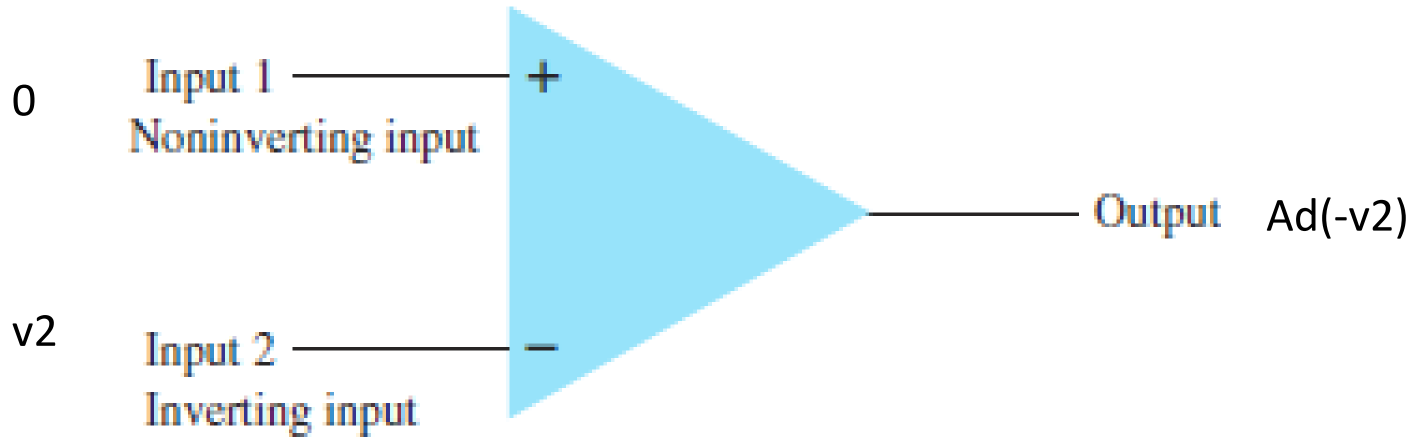
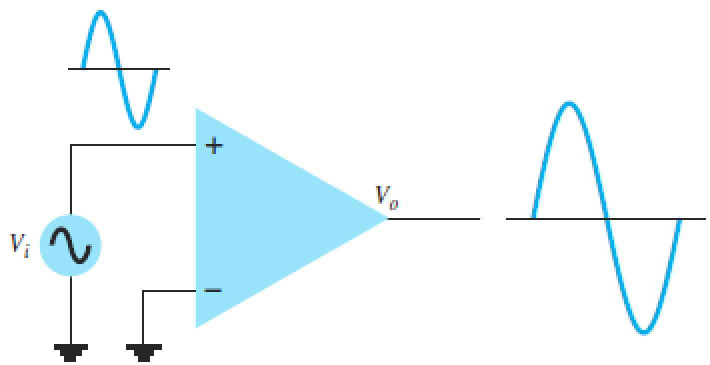
Operational Amplifiers
Op-Amp

