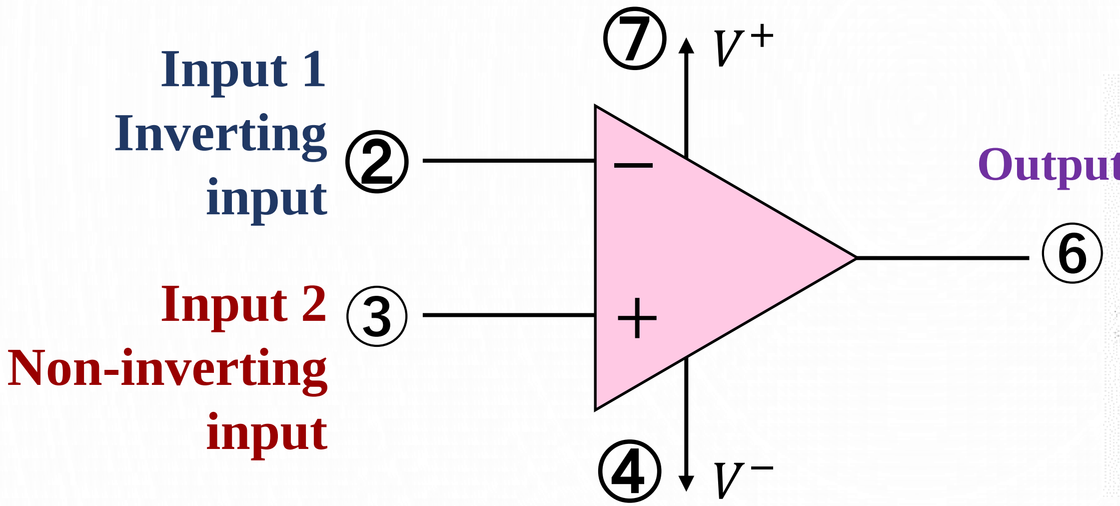
- Finite gain
- Non-zero input impedance
- Non-zero output impedance
- Limited bandwidth
- Finite CMRR

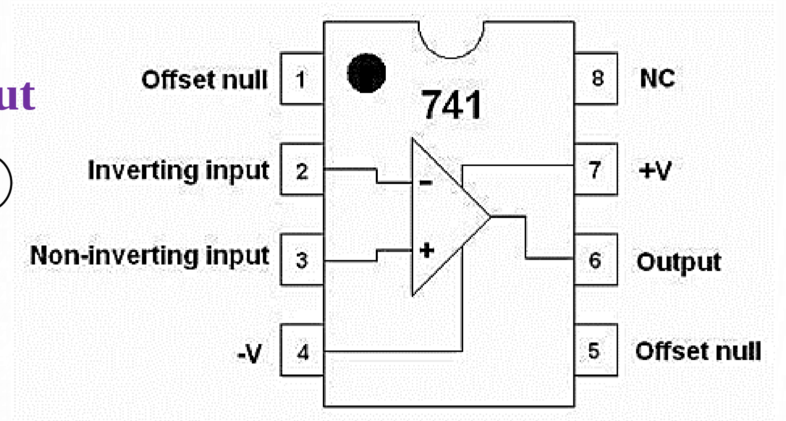
6.5 Electrical Characteristics, LM741[1]

