ĐẠI HỌC BÁCH KHOA HÀ NỘI
VIỆN CÔNG NGHỆ THÔNG TIN VÀ TRUYỀN THÔNG

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Electronics for Information Technology

(Điện tử cho Công nghệ Thông tin)

IT3420E

Đỗ Công Thuần

Department of Computer Engineering

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General Information

- Course: **Electronics for Information Technology**
- ID Number: IT3420
- Credits: 2 (2-1-0-4)
- Lecture/Exercise: 32/16 hours (48 hours, 16 weeks)
- Evaluation:
  - Midterm examination and weekly assignment: **50%**
  - Final examination: **50%**
- Learning Materials:
  - Lecture slides
  - Textbooks
    - ***Introductory Circuit Analysis*** (2015), 10th – 13th ed., Robert L. Boylestad
    - ***Electronic Device and Circuit Theory*** (2013), 11th ed., Robert L. Boylestad, Louis Nashelsky
    - ***Microelectronics Circuit Analysis and Design*** (2006), 4th ed., Donald A. Neamen
    - ***Digital Electronics: Principles, Devices and Applications*** (2007), Anil K. Maini

Contact Your Instructor

- You can reach me through office in **Room 802, B1 Building**, HUST.
  - You should make an appointment by email before coming.
  - If you have urgent things, just come and meet me!
- You can also reach me at the following **email** any time. This is the best way to reach me!
  - thuandc@soict.hust.edu.vn

Course Contents

- The Concepts of Electronics for IT
- **Chapter 1**: Passive Electronic Components and Applications
- **Chapter 2**: Semiconductor Components and Applications
- **Chapter 3**: Operational Amplifiers
- **Chapter 4**: Fundamentals of Digital Circuits
- **Chapter 5**: Logic Gates
- **Chapter 6**: Combinational Logic
- **Chapter 7**: Sequential Logic

Chapter 3: **Operational Amplifiers**

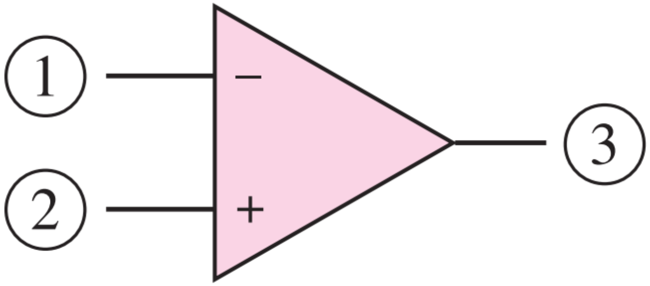
- Operational Amplifier
- Ideal Parameters
- Operational Amplifier Circuits
- Applications

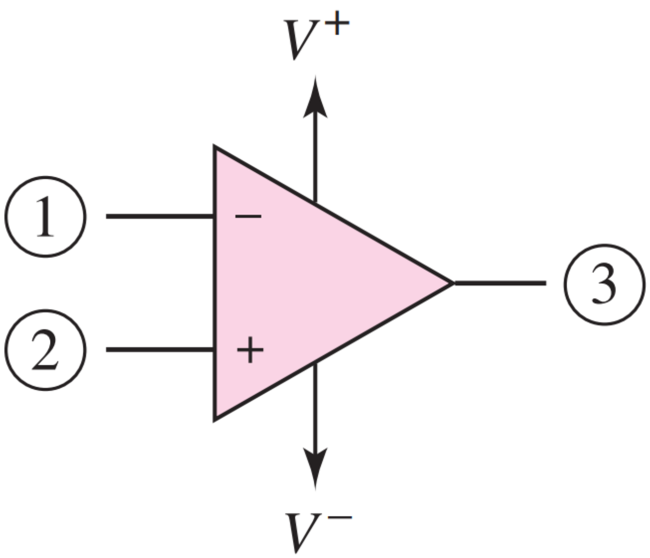
Operational Amplifier

- 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 prevalent in analog electronics.
- The op-amp can be thought of as another electronic device (in much the same way as the bipolar or field-effect transistor).

Operational Amplifier

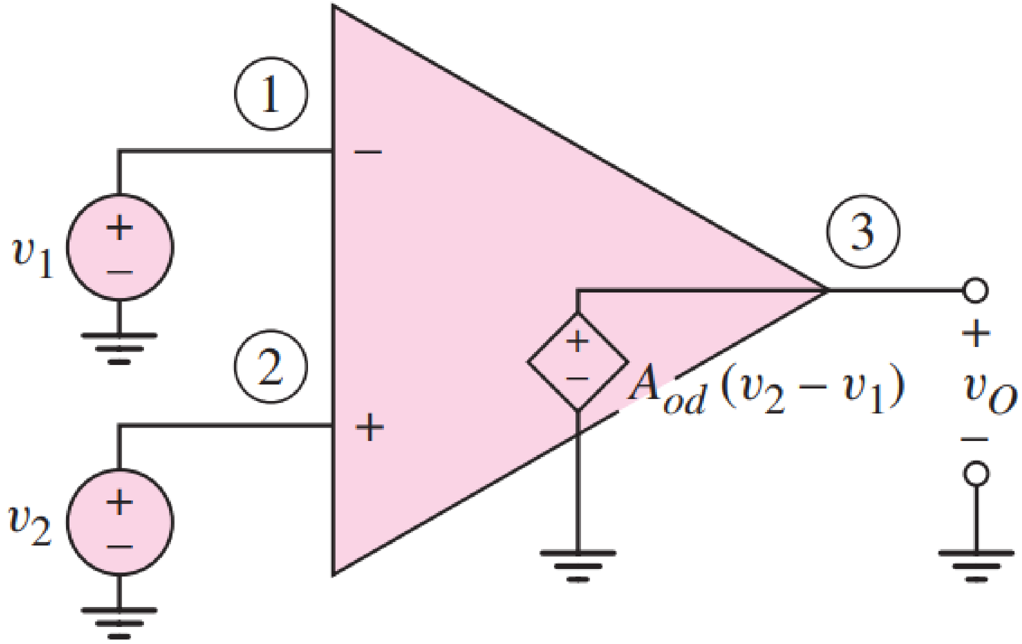
- 2 input terminalss: ①-② and 1 output terminal: ③
- There are normally tens of transistors that make up an op-amp circuit → it requires dc power so that the transistors are biased in the active region.
- Most op-amps are biased with both a positive and a negative voltage supply, V^+ and V^-.





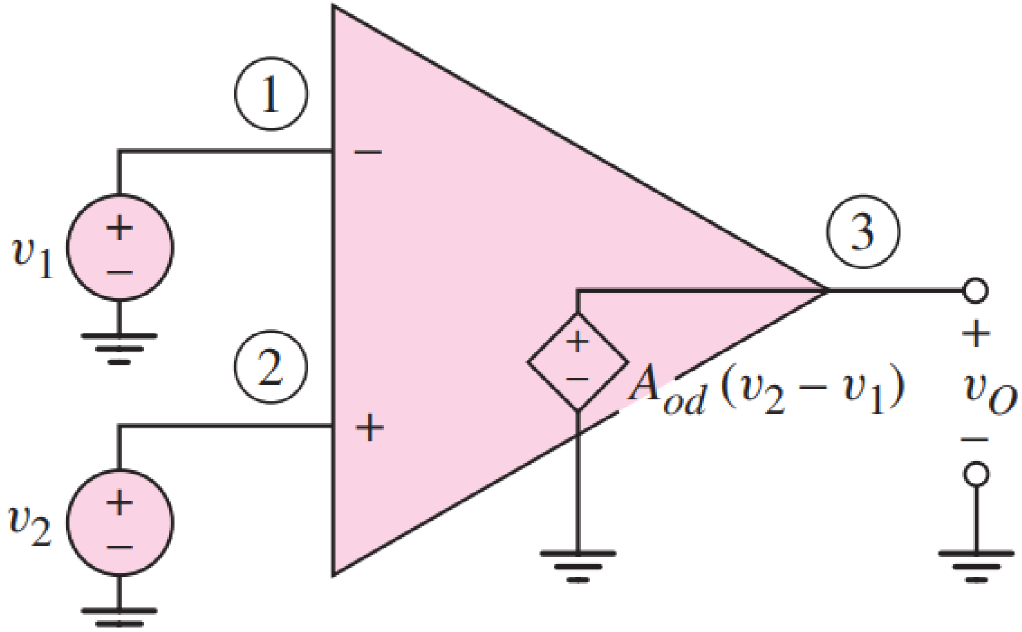
Ideal Parameters

- The ideal op-amp senses the difference between two input signals and amplifies this difference to produce an output signal.
- The terminal voltage is the voltage at a terminal measured with respect to ground.



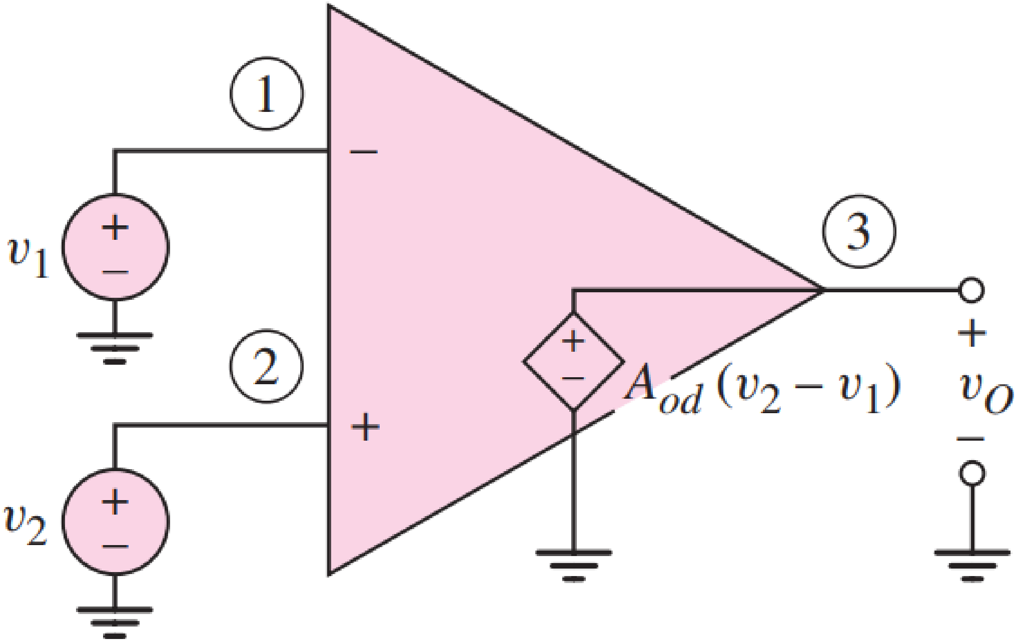
Ideal Parameters

- The input resistance between ① and ② is infinite, $R_i = \infty$ → the input current at each termial is zero.
- The output terminal ③ of an ideal op-amp acts as the output of an ideal voltage source → $R_o = 0$.



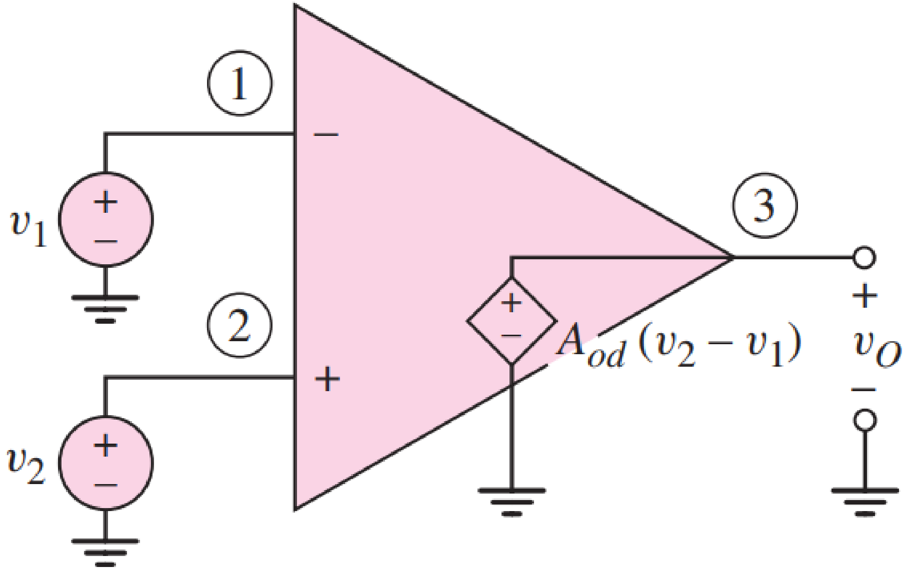
Ideal Parameters

- A_{od} the open-loop differential voltage gain of the op-amp.
- A_{od} is very large and approaches to infinity.



