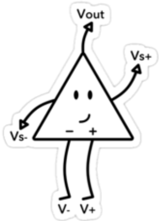
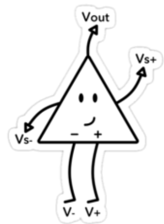
Lecture 10 Operational Amplifiers and its applications



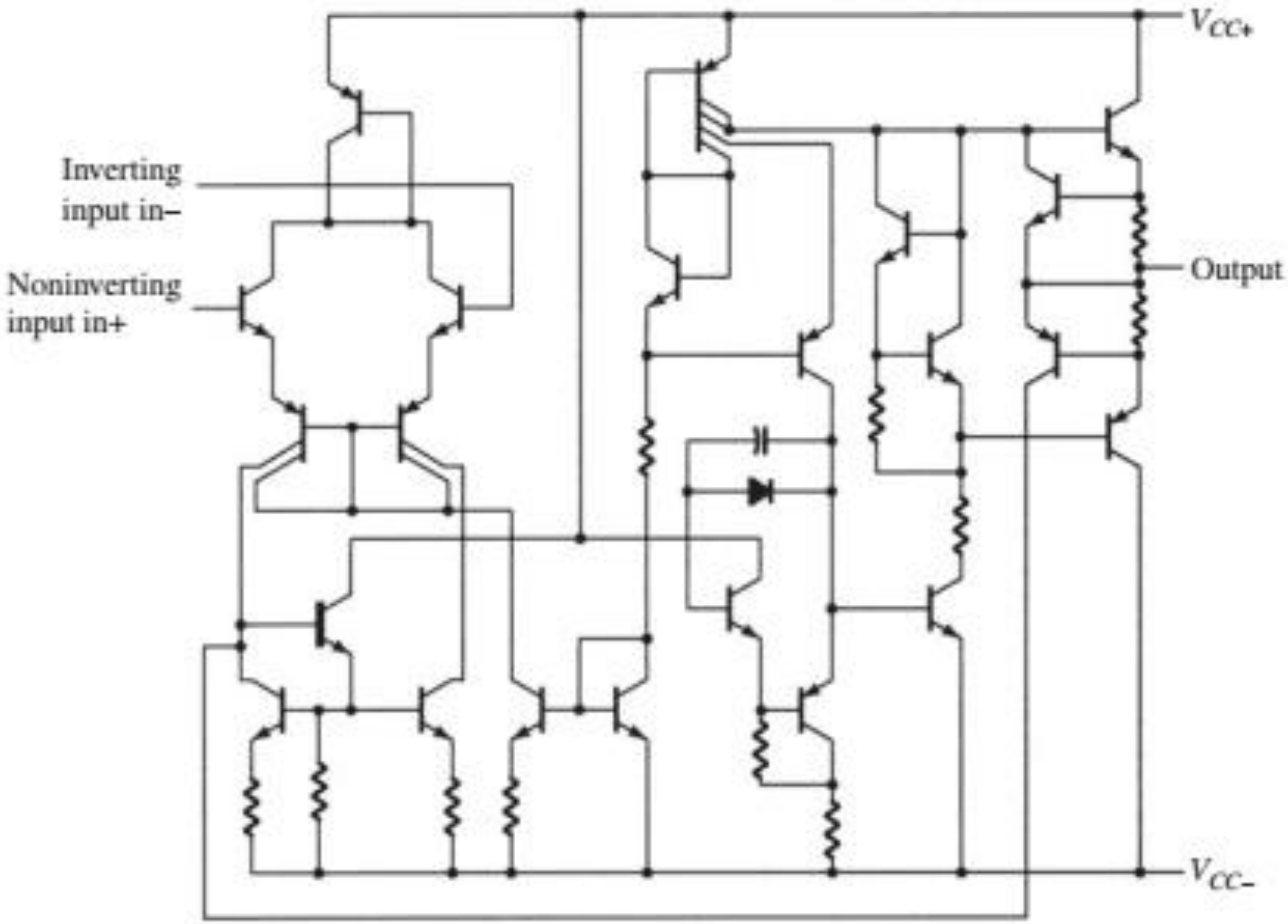
- Operational Amplifiers:
- Basic circuit shapes,
- PRACTICAL OP-AMP CIRCUITS
- Inverting Amplifier
- OP –AMP Application: VOLTAGE CONTROLLED- VOLTAGE SOURCES
- Noninverting Amplifier
- OP –AMP Application: Multiple-Stage Gains
- follower circuits,
- Unity Follower
- OP –AMP Application: VOLTAGE BUFFER
- Summing Amplifier
- OP –AMP Application: VOLTAGE SUMMING
- idea of feedback,
- Integrator
- Differentiator

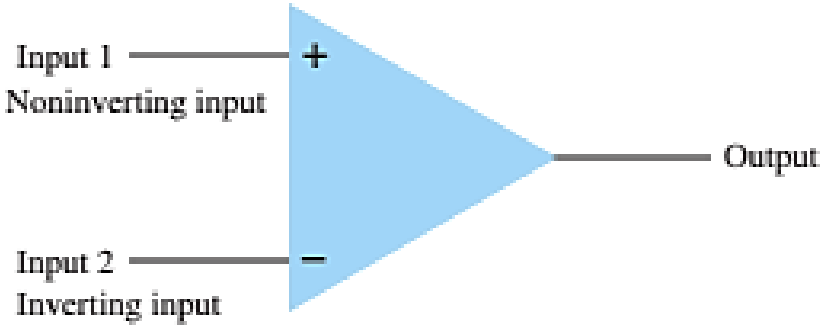
Course Name: Electric and electronic circuits
Course Code: CSE 113

Operational Amplifier (Op-Amp)



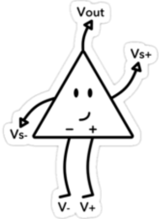
Basic circuit shapes



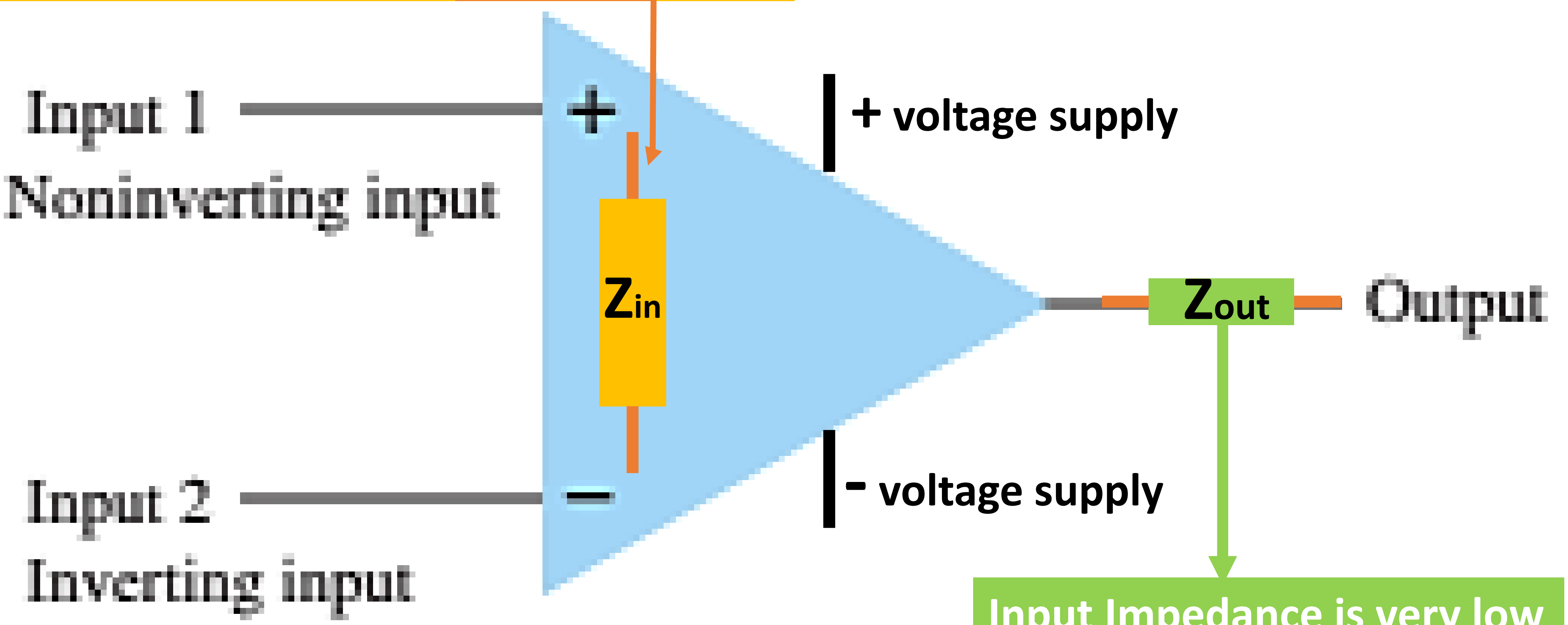


Operational Amplifier (Op-Amp)