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage		$R_S \le 10$ kΩ	$T_A = 25°C$		1	5	mV
			$T_{AMIN} \le T_A \le T_{AMAX}$			6	mV
Input offset voltage adjustment range		$T_A = 25°C$, $V_S = \pm 20$ V			±15		mV
Input offset current		$T_A = 25°C$			20	200	nA
		$T_{AMIN} \le T_A \le T_{AMAX}$			85	500	nA
Input bias current		$T_A = 25°C$			80	500	nA
		$T_{AMIN} \le T_A \le T_{AMAX}$				1.5	μA
Input resistance		$T_A = 25°C$, $V_S = \pm 20$ V		0.3	2		MΩ
Input voltage range		$T_{AMIN} \le T_A \le T_{AMAX}$		±12	±13		V
Large signal voltage gain		$V_S = \pm 15$ V, $V_O = \pm 10$ V, $R_L \ge 2$ kΩ	$T_A = 25°C$	50	200		V/mV
			$T_{AMIN} \le T_A \le T_{AMAX}$	25			V/mV
Output voltage swing		$V_S = \pm 15$ V	$R_L \ge 10$ kΩ	±12	±14		V
			$R_L \ge 2$ kΩ	±10	±13		V
Output short circuit current		$T_A = 25°C$			25		mA
Common-mode rejection ratio		$R_S \le 10$ Ω, $V_{CM} = \pm 12$ V, $T_{AMIN} \le T_A \le T_{AMAX}$		80	95		dB
Supply voltage rejection ratio		$V_S = \pm 20$ V to $V_S = \pm 5$ V, $R_S \le 10$ Ω, $T_{AMIN} \le T_A \le T_{AMAX}$		86	96		dB
Transient response	Rise time	$T_A = 25°C$, unity gain			0.3		μs
	Overshoot				5%		
Slew rate		$T_A = 25°C$, unity gain			0.5		V/μs
Supply current		$T_A = 25°C$			1.7	2.8	mA
Power consumption		$V_S = \pm 15$ V	$T_A = 25°C$		50	85	mW
			$T_A = T_{AMIN}$		60	100	mW
			$T_A = T_{AMAX}$		45	75	mW

(1) Unless otherwise specified, these specifications apply for $V_S = \pm 15$ V, $-55°C \le T_A \le +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \le T_A \le +70°C$.