CM



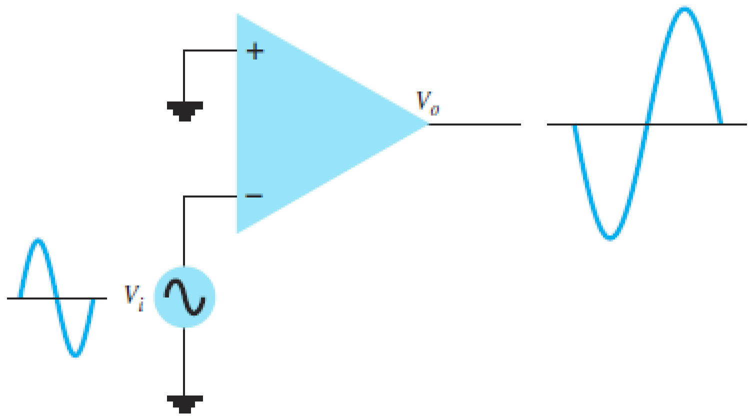


$Ad=10^6$

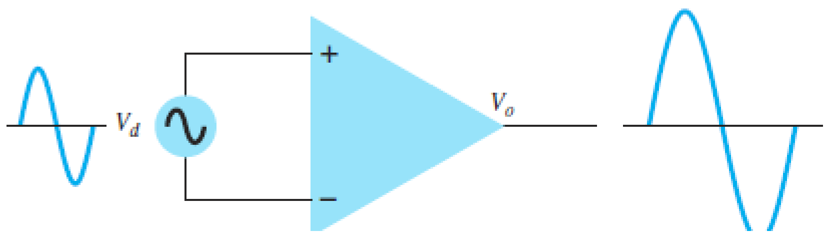
$Vi=1V$

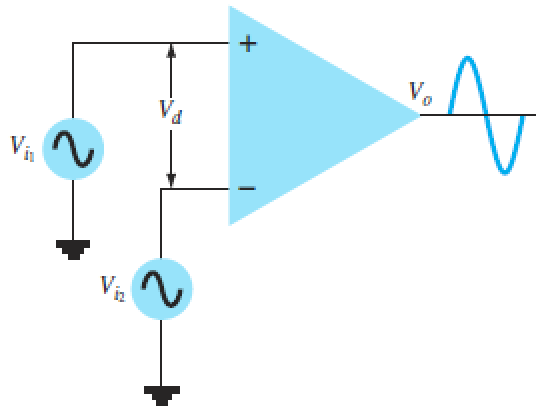
$V0max=\pm VCC=\pm Vsat=15V$

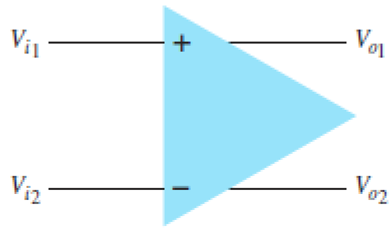
$Vmmax = 15\mu V$

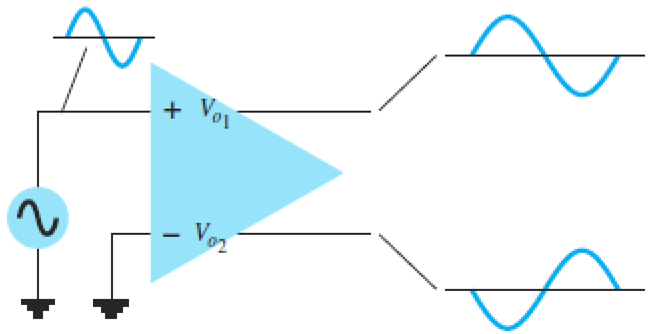


Double-ended (differential) operation

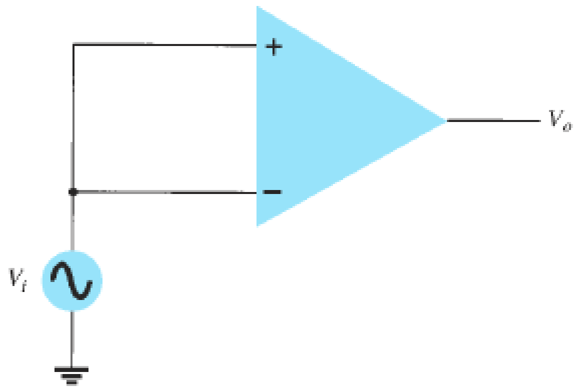




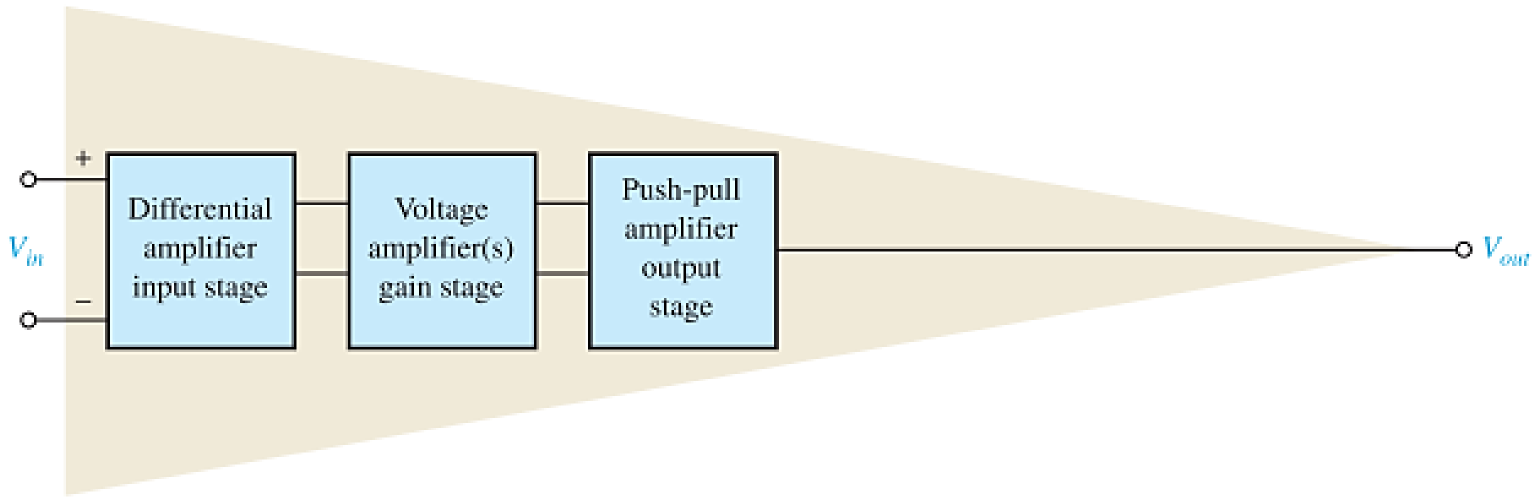

V_{i_1}
+
V_{o_1}
V_{i_2}
−
V_{o_2}


+
V_{o_1}
−
V_{o_2}

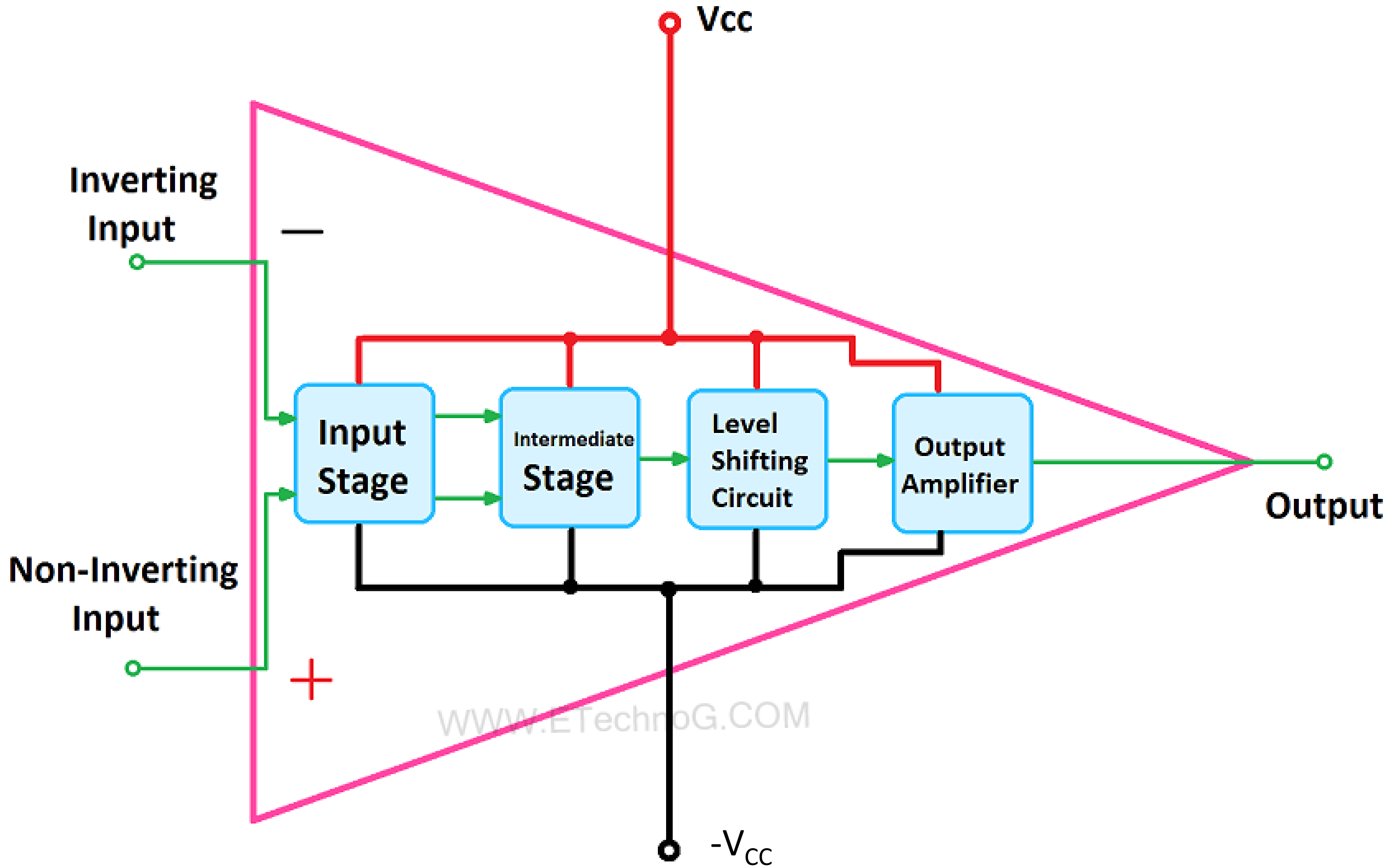
Common-Mode Operation



Common Mode Rejection Ratio (CMRR)=Ad/Ac= ∞

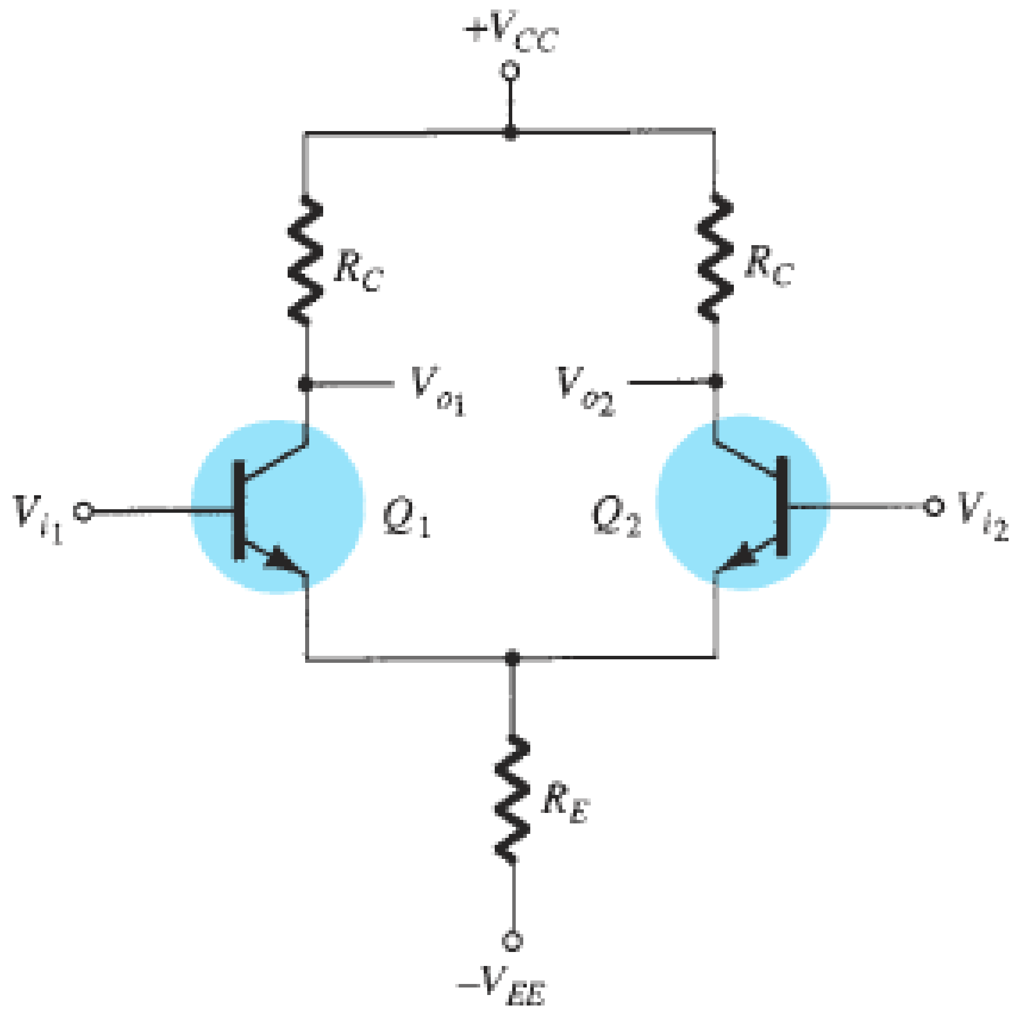


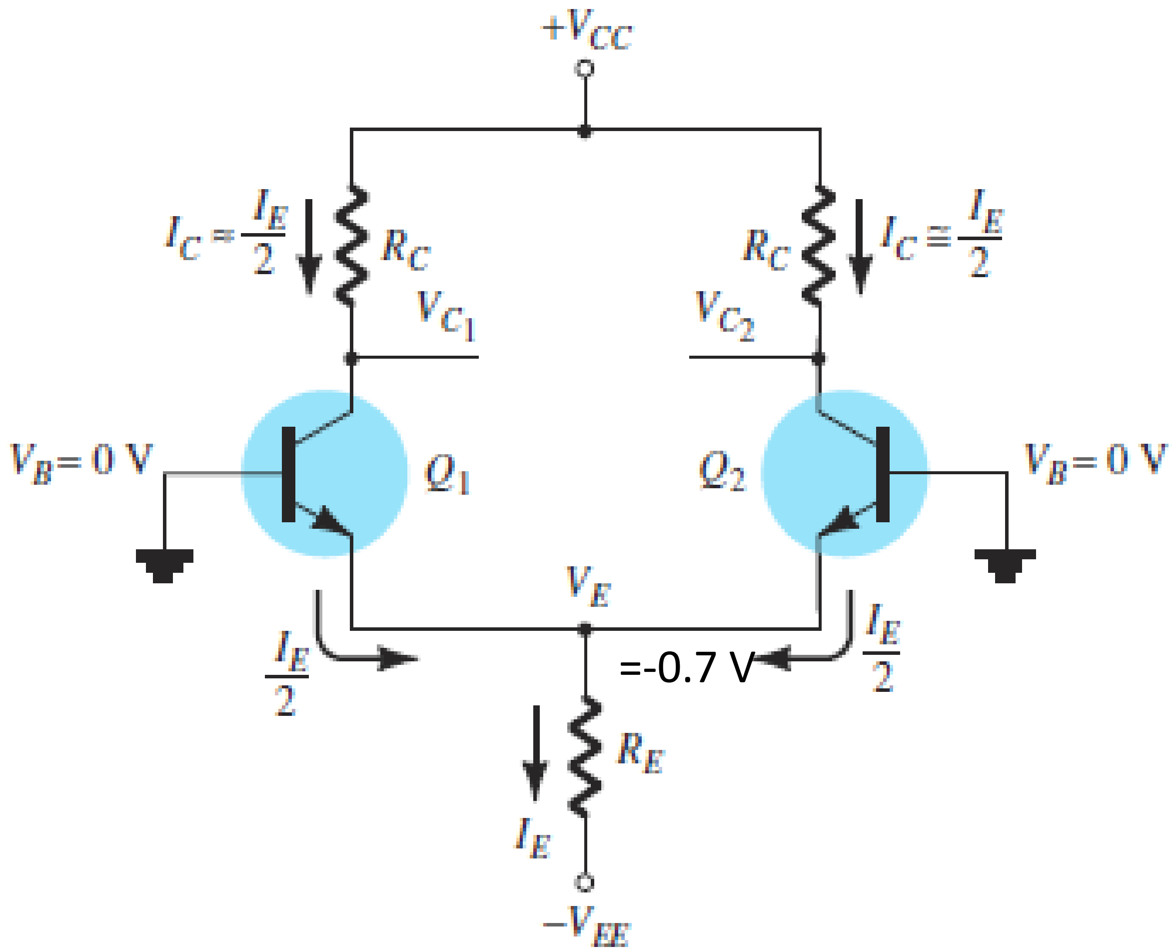
+
−
V_{in}
Differential amplifier input stage
Voltage amplifier(s) gain stage
Push-pull amplifier output stage
V_{out}



