Electronics

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Chapter(3)

Operational Amplifiers

Operational Amplifier

- The op amp is an electronic unit that behaves like a voltage-controlled voltage source.
- An op amp is an active circuit element designed to perform mathematical operations of addition, subtraction, multiplication, division, differentiation, and integration.
- Fig.1 shows a typical op amp package.

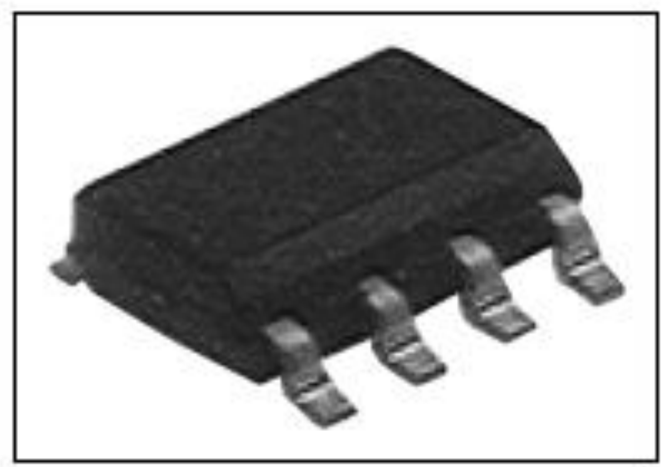


Figure A typical operational amplifier.

Operational Amplifier

- Op amps are commercially available in integrated circuit packages in several forms.
- A typical one is the eight-pin dual in-line package (or DIP), shown in Fig.2(a).

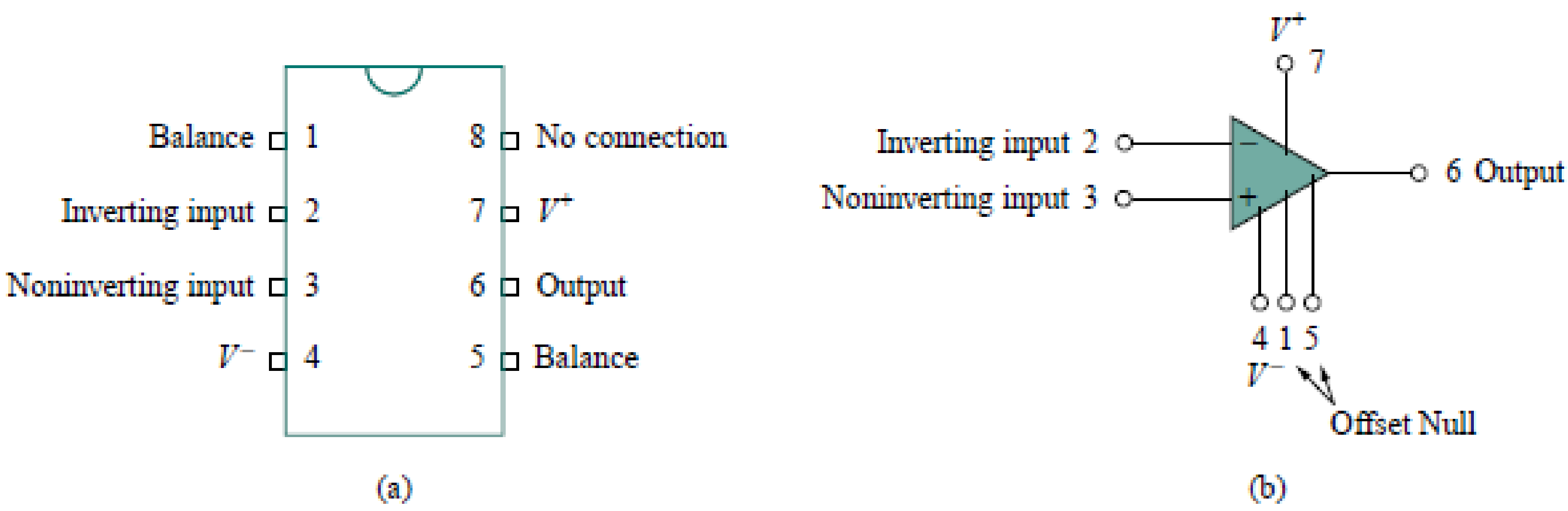


Figure A typical op amp: (a) pin configuration, (b) circuit symbol.