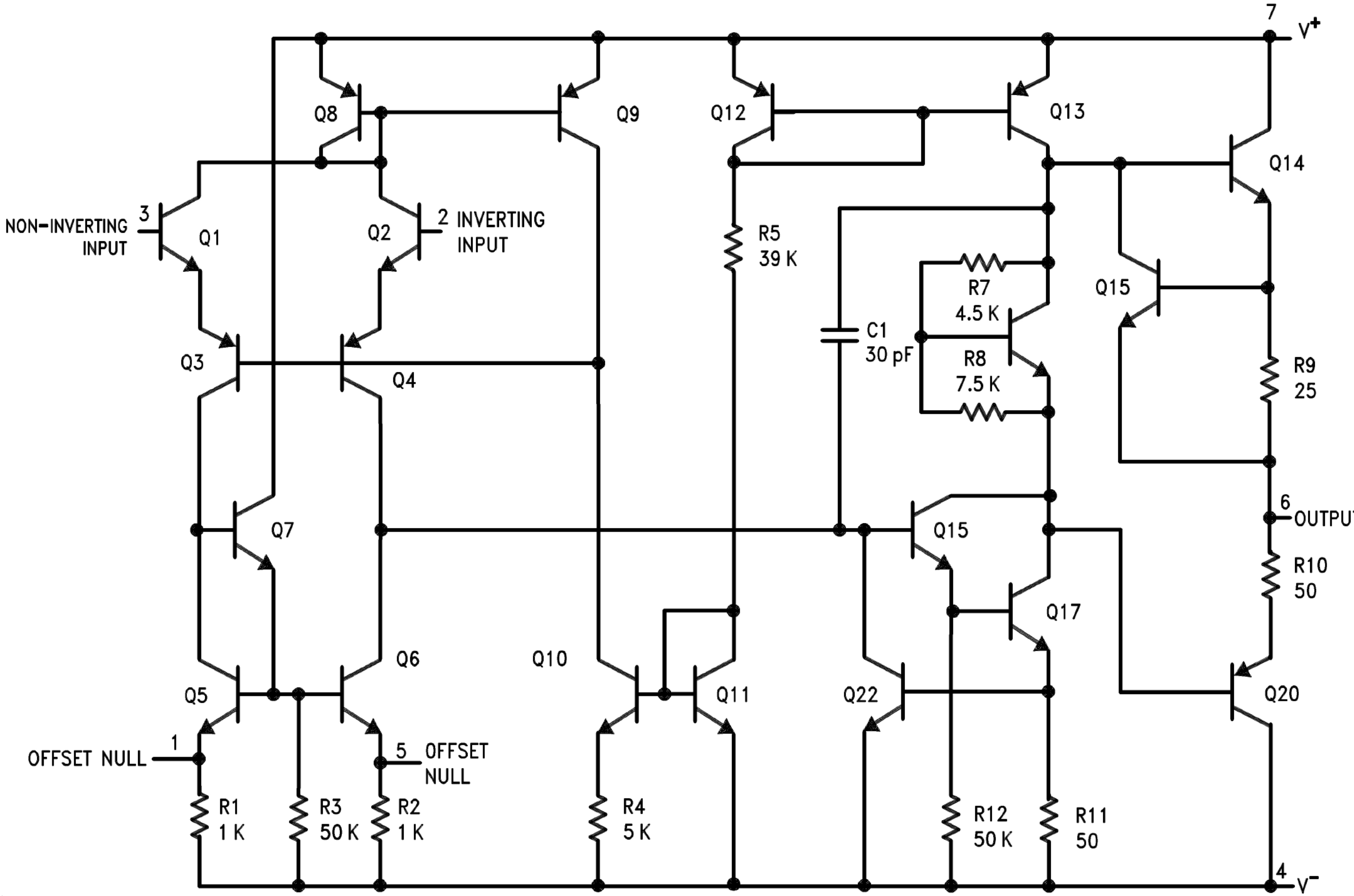
The Operational Amplifiers





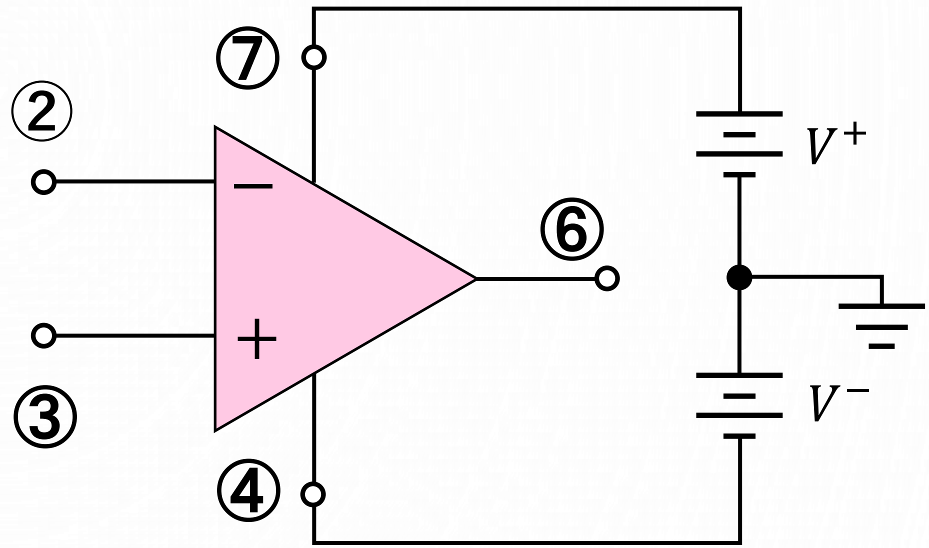
- A **very high gain** differential amplifier with **HIGH input impedance** and **LOW output impedance**
- **Used in**: Voltage amplifiers, oscillators, filter circuits, in instrumentational circuits
- Contains **a number of differential amplifier stages** for a very high gain
- 20 to 30 or more **transistors** are used to make up an op-amp circuit
- Op-amp requires **dc power**, and the transistors are biased in the active region
- Most op-amps are biased with both a positive and a negative voltage supply

