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Electronics part C

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Differential Amplifier

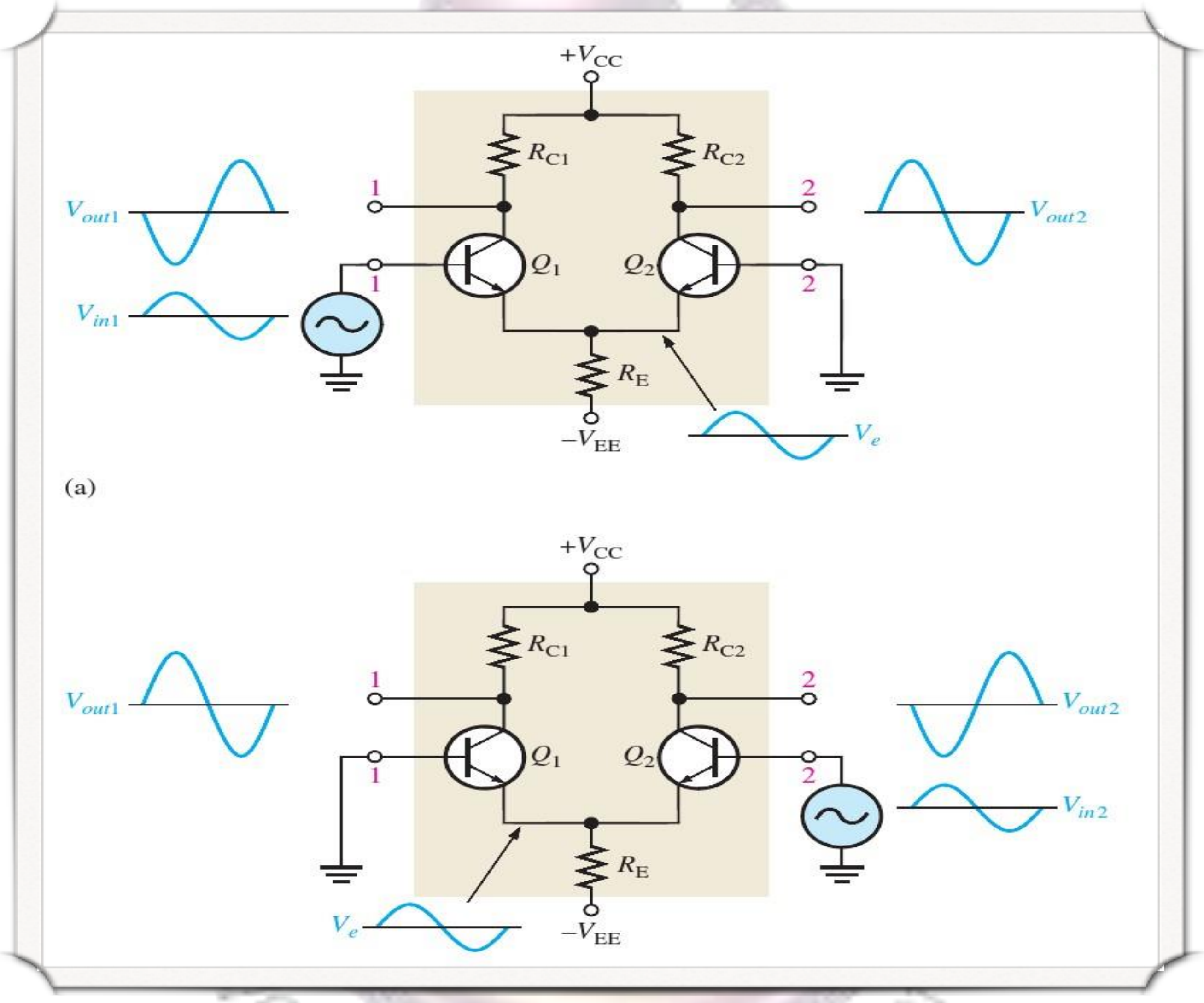
AN AMPLIFIER THAT PRODUCES OUTPUTS THAT ARE A FUNCTION OF THE DIFFERENCE BETWEEN TWO INPUT VOLTAGES. THE DIFFERENTIAL AMPLIFIER HAS TWO BASIC MODES OFOPERATION:

- DIFFERENTIAL (IN WHICH THE TWO INPUTS ARE DIFFERENT)
- COMMON MODE(INWHICH THE TWO INPUTS ARE THE SAME).

THE DIFFERENTIAL AMPLIFIER IS IMPORTANT IN OPERATIONAL AMPLIFIERS

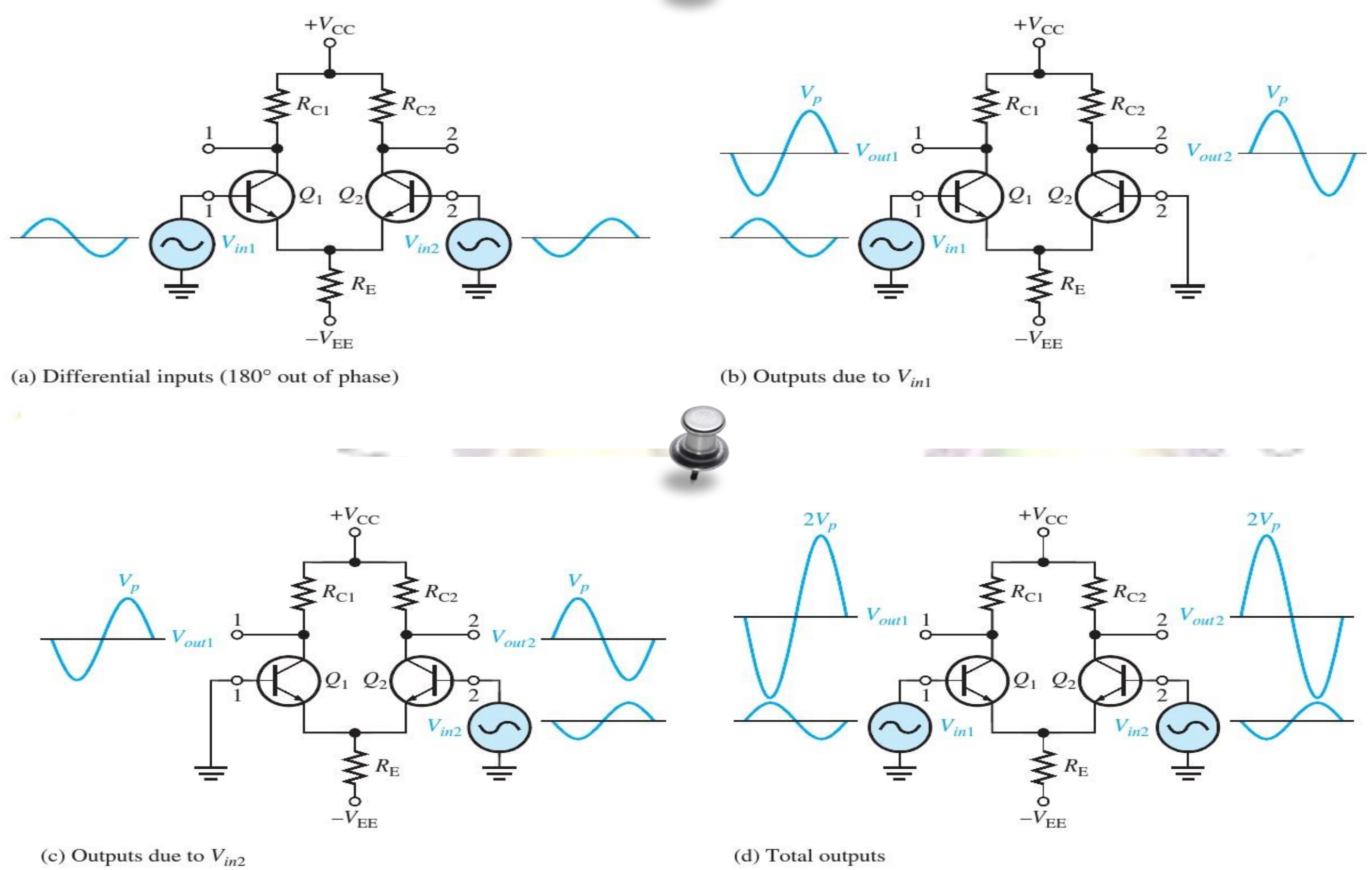
MODES OF SIGNAL OPERATION

- SINGLE-ENDED DIFFERENTIAL



➢ DOUBLE-ENDED DIFFERENTIAL INPUTS

IN THIS INPUT CONFIGURATION, TWO OPPOSITE-POLARITY (OUT-OF- PHASE) SIGNALS ARE APPLIED TO THE INPUTS.