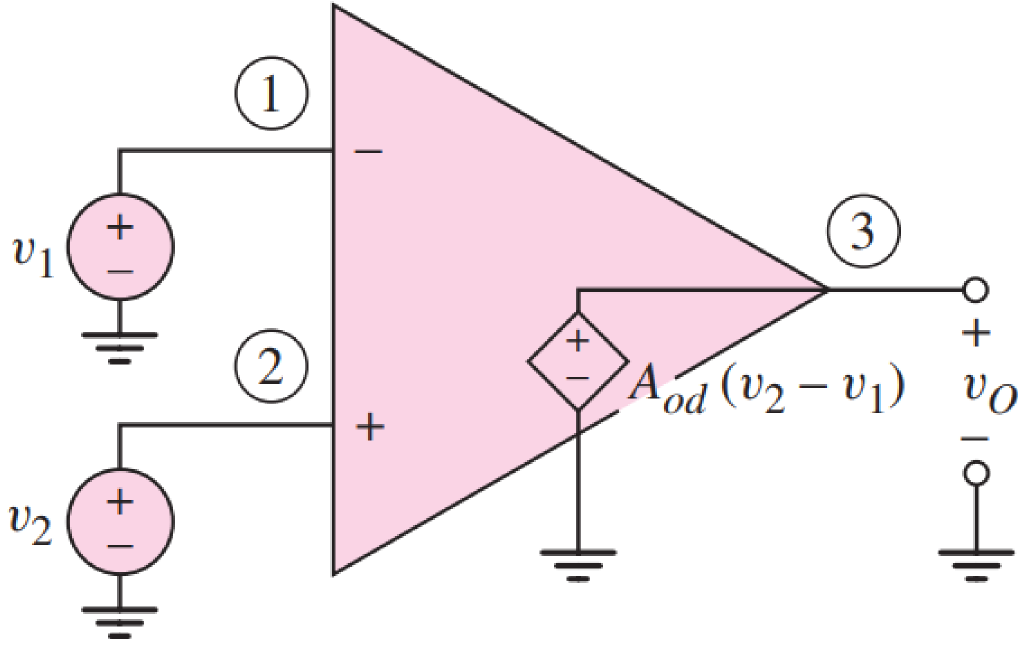
Ideal Parameters

- The output is out of phase with respect to v_1 and in phase with respect to v_2
- v_1: the inverting input terminal, designated by the "–" notation
- v_2: the noninverting input terminal, designated by the "+" notation



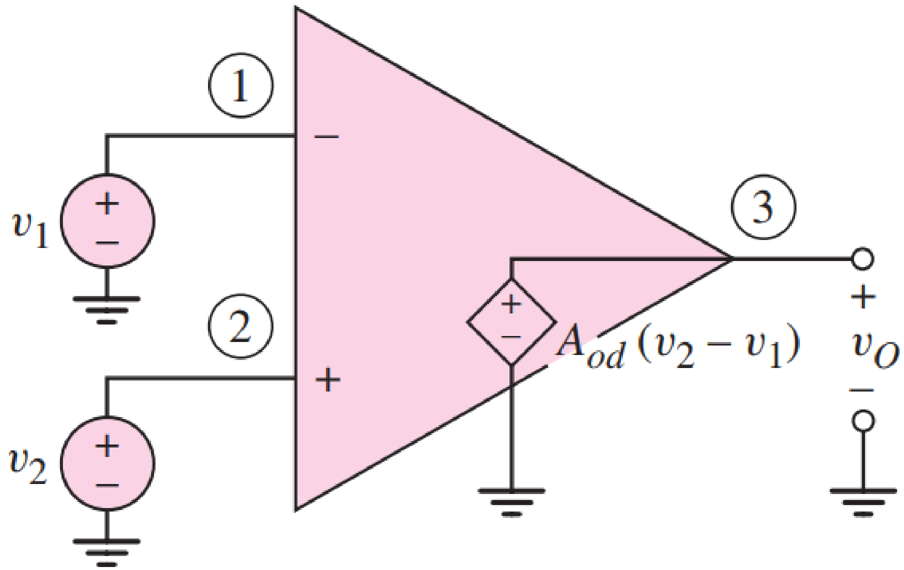
Ideal Parameters

- The ideal op-amp responds only to the difference between the two input signals v_1 and v_2.
- For $v_1 = v_2$, the ideal op-amp maintains a zero output ($v_O = 0$).



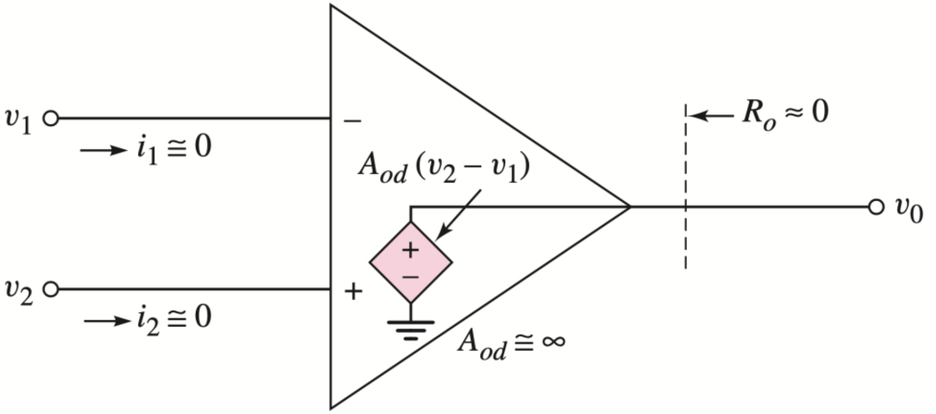
Ideal Parameters

- When $v_1=v_2\neq0$, there is a common-mode input signal.
- For the ideal op-amp, the common-mode output signal is zero.
- This characteristic is referred to as common-mode rejection.



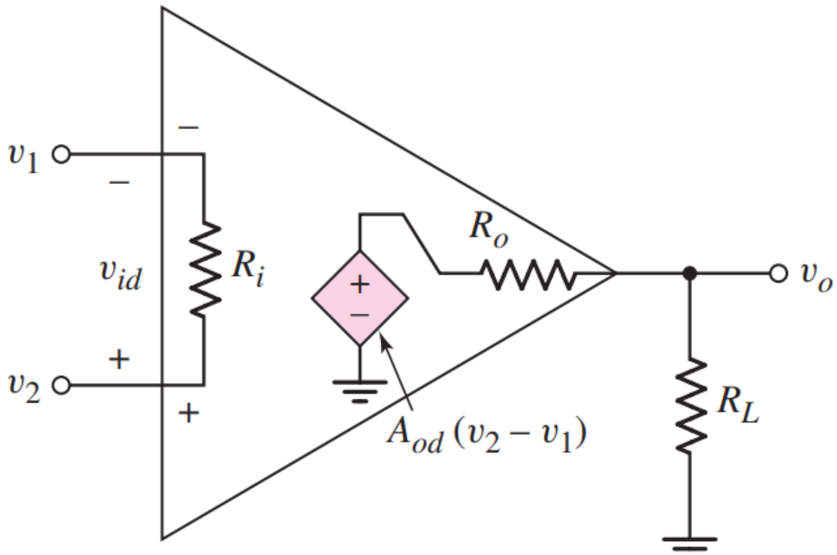
Ideal Parameters

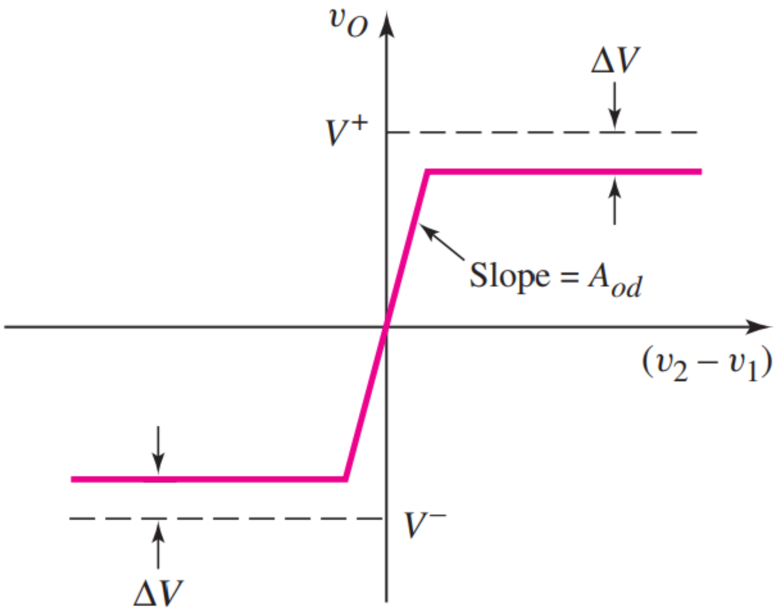
- For an ideal op-amp: $A_{od} \cong \infty$
- If A_{od} is very large and v_o is finite: $(v_2 - v_1) \cong 0$
- The effective input resistance to the op-amp is assumed to be infinite: $i_1 \cong 0 \quad i_2 \cong 0$
- The output resistance $R_o \approx 0$ (ideal case) → the output voltage is connected directly to the dependent voltage source, and it is independent of any load connected to the output.



Practical Op-amps

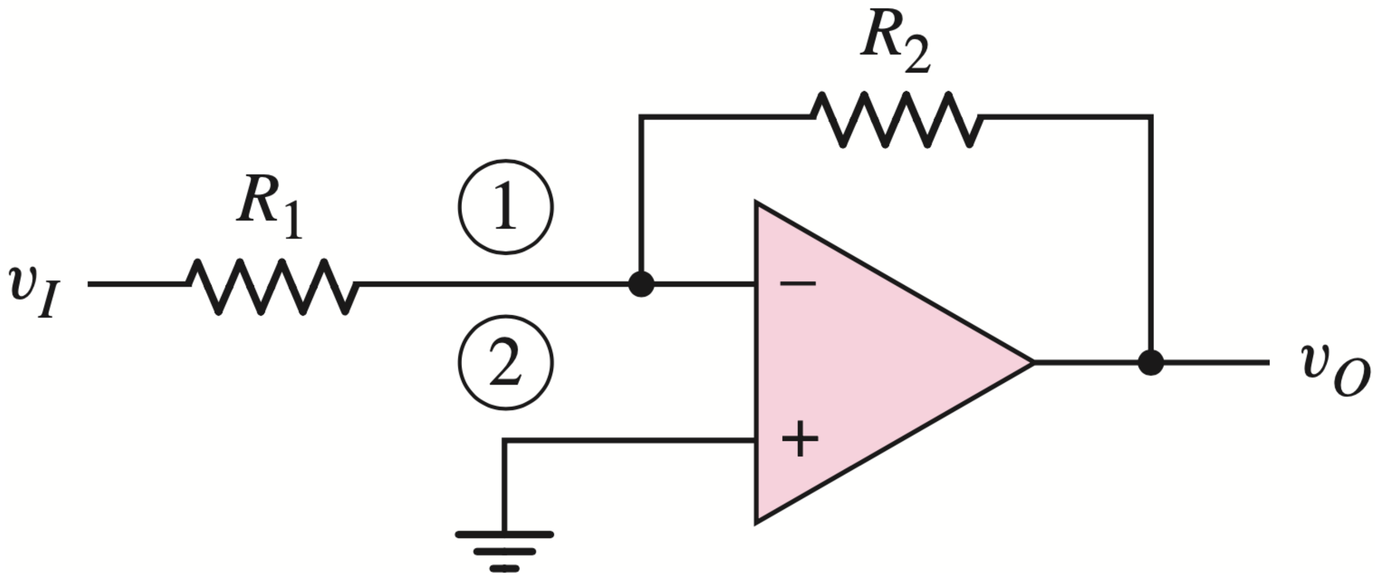
- The properties of a practical op-amp approach those of an ideal op-amp.
- If Ri is very large and Ro is very small, we can consider a practical op-amp as an ideal op-amp, and then can use it as a simple device.





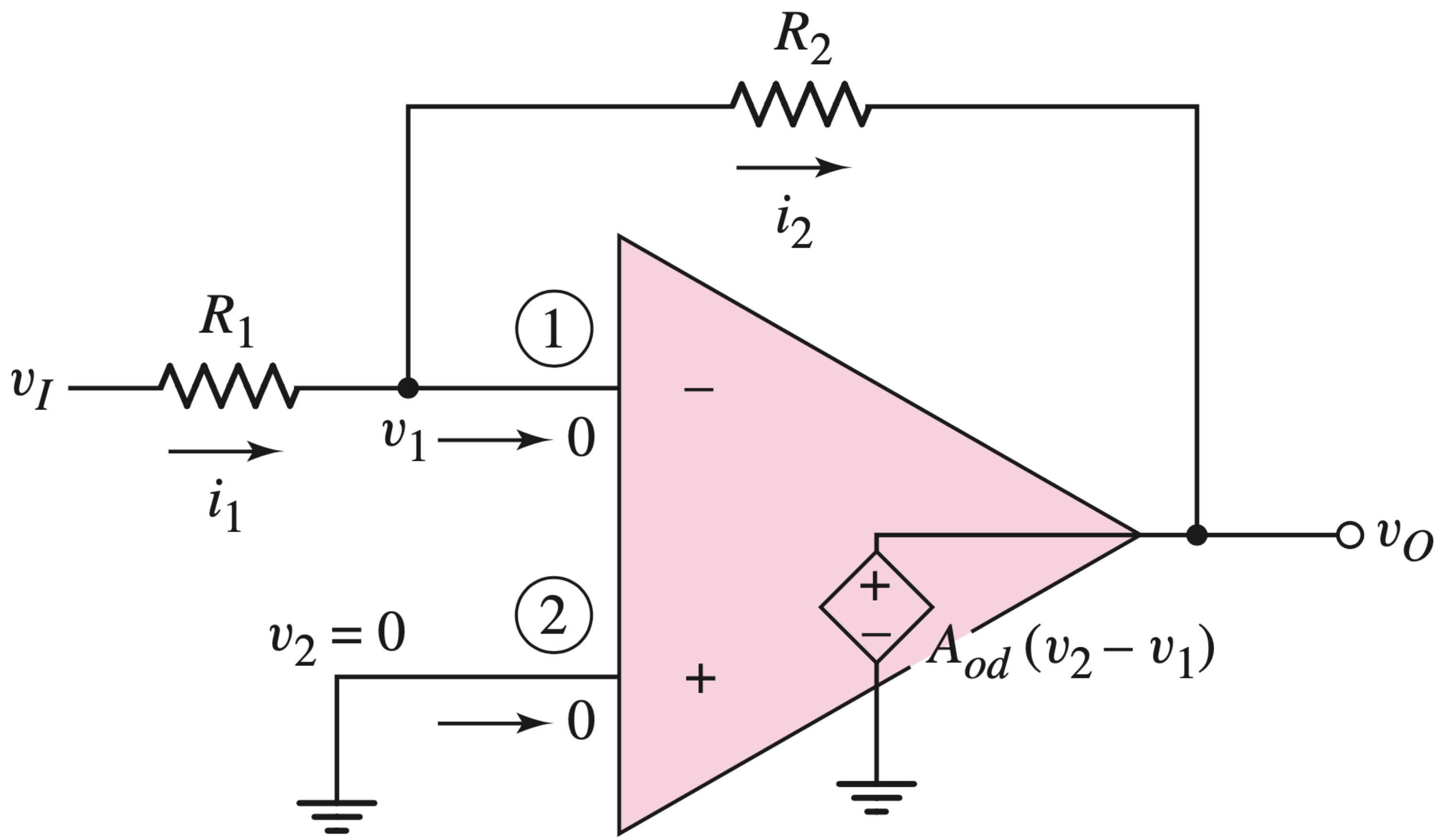
Inverting Amplifier

- One of the most widely used op-amp circuits.
- Applying the closed-loop configuration for stability.
- The op-amp is biased with dc voltages (not shown in the figure).