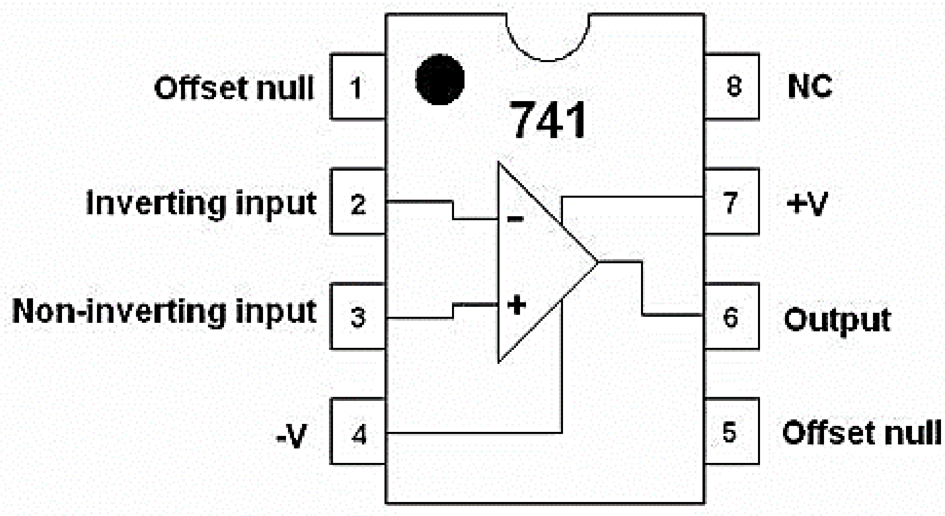
Functional Block Diagram of LM741



The Operational Amplifiers

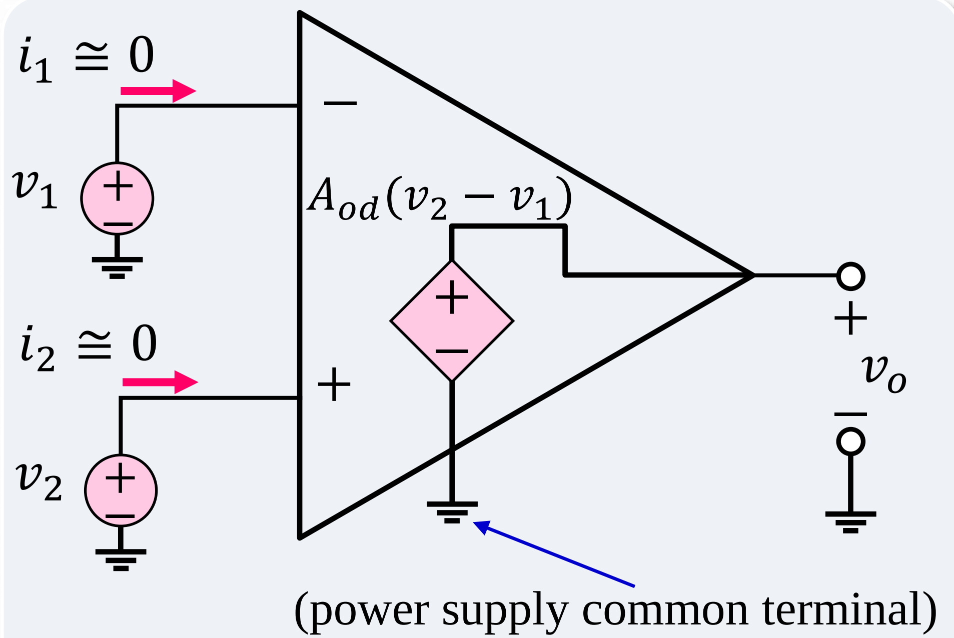
- We explicitly show two **dc power supplies as batteries with a common ground**.
- It is interesting to note that the reference grounding point in op-amp circuits is just the common terminal of the two power supplies; that is, **no terminal of the op-amp package is physically connected to ground.**





Ideal Parameters

- The ideal op-amp senses the **difference between two input signals** and amplifies this difference to produce an output signal.
- Ideally, the **input resistance** R_i between terminals 1 and 2 is **infinite** (i.e. input current at each terminal is zero).