Operational Amplifier

- The differential input voltage *vd is given by:*

$$v_d = v_2 - v_1$$

- where *v1 is the voltage between the inverting terminal and ground and v2* is the voltage between the noninverting terminal and ground.

$$v_o = Av_d = A(v_2 - v_1)$$

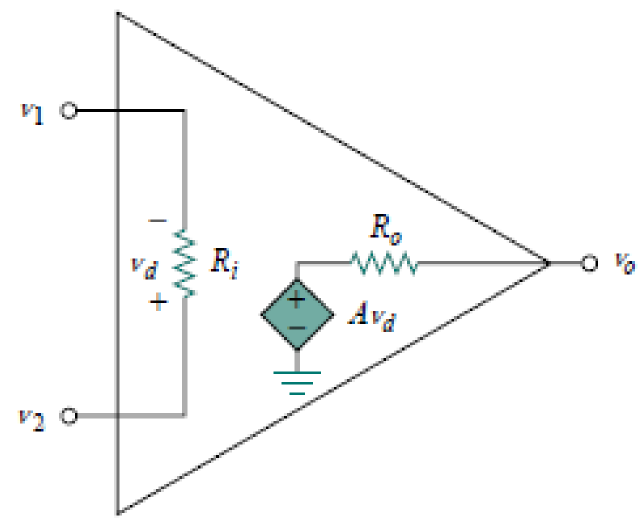


Figure The equivalent circuit of the non-ideal op amp.

Operational Amplifier

- *A is called the open-loop voltage gain because it is the gain of the op amp* without any external feedback from output to input.

Ideal Op Amp

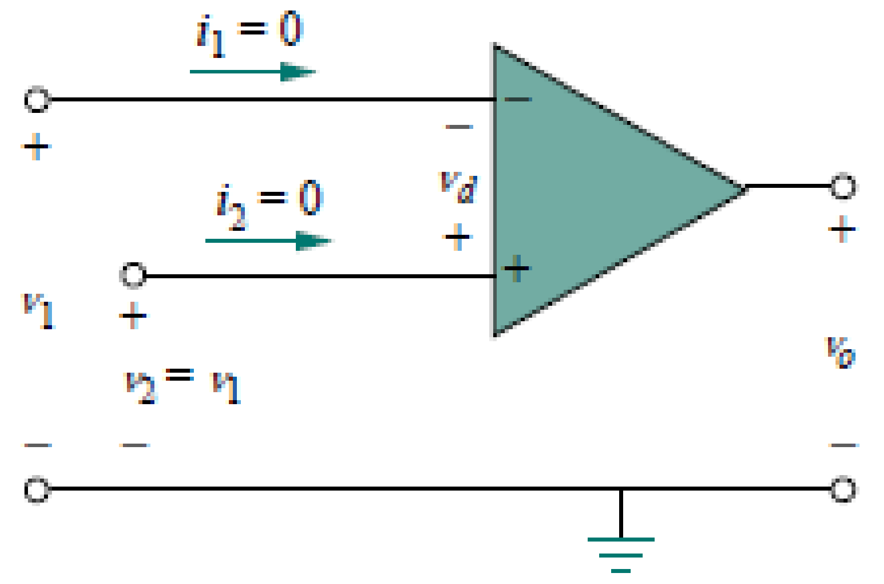
- An op amp is **ideal** if it has the following characteristics:
- 1. Infinite open-loop gain, $A = \infty$.
- 2. Infinite input resistance, $R_i = \infty$.
- 3. Zero output resistance, $R_o = 0$.
- An **ideal** op amp is an amplifier with infinite open-loop gain, infinite input resistance, and zero output resistance.