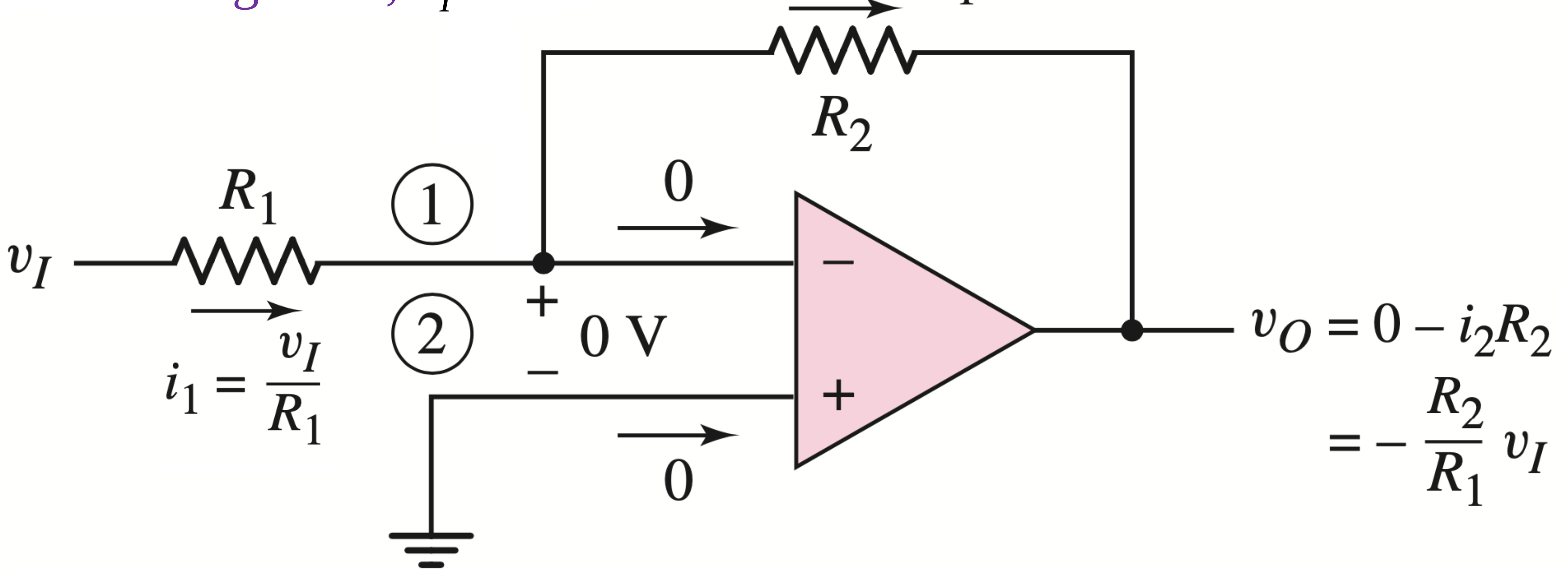
Inverting Amplifier

- Inverting op-amp equivalent circuit:



Inverting Amplifier

Virtual ground, $v_I = 0$



- **Closed-loop voltage gain:**

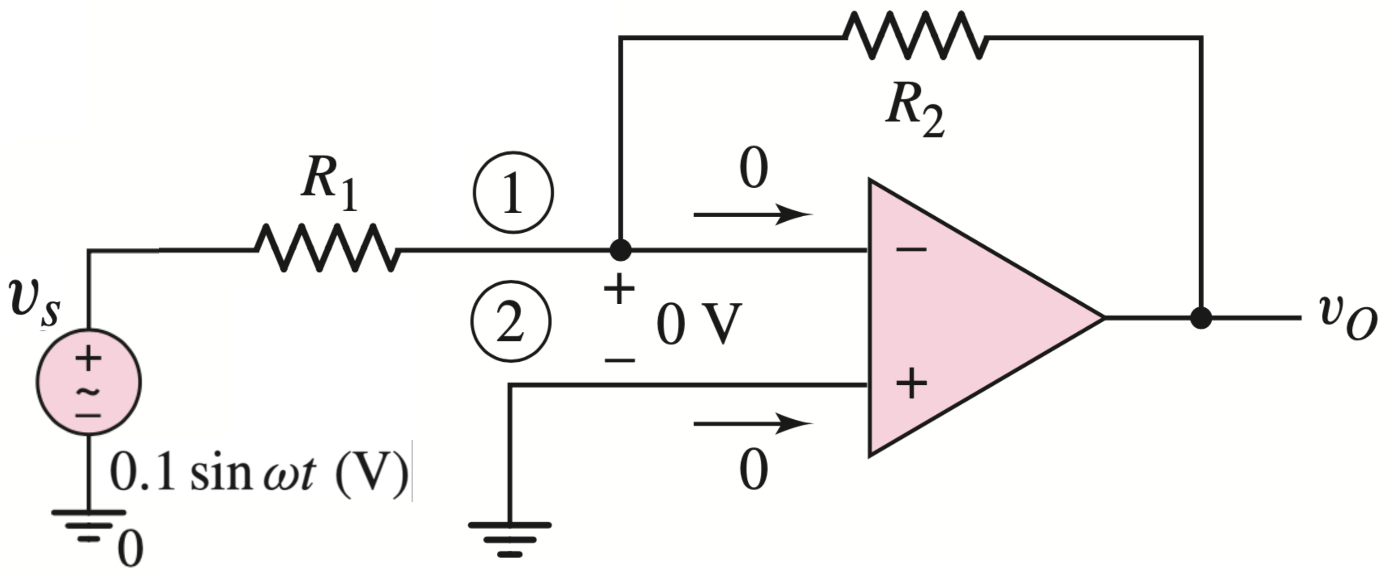
$$\boxed{A_v = \frac{v_O}{v_I} = -\frac{R_2}{R_1}}$$

- **Input resistance**

$$R_i = \frac{v_I}{i_1} = R_1$$

Example 3.1

- Design an inverting amplifier with a specified voltage gain: $v_s = 0.1\ \sin\omega t$ (V) so that the voltage gain: A_v=-5
- Assume that the source can supply a maximum current of 5μA.

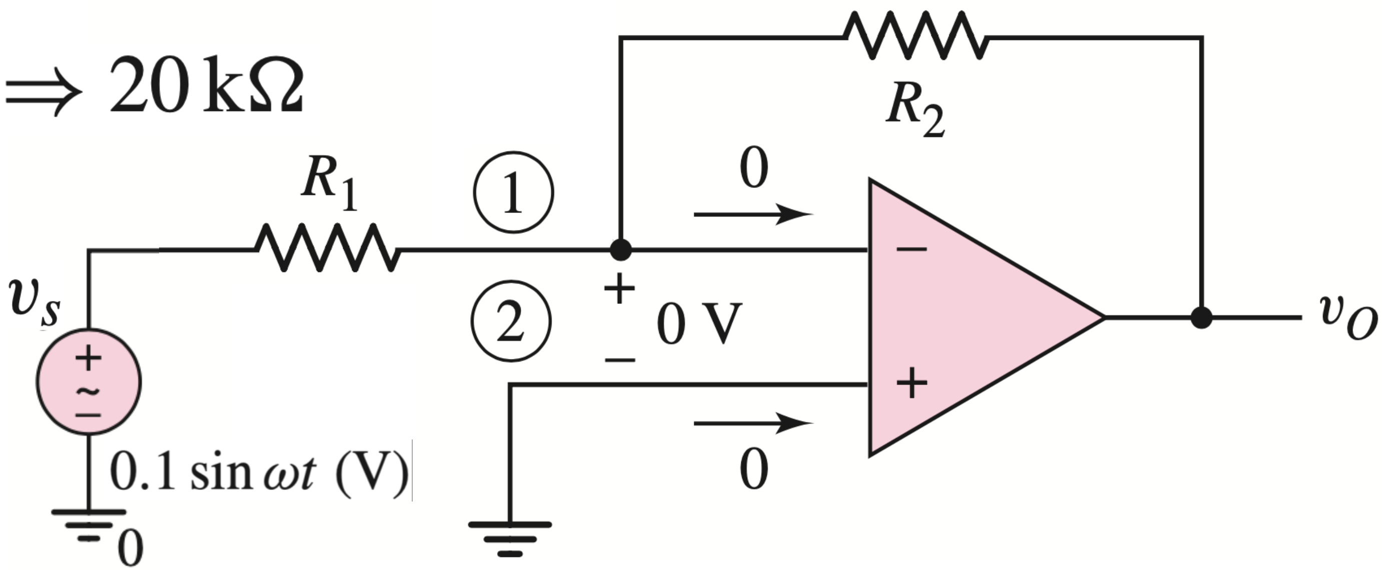


Example 3.1

$$R_1 = \frac{v_s\,(\text{max})}{i_1\,(\text{max})} \qquad A_v = \frac{-R_2}{R_1} = -5$$

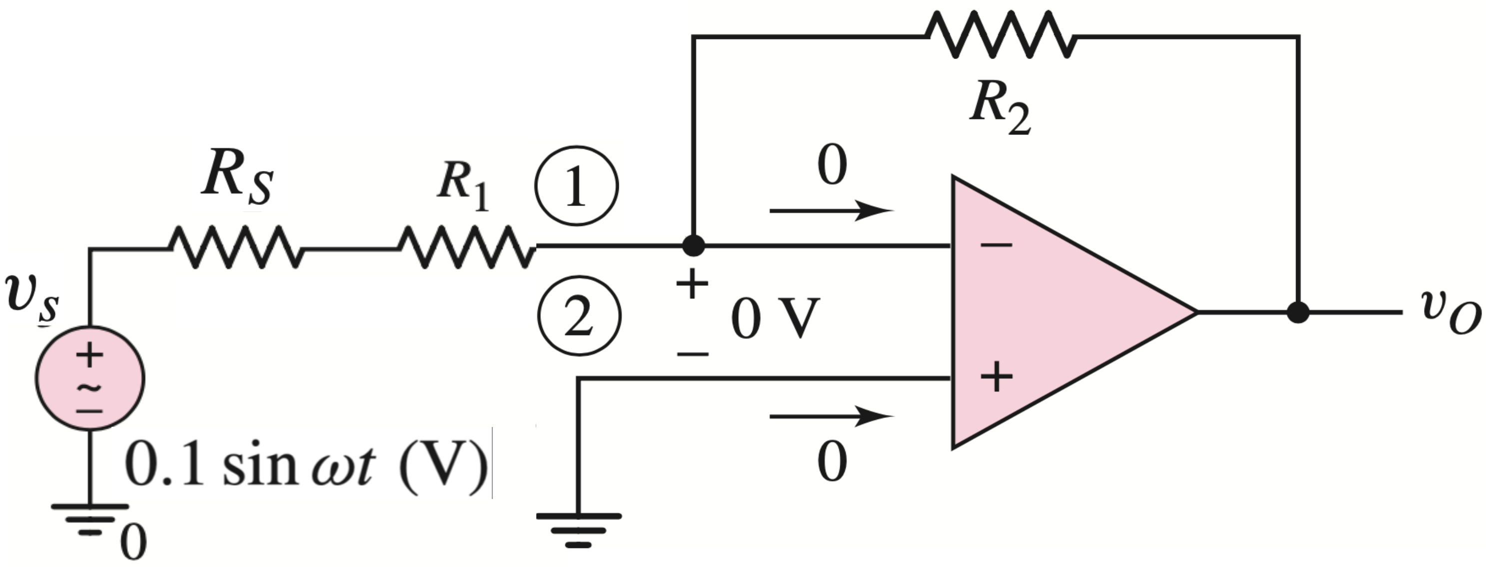
$$= \frac{0.1}{5 \times 10^{-6}} \qquad R_2 = 5R_1 = 5(20) = 100\ \text{k}\Omega$$