Operational Amplifier or Op Amp Block Diagram

DIFFERENTIAL AMPLIFIER CIRCUIT

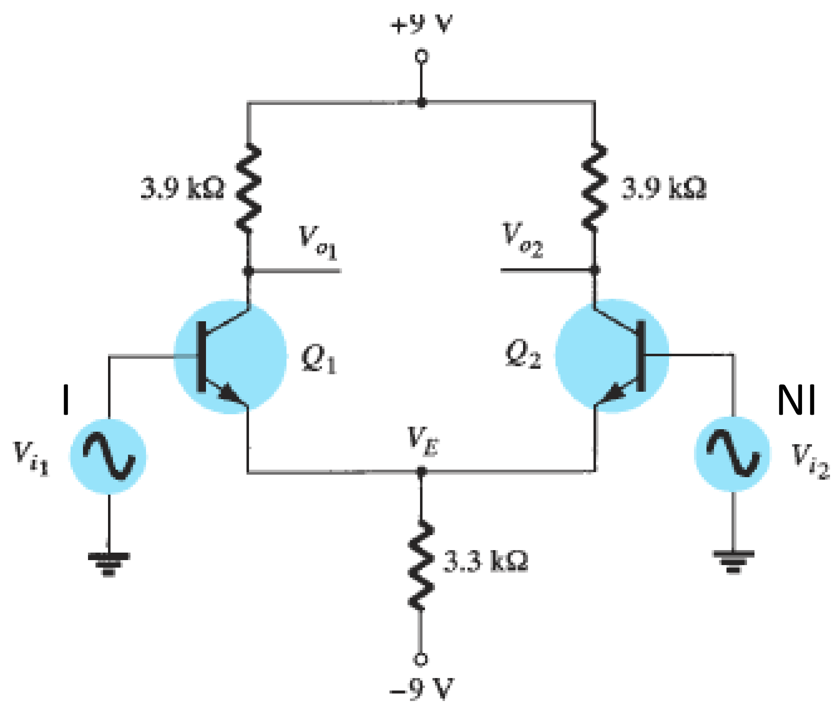




$$I_E = \frac{V_E - (-V_{EE})}{R_E} \approx \frac{V_{EE} - 0.7\text{ V}}{R_E}$$

$$V_{C_1} = V_{C_2} = V_{CC} - I_C R_C = V_{CC} - \frac{I_E}{2} R_C$$

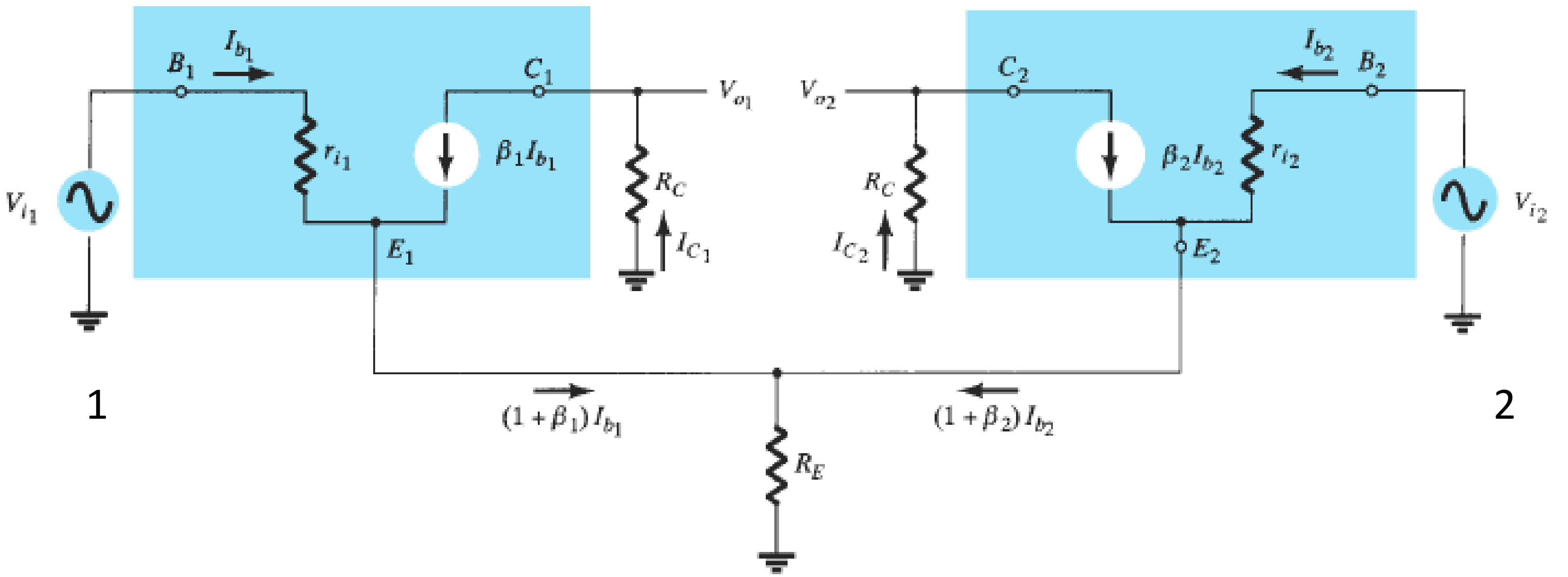
(VCC-IE/2 RC , IE/2)



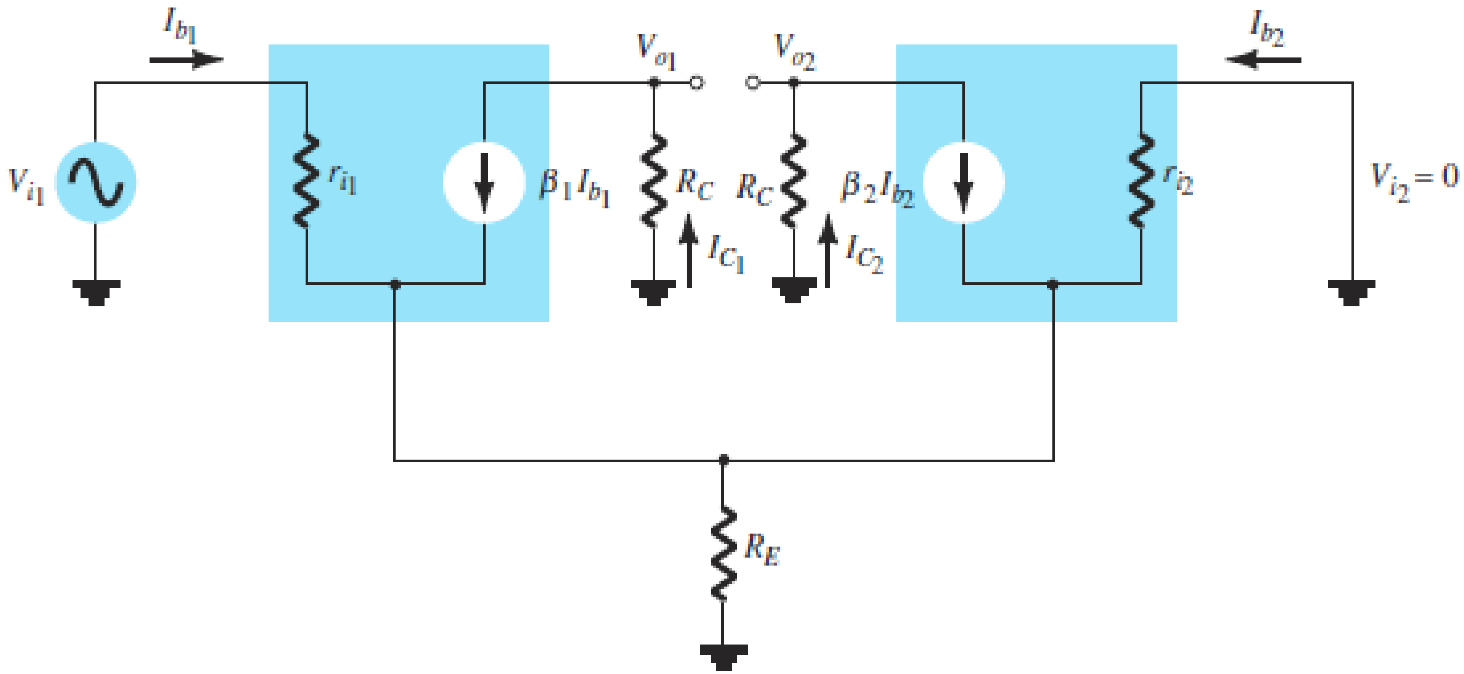
$$I_E = \frac{V_{EE} - 0.7\text{ V}}{R_E} = \frac{9\text{ V} - 0.7\text{ V}}{3.3\text{ k}\Omega} \approx \mathbf{2.5\text{ mA}}$$

$$I_C = \frac{I_E}{2} = \frac{2.5\text{ mA}}{2} = \mathbf{1.25\text{ mA}}$$

$$V_C = V_{CC} - I_C R_C = 9\text{ V} - (1.25\text{ mA})(3.9\text{ k}\Omega) \approx \mathbf{4.1\text{ V}}$$



B_1
I_{b_1}
r_{i_1}
C_1
$\beta_1 I_{b_1}$
V_{o_1}
R_C
I_{C_1}
V_{i_1}
E_1
V_{o_2}
C_2
I_{b_2}
B_2
R_C
I_{C_2}
$\beta_2 I_{b_2}$
r_{i_2}
V_{i_2}
E_2
1
2
$(1+\beta_1)I_{b_1}$
$(1+\beta_2)I_{b_2}$
R_E



$$I_{b_1} = -I_{b_2} = I_b$$

$$r_{i_1} = r_{i_2} = r_i = \beta r_e$$

$$V_{i_1} - I_b r_i - I_b r_i = 0$$

$$I_b = \frac{V_{i_1}}{2r_i} = \frac{V_i}{2\beta r_e}$$

$$I_C = \beta I_b = \beta \frac{V_i}{2\beta r_e} = \frac{V_i}{2r_e}$$

r_e=Vt/IE

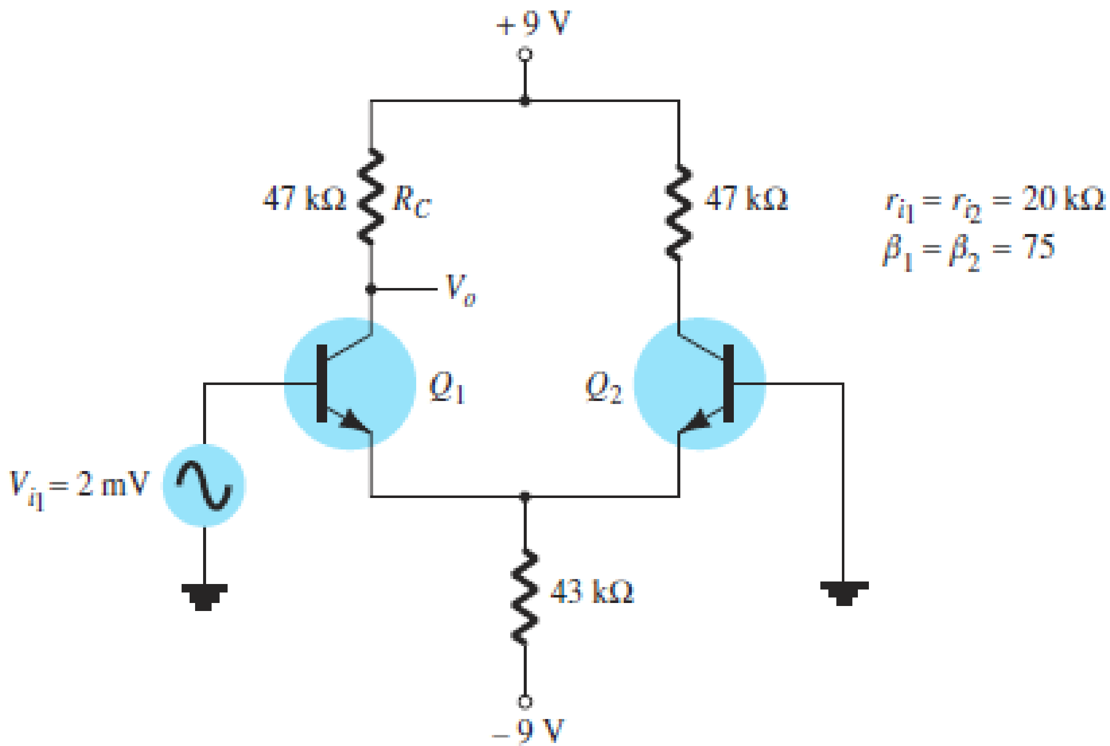
$$Vo = -\frac{V_i}{2r_e} R_C = \frac{R_C}{2r_e} V_i$$