Introduction



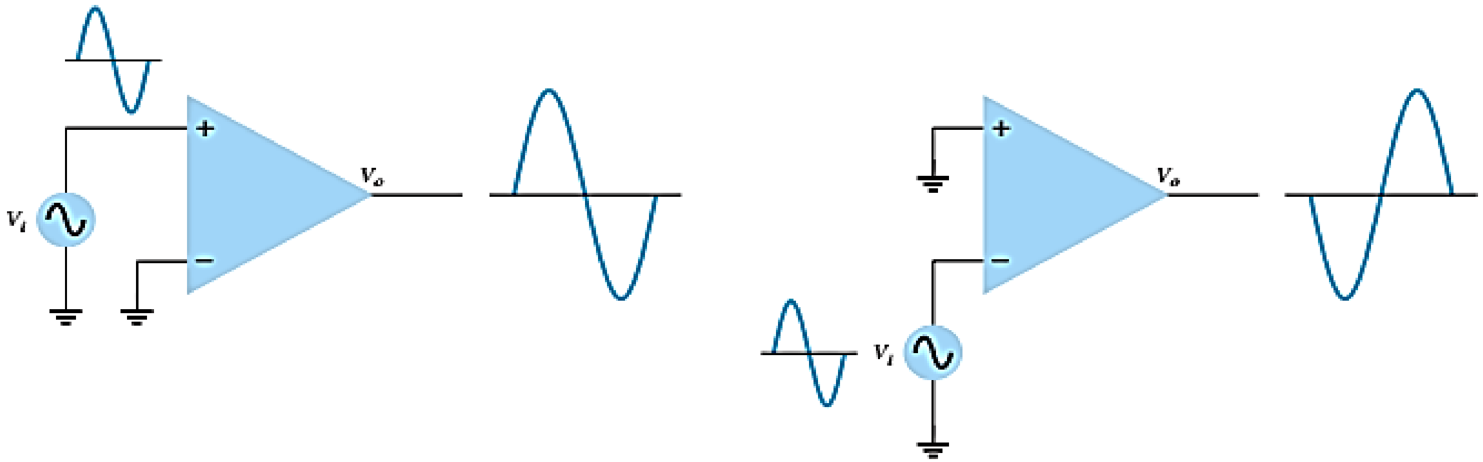
Input Impedance is very high
no current between the two input terminals



Input Impedance is very low
With very high voltage gain

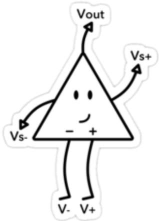
Single-Ended Input

- Single-ended input operation results when the input signal is connected to one input with the other input connected to ground.
- Figure shows the signals connected for this operation. In Figure a, the input is applied to the plus input (with minus input at ground), which results in an output having the same polarity as the applied input signal.
- Figure b shows an input signal applied to the minus input, the output then being opposite in phase to the applied signal



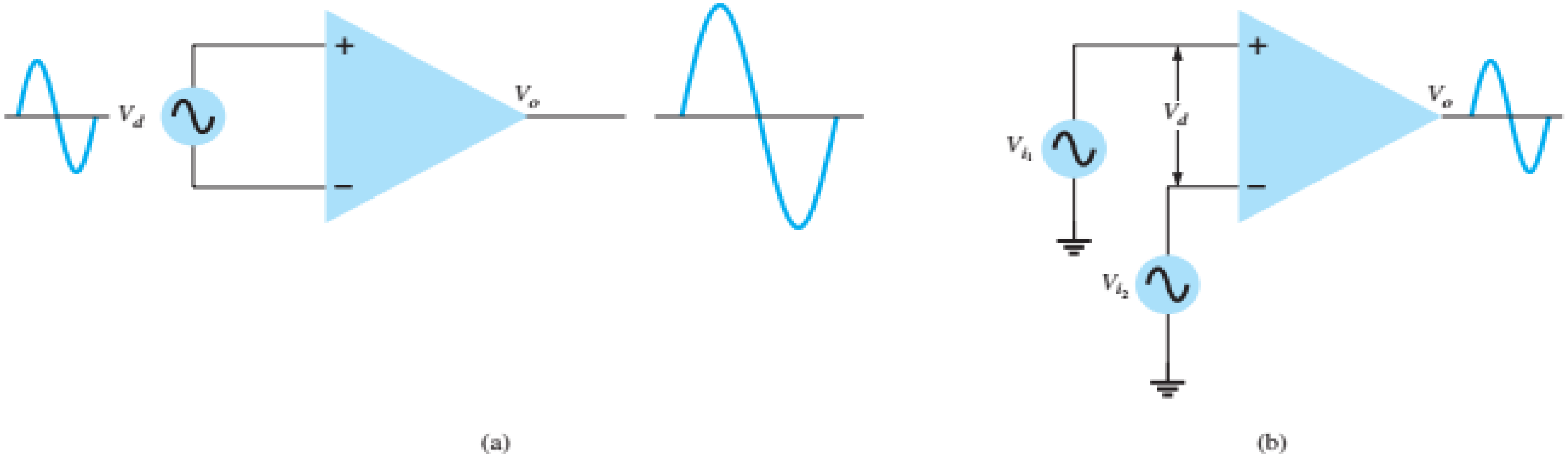
(a) (b)

Single-ended operation.



Single-Ended (Differential) Input

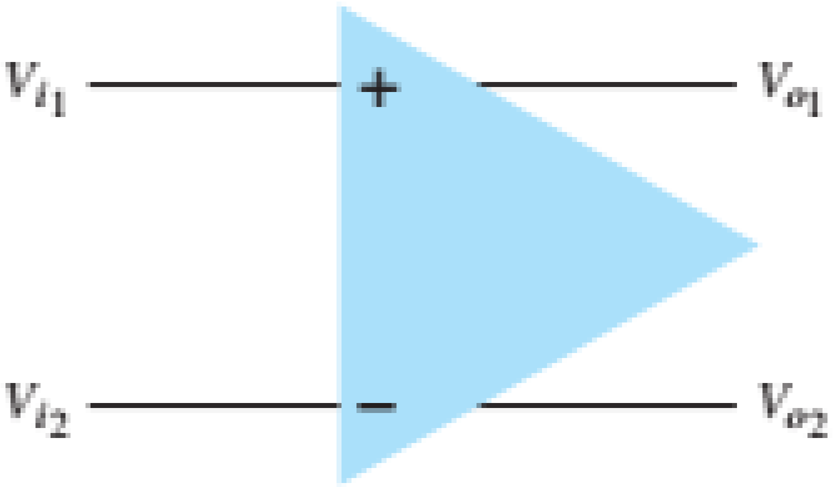
- it is possible to apply signals at each input—this being a double-ended operation.
- Figure a shows an input, V_d, applied between the two input terminals (recall that neither input is at ground), with the resulting amplified output in phase with that applied between the plus and minus inputs.
- Figure b shows the same action resulting when two separate signals are applied to the inputs, the difference signal being $V_{i1} - V_{i2}$.



Double-ended (differential) operation.

Double-Ended Output

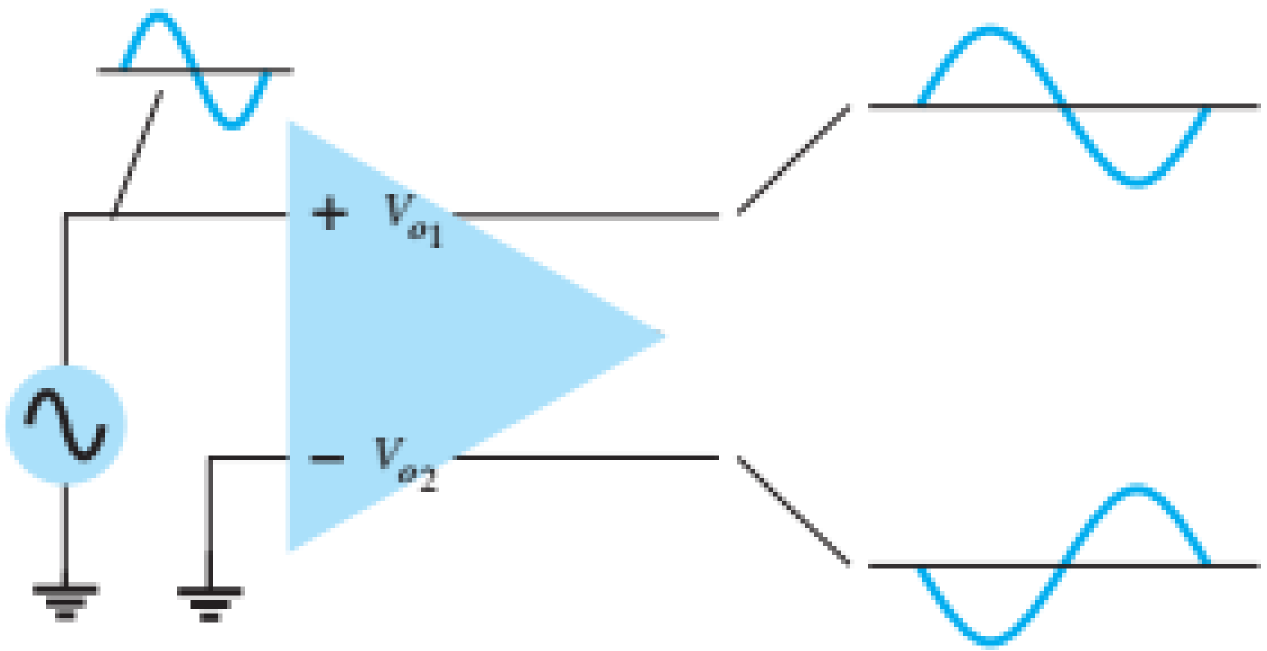
- the op-amp can also be operated with opposite outputs, as shown in Figure .
- An input applied to either input will result in outputs from both output terminals, these outputs always being opposite in polarity.