(a) Differential inputs (180° out of phase)

(b) Outputs due to V_{in1}

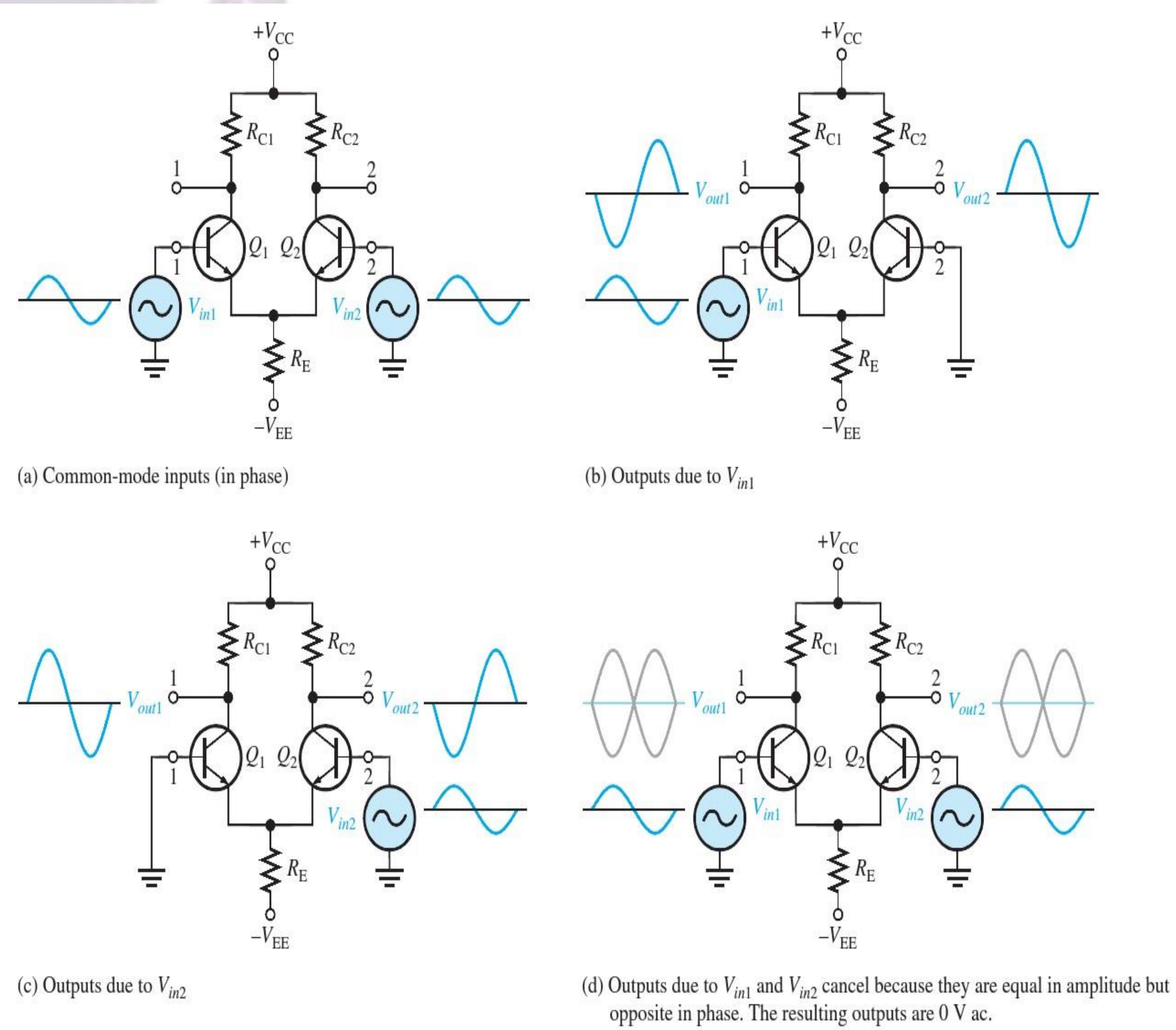
(c) Outputs due to V_{in2}

(d) Total outputs

COMMON-MODE INPUTS

COMMON-MODE CONDITION WHERE TWO SIGNAL VOLTAGES OF THE SAME PHASE, FREQUENCY, AND AMPLITUDE ARE APPLIED TO THE TWO INPUTS,

This action is called common mode rejection. Its importance lies in the situation where an unwanted signal appears commonly on both diff-amp inputs. Common-mode rejection means that this unwanted signal will not appear on the outputs and distort the desired signal. Common-mode signals (noise) generally are the result of the pick-up of radiated energy on the input lines from adjacent lines, the 60 Hz power line, or other sources



(a) Common-mode inputs (in phase)

(b) Outputs due to V_{in1}

(c) Outputs due to V_{in2}

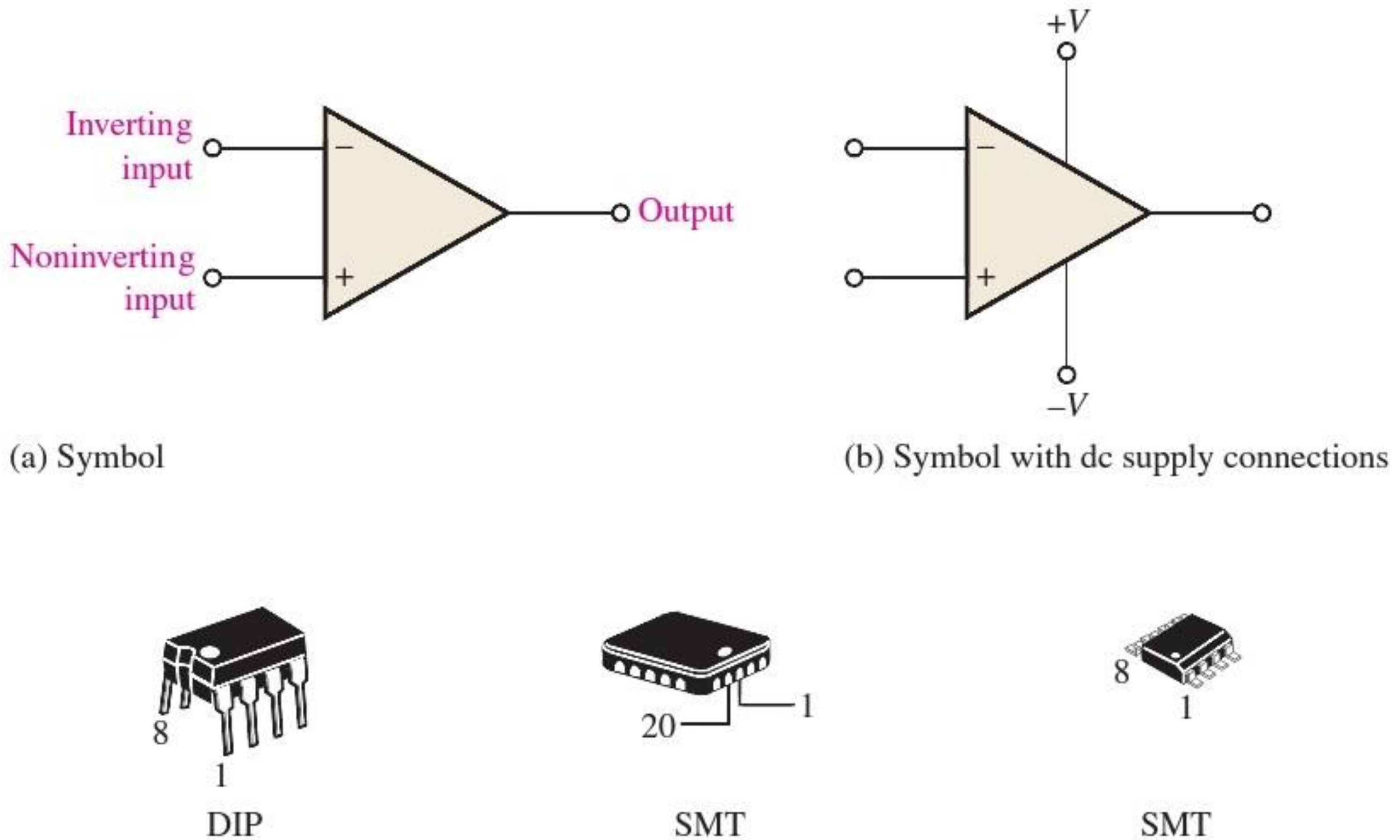
(d) Outputs due to V_{in1} and V_{in2} cancel because they are equal in amplitude but opposite in phase. The resulting outputs are 0 V ac.