Av=-Rc/2re
Av=-Rc/2re

Vo1=-Rc/2re vi1+Rc/2re vi2

Vo2=Rc/2re vi1-Rc/2re vi2

vi=vi1-vi2
Vo=vo1-vo2= -Rc/re (vi1-vi2)
=-Rc/re vd



Av=-47/2*0.267

= -88

Vo= -176 mV

IE= 8.3/43 mA

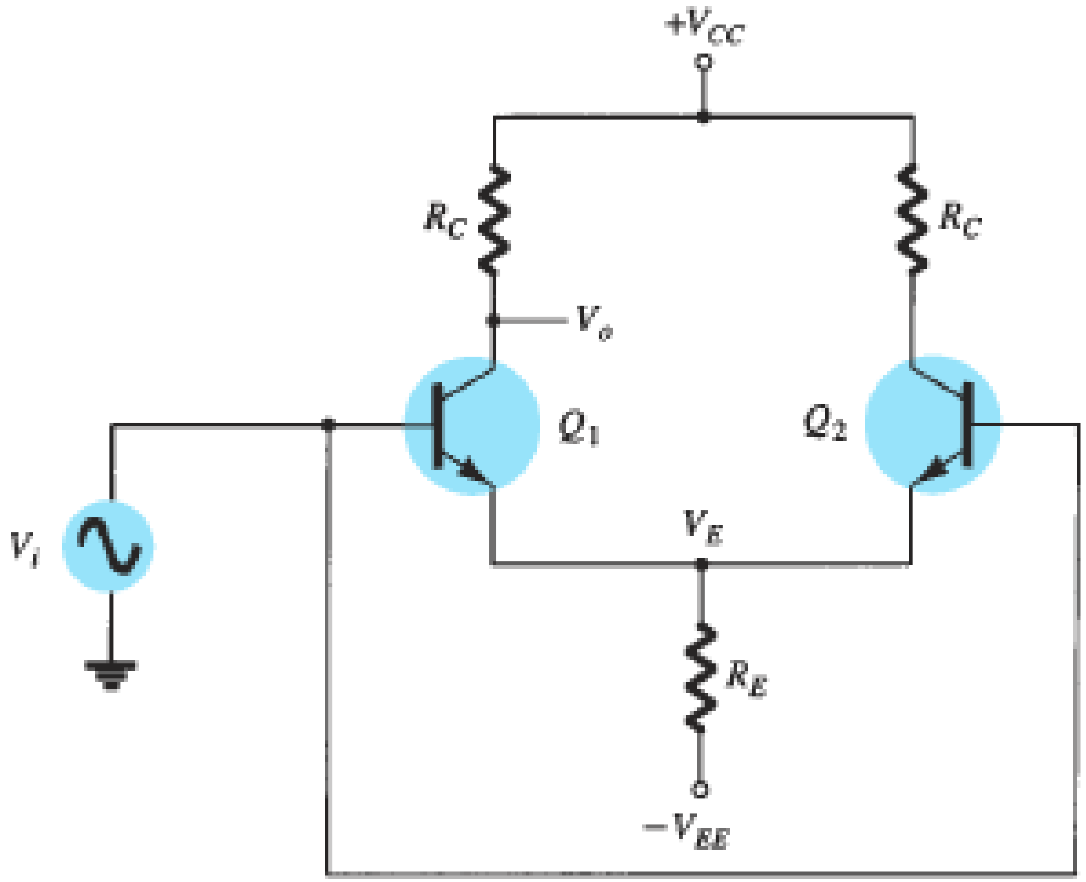
re =25*43*2/8.3 Ω=269 Ω

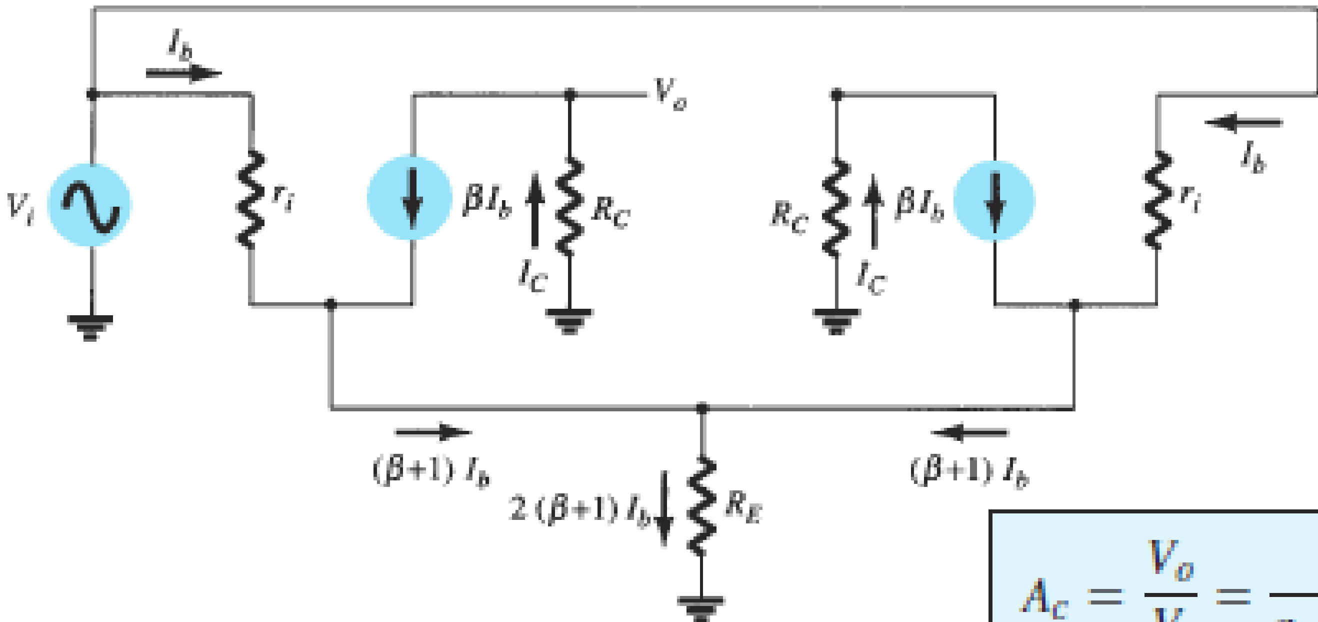
Re= 20/75 kΩ=267 Ω

sayak mandal
2:22 PM
001910701014
Tandeep Singh
2:22 PM
001910701002
Abhishek Sarkar
2:22 PM
Abhishek Sarkar 001910701027
Sandip Dutta
2:22 PM
Sandip Dutta - 0019 1070 1017
Sagnik Banerjee
2:22 PM
001910701015
Snehasish Roy
2:22 PM
Snehasish Roy 001910701013
sagar sarkar
2:22 PM
0019107010141
Roudrini Mukherjee
2:22 PM
001910701053- Roudrini Mukherjee
ajoy dey

The properties associated with an ideal Amplifier are:

1. infinite voltage gain ($A_v \to \infty$)
2. Infinite input impedance ($Z_{in} \to \infty$)
3. Zero output impedance($Z_{out} \to 0$)
4. Output voltage $V_{out} = 0$ when input voltages $V_1 = V_2$
5. Infinite bandwidth (no delay of the signal through the amplifier)


+V_CC
R_C
R_C
V_o
Q_1
Q_2
V_i
V_E
R_E
−V_EE



$$A_c = \frac{V_o}{V_i} = \frac{-\beta R_C}{r_i + 2(\beta + 1)R_E}$$

$$I_b = \frac{V_i}{r_i + 2(\beta + 1)R_E}$$

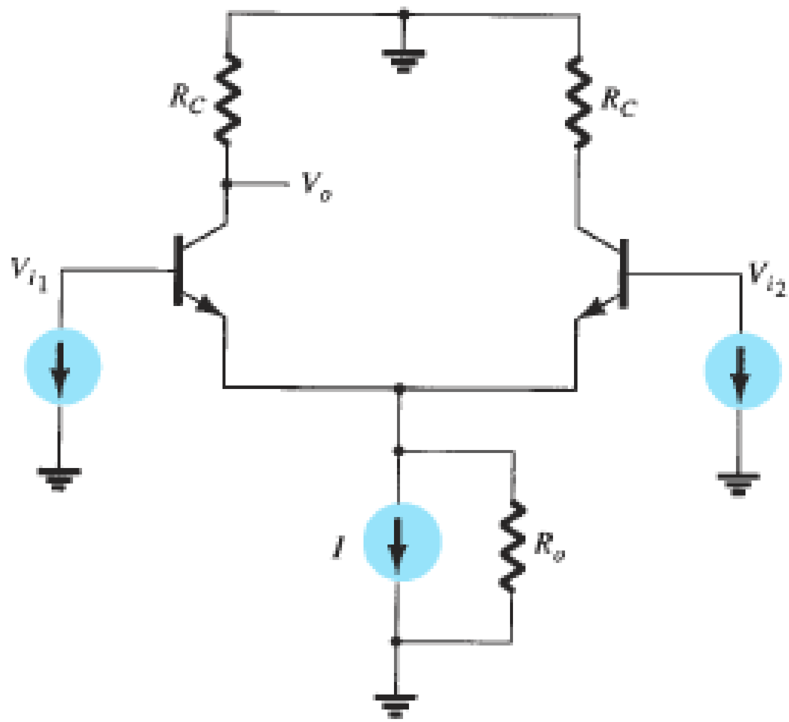
$Ac=-R_C/(re+2R_E)$

$$V_o = -I_C R_C = -\beta I_b R_C = \frac{-\beta V_i R_C}{r_i + 2(\beta + 1)R_E}$$

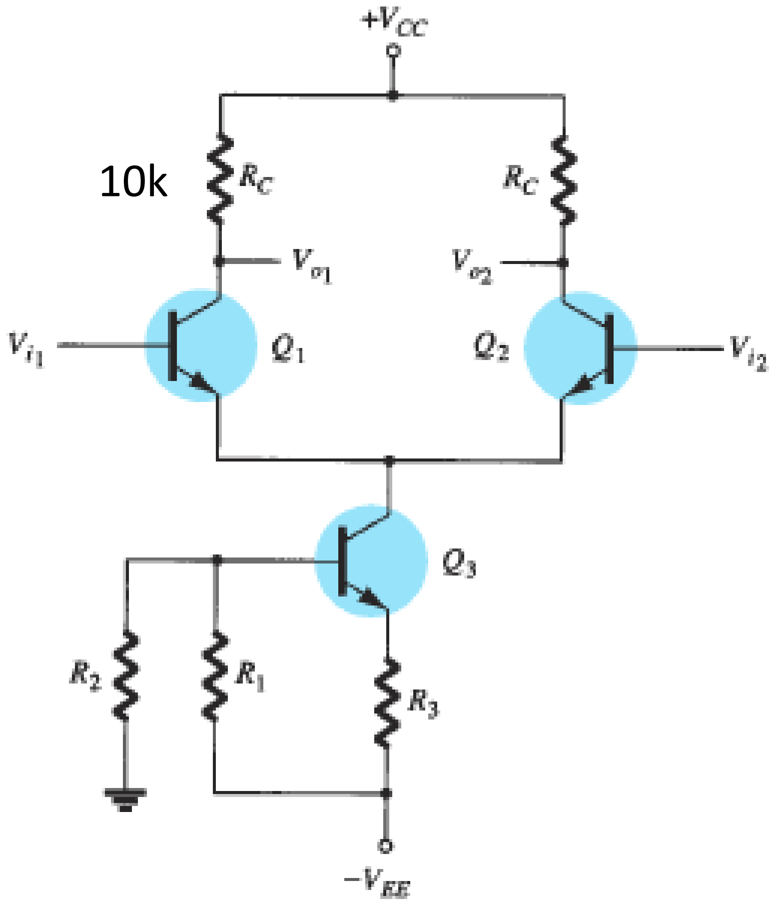
$\beta 1$ $\beta 2$
RC1 RC2

A_{CM}=?