Ideal Op Amp

$$i_1 = 0, \qquad i_2 = 0$$

$$v_d = v_2 - v_1 \simeq 0$$

$$\boxed{v_1 = v_2}$$



Ideal op amp model.

Inverting Amplifier

$$i_1 = i_2 \quad \Longrightarrow \quad \frac{v_i - v_1}{R_1} = \frac{v_1 - v_o}{R_f}$$

- But *v1 = v2 = 0 for an ideal op amp, since the noninverting terminal is* grounded. Hence,

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

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

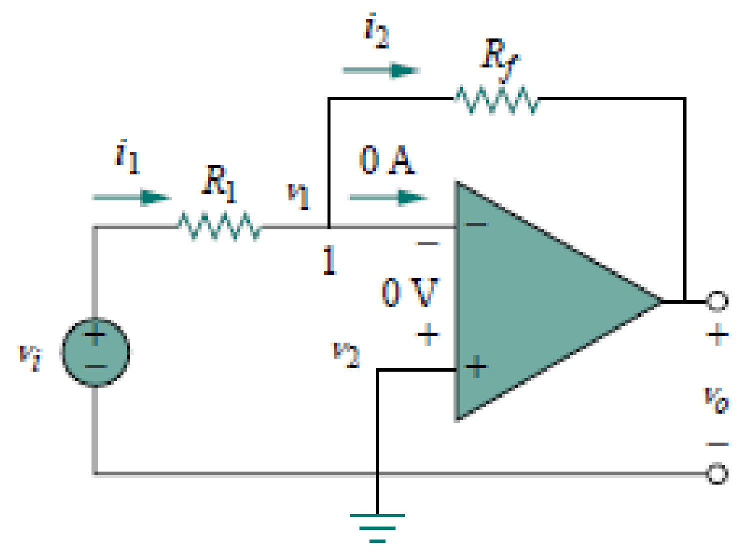


Fig The inverting amplifier.

- The voltage gain is *Av = vo/vi*
- *= −Rf /R1.*

Inverting Amplifier

- An **inverting** amplifier reverses the polarity of the input signal while amplifying it.

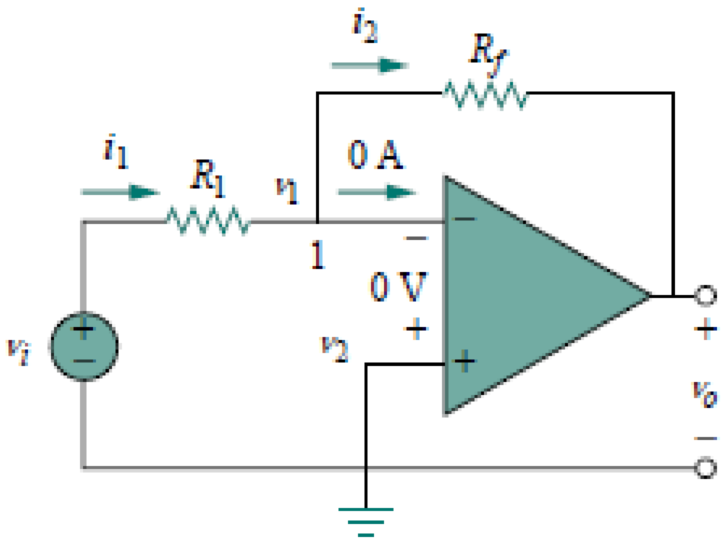
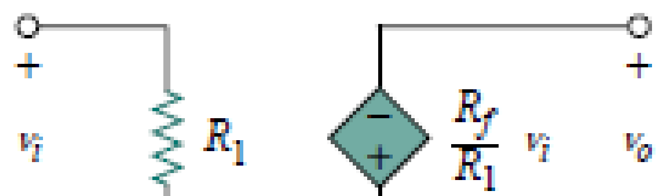


Fig The inverting amplifier.