COMMON-MODE REJECTION RATIO

$$CMRR = Av(d)/Acm$$

CMRR Av(d) Acm The higher the CMRR, the better. A very high value of CMRR means that the differential gain Av(d) is high and the common-mode gain Acm is low. The CMRR is often expressed in decibels (dB) as CMRR 20 loga Av(d)/ Acm b

Operational Amplifier Principles



(a) Symbol

(b) Symbol with dc supply connections

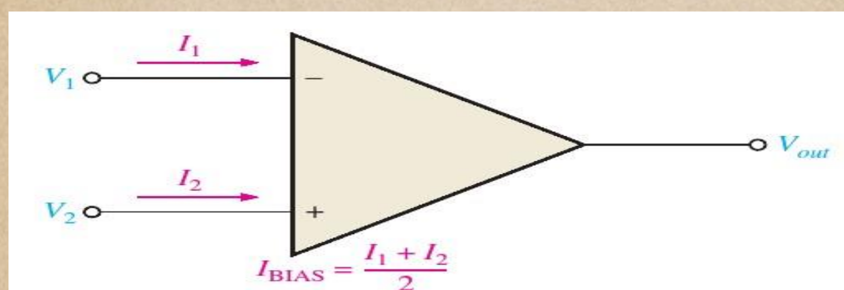
(c) Typical packages. Pin 1 is indicated by a notch or dot on dual in-line (DIP) and surface-mount technology (SMT) packages, as shown.

Operational Amplifier parameters

Common-Mode Rejection Ratio

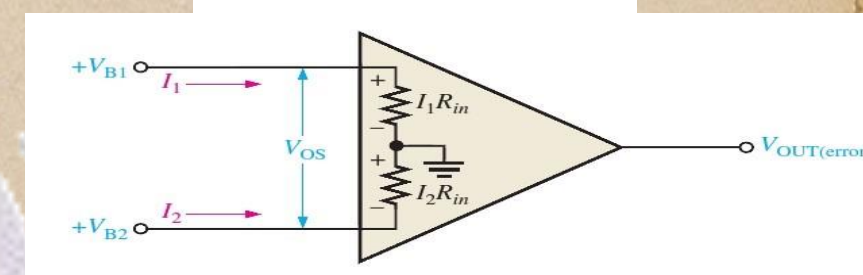
$$\mathrm{CMRR} = \frac{A_{ol}}{A_{cm}}$$

Input Bias Current

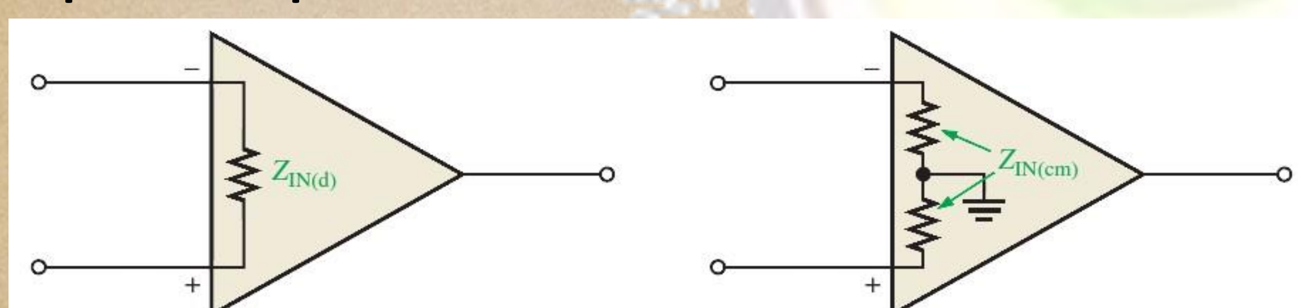


input offset current

$$I_{OS} = |I_1 - I_2|$$



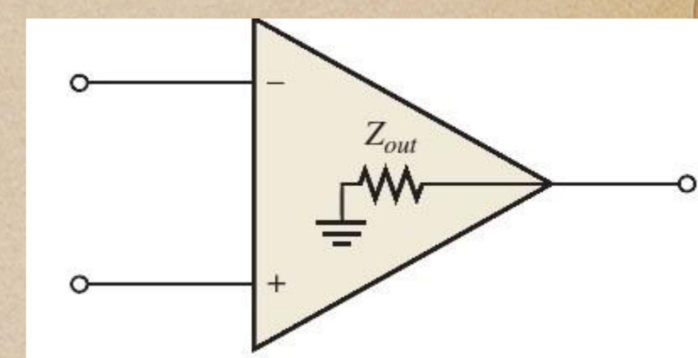
Input Impedance



(a) Differential input impedance

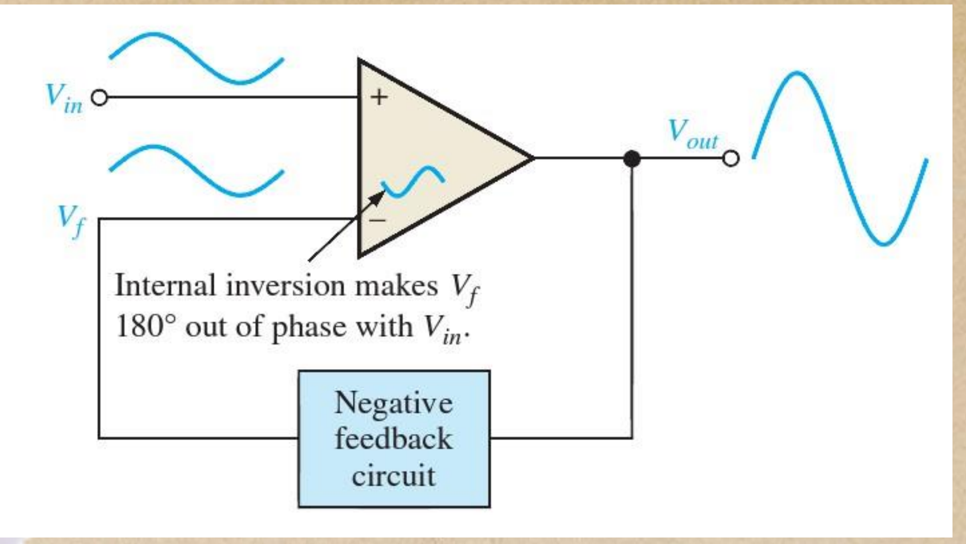
(b) Common-mode input impedance

Output Impedance



NEGATIVE FEEDBACK

Negative feedback is the process whereby a portion of the output voltage of an amplifier is returned to the input with a phase angle that opposes (or subtracts from) the input signal. The inverting makes the feedback signal 180° out of phase with the input signal.