$$A_c = \frac{V_o}{V_i} = \frac{-\beta R_C}{r_i + 2(\beta + 1)R_E} = \frac{-75(47\ \text{k}\Omega)}{20\ \text{k}\Omega + 2(76)(43\ \text{k}\Omega)} = -0.54$$



R_C
R_C
V_o
V_{i1}
V_{i2}
I
R_o



$\beta_1 = \beta_2 = \beta = 75$

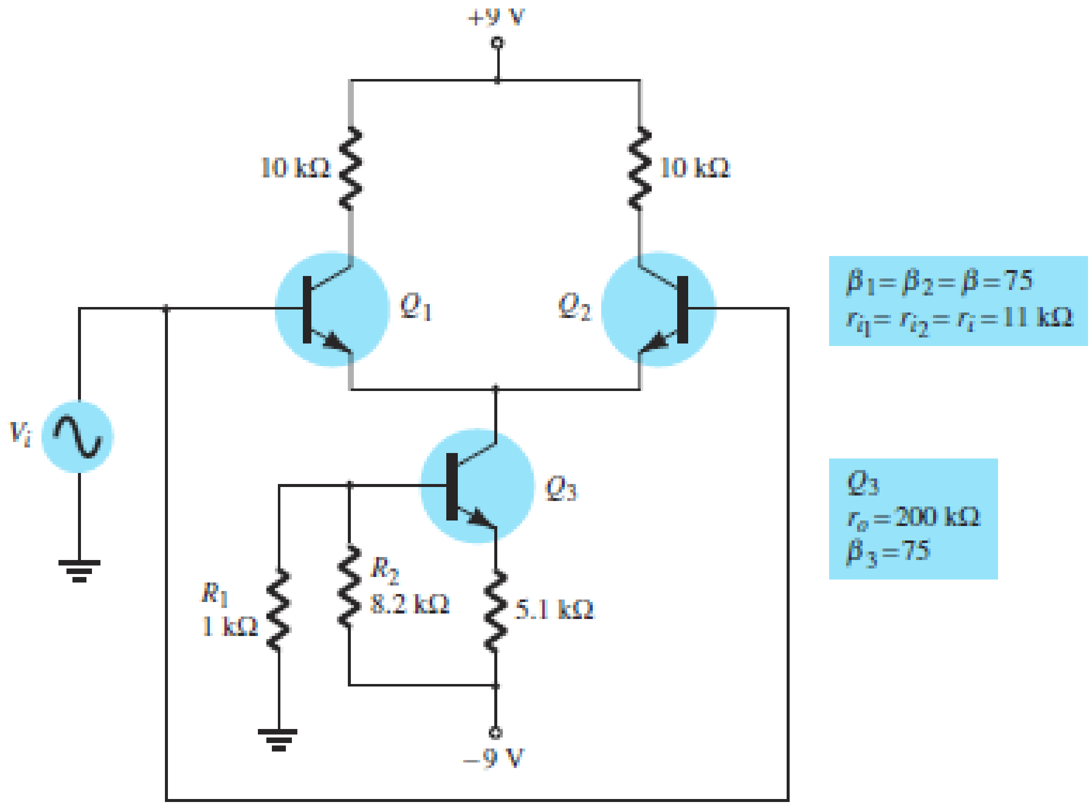
$r_{i1} = r_{i2} = r_i = 11\ \text{k}\Omega$

Q_3

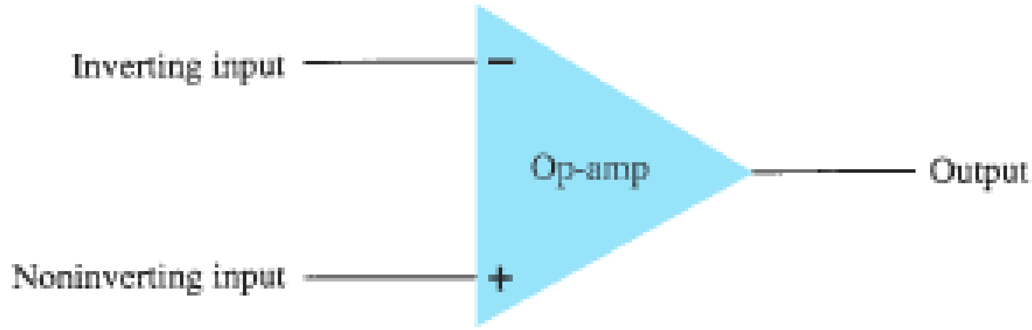
$r_o = 200\ \text{k}\Omega$

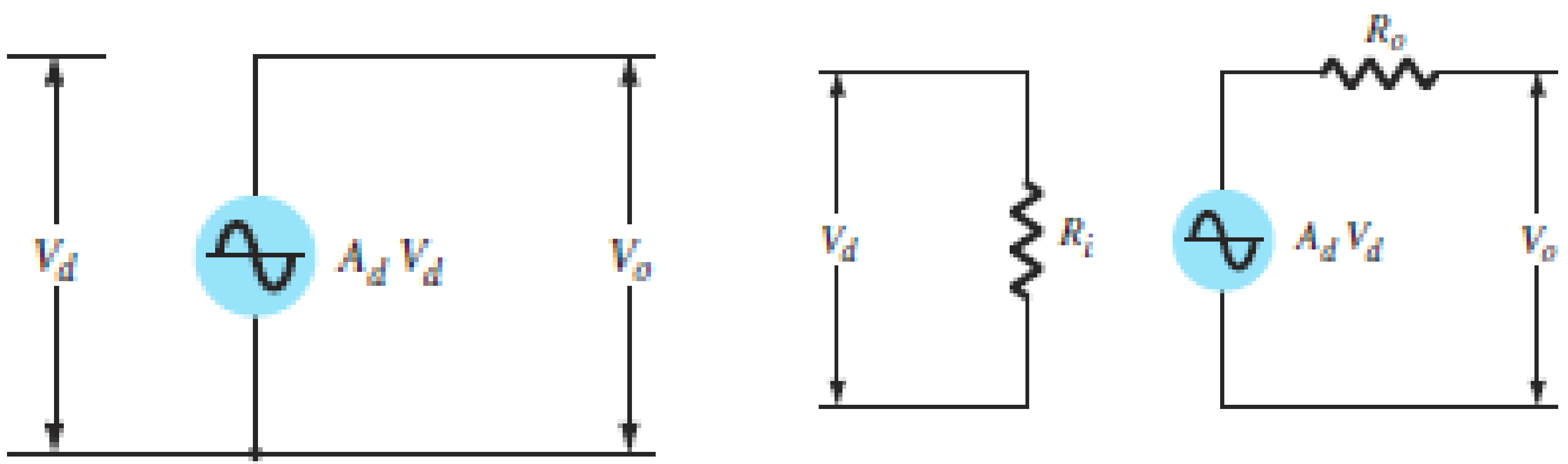
$\beta_3 = 75$

R2=1k



$$A_c = \frac{\beta R_C}{r_i + 2(\beta + 1)R_E} = \frac{75(10\ \text{k}\Omega)}{11\ \text{k}\Omega + 2(76)(200\ \text{k}\Omega)} = 24.7 \times 10^{-3}$$


Inverting input
Noninverting input
Op-amp
Output

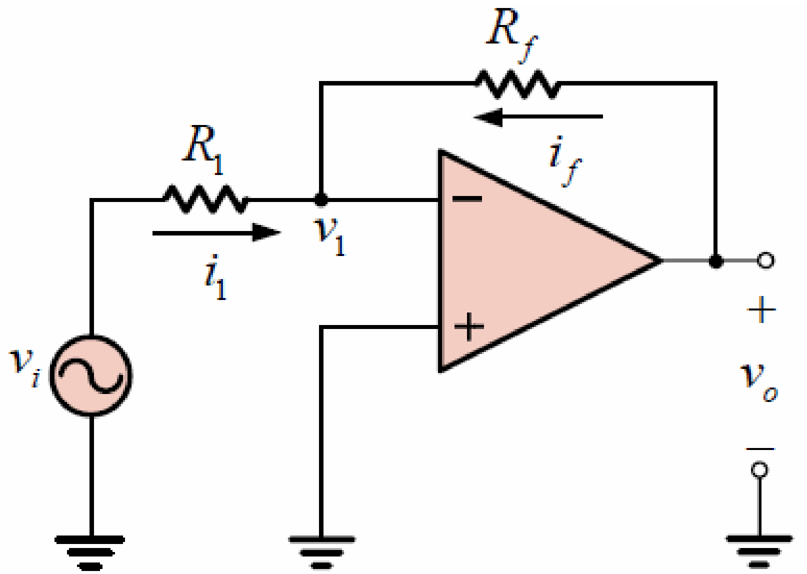

V_d
$A_d V_d$
V_o
V_d
R_i
R_o
$A_d V_d$
V_o

Closed-loop

The inverting configuration

Vo=-i1Rf

Gm vin=Iout



vd=v1

Ad=∞

Vo = -Ad(v1-v2)

(v1-v2)=-vo/Ad =0

v1=v2=0

Virtual short

Virtual ground

$$I_i = 0, R_{in} = \infty$$

$$i_1 = \frac{v_i - v_1}{R_1} = \frac{v_i - 0}{R_1} = \frac{v_i}{R_1}$$

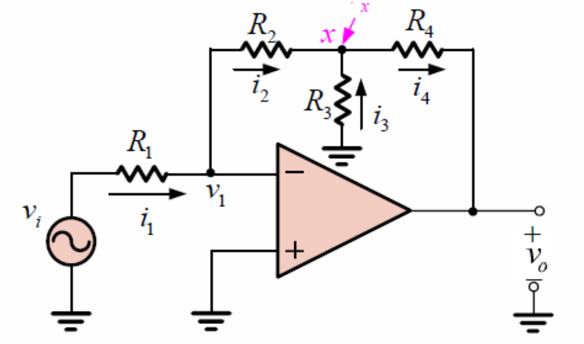
$$v_o = v_1 + i_f R_f = v_1 - i_1 R_f$$

$Av=-R_f/R_1$

$$i_1 = \frac{v_i - \left(-\frac{v_o}{A}\right)}{R_1} = \frac{v_i + \left(\frac{v_o}{A}\right)}{R_1}$$

$$v_o = -\frac{v_o}{A} - i_1 R_f$$

$$\frac{v_o}{v_i} = \frac{-R_f / R_1}{1 + (1 + R_f / R_1) / A}$$



$$v_x = v_1 - i_2 R_2 = 0 - \left(\frac{v_i R_2}{R_1} \right)$$

$$= -v_i R_2 / R_1$$

$$i_3 = \frac{0 - v_x}{R_3} = \frac{R_2}{R_1 R_3} v_i$$

$$i_4 = i_2 + i_3 = \frac{v_i}{R_1} + \frac{R_2}{R_1 R_3} v_i$$

$$v_0 = v_x - i_4 R_4$$

$$= -\frac{v_i}{R_1} R_2 - \left(\frac{v_i}{R_1} + \frac{R_2}{R_1 R_3} v_i \right) R_4$$

$$\frac{v_0}{v_i} = -\frac{R_2}{R_1} \left(1 + \frac{R_4}{R_2} + \frac{R_4}{R_3} \right)$$