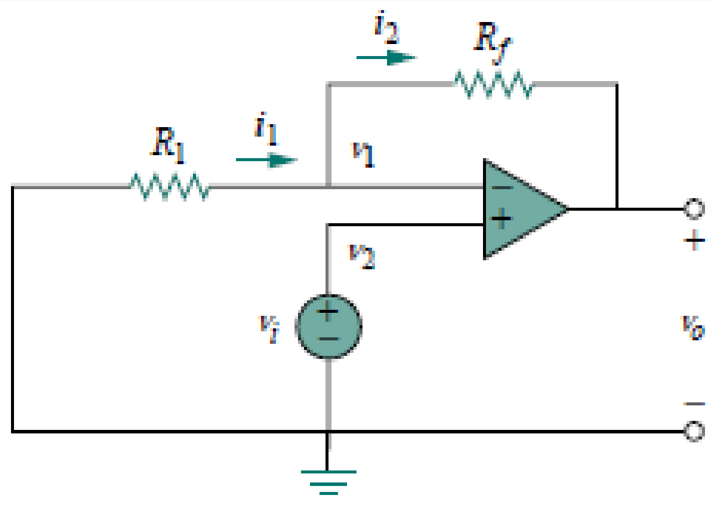


An equivalent circuit for the inverter in Fig. 5.10.

Noninverting Amplifier

$$i_1 = i_2 \qquad \Longrightarrow \qquad \frac{0 - v_1}{R_1} = \frac{v_1 - v_o}{R_f}$$

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



The noninverting amplifier.

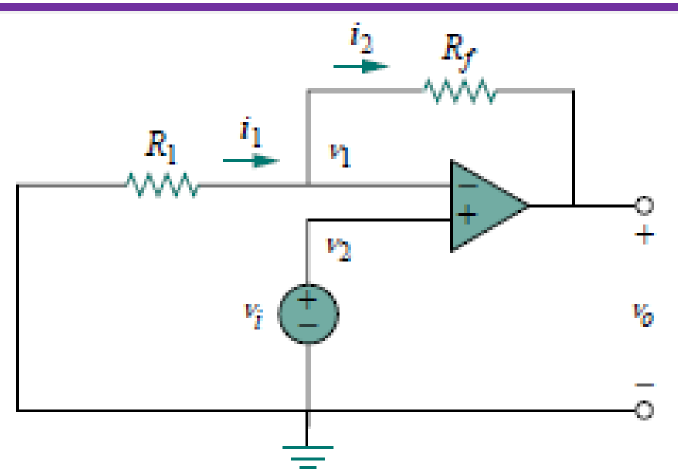
Noninverting Amplifier

- The voltage gain is $A_v = v_o/v_i = 1 + R_f / R_1$, *which does not have a* negative sign. Thus, the output has the same polarity as the input.
- A **noninverting** amplifier is an op amp circuit designed to provide a positive voltage gain.

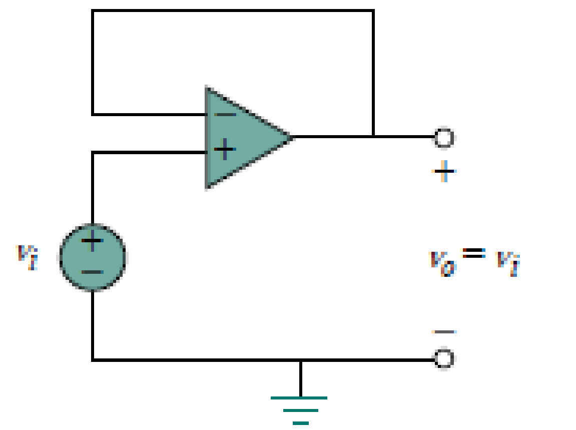
Voltage Follower

- Notice that if feedback resistor *Rf = 0 (short circuit) or R1* = ∞ (open circuit) or both, the gain becomes 1. Under these conditions (*Rf* =0 and *R1 =∞), the circuit shown* is called a *voltage follower (or unity gain amplifier) because the* output follows the input. Thus, for a voltage follower