Why use negative feedback

Control over all gain

Stable voltage gain

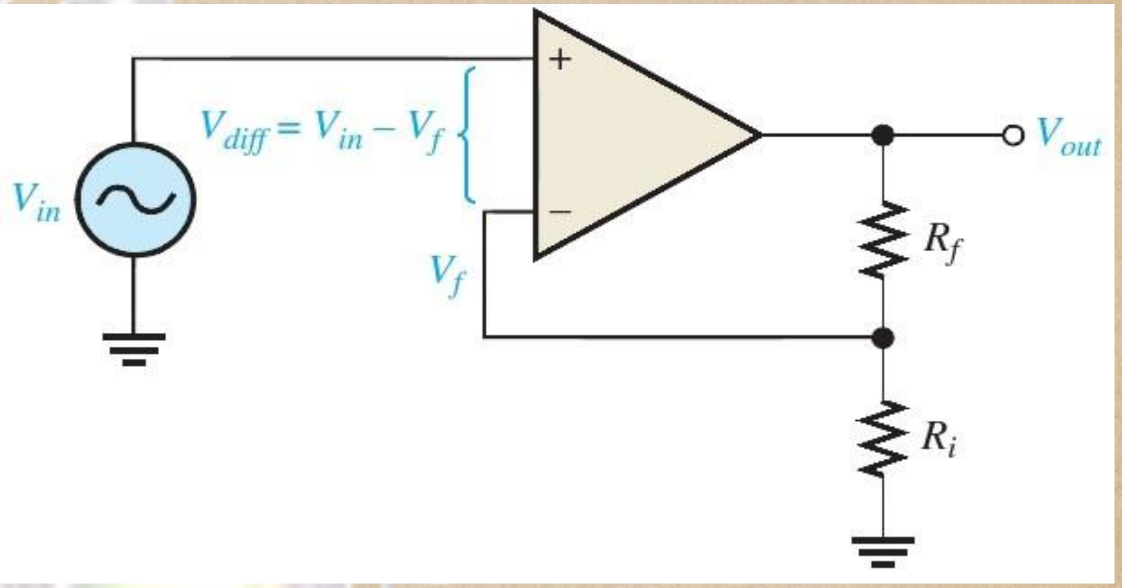
Control input impedance and output impedance

Control amplifier bandwidth

Op. Amp. With negative feedback

The feedback circuit (closed loop) formed by the input resistor Ri and the feedback resistor Rf.

$$V_f = \left(\frac{R_i}{R_i + R_f}\right)V_{out}$$



$$A_{cl(NI)} = \frac{V_{out}}{V_{in}} \cong \frac{1}{B} = \frac{R_i + R_f}{R_i}$$

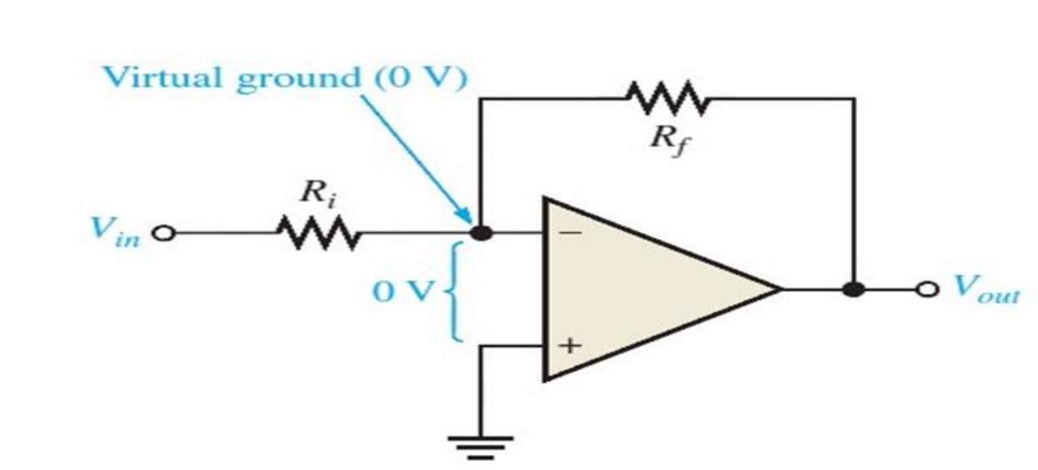
$$A_{cl(NI)} = 1 + \frac{R_f}{R_i}$$

The closed-loop gain can be set by selecting values of Ri and Rf.

Voltage-Follower

Is a special case of the noninverting amplifier where all of the output voltage is fed back to the inverting (-) input by a straight connection The most important features of the voltage-follower configuration are its very high input impedance and its very low output impedance. These features make it a nearly ideal buffer amplifier for interfacing high-impedance sources and low-impedance loads.

Inverting Amplifier



(a) Virtual ground

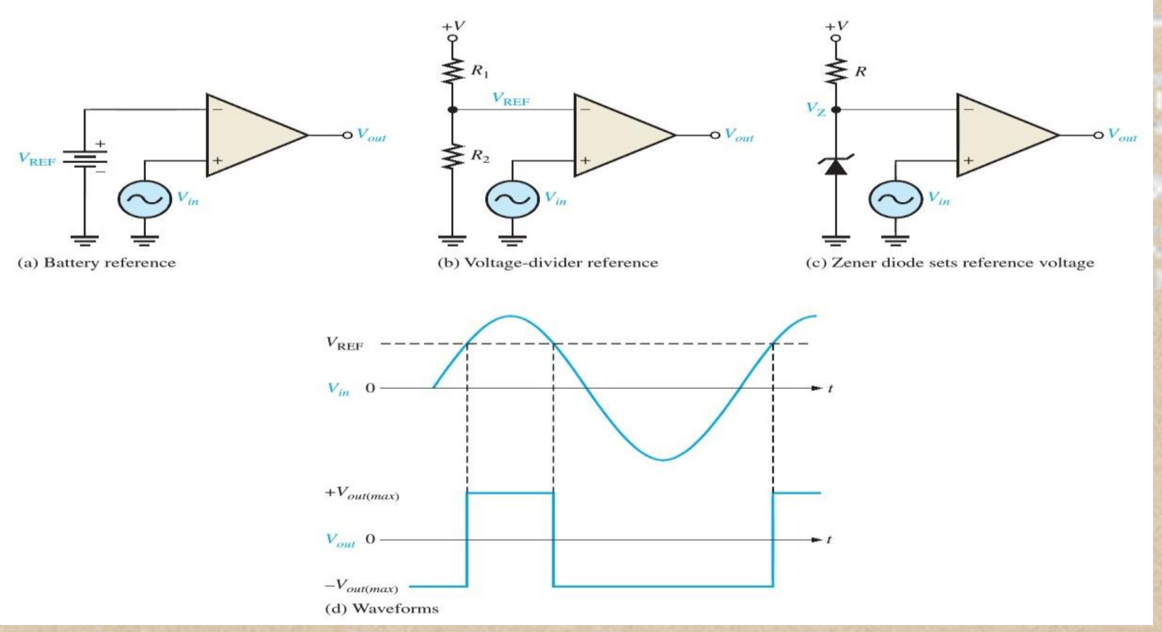
$$A_{cl(I)} = -\frac{R_f}{R_i}$$

Operational amplifier applications

COMPARATORS

A comparator is a specialized op-amp circuit that compares two input voltages and produces an output that is always at either one less than relationship between the inputs. An op-amp running without negative feedback (open-loop) is often used as a comparator.