$$v_x = v_1 - i_2 R_2 = 0 - \left(\frac{v_i R_2}{R_1} \right)$$

$$= -v_i R_2 / R_1$$

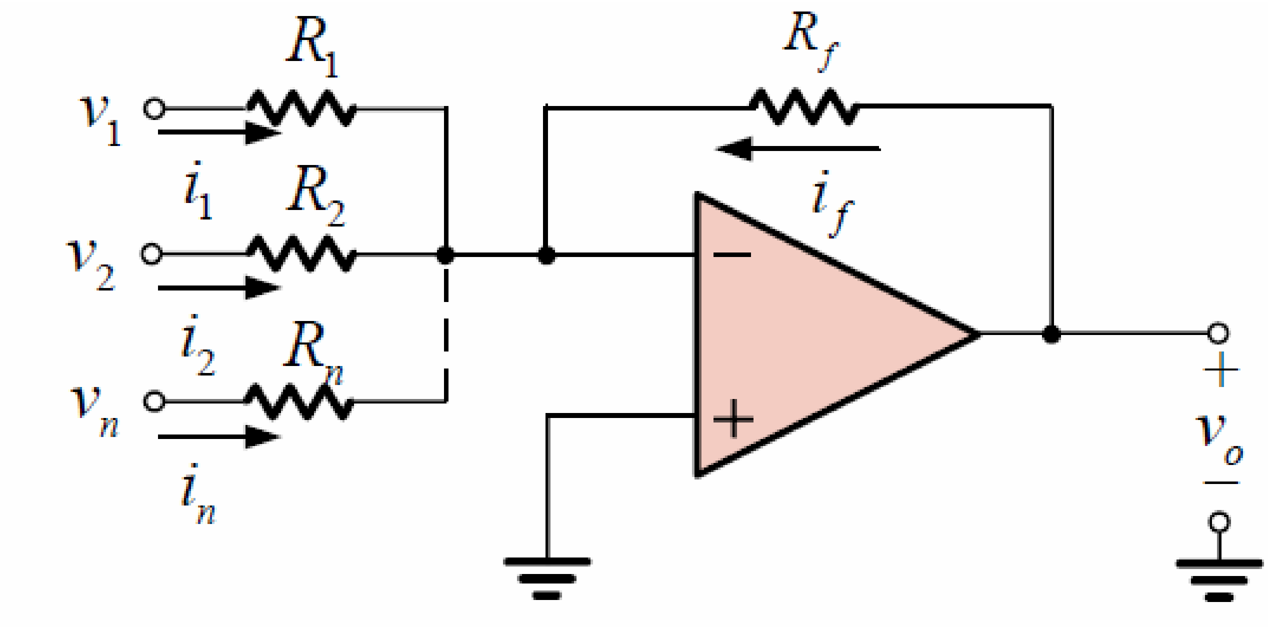
$$i_3 = \frac{0 - v_x}{R_3} = \frac{R_2}{R_1 R_3} v_i$$

$$i_4 = i_2 + i_3 = \frac{v_i}{R_1} + \frac{R_2}{R_1 R_3} v_i$$

$$v_0 = v_x - i_4 R_4$$

$$= -\frac{v_i}{R_1} R_2 - \left(\frac{v_i}{R_1} + \frac{R_2}{R_1 R_3} v_i \right) R_4$$

The Weighted Summer

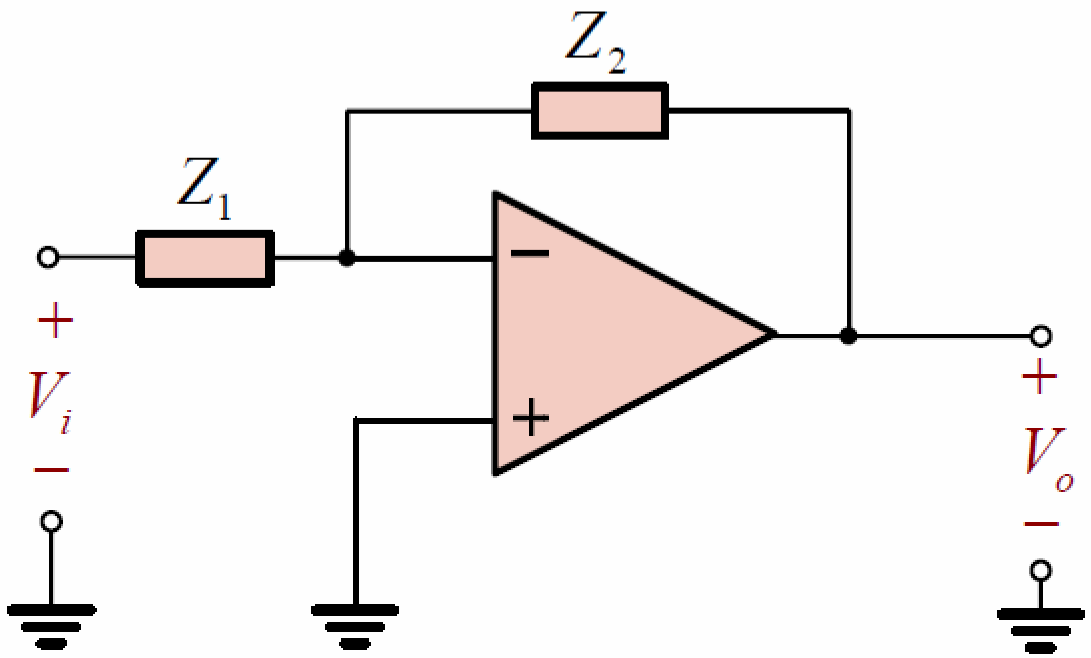


$$i_1 = \frac{v_1}{R_1}, i_2 = \frac{v_2}{R_2}, I_n = \frac{v_n}{R_n}, \quad I_f = \frac{v_o}{R_f}$$

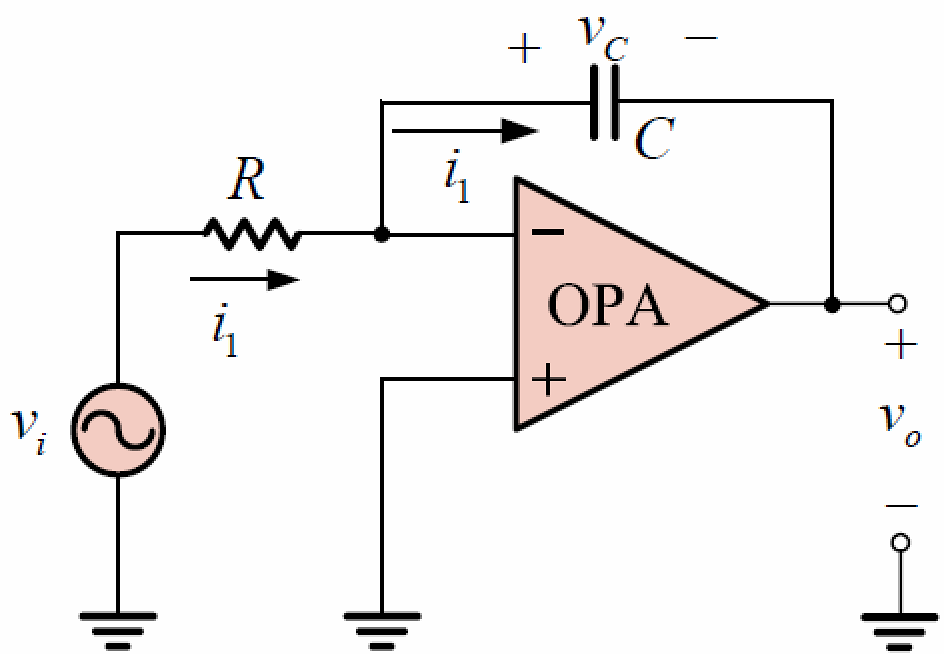
$$I_f = -(I_1 + I_2 + \cdots + I_3) \quad \Rightarrow \frac{v_o}{R_f} = -\left(\frac{v_1}{R_1} + \frac{v_2}{R_2} + \cdots + \frac{v_n}{R_n}\right)$$

$R_1 = R_2 = \cdots = R_n = R_f$ Then $v_o = -(v_1 + v_2 + \cdots + v_n)$

Integrators and Differentiators



$$\frac{V_o}{V_i} = -\frac{Z_2}{Z_1}$$



$$v_C(t) = V_C + \frac{1}{C}\int_0^t i_1(t)\ \mathrm{dt}$$

$$v_o(t) = -v_C(t) = -V_C - \frac{1}{C}\int_0^t i_1(t)\mathrm{dt} = -V_C - \frac{1}{RC}\int_0^t v_i(t)\ \mathrm{dt}$$

s=jw

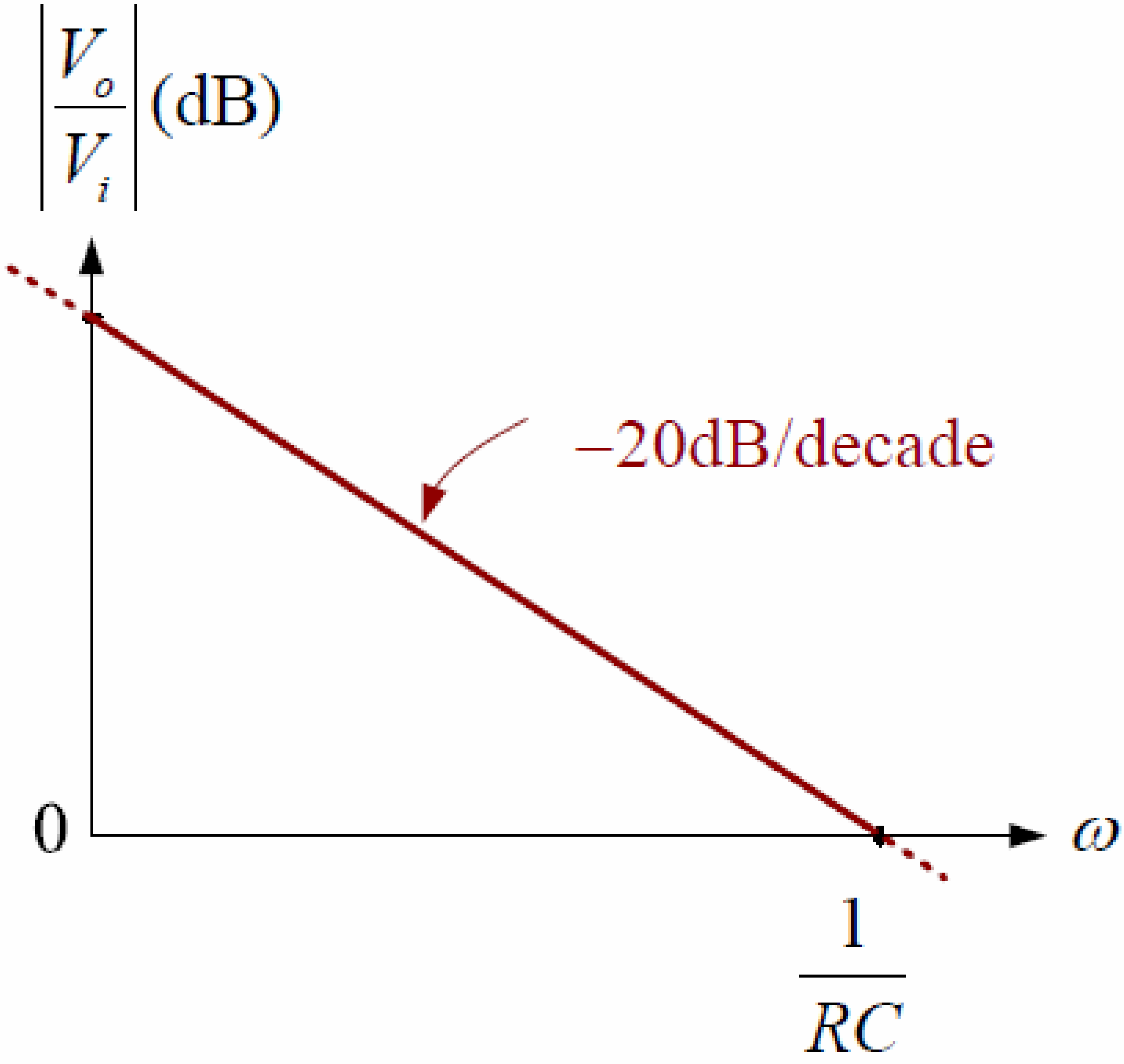
$$\frac{v_o(s)}{v_1(s)} = -\frac{1}{sRC}$$