$$\boxed{v_o = v_i}$$



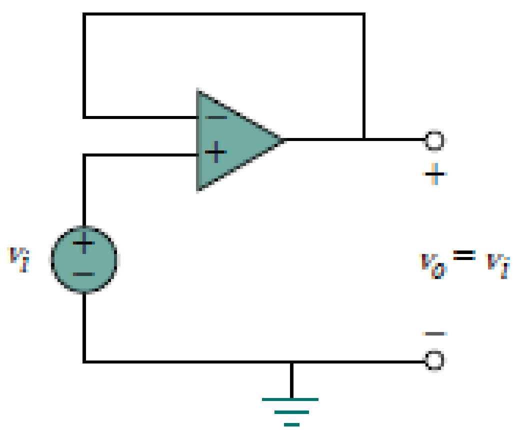
The noninverting amplifier.



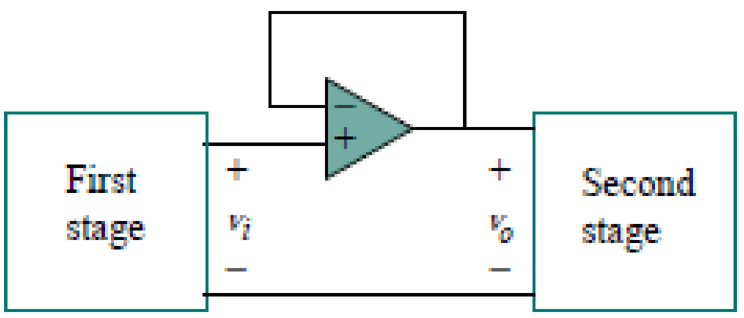
The voltage follower.

Voltage Follower

- Such a circuit has a very high input impedance and is therefore useful as an intermediate-stage (or buffer) amplifier to **isolate** one circuit from another as shown in Fig. The voltage follower minimizes interaction between the two stages and eliminates interstage loading.



The voltage follower.



A voltage follower used to isolate two cascaded stages of a circuit.

Summing Amplifier

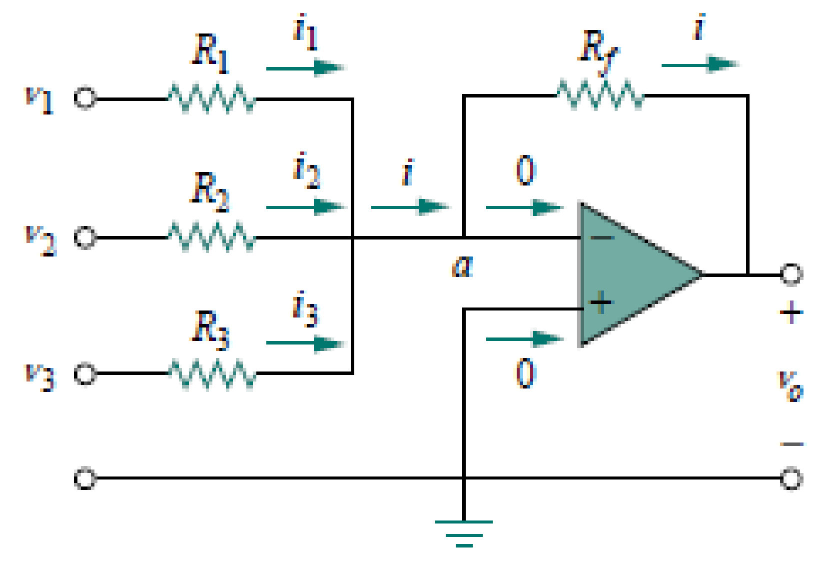
- A summing amplifier is an op amp circuit that combines several inputs and produces an output that is the weighted sum of the inputs.