$$\Rightarrow 20\ \text{k}\Omega$$



Example 3.2

- Similar to Example 3.1, except that $R_S = 1\ \mathrm{k}\Omega$



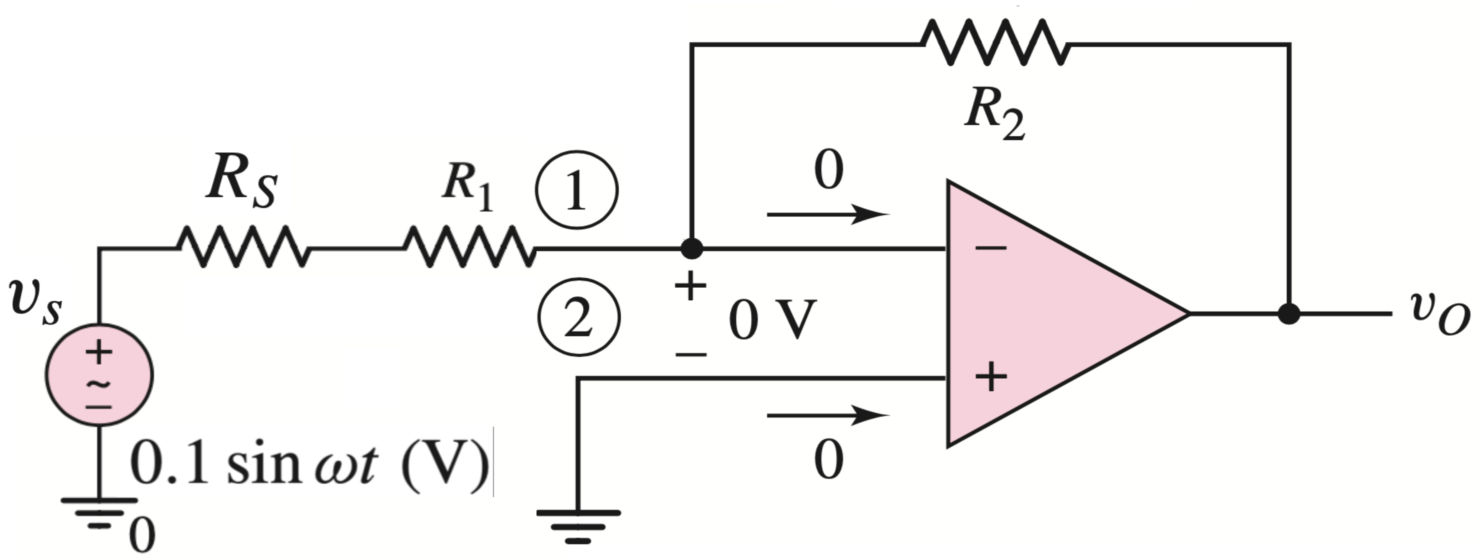
Example 3.2

$$R_1 + R_S = \frac{v_s(\max)}{i_1(\max)} = \frac{0.1}{5 \times 10^{-6}} \Rightarrow 20\,\mathrm{k\Omega}$$

$$R_S = 1\ \mathrm{k\Omega}$$

$$\Rightarrow R_1 = 19\ \mathrm{k\Omega}$$

$$R_2 = 5(R_1 + R_S) = 5(19 + 1) = 100\,\mathrm{k\Omega}$$



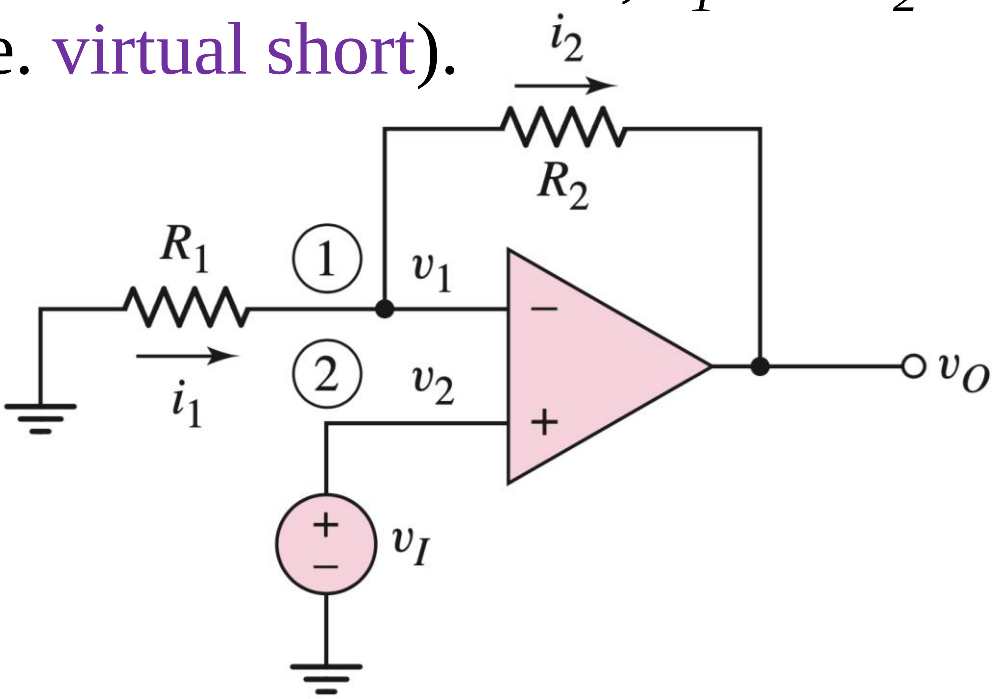
Problem-Solving Technique: Ideal Op-Amp Circuits

1. If the (+) terminal of the op-amp is **at ground potential**, then the (-) terminal is at virtual ground. Sum currents at this node, assuming zero current enters the op-amp itself.
2. If the (+) terminal of the op-amp is **not at ground potential**, then the (-) terminal is equal to that at the (+) terminal. Sum currents at the (-) terminal node, assuming zero current enters the op-amp itself.
3. For the ideal op-amp circuit, the output voltage is determined from either Step 1 or Step 2 above and is independent of any load connected to the output terminal.

Noninverting Amplifier

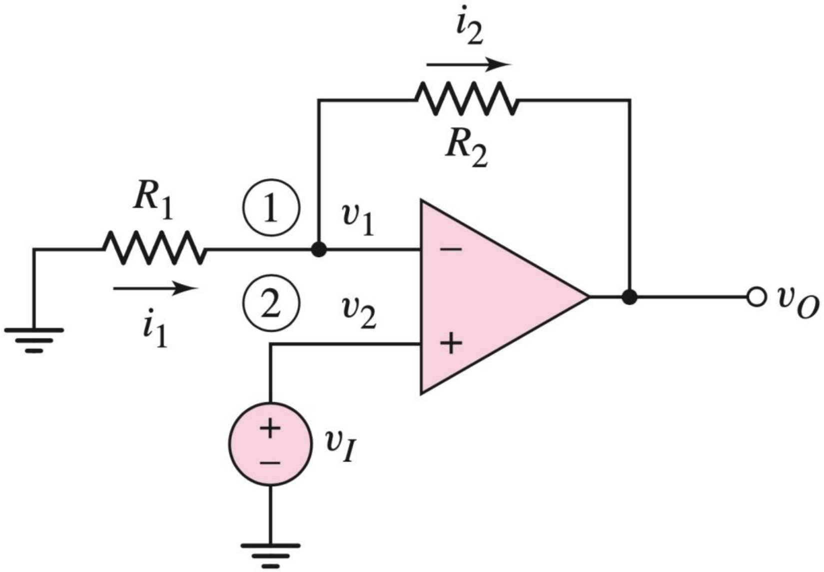
- The input voltage v_I is applied directly to the (+) terminal, while one side of R_1 is connected to the (-) terminal and the other side is at ground.
- Due to the negative feedback connection, v_1 and v_2 are essentially equal (i.e. virtual short).

$\Rightarrow v_1 = v_2$



Noninverting Amplifier

$$i_1 = -\frac{v_1}{R_1} = -\frac{v_I}{R_1}$$



$$i_2 = \frac{v_1 - v_O}{R_2}$$

$$= \frac{v_I - v_O}{R_2}$$

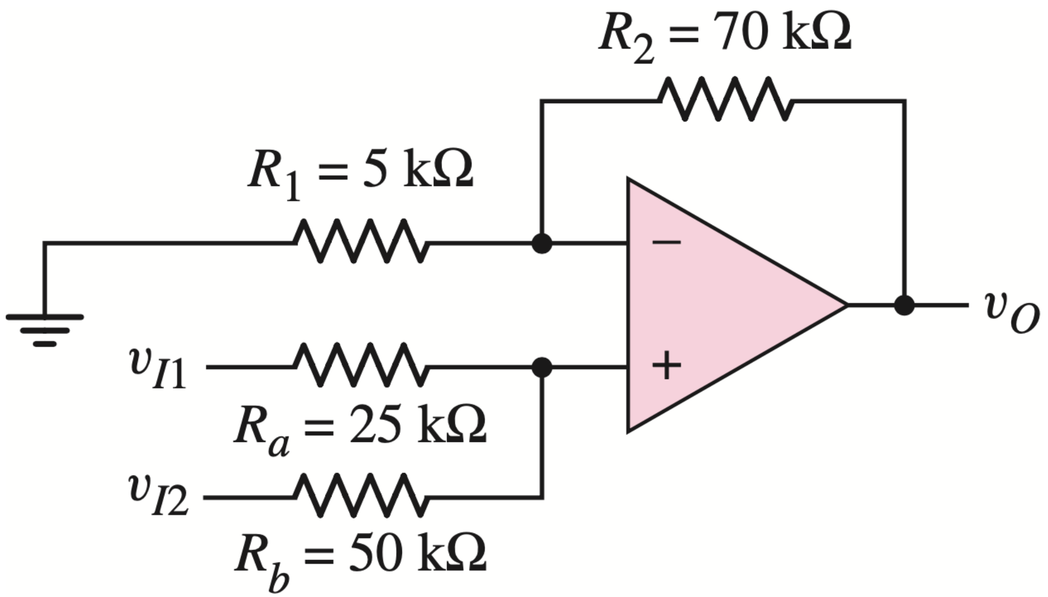
$$\boxed{A_v = \frac{v_O}{v_I} = 1 + \frac{R_2}{R_1}}$$

- As before:

$$i_1 = i_2 \quad \Rightarrow \quad -\frac{v_I}{R_1} = \frac{v_I - v_O}{R_2}$$

Example 3.3

- Use superposition to determine the output voltage v_O in the ideal op-amp circuit in the following figure:



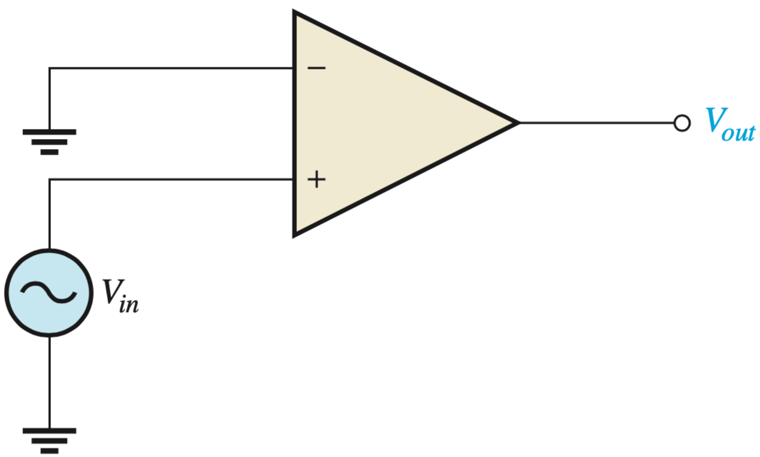
- Answer: $v_O = 10v_{I1} + 5v_{I2}$

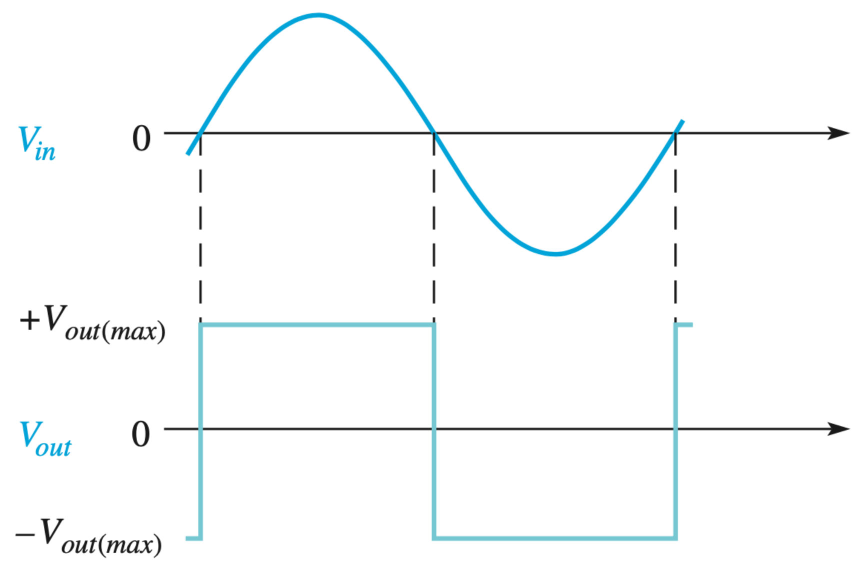
Comparator

- A comparator is a circuit that can determine if an input voltage exceeds a certain level.
- When an op-amp is used as a comparator, there is no negative feedback.
- The op-amp output will be saturated in one of two states (usually a positive or negative voltage).
- **Zero-Level Detection**
- **Nonzero-Level Detection**

Zero-Level Detection

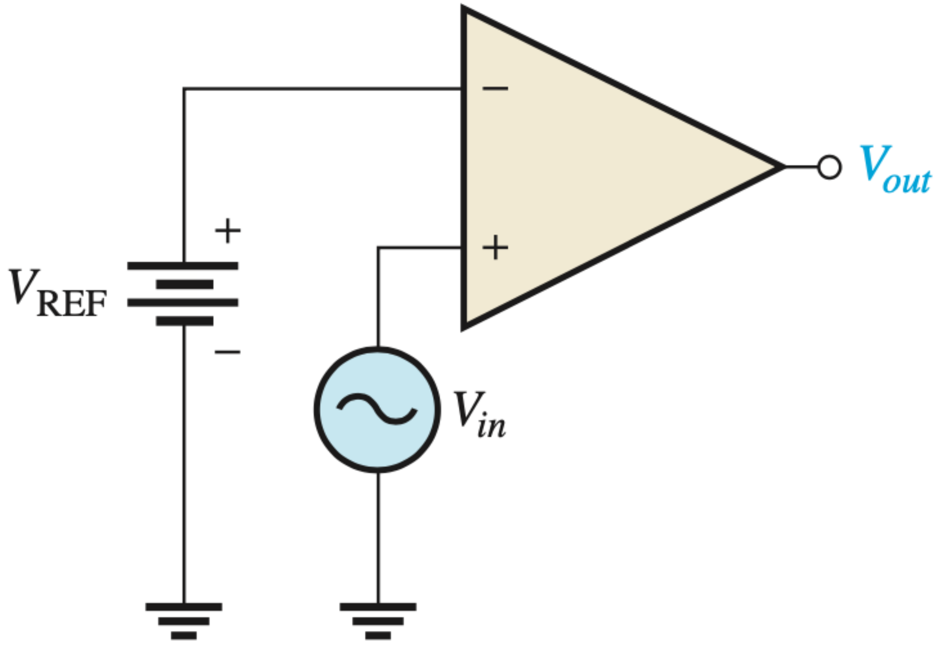
- The inverting input is grounded and will serve as a 0V reference.
- The signal is applied to the noninverting input.
- As the input signal crosses the 0V reference point, the output suddenly switches from one saturated state to the other.