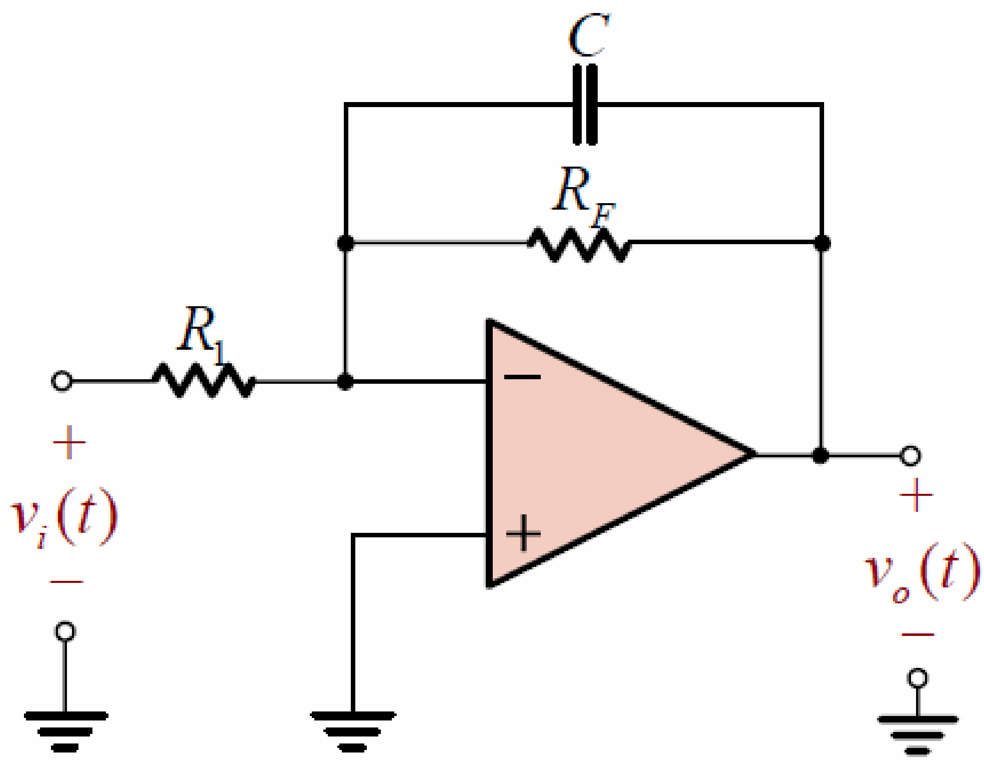
$$\Rightarrow \frac{v_o(j\omega)}{v_1(j\omega)} = -\frac{1}{j\omega RC}$$

$$\left|\frac{v_o}{v_1}\right| = \frac{1}{\omega RC} = \frac{\omega_t}{\omega}, \quad \angle v_o / v_1 = +90^o$$

The unity gain frequency ω_t as

$$\omega_t = \frac{1}{RC}$$

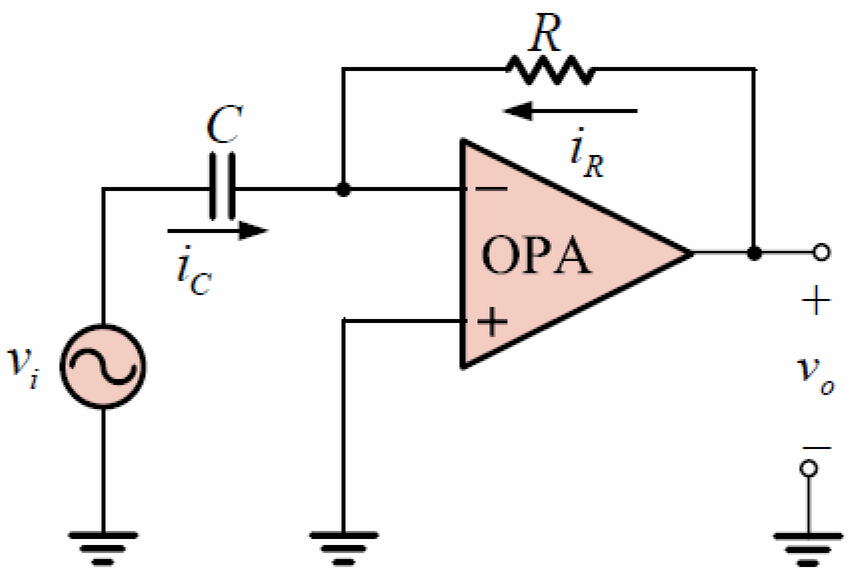

$\left|\frac{V_o}{V_i}\right|$ (dB)
–20dB/decade
0
ω
$\frac{1}{RC}$



C
R_F
R_1
−
+
+
$v_i(t)$
−
+
$v_o(t)$
−

$$\frac{v_o(s)}{v_1(s)} = -\frac{\dfrac{R_F}{1 + sR_F C}}{R} = -\frac{R_F / R}{1 + sR_F C}$$

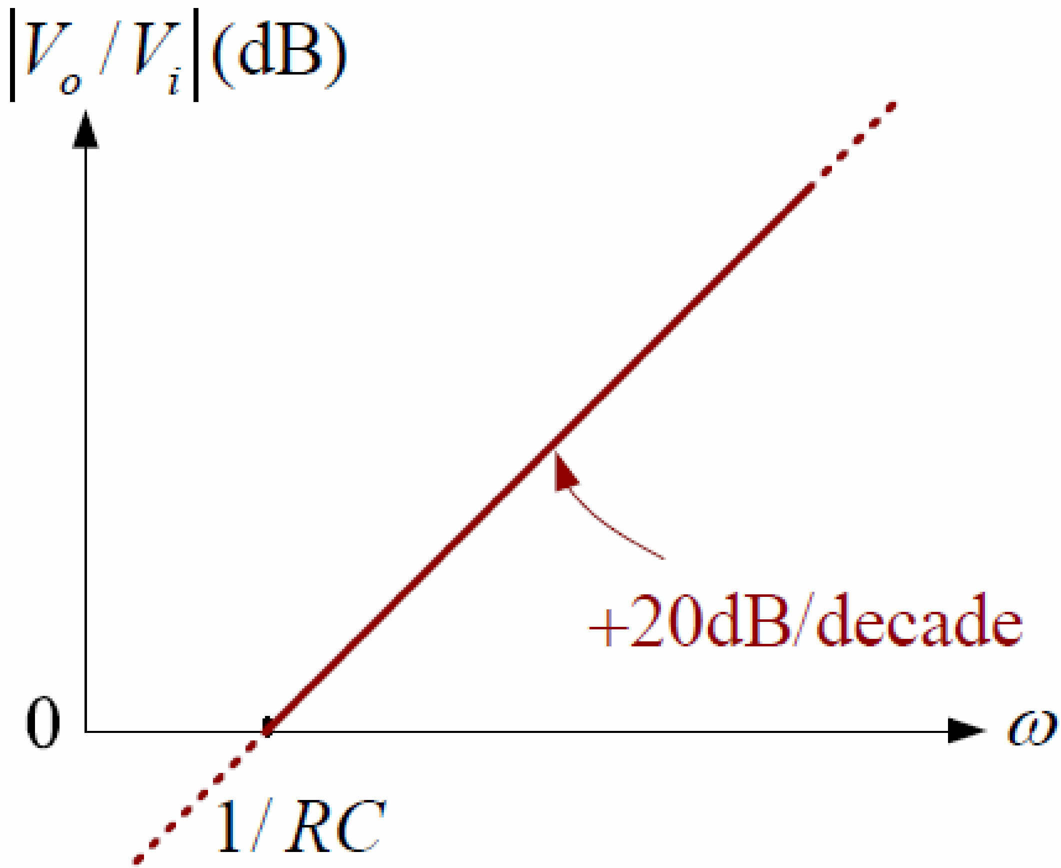
The Op-Amp Differentiator



$$Q = Cv_i, \quad i_C = \frac{dQ}{dt} \Rightarrow i_C = C\frac{dv_i}{dt}, \qquad I_R = \frac{v_o}{R}$$

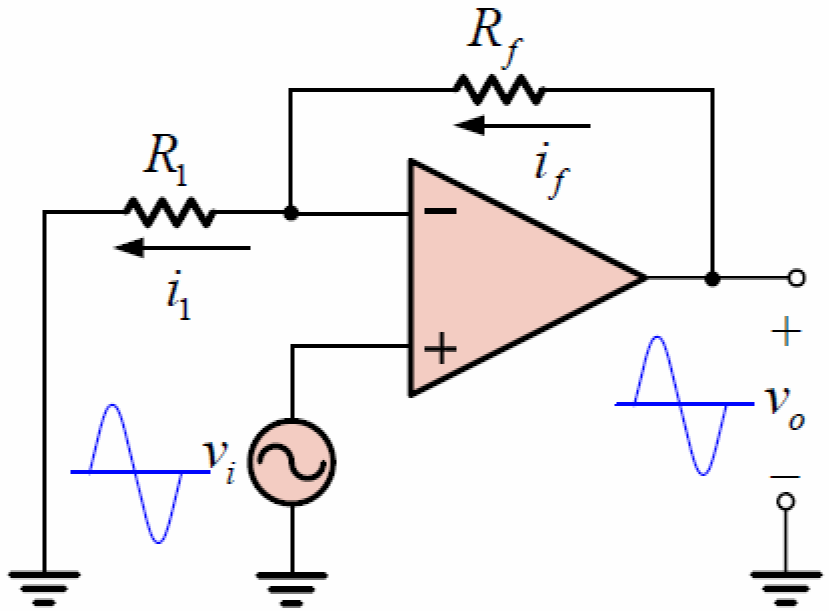
$$-i_R = i_C \Rightarrow C\frac{dv_i}{dt} = -\frac{v_o}{R} \quad \Rightarrow v_o = -RC\frac{dv_i}{dt}$$

$$\frac{v_o(s)}{v_1(s)} = -sRC \Rightarrow \frac{v_o(j\omega)}{v_1(j\omega)} = -j\omega RC$$



$$\left|\frac{v_o}{v_1}\right| = \omega RC = \frac{\omega}{\omega_t},$$

Noninverting Configuration



$$i_1 = \frac{v_i}{R_1}, \quad i_f = \frac{v_o - v_i}{R_f}$$

$$i_1 = i_f \Rightarrow \frac{v_i}{R_1} = \frac{v_o - v_i}{R_f} \qquad \Rightarrow v_o = (1 + \frac{R_f}{R_1})v_i$$