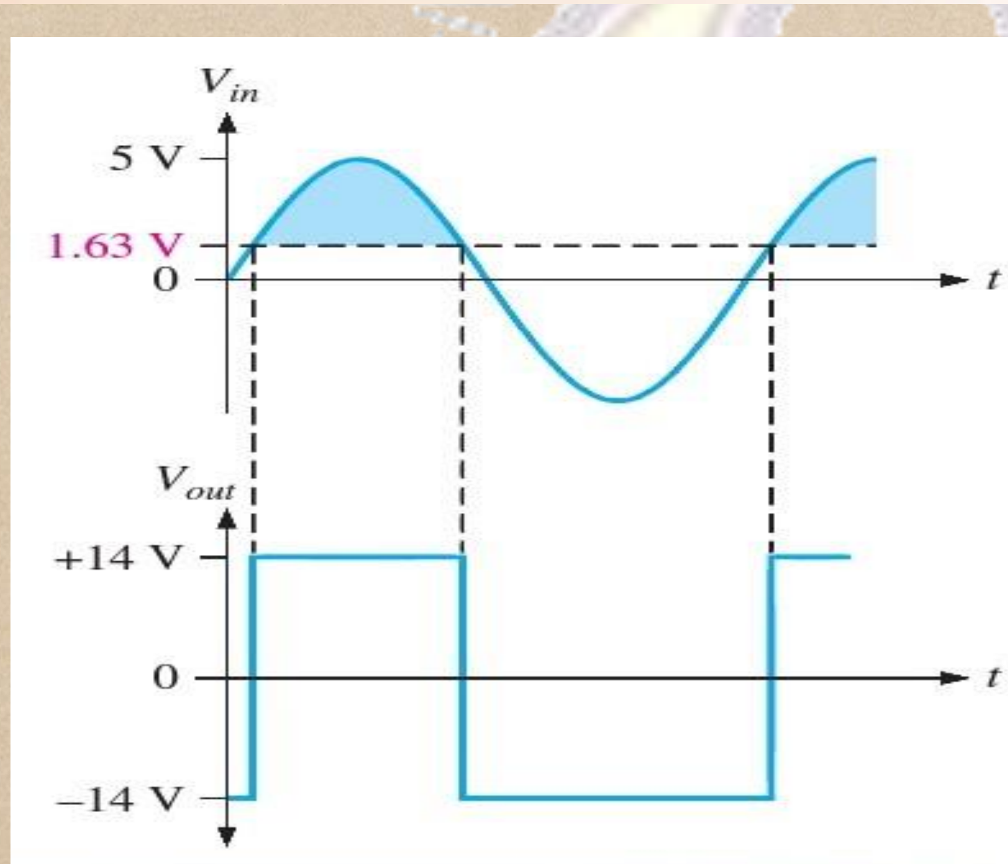
Consider an op-amp having Aol 100,000. A voltage difference of only 0.25 mV between the inputs could produce an output voltage of (0.25 mV)(100,000) 25 V if the op-amp were capable. However, since most op-amps have maximum output voltage limitations near the value of their dc supply voltages, the device would be driven into saturation

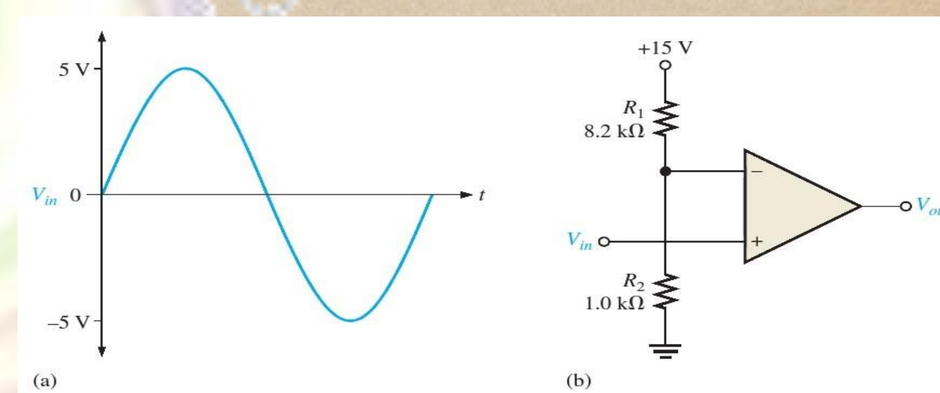


Example 1

input signal in the Figure is applied to the comparator.Draw the output showing its proper relationship to the input signal. Assume the maxi-mum output levels of the comparator are ;14V.

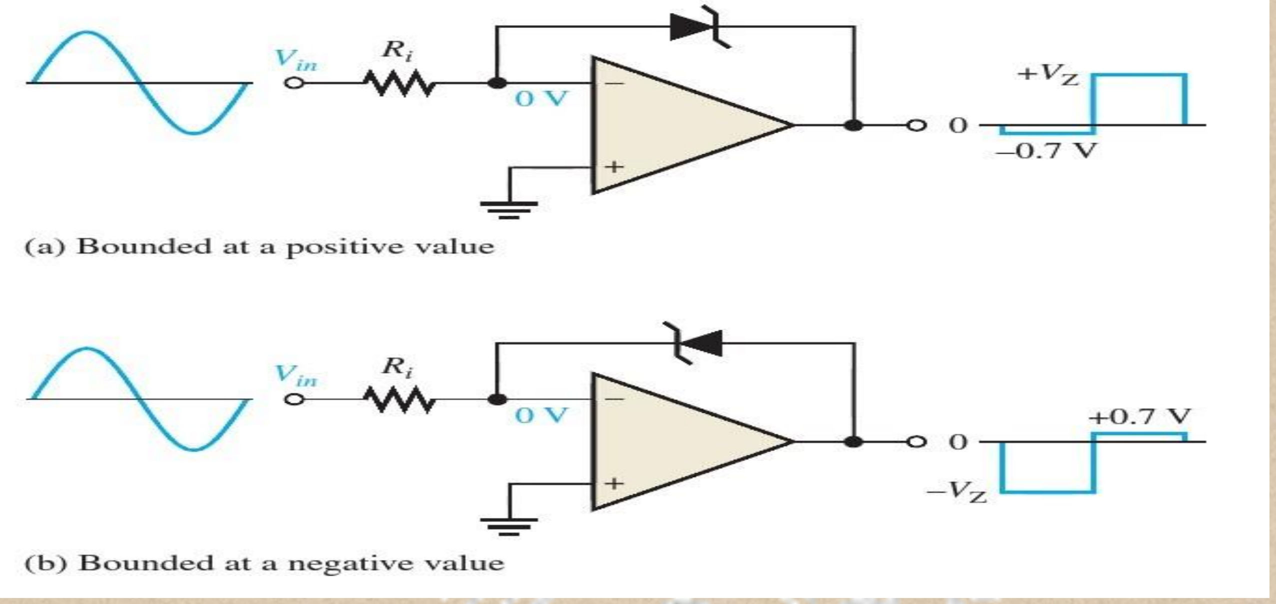
$$V_{REF} = \frac{R_2}{R_1 + R_2}(+V) = \frac{1.0\,\text{k}\Omega}{8.2\,\text{k}\Omega + 1.0\,\text{k}\Omega}(+15\text{ V}) = 1.63\text{ V}$$





Output Bounding

In some applications, it is necessary to limit the output voltage levels of a comparator to a qvalue less than that provided by the saturated op-amp. A single zener diode can be used, as shown in the Figure to limit the output voltage to the zener voltage in one direction and to the forward diode voltage drop in the other. This process of limiting the output range is called bounding.

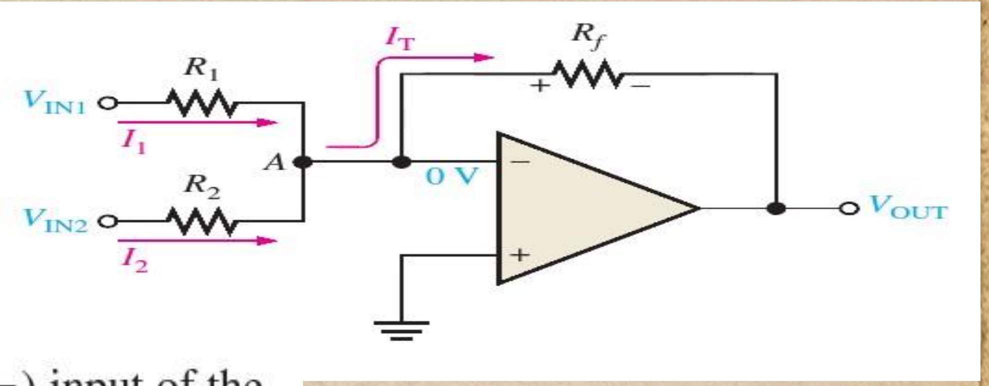


(a) Bounded at a positive value

(b) Bounded at a negative value

Summing Amplifier with Unity Gain

has two or more inputs, and its output voltage is proportional to the negative of the algebraic sum of its input voltages.



input impedance and virtual ground, you can determine that the inverting (−) input of the op-amp is approximately 0 V and has no current through it. This means that both input currents I_1 and I_2 combine at a summing point, A, and form the total current (I_T), which goes through R_f, as indicated in Figure 13–20.

$$I_T = I_1 + I_2$$

Since $V_{OUT} = -I_T R_f$, the following steps apply:

$$V_{OUT} = -(I_1 + I_2)R_f = -\left(\frac{V_{IN1}}{R_1} + \frac{V_{IN2}}{R_2}\right)R_f$$

If all three of the resistors are equal ($R_1 = R_2 = R_f = R$), then

$$V_{OUT} = -\left(\frac{V_{IN1}}{R} + \frac{V_{IN2}}{R}\right)R = -(V_{IN1} + V_{IN2})$$

The previous equation shows that the output voltage has the same magnitude as the sum of the two input voltages but with a negative sign, indicating inversion.