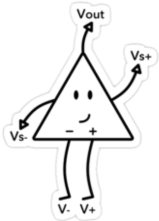
Double-ended input with double-ended output.

Double-Ended Output

Figure shows a single-ended input with a double-ended output. As shown, the signal applied to the plus input results in two amplified outputs of opposite polarity.

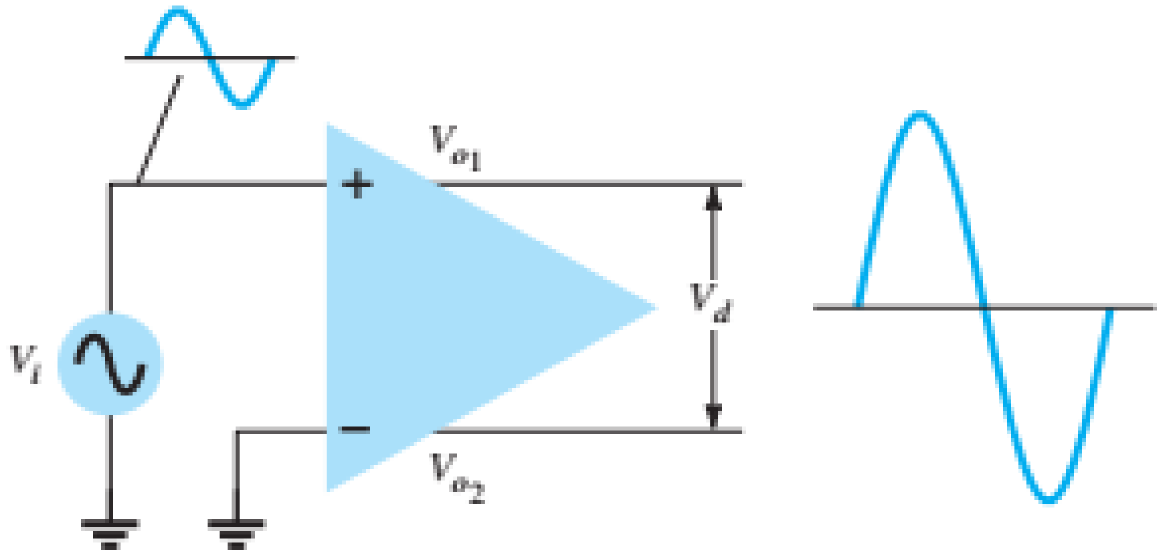


Single-ended input with double-ended output.



Double-Ended Output

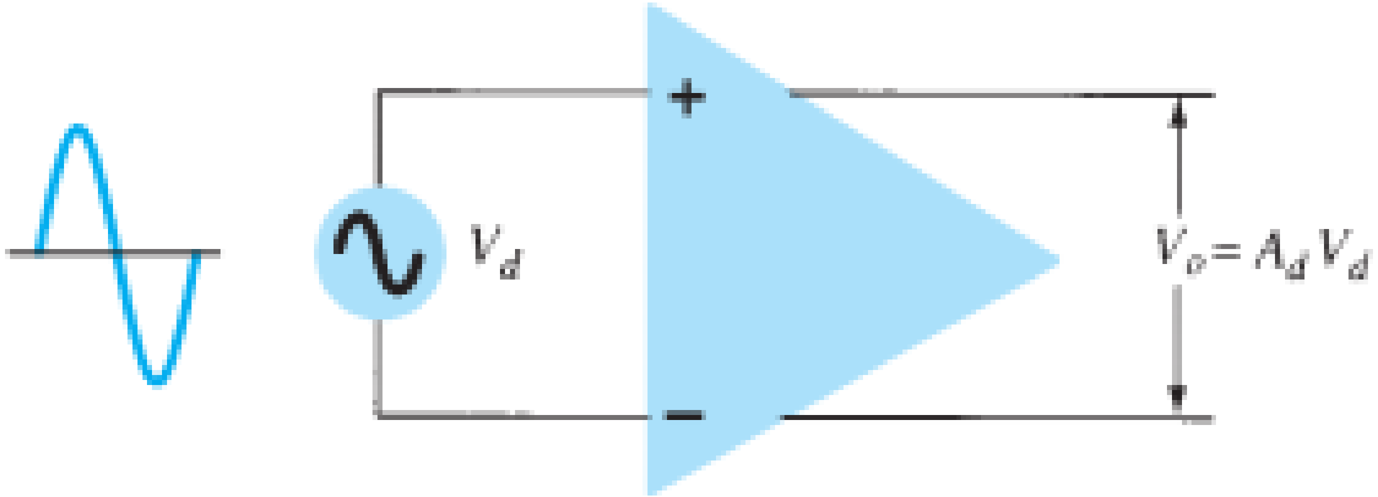
- Figure shows the same operation with a single output measured between output terminals (not with respect to ground).
- This difference output signal is V_{O1} - V_{O2}. The difference output is also referred to as a *floating signal* since neither output terminal is the ground (reference) terminal.
- The difference output is twice as large as either V_{O1} or V_{O2} because they are of opposite polarity and subtracting them results in twice their amplitude [e.g., 10 V - (-10 V) = 20 V].



Differential-output.

Double-Ended Output

Figure shows a differential input, differential output operation. The input is applied between the two input terminals and the output taken from between the two output terminals. This is fully differential operation



Differential-input, differential-output operation.

Inverting Amplifier

The output is obtained by multiplying the input by a fixed or constant gain, set by the input resistor (R_1) and feedback resistor (R_f)—this output also being inverted from the input.

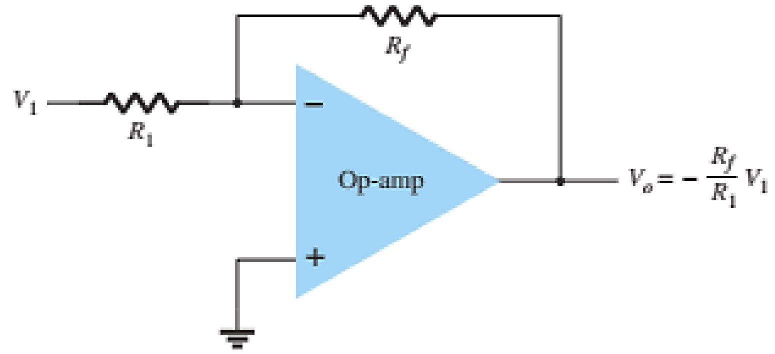
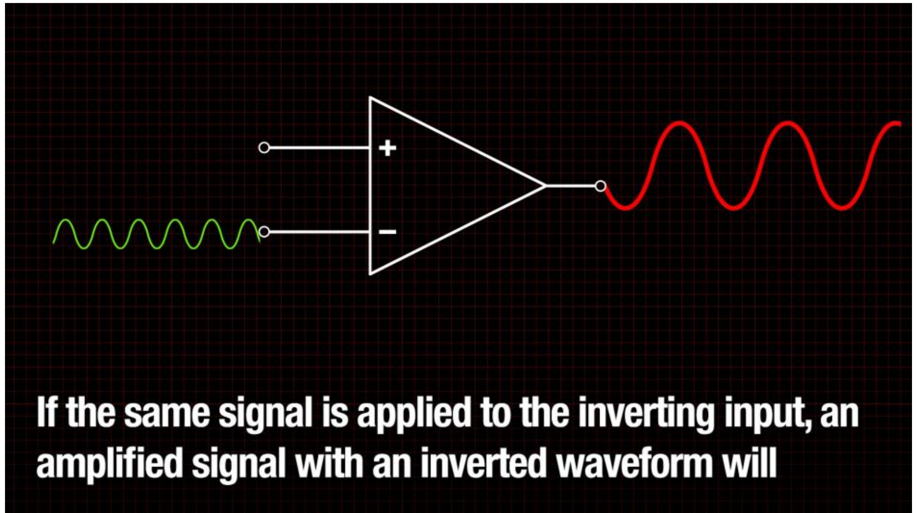