Nonzero-Level Detection

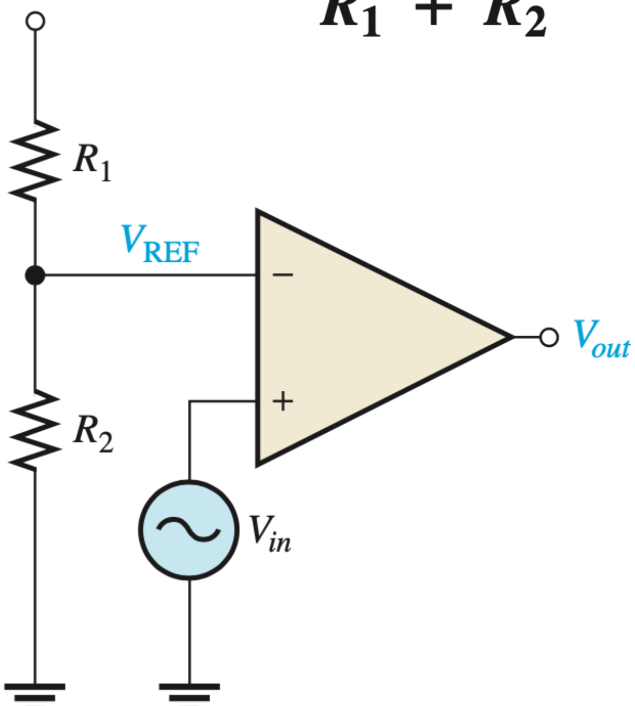
- Connecting a fixed reference to the (-) input of the op-amp (instead of the 0V reference).

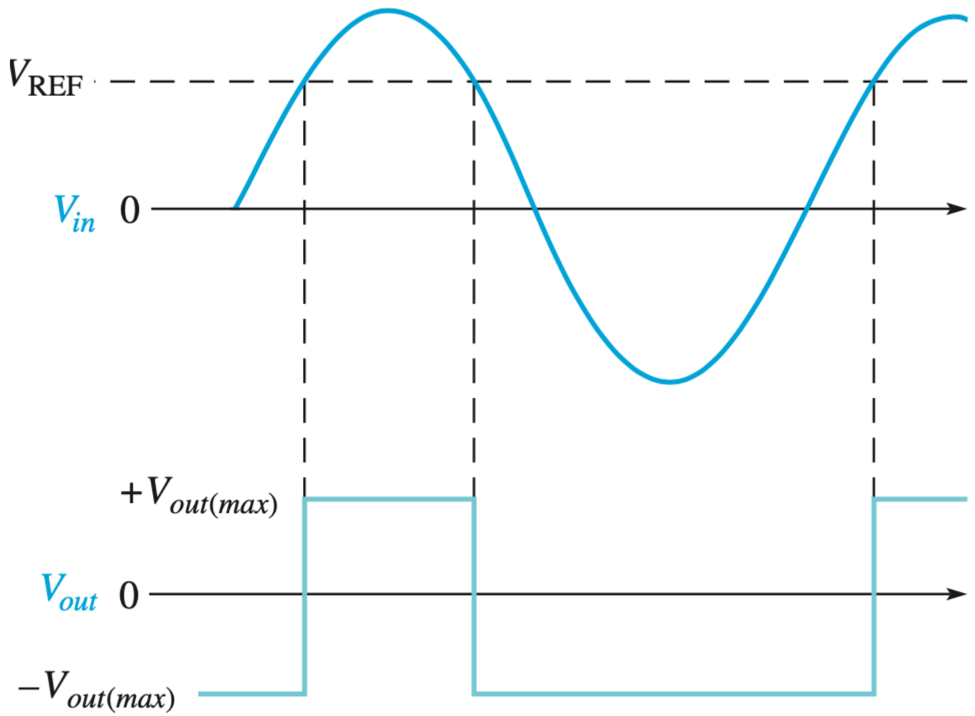


Nonzero-Level Detection

- A practical arrangement is to use a voltage divider to set the reference voltage:

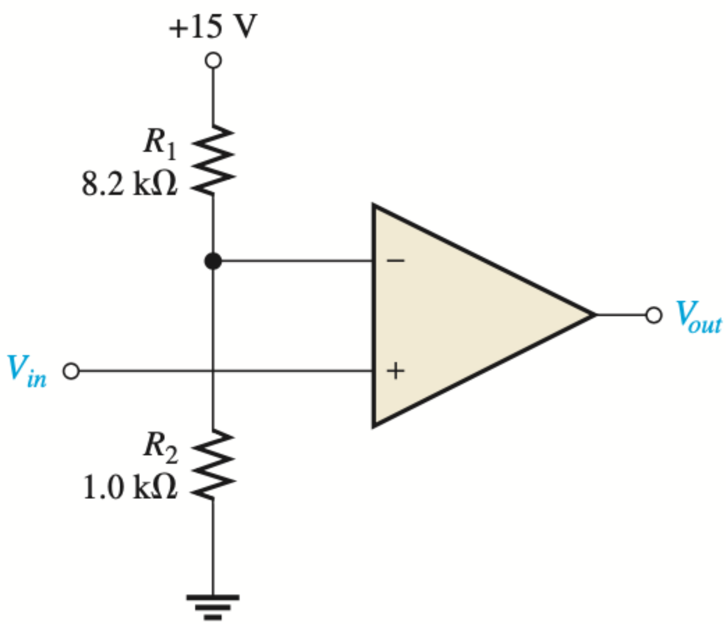
$$V_{\text{REF}} = \frac{R_2}{R_1 + R_2}(+V)$$

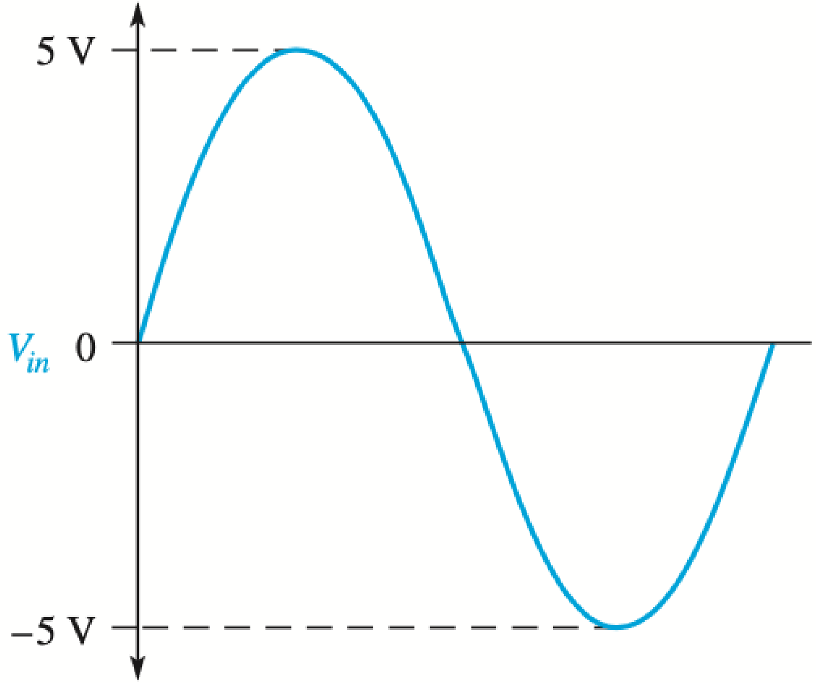




Example 3.4

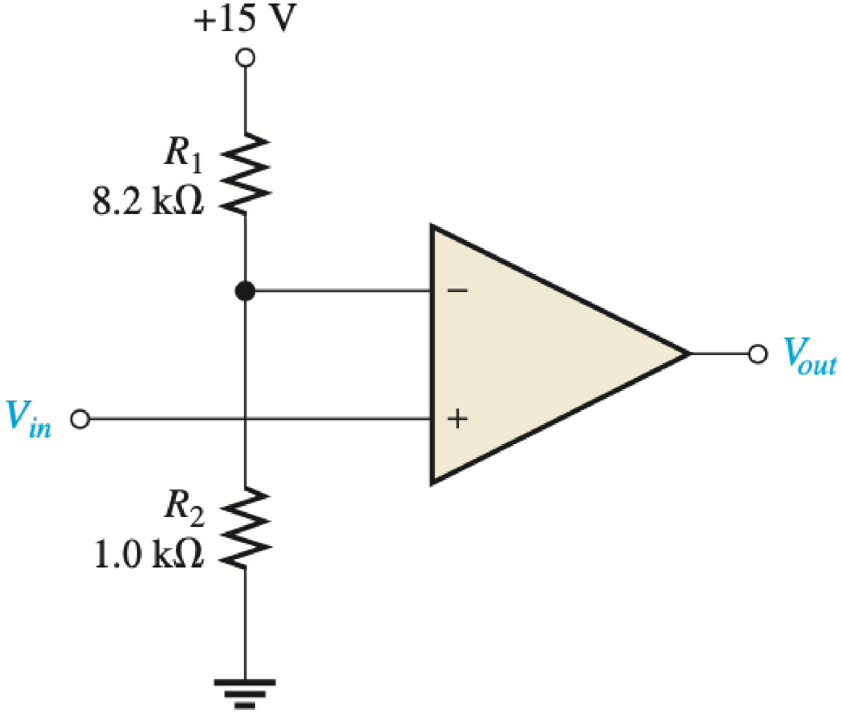
- The input signal is applied to the comparator circuit. Draw the output showing its proper relationship to the input signal. Assume that the maximum output levels of the op-amp are 12V.

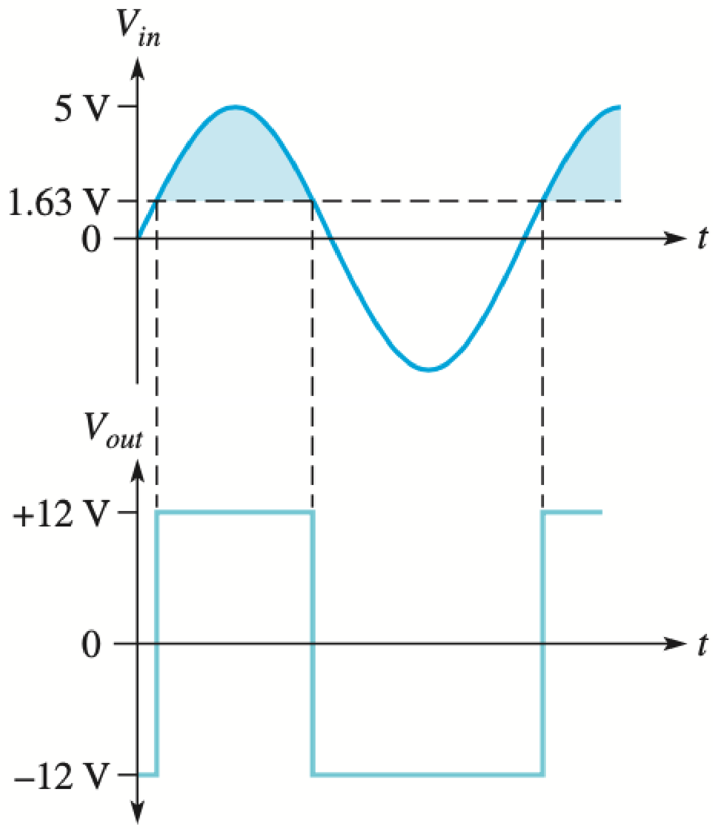




Example 3.4

- Reference voltage:

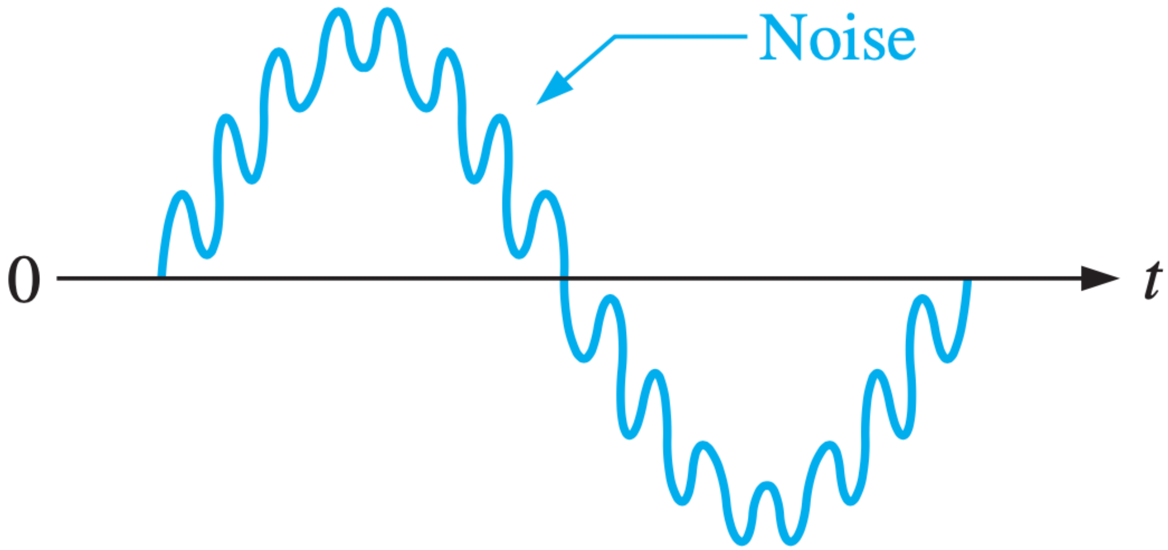




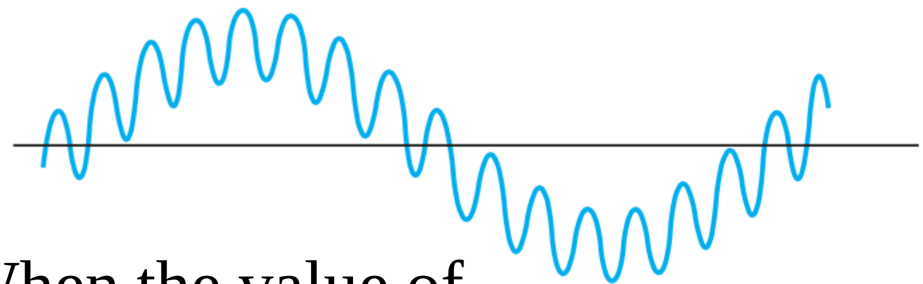
$$V_{ref} = \frac{R_2}{R_1 + R_2}(+V) = \frac{1.0}{8.2 + 1.0} \times 15 = 1.63V$$

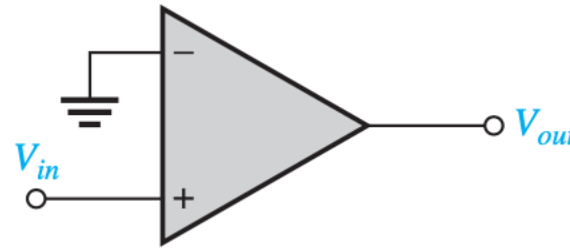
Effects of Input Noise on Comparator

- Consider the sine wave with superimposed noise:

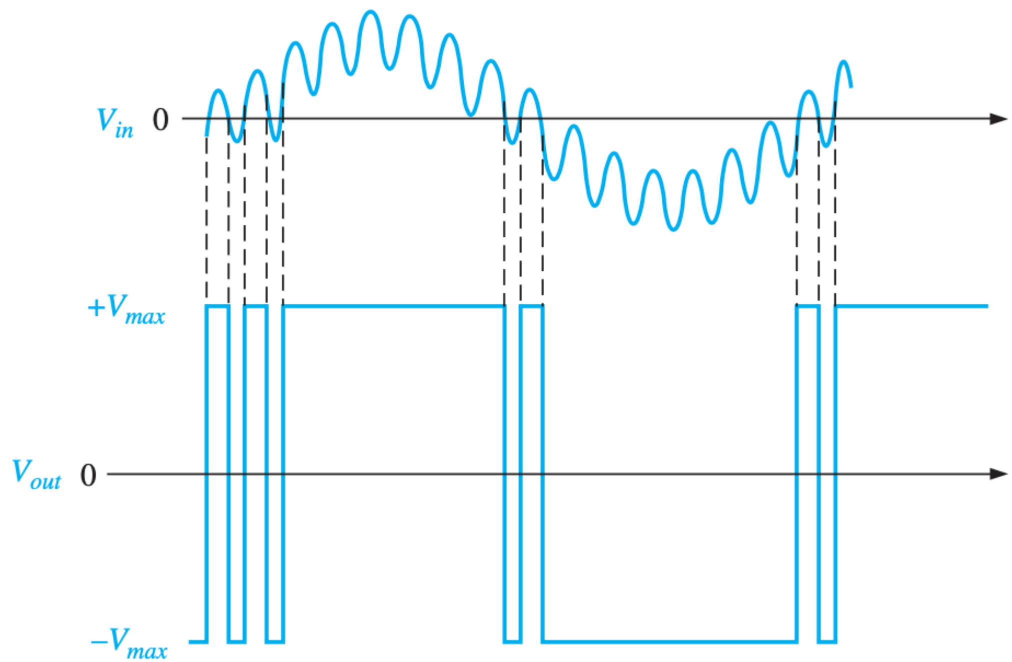


Effects of Input Noise on Comparator





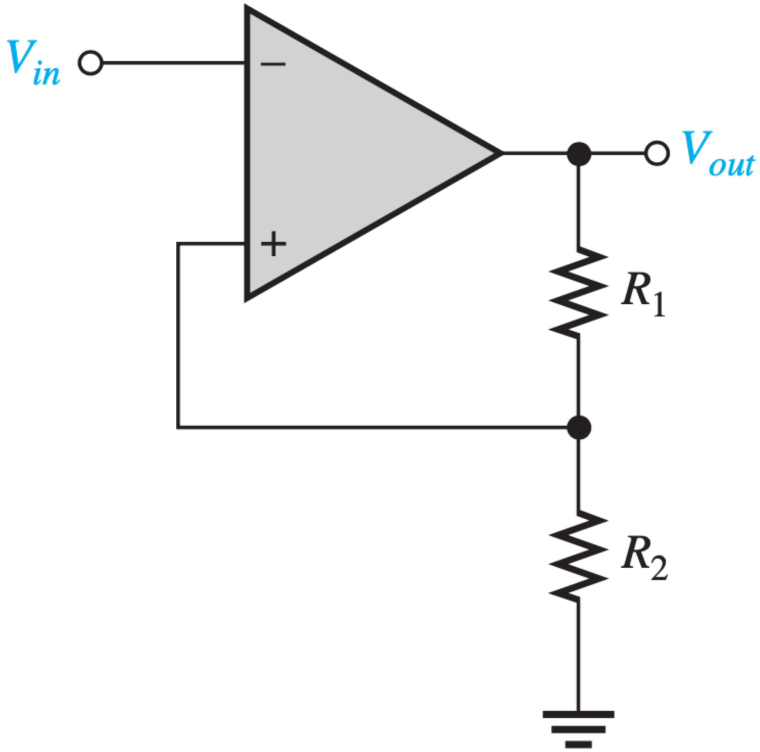
When the value of sine wave goes to the zero the variation caused by the noise can cause the **net input fluctuate over zero value** certain time.



Faulty output voltage

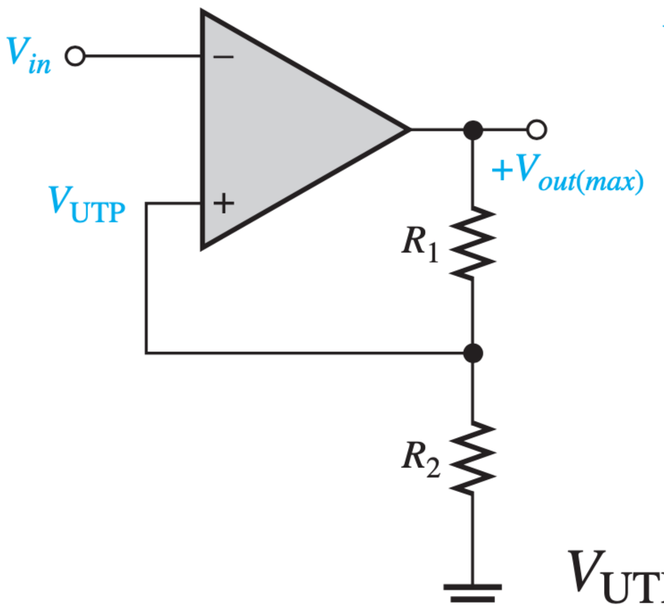
Effects of Input Noise on Comparator

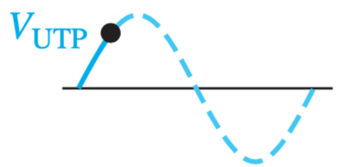
- To decrease the response of comparator towards the noise the method incorporating positive feedback (aka hysteresis) is used.
- 2 reference points:
  - V_{LTP}: lower trigger point
  - V_{UTP}: upper trigger point

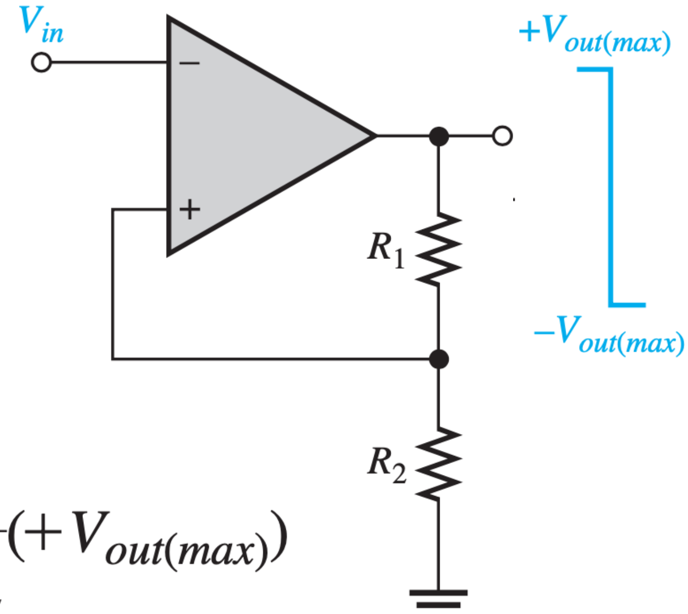


Effects of Input Noise on Comparator

- For $V_{in} < V_{UTP}$, V_{out} is locked at $+V_{out}$(max) (extreme positive value)
- For $V_{in} > V_{UTP}$, V_{out} is locked at $–V_{out}$(max) (extreme negative value)



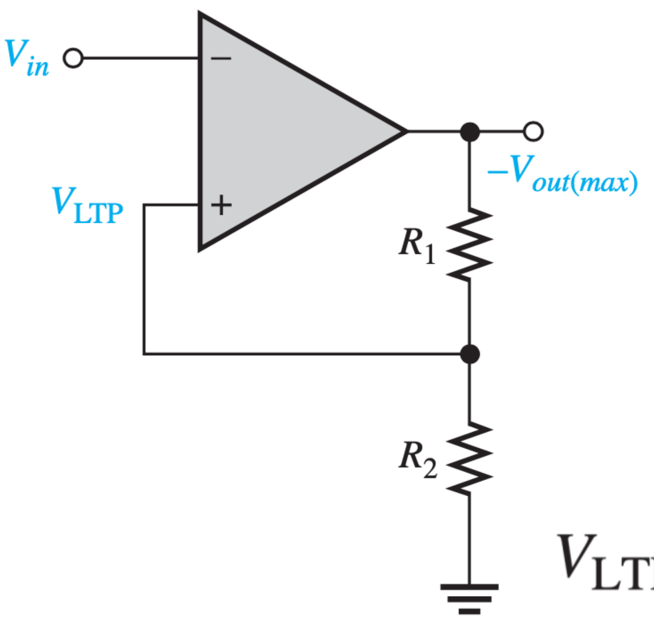


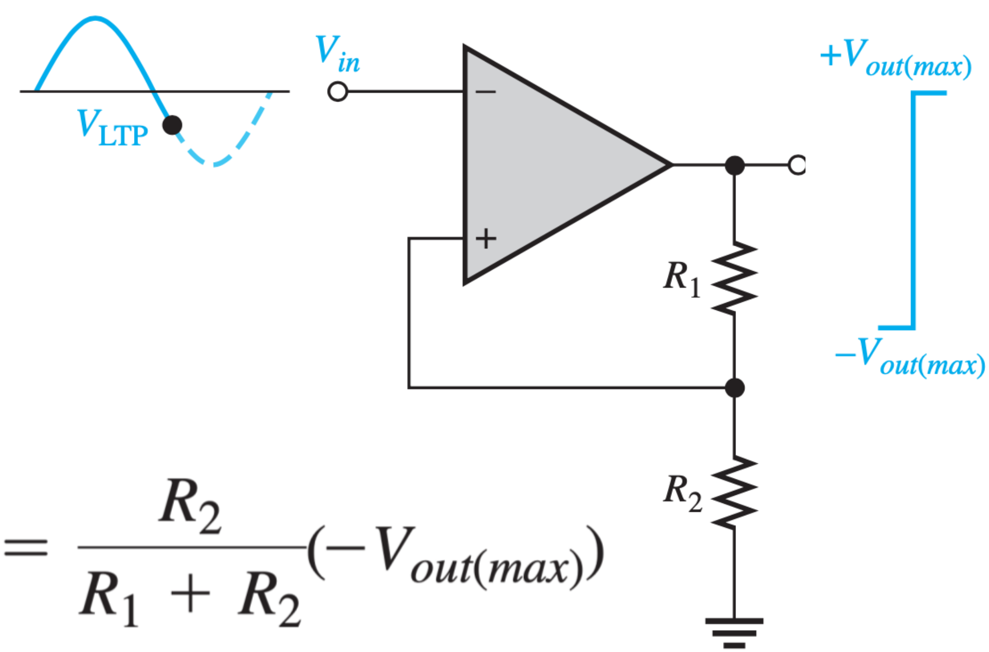


$$V_{UTP} = \frac{R_2}{R_1 + R_2}(+V_{out(max)})$$

Effects of Input Noise on Comparator

- For $V_{in} > V_{LTP}$, V_{out} is locked at $-V_{out}(max)$ (extreme negative value)
- For $V_{in} < V_{LTP}$, V_{out} is locked at $+V_{out}(max)$ (extreme positive value)