A general expression is given in Equation 13–4 for a unity-gain summing amplifier with n inputs, as shown in Figure 13–21 where all resistors are equal in value.

$$\mathbf{V_{OUT} = -(V_{IN1} + V_{IN2} + V_{IN3} + \cdots + V_{INn})}$$

Summing Amplifier with Gain Greater Than Unity

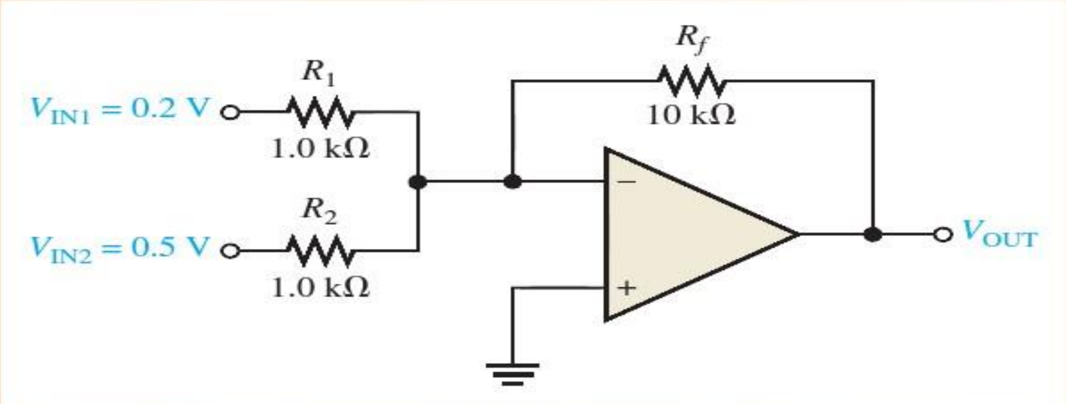
When Rf is larger than the input resistors, the amplifier has a gain of Rf/R, where R is the value of each equal-value input resistor. The general expression for the output is

$$V_{OUT} = -\frac{R_f}{R}(V_{IN1} + V_{IN2} + \cdots + V_{INn})$$

The output voltage has the same magnitude as the sum of all the input voltages multiplied by a constant determined by the ratio -(Rf/R).

Example

Determine the output voltage for the summing amplifier in Figure 13–23.



$R_f = 10\,k\Omega$ and $R = R_1 = R_2 = 1.0\,k\Omega$. Therefore,

$$V_{OUT} = -\frac{R_f}{R}(V_{IN1} + V_{IN2}) = -\frac{10\,k\Omega}{1.0\,k\Omega}(0.2\text{ V} + 0.5\text{ V}) = -10(0.7\text{ V}) = \mathbf{-7\text{ V}}$$

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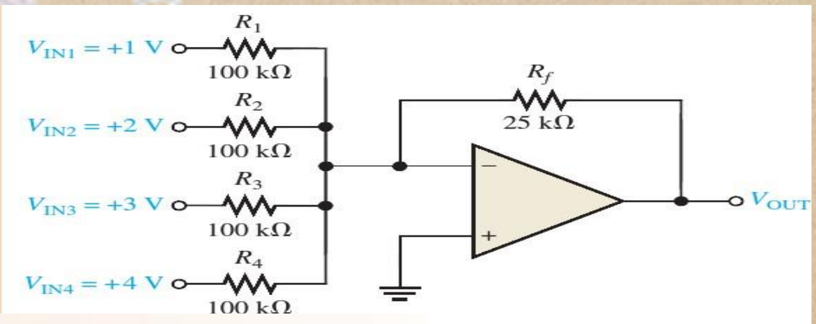
Averaging Amplifier

A summing amplifier can be made to produce the mathematical average of the input voltages. This is done by setting the ratio Rf/R equal to the reciprocal of the number of inputs (n).

Example

Show that the amplifier in Figure produces an output whose magnitude is the mathematical average of the input voltages.



Since the input resistors are equal, $R = 100\ \text{k}\Omega$. The output voltage is

$$V_{OUT} = -\frac{R_f}{R}(V_{IN1} + V_{IN2} + V_{IN3} + V_{IN4})$$
$$= -\frac{25\ \text{k}\Omega}{100\ \text{k}\Omega}(1\text{ V} + 2\text{ V} + 3\text{ V} + 4\text{ V}) = -\frac{1}{4}(10\text{ V}) = \mathbf{-2.5\ V}$$

A simple calculation shows that the average of the input values is the same magnitude as V_{OUT} but of opposite sign.

$$V_{IN(avg)} = \frac{1\text{ V} + 2\text{ V} + 3\text{ V} + 4\text{ V}}{4} = \frac{10\text{ V}}{4} = 2.5\text{ V}$$

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Scaling Adder

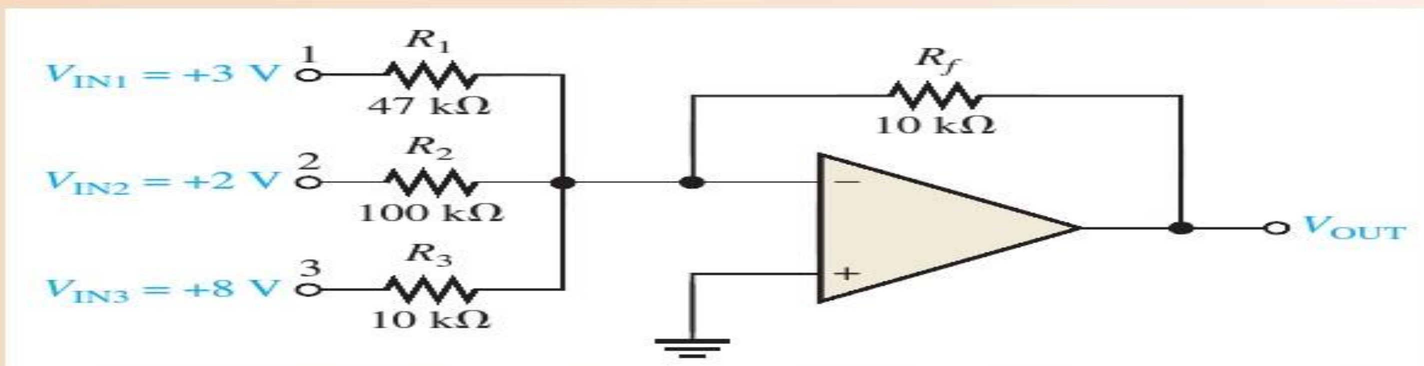
A different weight can be assigned to each input of a summing amplifier by simply adjusting the values of the input resistors. As you have seen, the output voltage can be expressed as

$$V_{OUT} = -\left(\frac{R_f}{R_1}V_{IN1} + \frac{R_f}{R_2}V_{IN2} + \cdots + \frac{R_f}{R_n}V_{INn}\right)$$

The weight of a particular input is set by the ratio of Rf to the resistance, Rx, for that input (Rx R1,R2,...Rn). For example, if an input voltage is to have a weight of 1, then Rx =Rf. Or, if a weight of 0.5 is required, Rx = 2Rf. The smaller the value of input resist-anceRx, the greater the weight, and vice versa

Example

Determine the weight of each input voltage for the scaling adder in the fig. and find the output voltage.