FIG. 10.34
Inverting constant-gain multiplier.

$$V_o = \boxed{-\frac{R_f}{R_1}} V_1$$

Gain Factor

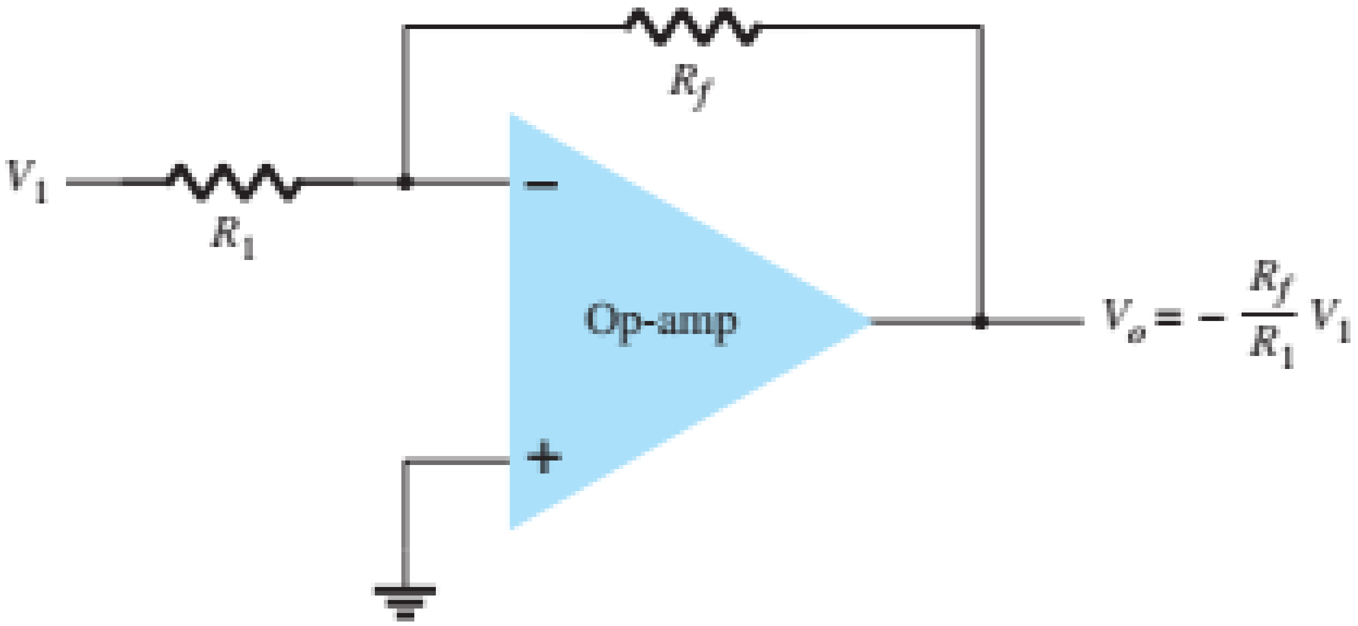


EXAMPLE

If the circuit of Figure has R_1 =100 k and R_f = 500 k, what output voltage results for an input of V_1 = 2 V

Solution:

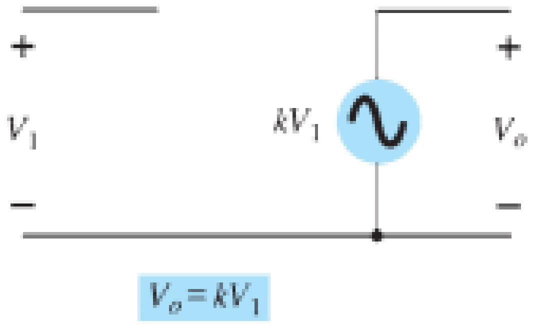
$$V_o = -\frac{R_f}{R_1}V_1 = -\frac{500\ \text{k}\Omega}{100\ \text{k}\Omega}(2\ \text{V}) = \mathbf{-10\ V}$$



Inverting constant-gain multiplier.

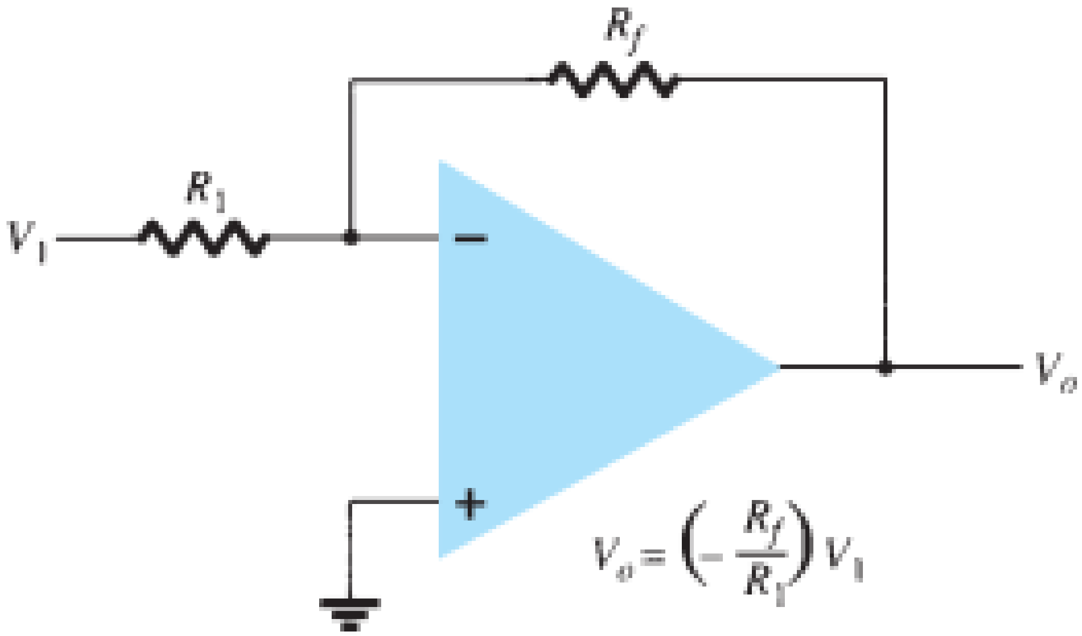
Voltage-Controlled Voltage Source

An ideal form of a voltage source whose output V_o is controlled by an input voltage V_1 is shown in Figure . The output voltage is seen to be dependent on the input voltage (times a scale factor k).



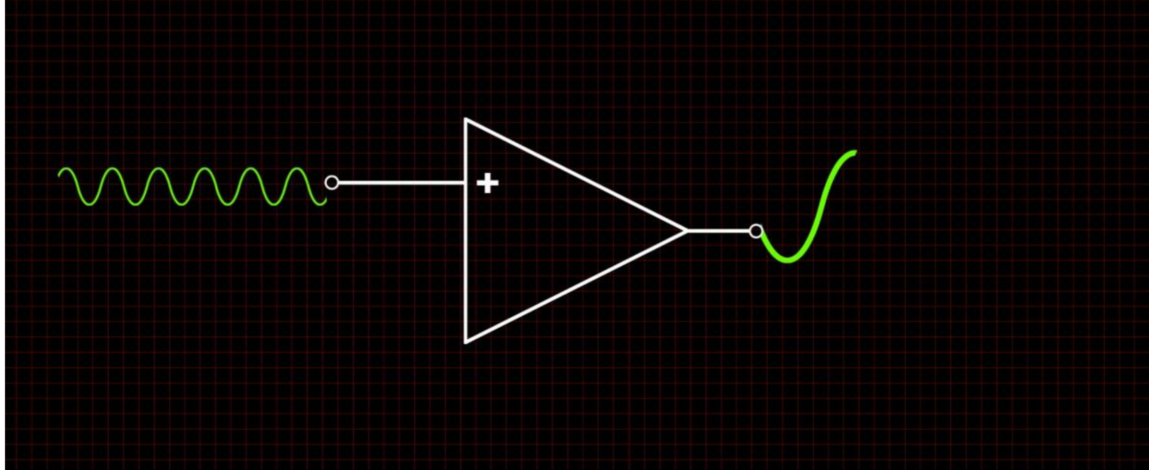
Ideal voltage-controlled voltage source.