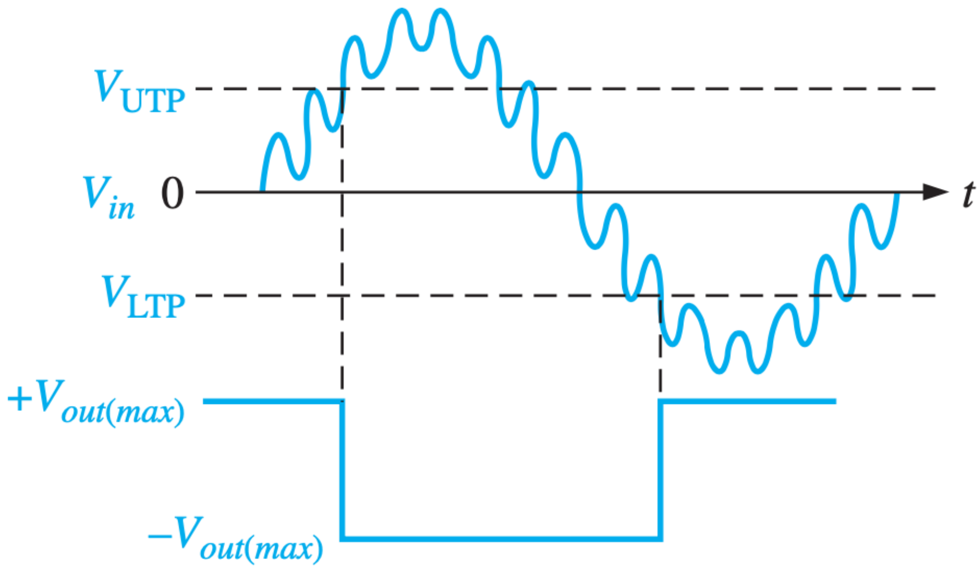


$$V_{LTP} = \frac{R_2}{R_1 + R_2}(-V_{out(max)})$$

Effects of Input Noise on Comparator

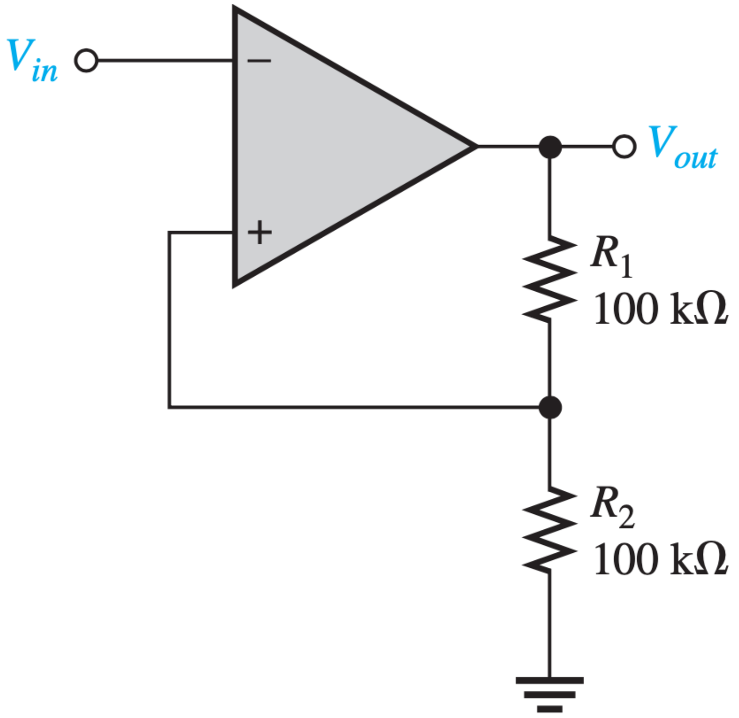
- The comparator created with the hysteresis is called a Schmitt trigger.
  - Less quantity of noise voltage provides no influence at the output.

$$V_{HYS} = V_{UTP} - V_{LTP}$$



Example 3.5

- Consider the following circuit.
- Assume: $+V_{out(max)}$ = +5 V and $-V_{out(max)}$ = -5 V
- Find: V_{UTP} V_{LTP} V_{HYS}



$$V_{UTP} = \frac{R_2}{R_1 + R_2}(+V_{out(max)})$$

$$= 0.5(5\text{ V}) = \mathbf{+2.5\text{ V}}$$

$$V_{LTP} = \frac{R_2}{R_1 + R_2}(-V_{out(max)})$$

$$= 0.5(-5\text{ V}) = \mathbf{-2.5\text{ V}}$$

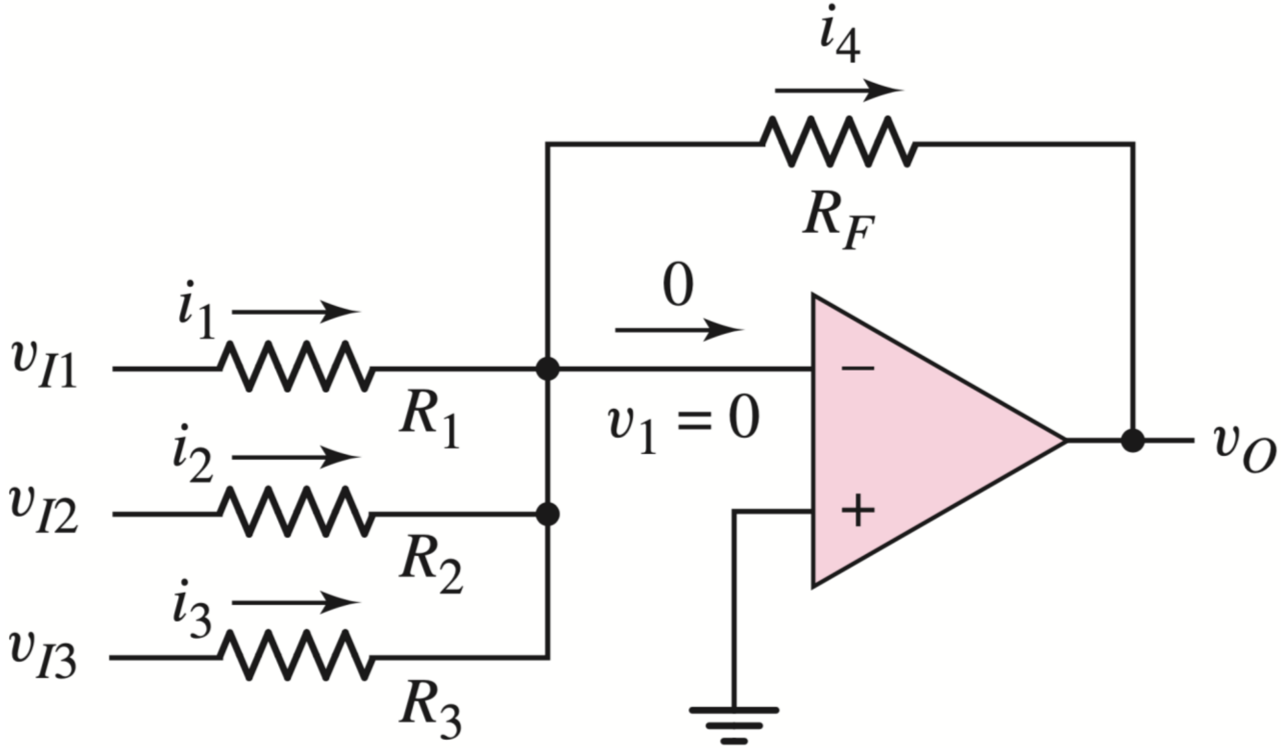
$$V_{HYS} = V_{UTP} - V_{LTP}$$

$$= 2.5\text{ V} - (-2.5\text{ V}) = \mathbf{5\text{ V}}$$

Summing Amplifier

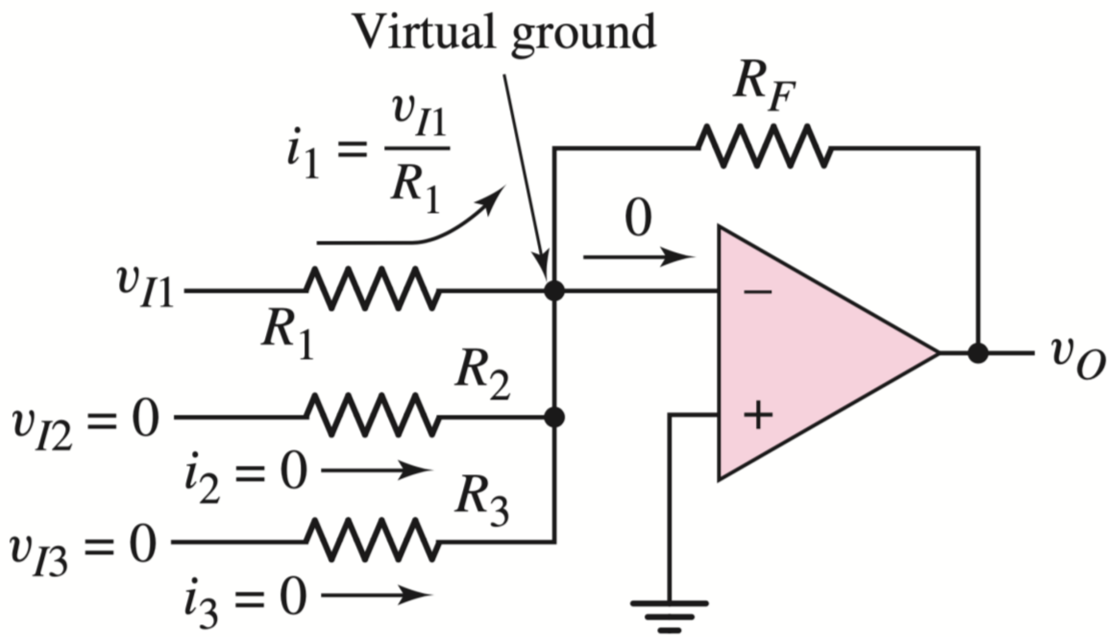
Objective:

- Analyze and understand the characteristics of the summing operational amplifier.



Summing Amplifier

- To analyze the op-amp circuit, use the **superposition theorem** and the **concept of virtual ground**.
- Algebraically sum these terms to determine the total output.



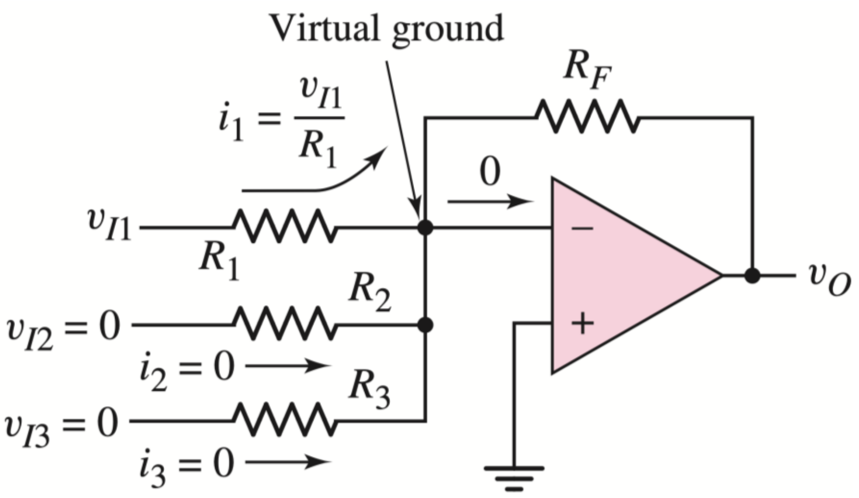
Summing Amplifier

- If we set:

$$v_{I2} = v_{I3} = 0 \Rightarrow i_1 = \frac{v_{I1}}{R_1}$$

- We have:

$$v_O(v_{I1}) = -i_1 R_F$$
$$= -\left(\frac{R_F}{R_1}\right) v_{I1}$$



- Similarly, we have:

$$\begin{cases} v_O(v_{I2}) = -i_2 R_F = -\left(\frac{R_F}{R_2}\right) v_{I2} \\ v_O(v_{I3}) = -i_3 R_F = -\left(\frac{R_F}{R_3}\right) v_{I3} \end{cases}$$

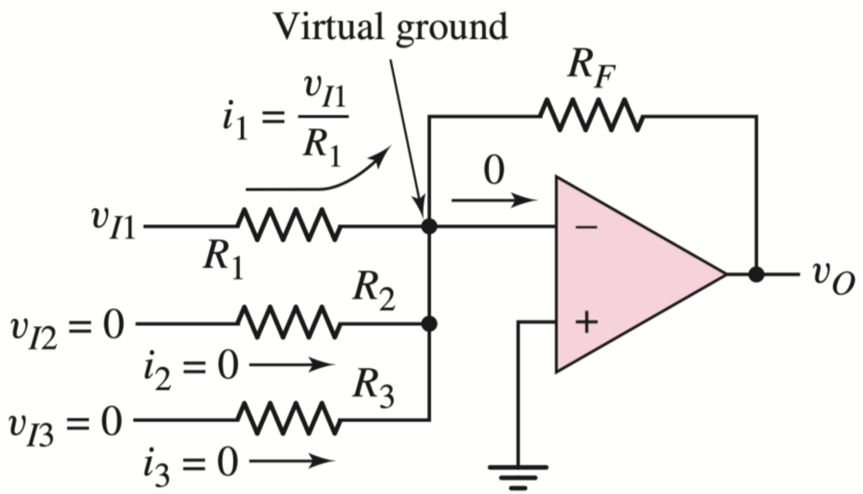
- The total voltage:

$$v_O = v_O(v_{I1}) + v_O(v_{I2}) + v_O(v_{I3})$$

$$\Rightarrow v_O = -\left(\frac{R_F}{R_1} v_{I1} + \frac{R_F}{R_2} v_{I2} + \frac{R_F}{R_3} v_{I3}\right)$$

Summing Amplifier

- The output voltage is the **sum of the three input voltages**, with different weighting factors.
- This circuit is called the inverting summing amplifier.