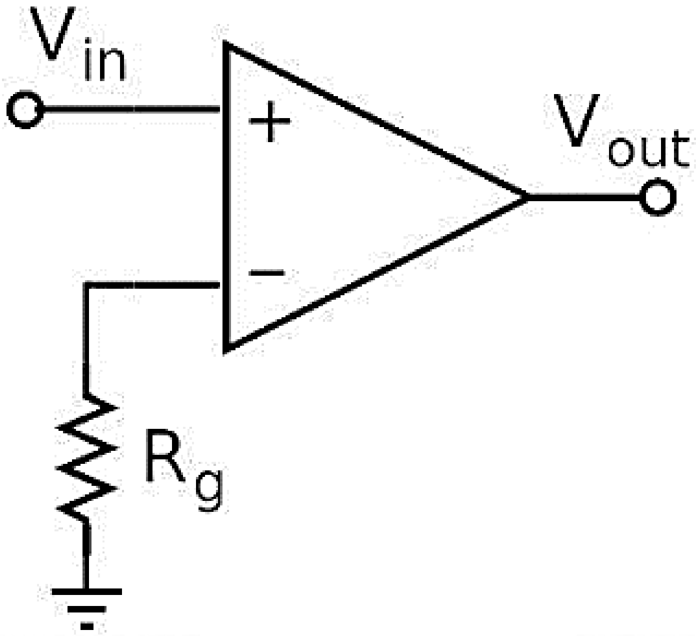
Ideal op-amp equivalent circuit

- The output terminal acts as the output of an **ideal dependent voltage source** (the small-signal **output resistance** R_o is **zero**). i.e. v_o is independent of the current that may be drawn by the load impedance.
- The parameter A_{od} : **open-loop differential voltage gain**, is about 10^5 at low frequencies.

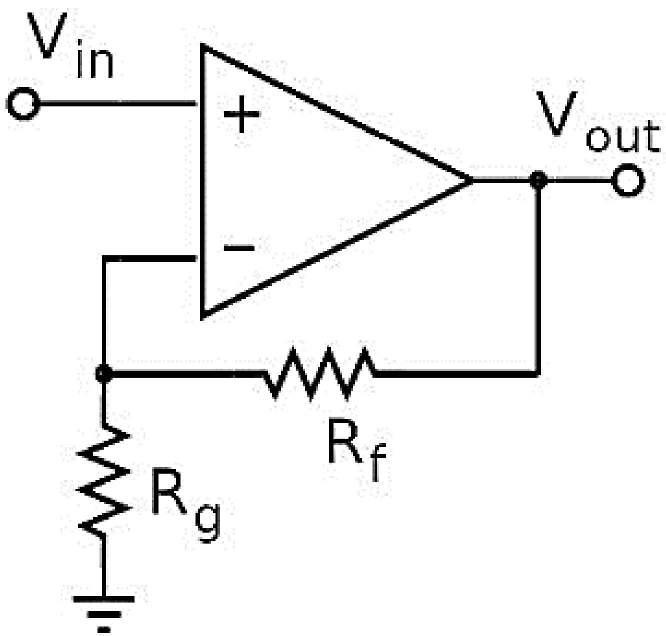
Analysis Method

- Usually, an op-amp **is not used in the open-loop configuration**
- Instead, feedback is added to close the loop between the output and the input