$$V_o = \underbrace{\boxed{-\frac{R_f}{R_1}}}_{\text{Gain Factor}} V_1 = kV_1$$

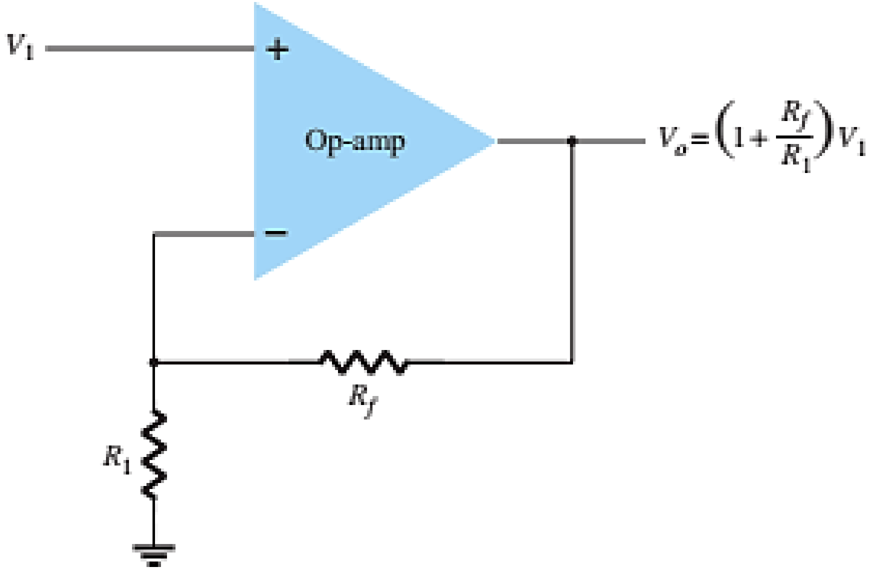


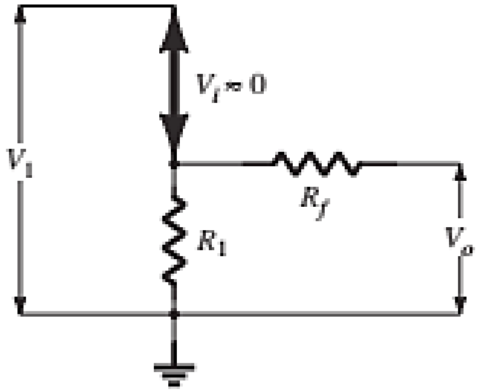
Noninverting Amplifier

The connection of Figure a shows an op-amp circuit that works as a noninverting amplifier or constant-gain multiplier.



To determine the voltage gain of the circuit, we can use the equivalent representation shown in Figure b.
Note that the voltage across $R1$ is $V1$ since $Vi = 0$ V. This must be equal to the output voltage, through a voltage divider of $R1$ and Rf, so that





$$V_1 = \frac{R_1}{R_1 + R_f} V_o$$

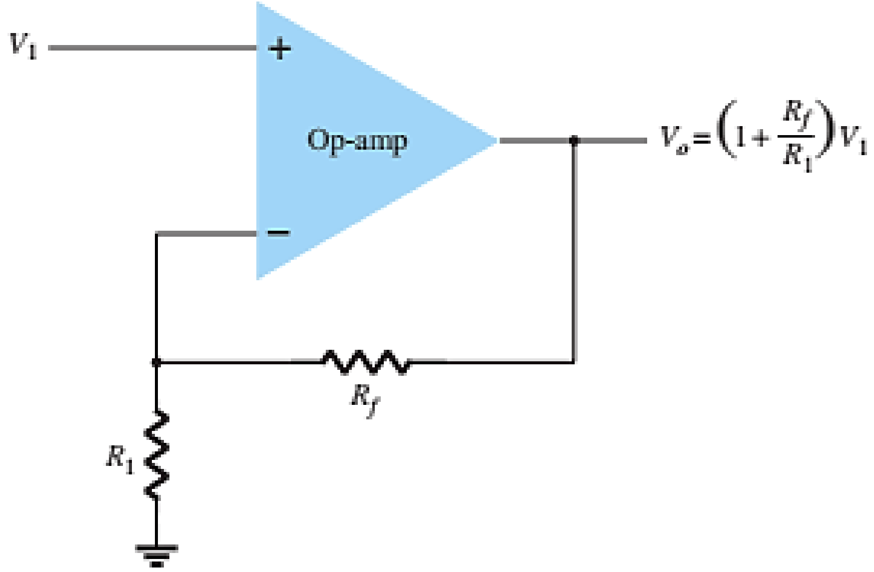
which results in

$$\frac{V_o}{V_1} = \frac{R_1 + R_f}{R_1} = \boxed{1 + \frac{R_f}{R_1}}$$

Gain Factor

EXAMPLE

Calculate the output voltage of a noninverting amplifier (as in Fig. 10.35) for values of $V_1 = 2$ V, $R_f = 500$ k, and $R_1 = 100$ k.



Solution:

$$V_o = \left(1 + \frac{R_f}{R_1}\right)V_1 = \left(1 + \frac{500\ \text{k}\Omega}{100\ \text{k}\Omega}\right)(2\ \text{V}) = 6(2\ \text{V}) = \mathbf{+12\ V}$$

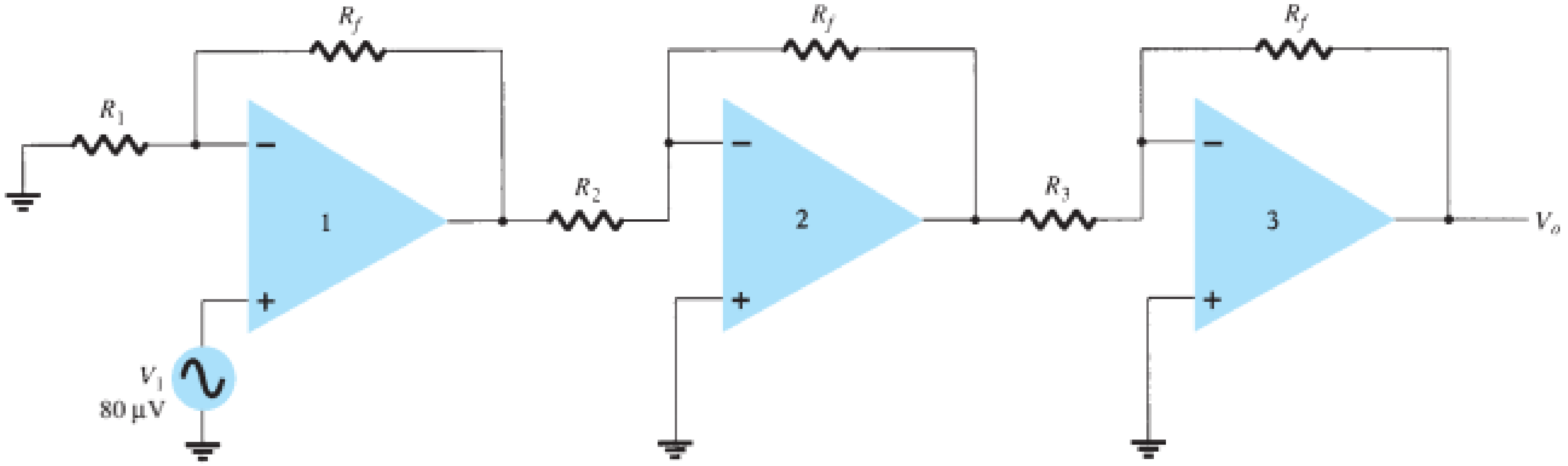
Multiple-Stage Gains

When a number of stages are connected in series, the overall gain is the product of the individual stage gains.

- Figure shows a connection of three stages.
- The first stage is connected to provide noninverting gain.
- The next two stages provide an inverting gain. The overall circuit gain is then noninverting and is calculated by

$$A = A_1 A_2 A_3$$

where $A_1 = 1 + R_f/R_1$, $A_2 = -R_f/R_2$, and $A_3 = -R_f/R_3$.



Constant-gain connection with multiple stages.

EXAMPLE

Calculate the output voltage using the circuit of Fig. for resistor components of value $R_f = 470\ \text{k}\Omega$, $R_1 = 4.3\ \text{k}\Omega$, $R_2 = 33\ \text{k}\Omega$, and $R_3 = 33\ \text{k}\Omega$ for an input of 80 μV.