$$i = i_1 + i_2 + i_3$$

$$i_1 = \frac{v_1 - v_a}{R_1}, \qquad i_2 = \frac{v_2 - v_a}{R_2}$$

$$i_3 = \frac{v_3 - v_a}{R_3}, \qquad i = \frac{v_a - v_o}{R_f}$$

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



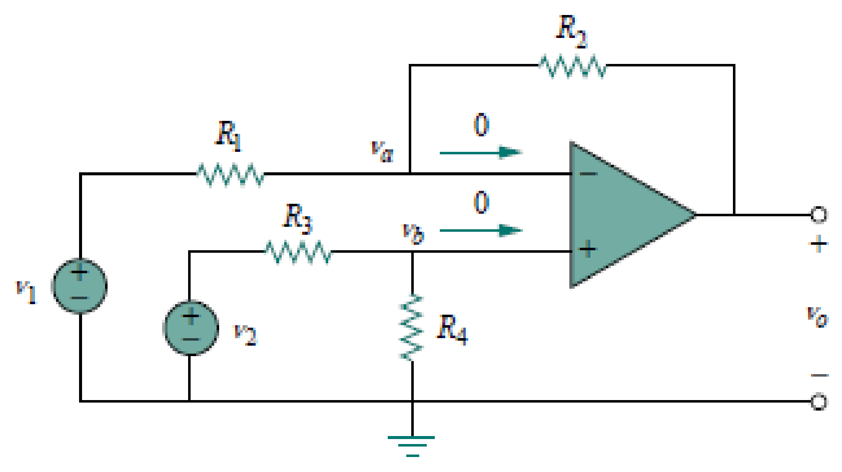
The summing amplifier.

Difference (Differential) Amplifier

- A difference amplifier is a device that amplifies the difference between two inputs.
- Apply KCL at node a:

$$\frac{v_1 - v_a}{R_1} = \frac{v_a - v_o}{R_2}$$

$$v_o = \left(\frac{R_2}{R_1} + 1\right) v_a - \frac{R_2}{R_1} v_1$$



Difference amplifier.

Difference (Differential) Amplifier

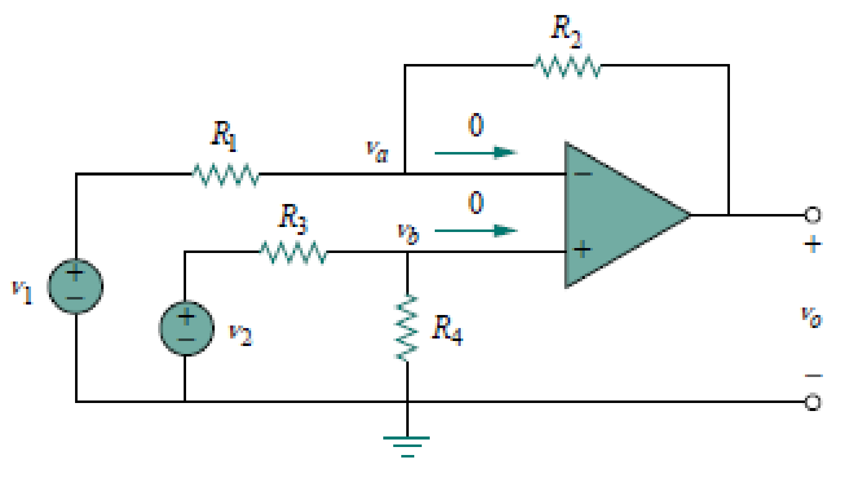
- Apply KCL at node b:

$$\frac{v_2 - v_b}{R_3} = \frac{v_b - 0}{R_4}$$

$$v_b = \frac{R_4}{R_3 + R_4} v_2$$

$$v_a = v_b$$

$$v_o = \left(\frac{R_2}{R_1} + 1\right) \frac{R_4}{R_3 + R_4} v_2 - \frac{R_2}{R_1} v_1$$



Difference amplifier.