Open Loop

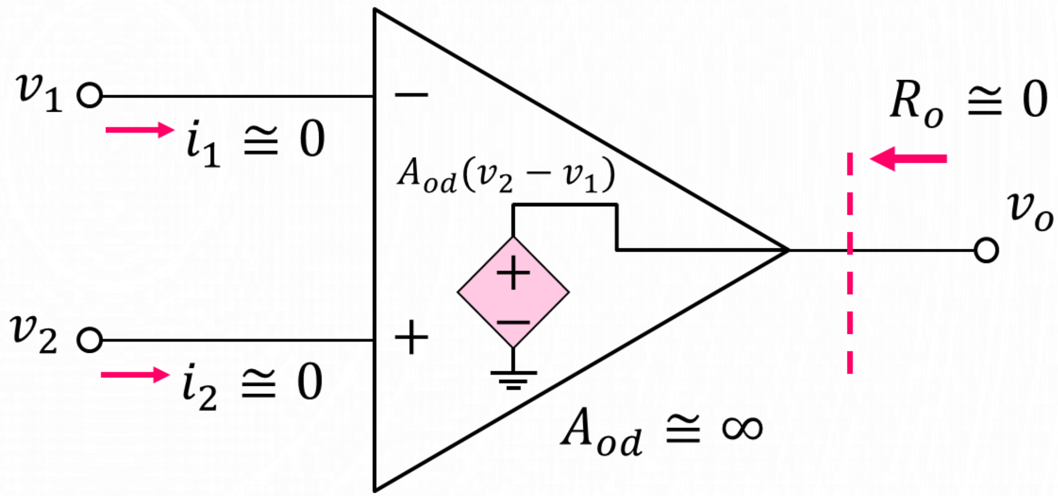


Closed Loop



Analysis Method

Summary



1. The internal differential gain A_{od} is considered to be **infinite**.

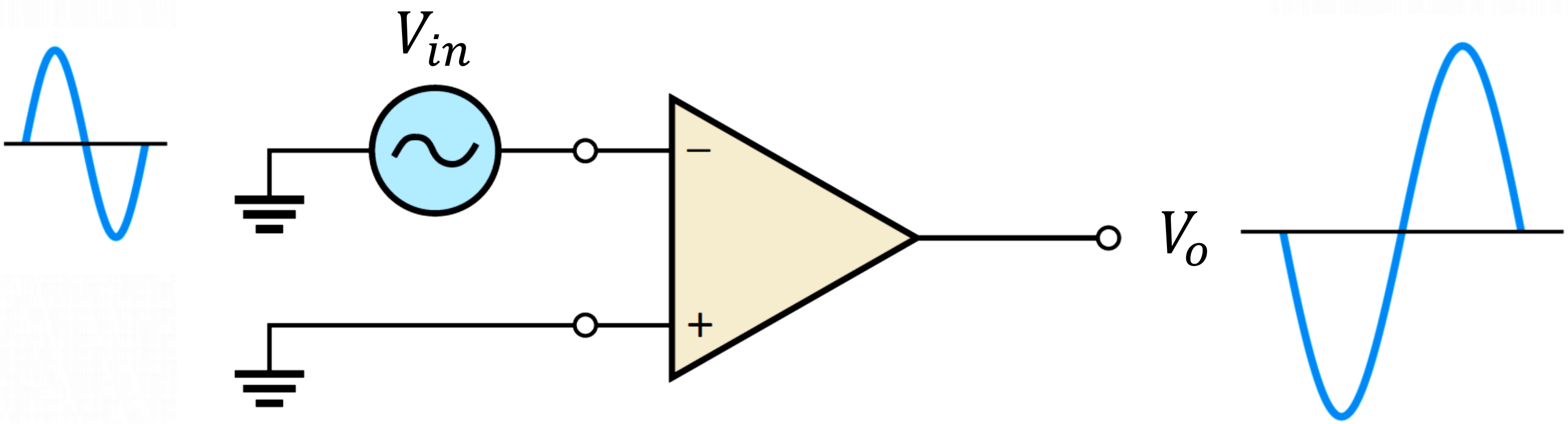
2. The **differential input voltage** $(v_2 - v_1)$ is assumed to be **zero**. If A_{od} is **very large** and if the output voltage v_O is finite, then the two input voltages must be nearly equal.

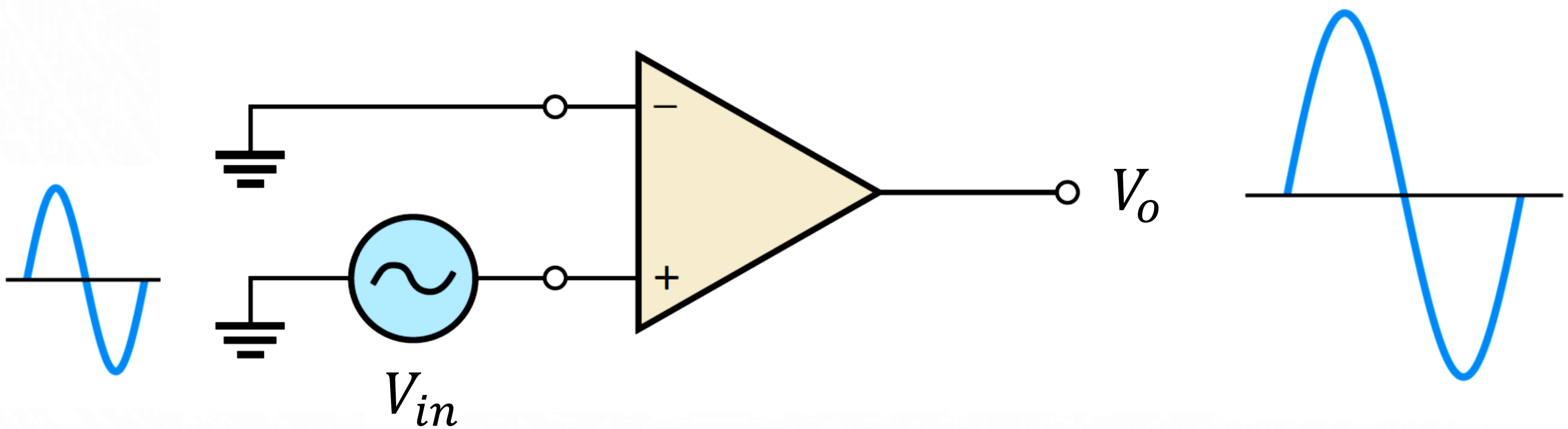
3. The effective input resistance to the op-amp is assumed to be **infinite**, so the two input currents, i_1 and i_2, are **essentially zero**.