Solution: The amplifier gain is calculated to be

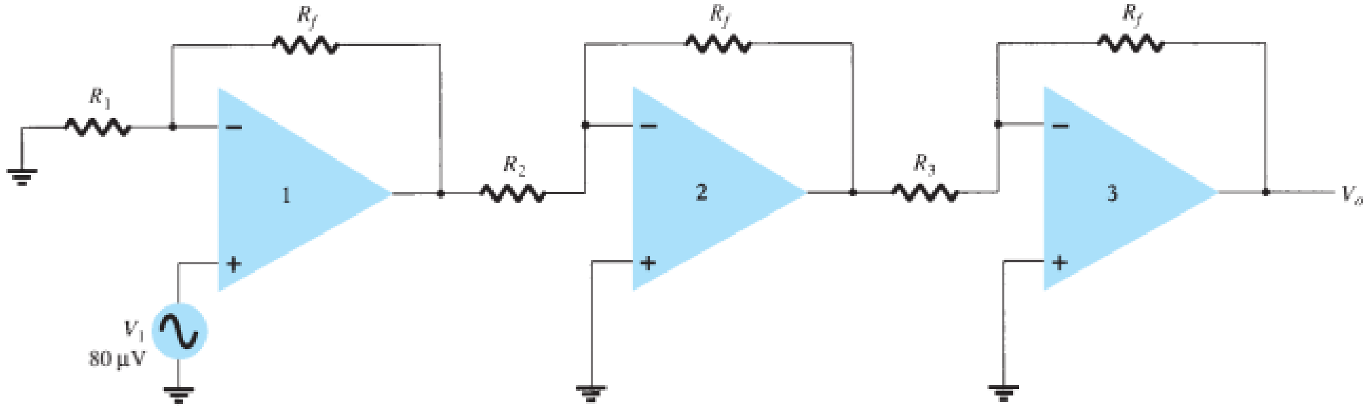
$$A = A_1A_2A_3 = \left(1 + \frac{R_f}{R_1}\right)\left(-\frac{R_f}{R_2}\right)\left(-\frac{R_f}{R_3}\right)$$

$$= \left(1 + \frac{470\ \text{k}\Omega}{4.3\ \text{k}\Omega}\right)\left(-\frac{470\ \text{k}\Omega}{33\ \text{k}\Omega}\right)\left(-\frac{470\ \text{k}\Omega}{33\ \text{k}\Omega}\right)$$

$$= (110.3)(-14.2)(-14.2) = 22.2 \times 10^3$$

so that

$$V_o = AV_i = 22.2 \times 10^3 (80\ \mu\text{V}) = \mathbf{1.78\ V}$$



EXAMPLE

Calculate the output voltage using the circuit of Figure for resistor components of value R_f = 470 k, R_1 = 4.3 k, R_2 = 33 k, and R_3 = 33 k for an input of 80 µV.

Solution:

For the gain of +10,

$$A_1 = 1 + \frac{R_f}{R_1} = +10$$

$$\frac{R_f}{R_1} = 10 - 1 = 9$$

$$R_1 = \frac{R_f}{9} = \frac{270\text{ k}\Omega}{9} = 30\text{ k}\Omega$$

For the gain of −18,

$$A_2 = -\frac{R_f}{R_2} = -18$$

$$R_2 = \frac{R_f}{18} = \frac{270\text{ k}\Omega}{18} = 15\text{ k}\Omega$$

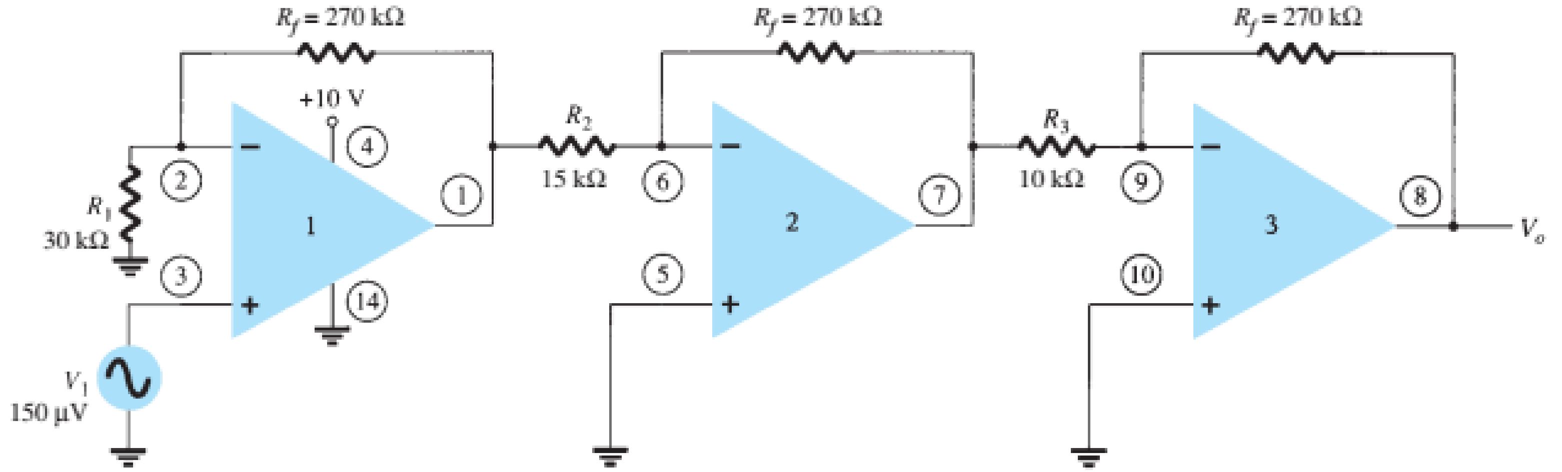
For the gain of −27,

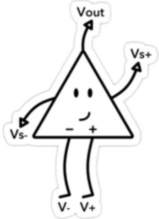
$$A_3 = -\frac{R_f}{R_3} = -27$$

$$R_3 = \frac{R_f}{27} = \frac{270\text{ k}\Omega}{27} = 10\text{ k}\Omega$$

The circuit showing the pin connections and all components used is given in Figure. For an input of V_1 = 150 µV, the output voltage is

$$V_o = A_1A_2A_3V_1 = (10)(-18)(-27)(150\ \mu\text{V}) = 4860(150\ \mu\text{V})$$
$$= \mathbf{0.729\ V}$$



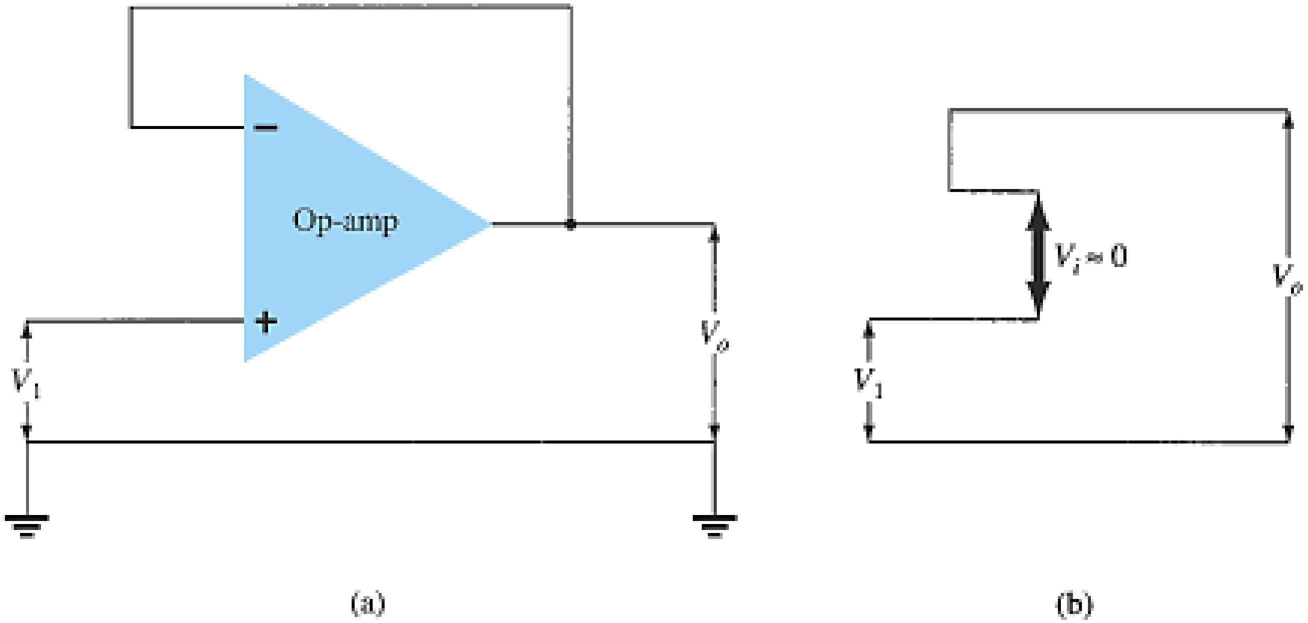


Unity Follower

VOLTAGE BUFFER

The unity-follower circuit, as shown in Figure , provides a gain of unity (1) with no polarity or phase reversal. From the equivalent circuit it is clear that