Difference (Differential) Amplifier

$$\boxed{v_o = \frac{R_2}{R_1}\frac{(1 + R_1/R_2)}{(1 + R_3/R_4)}v_2 - \frac{R_2}{R_1}v_1}$$

- Let $$\boxed{\frac{R_1}{R_2} = \frac{R_3}{R_4}}$$

- When the op amp circuit is a difference amplifier, the equation above becomes,

$$\boxed{v_o = \frac{R_2}{R_1}(v_2 - v_1)}$$

Difference (Differential) Amplifier

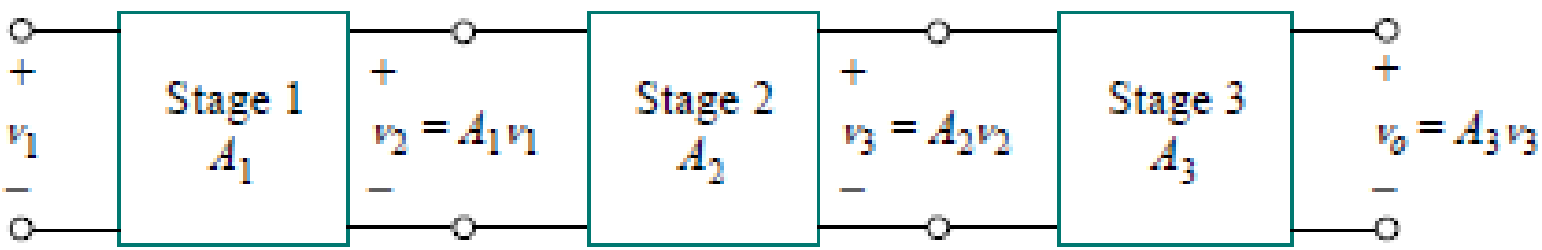
- If *R2 = R1 and R3 = R4, the difference amplifier becomes a* ***subtractor***, with the output:

$$\boxed{v_o = v_2 - v_1}$$

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

$$\boxed{A = A_1 A_2 A_3}$$

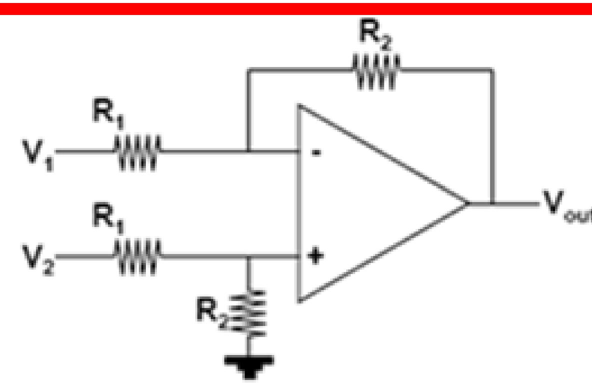


A three-stage cascaded connection.

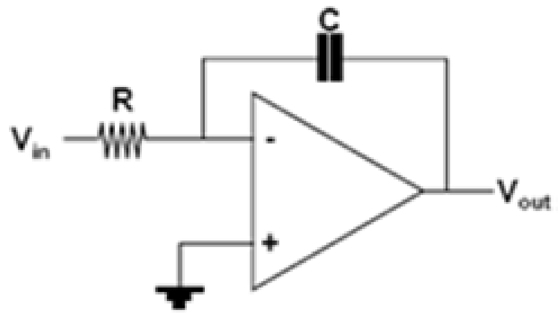
Question:

Differential Amp

$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$



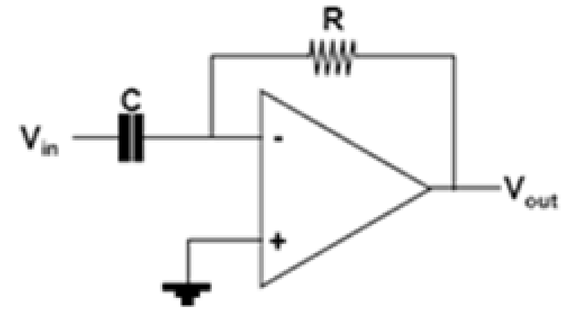
Integrating Amp



$$V_{out} = -\frac{1}{j\omega CR} V_{in} = -\frac{1}{RC}\int V_{in}\,dt$$

Differentiating Amp

$$V_{out} = -\frac{R}{\frac{1}{j\omega C}} V_{in} = -RC\frac{dV_{in}}{dt}$$



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