4. The output resistance R_o is **assumed to be zero** in the ideal case, so the output voltage is connected directly to the dependent voltage source, and the output voltage is independent of any load connected to the output.

Input Signal Modes: Differential Mode

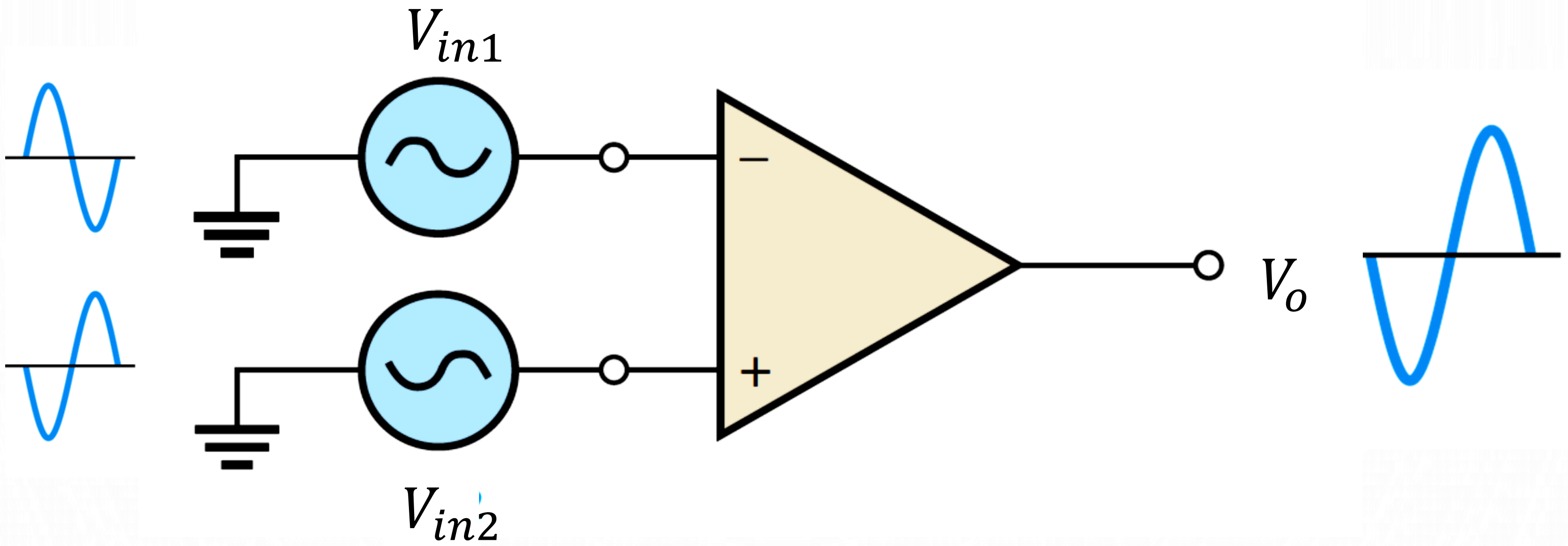
Single-Ended Input

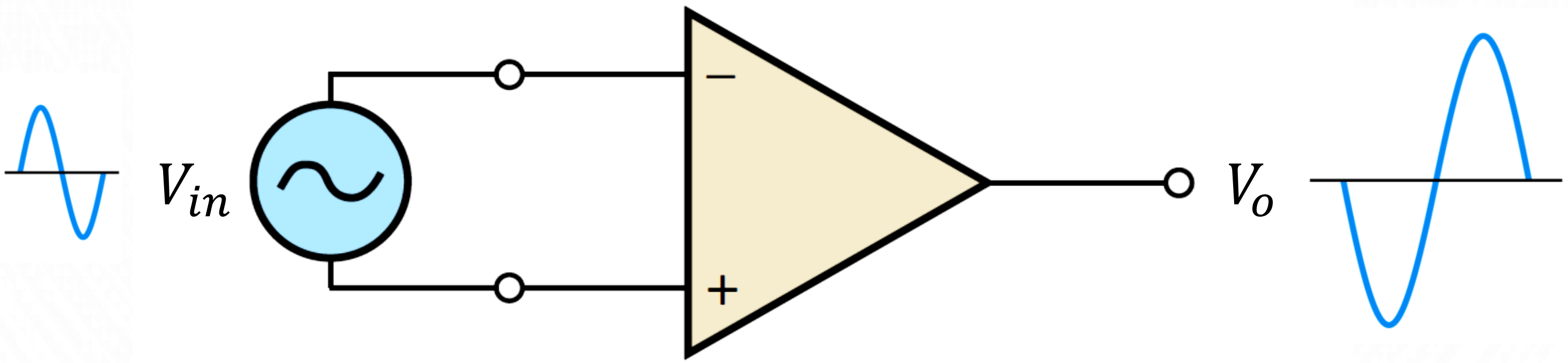




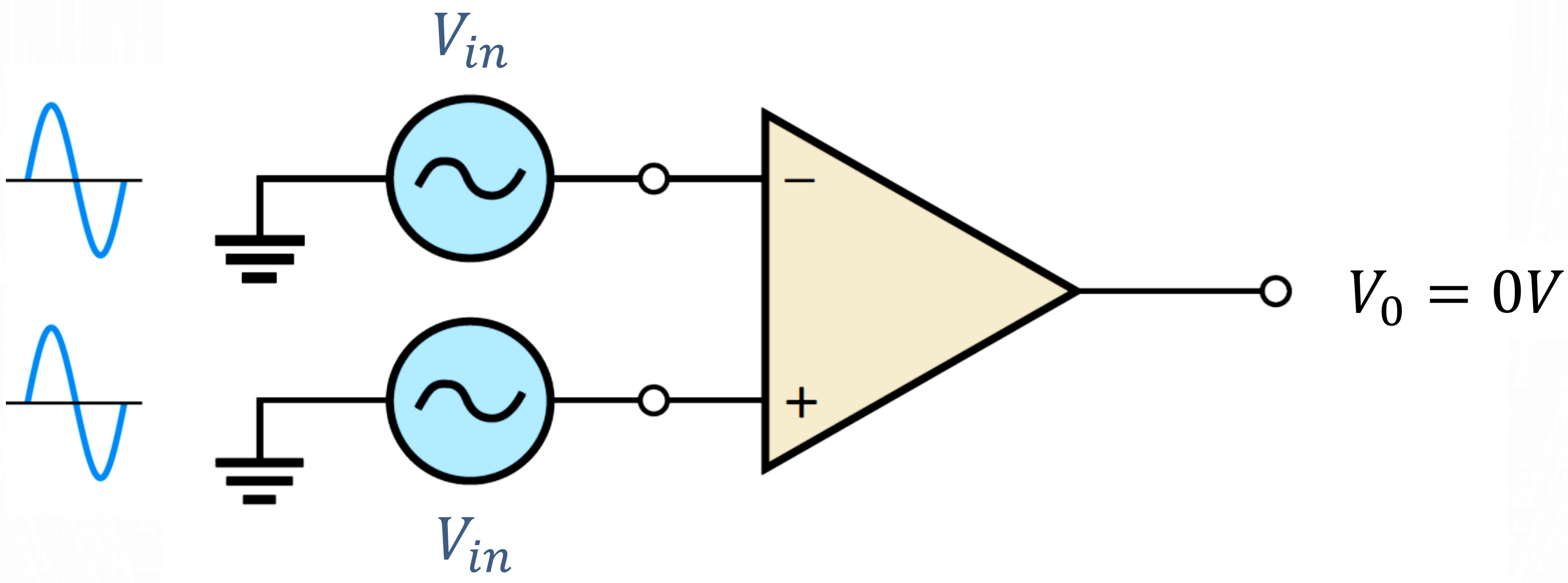
Input Signal Modes: Differential Mode

Double-Ended Input





Input Signal Modes: Common Mode



- Ideally 0V output
- What are the applications?