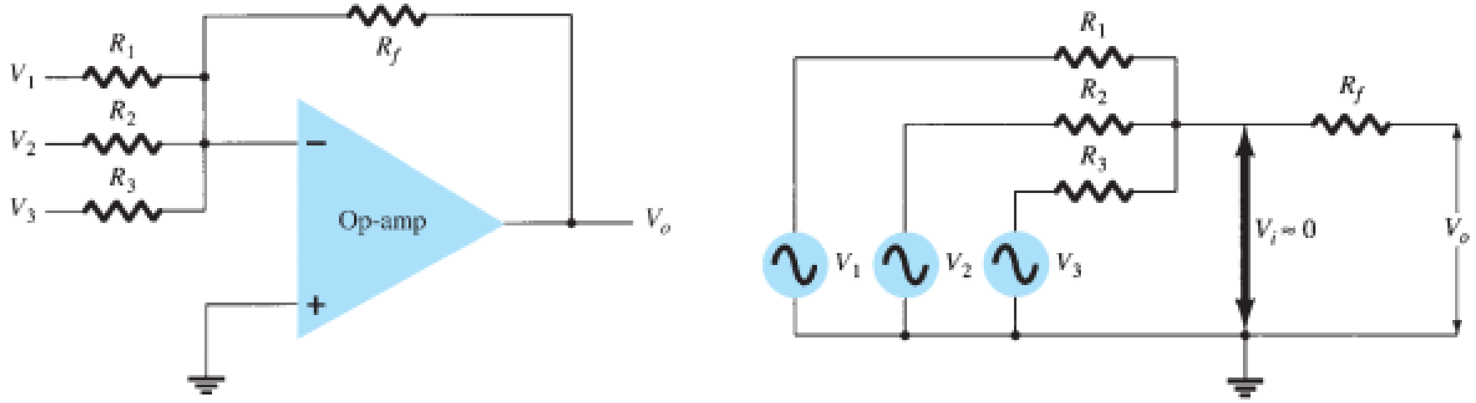
$$\boxed{V_o = V_1}$$



(a) Unity follower; (b) virtual-ground equivalent circuit.

Summing Amplifier

the most used of the op-amp circuits is the summing amplifier circuit shown in Figure. The circuit shows a three-input summing amplifier circuit, which provides a means of algebraically summing (adding) three voltages, each multiplied by a constant-gain factor. Using the equivalent representation shown in Figure b, we can express the output voltage in terms of the inputs as



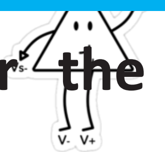
(a) (b)

$$V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$

(a) Summing amplifier; (b) virtual-ground equivalent circuit.

In other words, each input adds a voltage to the output multiplied by its separate constant-gain multiplier. If more inputs are used, they each add an additional component to the output.

EXAMPLE

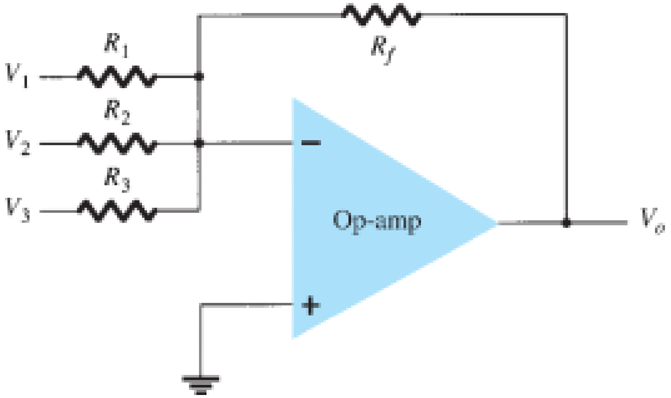


Calculate the output voltage of an op-amp summing amplifier for the following sets of voltages and resistors. Use R_f = 1 M in all cases.

a. $V_1 = +1\text{ V}, V_2 = +2\text{ V}, V_3 = +3\text{ V}, R_1 = 500\text{ k}\Omega, R_2 = 1\text{ M}\Omega, R_3 = 1\text{ M}\Omega.$
b. $V_1 = -2\text{ V}, V_2 = +3\text{ V}, V_3 = +1\text{ V}, R_1 = 200\text{ k}\Omega, R_2 = 500\text{ k}\Omega, R_3 = 1\text{ M}\Omega.$

Solution:

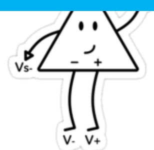
$$\boxed{V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)}$$



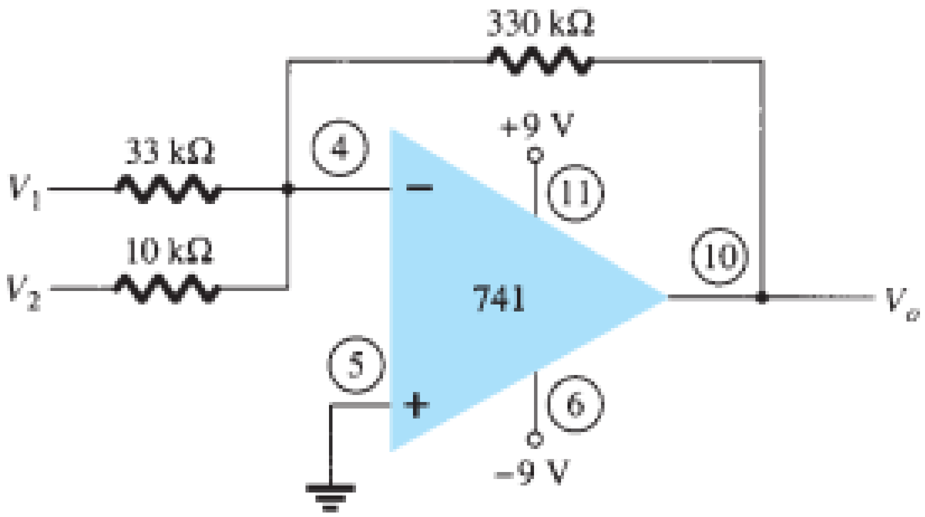
a. $$V_o = -\left[\frac{1000\text{ k}\Omega}{500\text{ k}\Omega}(+1\text{ V}) + \frac{1000\text{ k}\Omega}{1000\text{ k}\Omega}(+2\text{ V}) + \frac{1000\text{ k}\Omega}{1000\text{ k}\Omega}(+3\text{ V})\right]$$
$$= -[2(1\text{ V}) + 1(2\text{ V}) + 1(3\text{ V})] = \mathbf{-7\text{ V}}$$

b. $$V_o = -\left[\frac{1000\text{ k}\Omega}{200\text{ k}\Omega}(-2\text{ V}) + \frac{1000\text{ k}\Omega}{500\text{ k}\Omega}(+3\text{ V}) + \frac{1000\text{ k}\Omega}{1000\text{ k}\Omega}(+1\text{ V})\right]$$
$$= -[5(-2\text{ V}) + 2(3\text{ V}) + 1(1\text{ V})] = \mathbf{+3\text{ V}}$$

EXAMPLE



Calculate the output voltage for the circuit of Fig. . The inputs are $V1$ = 50 mV sin(1000t) and $V2$ =10 mV sin(3000t).



Solution: The output voltage is

$$V_o = -\left(\frac{330\text{ k}\Omega}{33\text{ k}\Omega}V_1 + \frac{330\text{ k}\Omega}{10\text{ k}\Omega}V_2\right) = -(10\,V_1 + 33\,V_2)$$

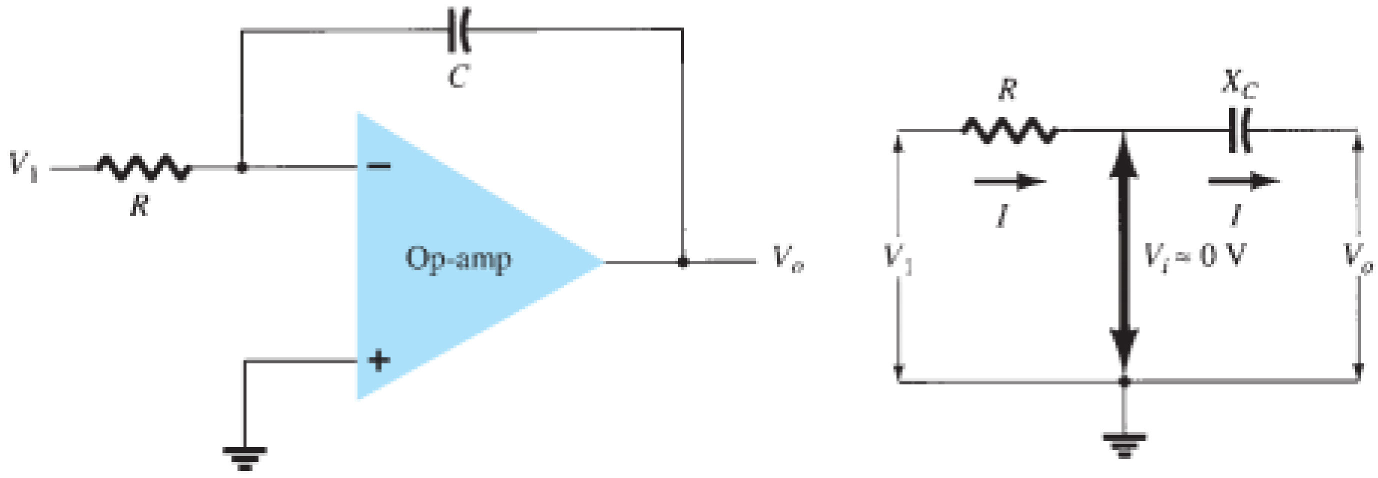
$$= -[10(50\text{ mV})\sin(1000t) + 33(10\text{ mV})\sin(3000t)]$$