Weight of input 1: $\frac{R_f}{R_1} = \frac{10\text{ k}\Omega}{47\text{ k}\Omega} = \mathbf{0.213}$

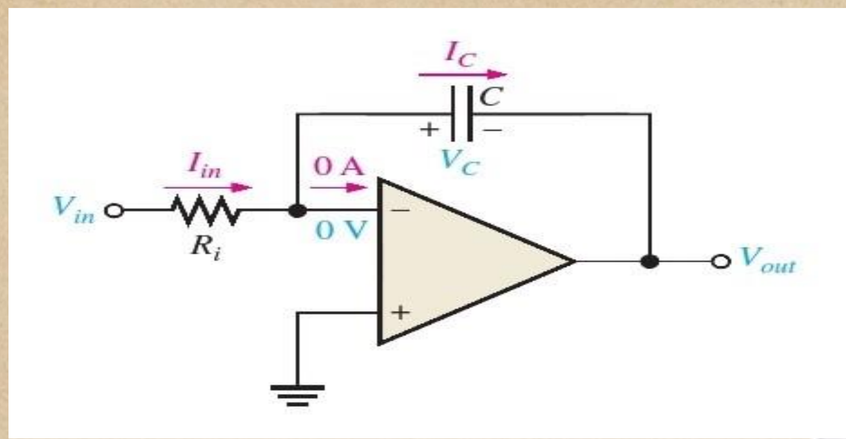
Weight of input 2: $\frac{R_f}{R_2} = \frac{10\text{ k}\Omega}{100\text{ k}\Omega} = \mathbf{0.100}$

Weight of input 3: $\frac{R_f}{R_3} = \frac{10\text{ k}\Omega}{10\text{ k}\Omega} = \mathbf{1.00}$

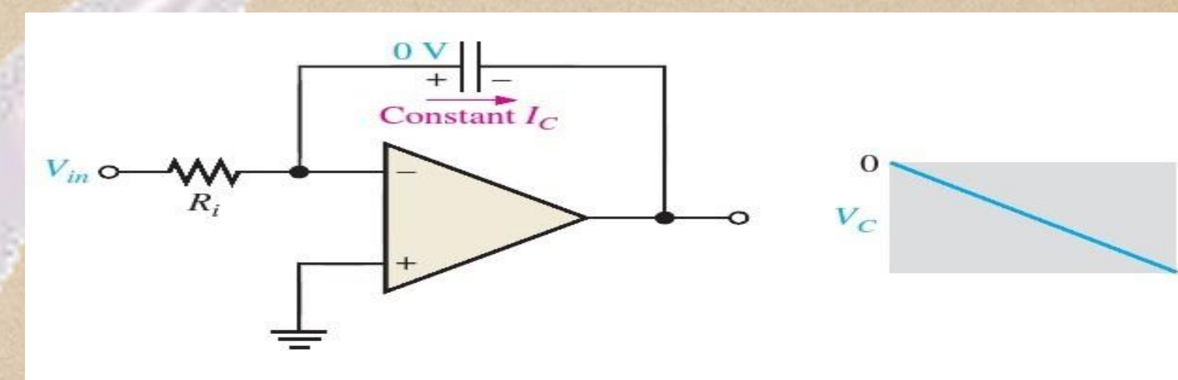
The output voltage is

$$
\begin{aligned}
V_{OUT} &= -\left(\frac{R_f}{R_1}V_{IN1} + \frac{R_f}{R_2}V_{IN2} + \frac{R_f}{R_3}V_{IN3}\right) \\
&= -[0.213(3\text{ V}) + 0.100(2\text{ V}) + 1.00(8\text{ V})] \\
&= -(0.639\text{ V} + 0.2\text{ V} + 8\text{ V}) = \mathbf{-8.84\text{ V}}
\end{aligned}
$$

The Op-Amp Integrator



Ic = Iin



Rate of Change of the Output Voltage

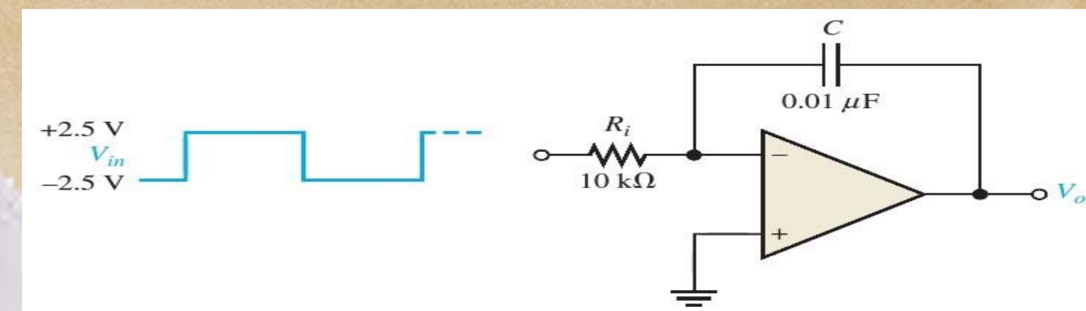
The rate at which the capacitor charges, and therefore the slope of the output ramp, is set by the ratio IC/C, as you have seen. Since IC Vin/Ri, the rate of change or slope of the integrator’s output voltage is

$$\frac{\Delta V_{out}}{\Delta t} = -\frac{V_{in}}{R_i C}$$

Example

(a) Determine the rate of change of the output voltage in response to the input square wave, as shown for the ideal integrator in Figure .The output voltage is initially zero. The pulse width is 100 ms.

(b) Describe the output and draw the waveform.



(a) The rate of change of the output voltage during the time that the input is at +2.5 V (capacitor charging) is

$$\frac{\Delta V_{out}}{\Delta t} = -\frac{V_{in}}{R_iC} = -\frac{2.5\ \text{V}}{(10\ \text{k}\Omega)(0.01\ \mu\text{F})} = -25\ \text{kV/s} = \mathbf{-25\ mV/\mu s}$$

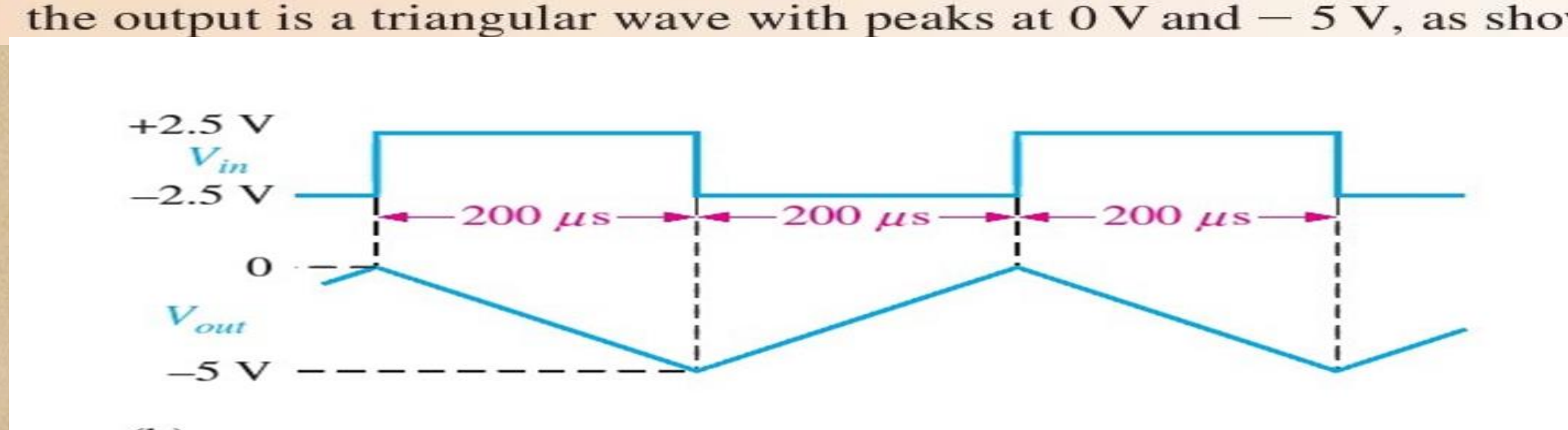
The rate of change of the output during the time that the input is negative (capacitor discharging) is the same as during charging except it is positive.

$$\frac{\Delta V_{out}}{\Delta t} = +\frac{V_{in}}{R_iC} = \mathbf{+25\ mV/\mu s}$$

(b) When the input is at +2.5 V, the output is a negative-going ramp. When the input is at −2.5 V, the output is a positive-going ramp.