- When:

$$R_1 = R_2 = R_3 \equiv R$$

$$v_O = -\frac{R_F}{R_1}(v_{I1} + v_{I2} + v_{I3})$$

Example 3.6

(a) Design an inverting amplifier with the output voltage: $v_O = -3(v_{I1} + 2v_{I2} + 0.3v_{I3} + 4v_{I4})$.

Max input resistance is 400kΩ.

(b) Using (a), find v_O for:

- (i) v_{I1} =0.1V, v_{I2} =−0.2V, v_{I3} =−1V, v_{I4} =0.05V;
- (ii) v_{I1} =−0.2V, v_{I2} =0.3V, v_{I3} =1.5V, v_{I4} =−0.1V.

Example 3.6

- Answer:

(a) $R_3 = 400k\Omega$, $R_F = 360k\Omega$,

$R_1 = 120k\Omega$, $R_2 = 60k\Omega$, $R_4 = 30k\Omega$;

(b)

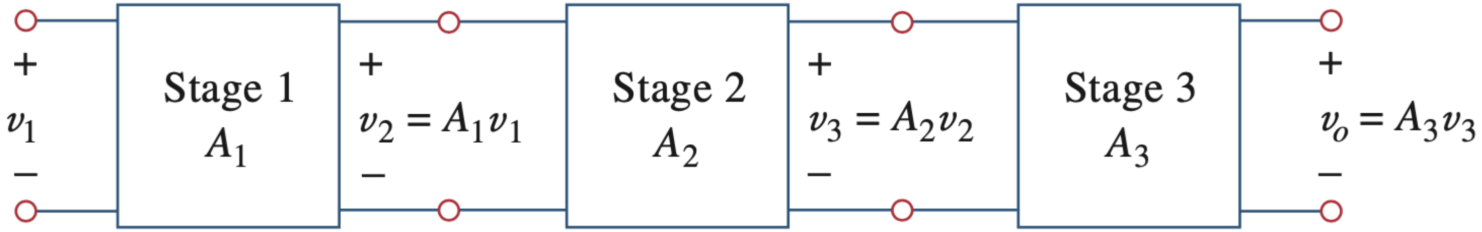
- (i) $v_O = +1.2V$,
- (ii) $v_O = -1.35V$

Cascaded Op-Amp Circuits

- A cascade connection is a head-to-tail arrangement of two or more op amp circuits such that the output of one is the input of the next.
- Each circuit in the string is called a *stage*.
- The original input signal is increased by the g ain of the individual stage.
- **Advantage**: Opamp circuits can be cascaded without changing their input -output relationships (due to the infinite input resistance and zero output resistance).

Cascaded Op-Amp Circuits

- A three-stage cascaded connection:



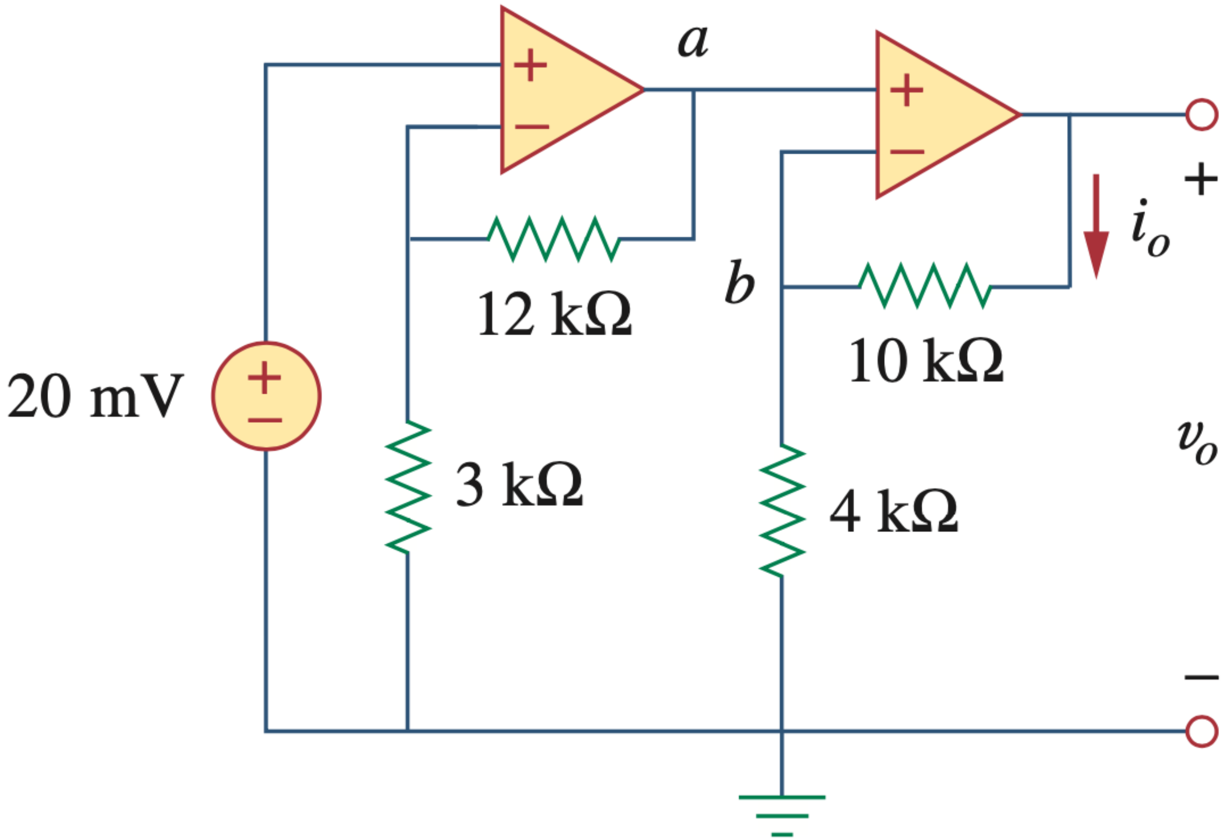
- The overall gain of the cascade connection is the product of the gains of the individual op amp circuits:

$$A = A_1 A_2 A_3$$

- The cascade connection does not afect the op amp input-output relationships.
- But, the design of an actual op-amp circuit must ensure that the load due to the next stage in the cascade does not saturate the op-amp.

Example 3.7

- Find v_o and i_o in the circuit:



Example 3.7

- This circuit consists of two noninverting amplifiers cascaded.
- At the output of the first op amp:

$$v_a = \left(1 + \frac{12}{3}\right)(20) = 100 \text{ mV}$$

- At the output of the second op amp:

$$v_o = \left(1 + \frac{10}{4}\right)v_a = (1 + 2.5)100 = 350 \text{ mV}$$

Example 3.7

- The required current i_o is the current through the 10-kΩ resistor:

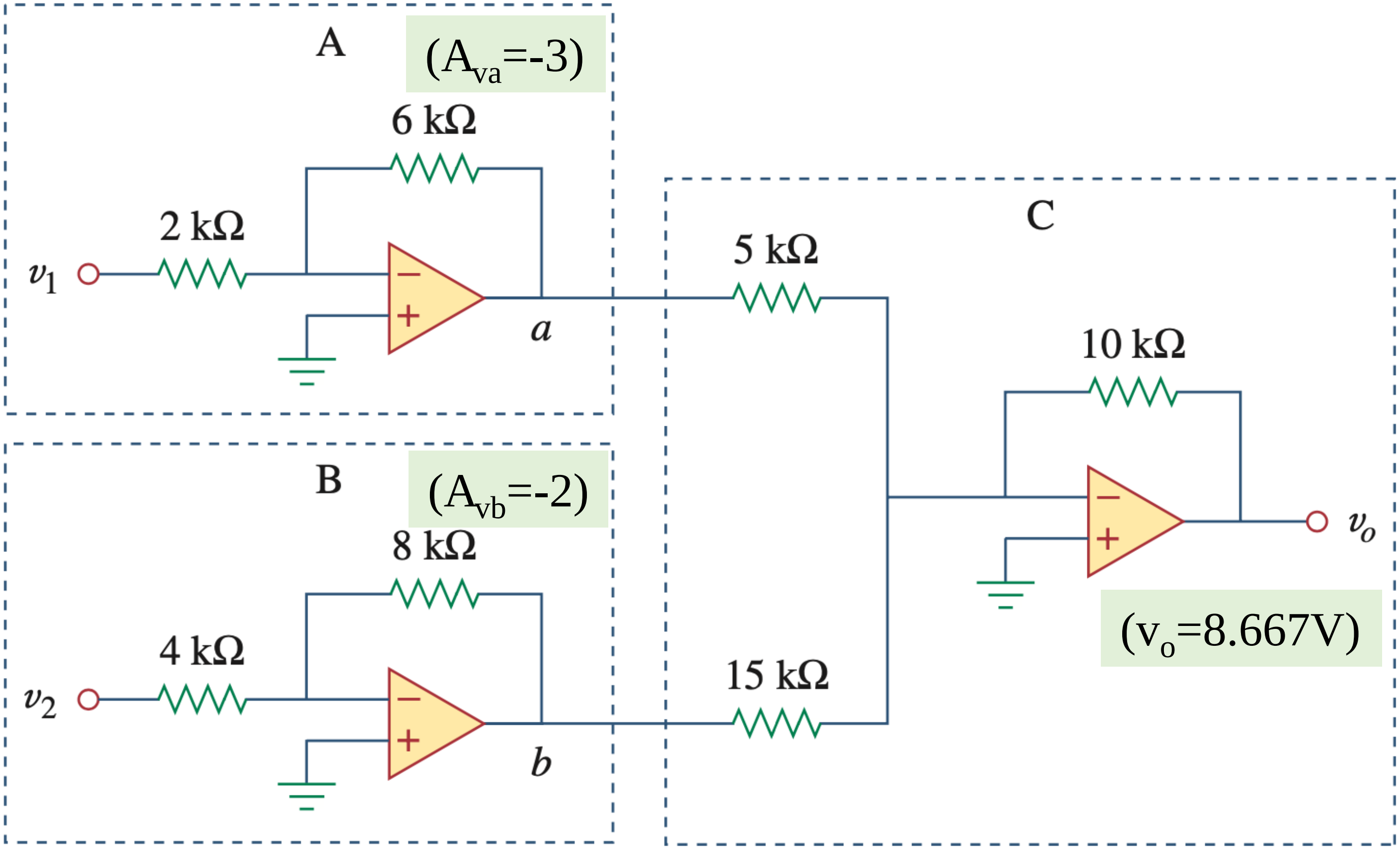
$$i_o = \frac{v_o - v_b}{10}\ \text{mA}$$

- But: $$v_b = v_a = 100\ \text{mV}$$

- Hence: $$i_o = \frac{(350 - 100) \times 10^{-3}}{10 \times 10^3} = 25\ \mu\text{A}$$

Example 3.8

- If v_1 = 1V and v_2 = 2V, find *vo* in the op-amp of the circuit.



Example 3.8

- Gain of the first op-amp (A) = -3
- Gain of the second op-amp (B) = -2
- The output of the first (A) and second (B) op-amps:

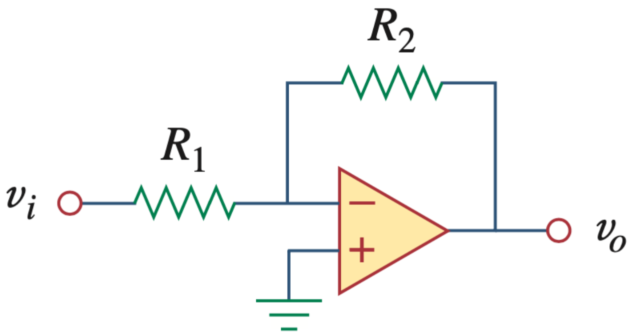
$$v_{11} = -3v_1 = -3 \times 1 = -3 \text{ V}$$

$$v_{22} = -2v_2 = -2 \times 2 = -4 \text{ V}$$

- The output of the third op-amp (C):

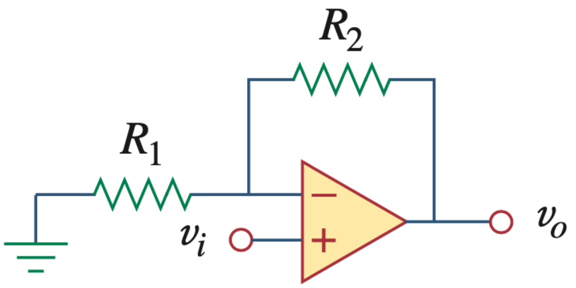
$$\begin{aligned} v_o &= -(10 \text{ k}\Omega/5 \text{ k}\Omega)\,v_{11} + \left[-(10 \text{ k}\Omega/15 \text{ k}\Omega)\,v_{22}\right] \\ &= -2(-3) - (2/3)(-4) \\ &= 6 + 2.667 = \mathbf{8.667\ V} \end{aligned}$$

Summary of Basic Op-amp Circuits



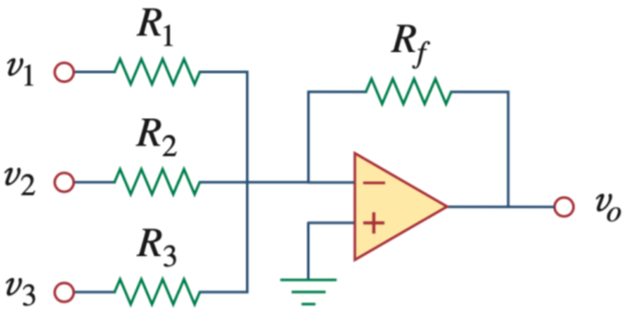
Inverting Amplifier

$$v_o = -\frac{R_2}{R_1} v_i$$



Noninverting Amplifier

$$v_o = \left(1 + \frac{R_2}{R_1}\right) v_i$$



Summing Amplifier (Summer)

$$v_o = -\left(\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2 + \frac{R_f}{R_3} v_3\right)$$