$$= \mathbf{-[0.5\sin(1000}t\mathbf{) + 0.33\sin(3000}t\mathbf{)]}$$

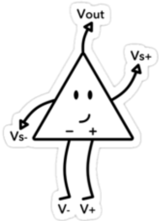
Integrator

- If the feedback component used is a capacitor, as shown in Figure a, the resulting connection is called an *integrator.*
- The virtual-ground equivalent circuit (Figure b) shows that an expression for the voltage between input and output can be derived in terms of the current *I* from input to output.
- Recall that virtual ground means that we can consider the voltage at the junction of *R* and X_C to be ground (since V_i =0 V) but that no current goes into ground at that point. The capacitive impedance can be expressed as

$$\boxed{v_o(t) = -\frac{1}{RC}\int v_1(t)\,dt}$$



(a) (b)



Integrator

The integration operation is one of summation, summing the area under a waveform or a curve over a period of time.
If a fixed voltage is applied as input to an integrator circuit, Equation shows that the output voltage grows over a period of time, providing a ramp voltage.

$$v_o(t) = \boxed{-\frac{1}{RC}} \int v_1(t)\,dt$$

Gain Factor

Equation can thus be understood to show that the output voltage ramp (for a fixed input voltage) is opposite in polarity to the input voltage and is multiplied by the factor $1/RC$.

Integrator

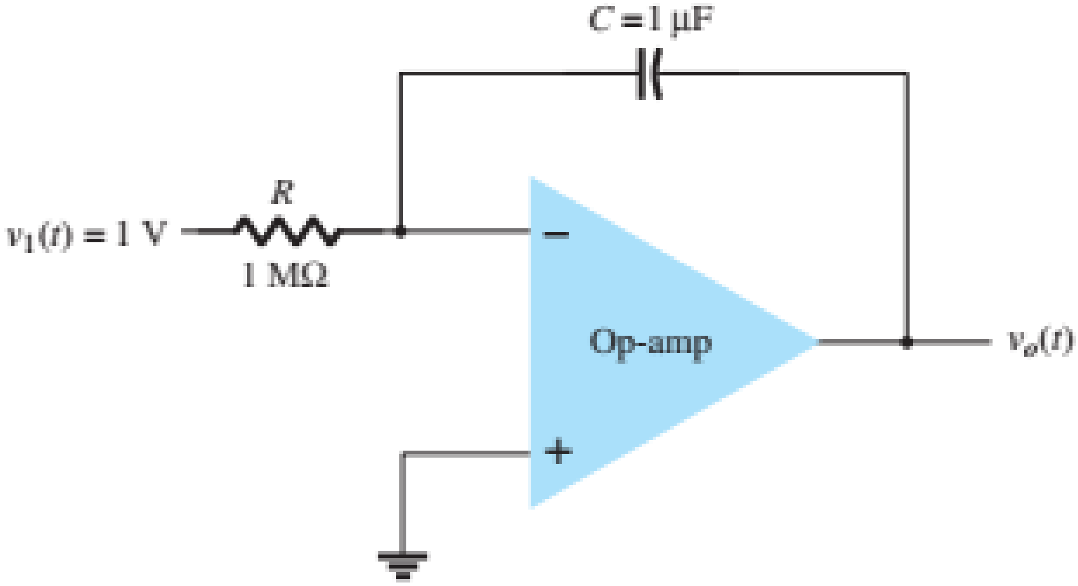
As an example, consider an input voltage $V_1 = 1$ V to the integrator circuit of Figure a. The scale factor of $1/RC$ is

R = 1 MΩ

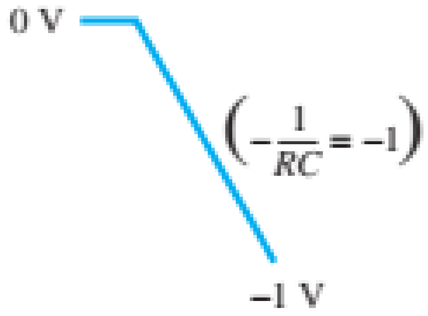
$$-\frac{1}{RC} = \frac{1}{(1\ \text{M}\Omega)(1\ \mu\text{F})} = -1$$

R = 100 KΩ

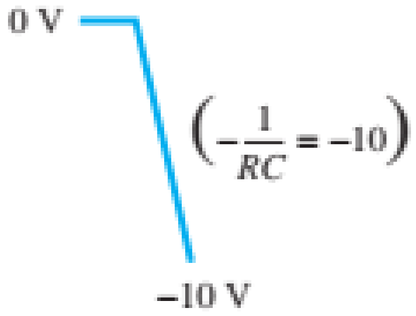
$$-\frac{1}{RC} = \frac{1}{(100\ \text{k}\Omega)(1\ \mu\text{F})} = -10$$



(a)



(b)



(c)

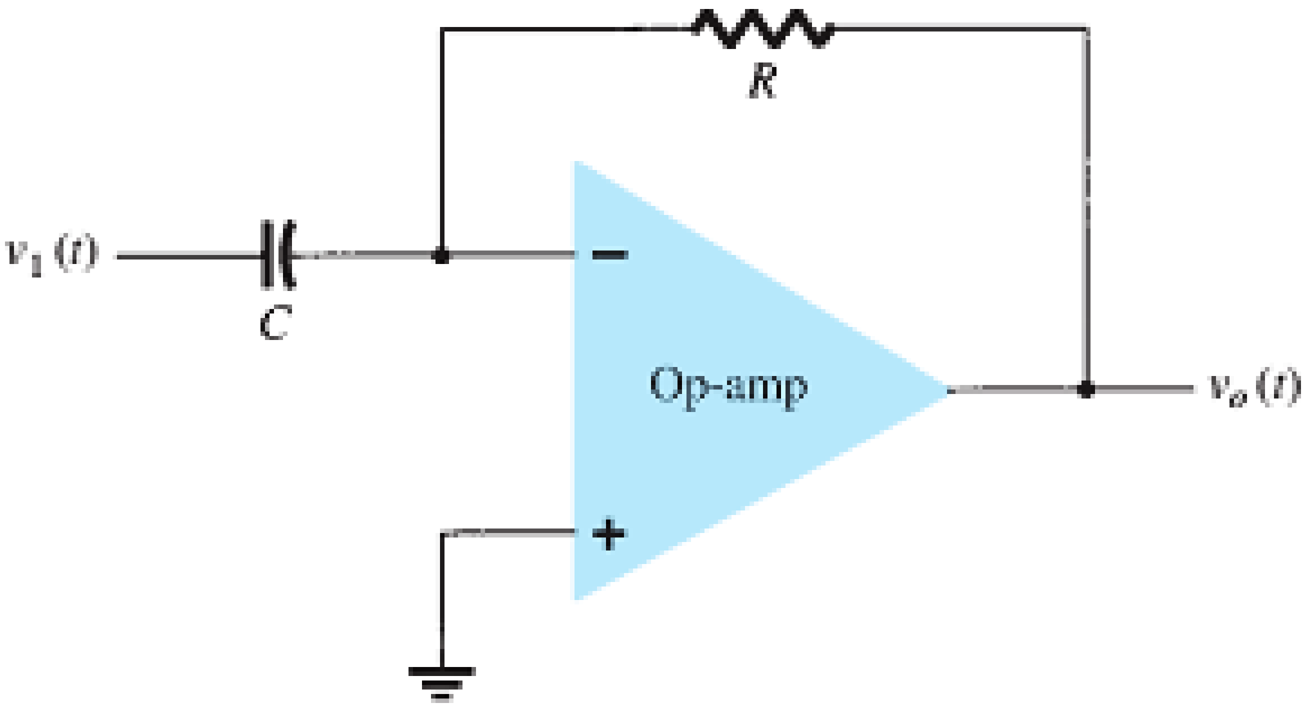
Differentiator

A differentiator circuit is shown in Figure .
the resulting relation for the circuit being

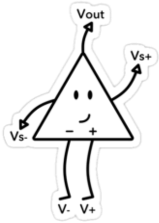
$$v_o(t) = \boxed{-RC}\frac{dv_1(t)}{dt}$$

Gain Factor

where the scale factor is -*RC*



Differentiator circuit.



THANK YOU!