$$\Delta V_{out} = (25\ \text{mV}/\mu\text{s})(200\ \mu\text{s}) = 5\ \text{V}$$

During the time the input is at +2.5 V, the output will go from 0 to −5 V. During the time the input is at −2.5 V, the output will go from −5 V to 0 V. Therefore, the output is a triangular wave with peaks at 0 V and − 5 V, as shown in Figure

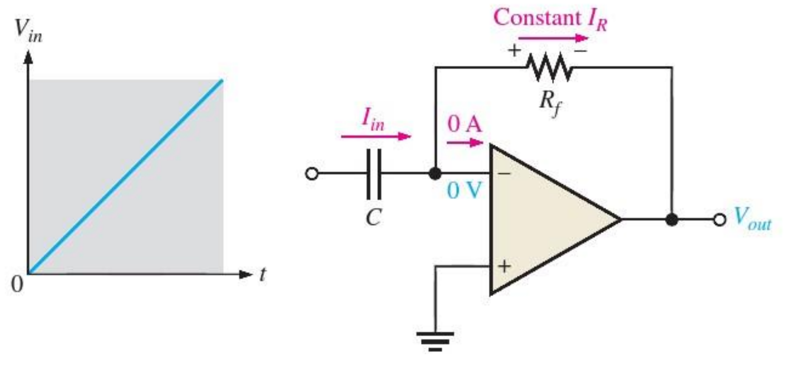


The Op-Amp Differentiator

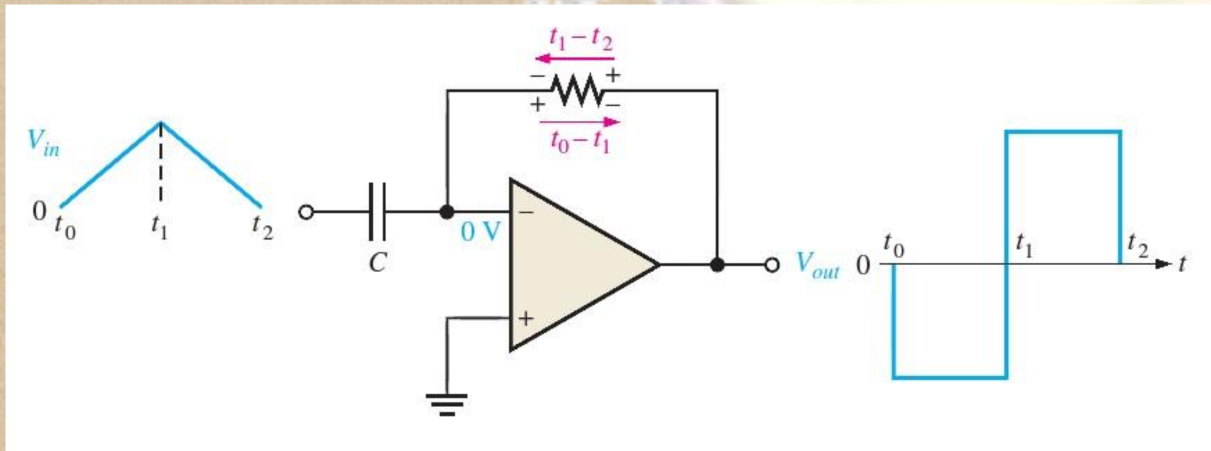
$$V_{out} = I_R R_f = I_C R_f$$

$$V_{out} = -\left(\frac{V_C}{t}\right) R_f C$$

$$I_C = \left(\frac{V_C}{t}\right) C$$



The output is negative when the input is a positive-going ramp and positive when the input is a negative-going ramp
the term VC/t is the slope of the input. If the slope increases, Vout increases. If the slope decreases, Vout decreases. The output voltage is proportional to the slope (rate of change) of the input. The constant of proportionality is the time constant, RfC.



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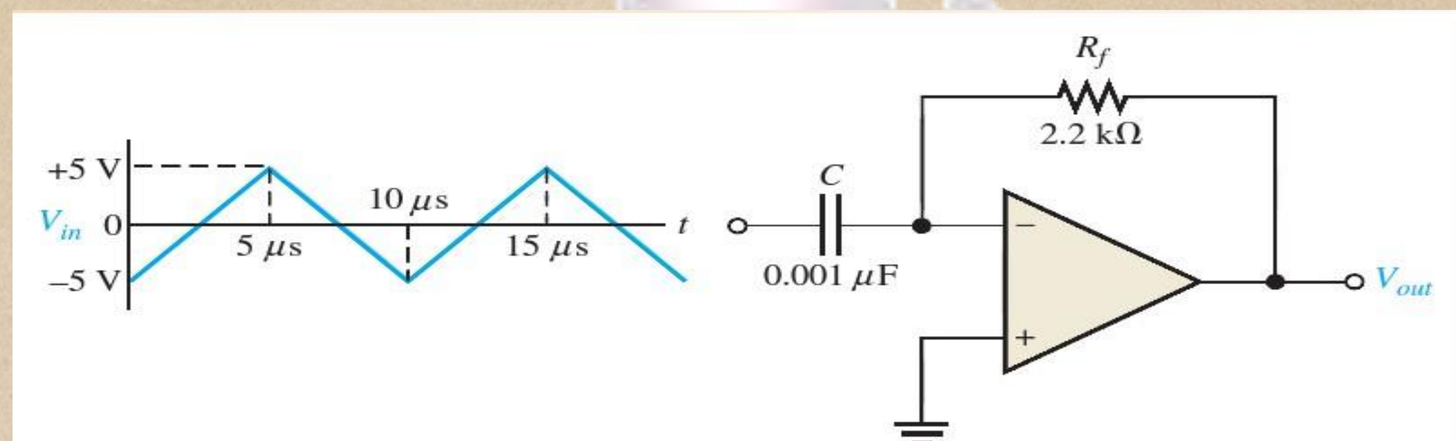
Example

Determine the output voltage of the ideal opamp differentiator in Figure for the triangular wave input shown.



Starting at $t = 0$, the input voltage is a positive-going ramp ranging from -5 V to $+5$ V (a $+10$ V change) in 5 μs. Then it changes to a negative-going ramp ranging from $+5$ V to -5 V (a -10 V change) in 5 μs.

The time constant is

$$R_f C = (2.2\,\text{k}\Omega)(0.001\,\mu\text{F}) = 2.2\,\mu\text{s}$$

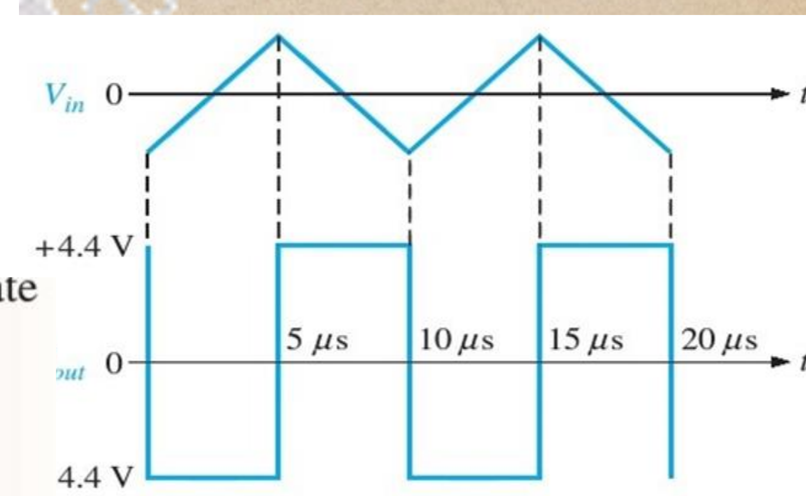
Determine the slope or rate of change (V_C/t) of the positive-going ramp and calculate the output voltage as follows:

$$\frac{V_C}{t} = \frac{10\text{ V}}{5\,\mu\text{s}} = 2\text{ V}/\mu\text{s}$$

$$V_{out} = -\left(\frac{V_C}{t}\right)R_f C = -(2\text{ V}/\mu\text{s})2.2\,\mu\text{s} = \mathbf{-4.4\text{ V}}$$

Likewise, the slope of the negative-going ramp is -2 V/μs, and the output voltage is

$$V_{out} = -(-2\text{ V}/\mu\text{s})2.2\,\mu\text{s} = \mathbf{+4.4\text{ V}}$$



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