$$v_- = v_i - (v_o / A)$$

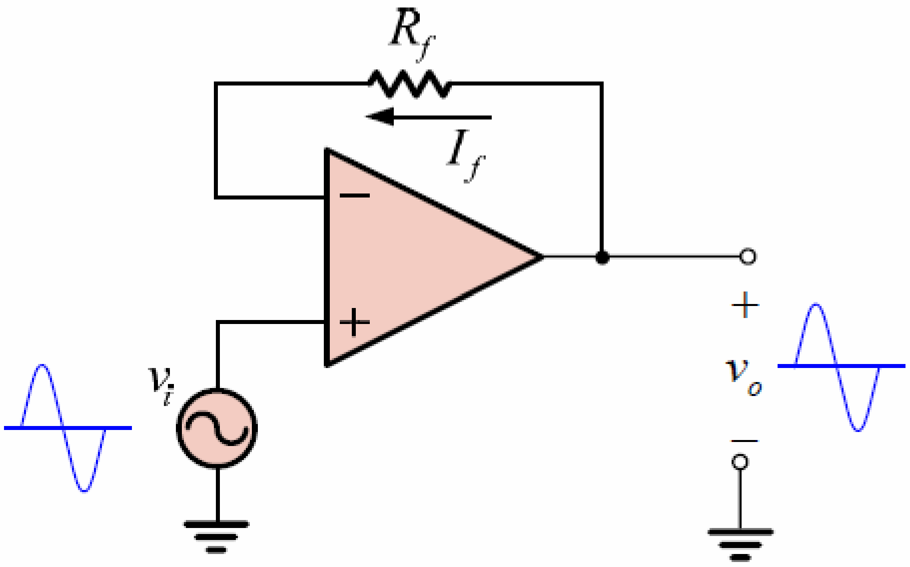
$$i_1 = \frac{v_i - (v_o / A)}{R_1}, i_f = \frac{v_o - \left[v_i - (v_o / A)\right]}{R_f} = \frac{v_o - v_i + \left(v_o / A\right)}{R_f},$$

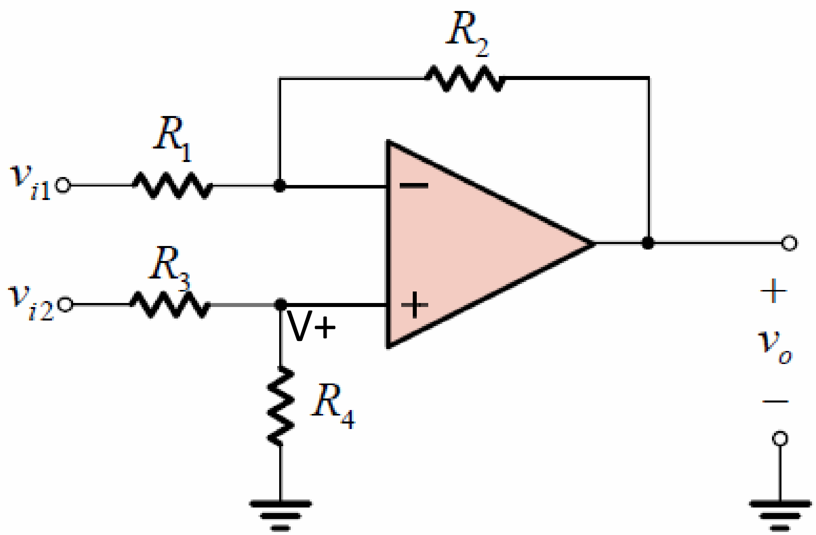
$$i_1 = i_f \Rightarrow \frac{v_i - (v_o / A)}{R_1} \bullet \bullet \frac{v_o - v_i + \left(v_o / A\right)}{R_f}$$

$$v_i A(R_1 + R_f) = v_o\left[(1 + A)R_1 + R_f\right]$$

$$\frac{v_o}{v_i} = \frac{1 + (R_f / R_1)}{1 + \frac{1 + (R_f / R_1)}{A}}$$

Voltage Follower





(1) Assume $v_{i1} = 0$,

then $v_O{}' = v_+ \left(1 + \frac{R_2}{R_1}\right)$

$$= \frac{R_4}{R_3 + R_4} v_{i2} \left(1 + \frac{R_2}{R_1}\right)$$

(2) Assume $v_{i2} = 0$,

then $v_O{}'' = v_{i1} \left(-\frac{R_2}{R_1}\right)$

$$v_o = v_O{}' + v_O{}''$$

$$= \frac{R_4}{R_3 + R_4} v_{i2} \left(1 + \frac{R_2}{R_1}\right) + v_{i1} \left(-\frac{R_2}{R_1}\right)$$

If $R_1 = R_3 = R_a, \quad R_2 = R_4 = R_b$

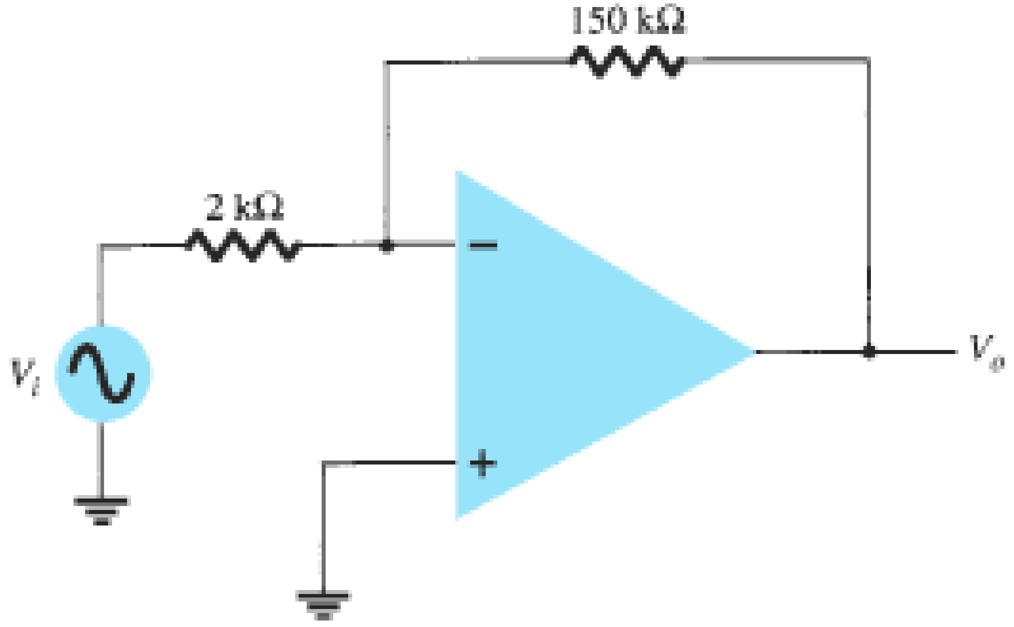
then $v_o = \frac{R_b}{R_a}(v_{i2} - v_{i1}) = \frac{R_b}{R_a} v_{id}$

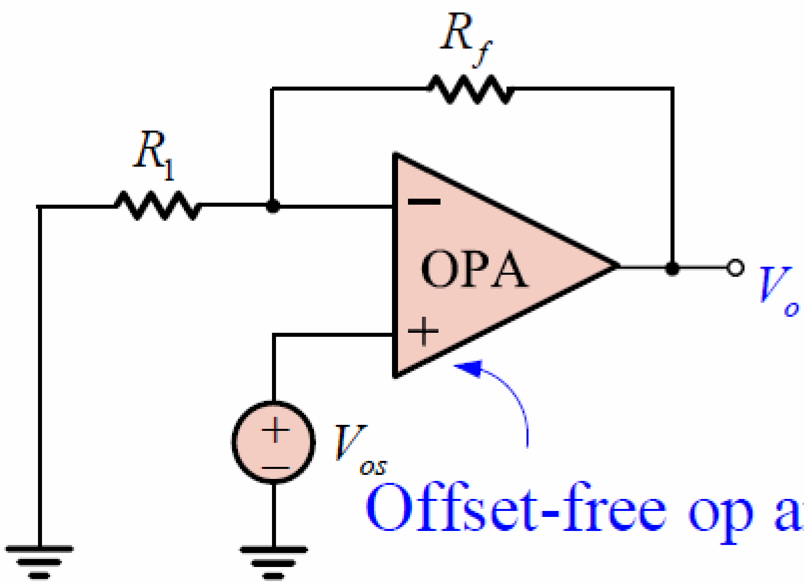
$$A_d = \frac{R_b}{R_a} \qquad (2.17)$$

001910701020
Keshav Jasrotia
2:17 PM
001910701003
Souvik Das
2:17 PM
001910701010 Souvik Das
MAINAK MONDAL
2:17 PM
001910701016
ajoy dey
2:17 PM
001910701068
Gaurav Nandy
2:17 PM
001910701074-Gaurav Nandy
Arijit Saha
2:17 PM
001910701019
Sagnik Das
2:17 PM
Sagnik Das 001910701075
Debadri Sengupta
2:18 PM
001910701045 Debadri Sengupta
Sanjoy Majee

DC Imperfections

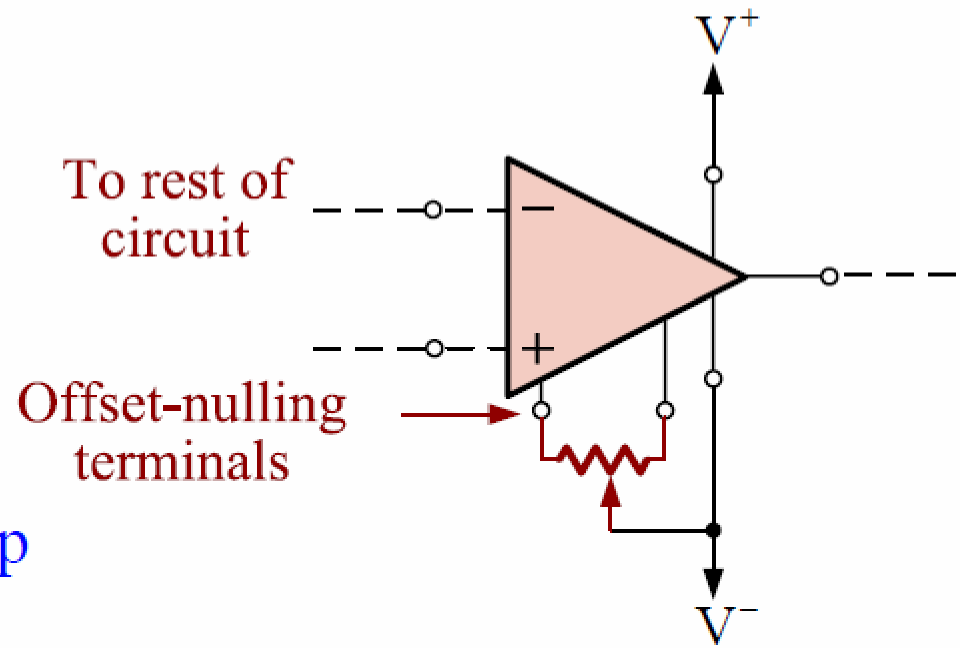
i/o Offset Voltage

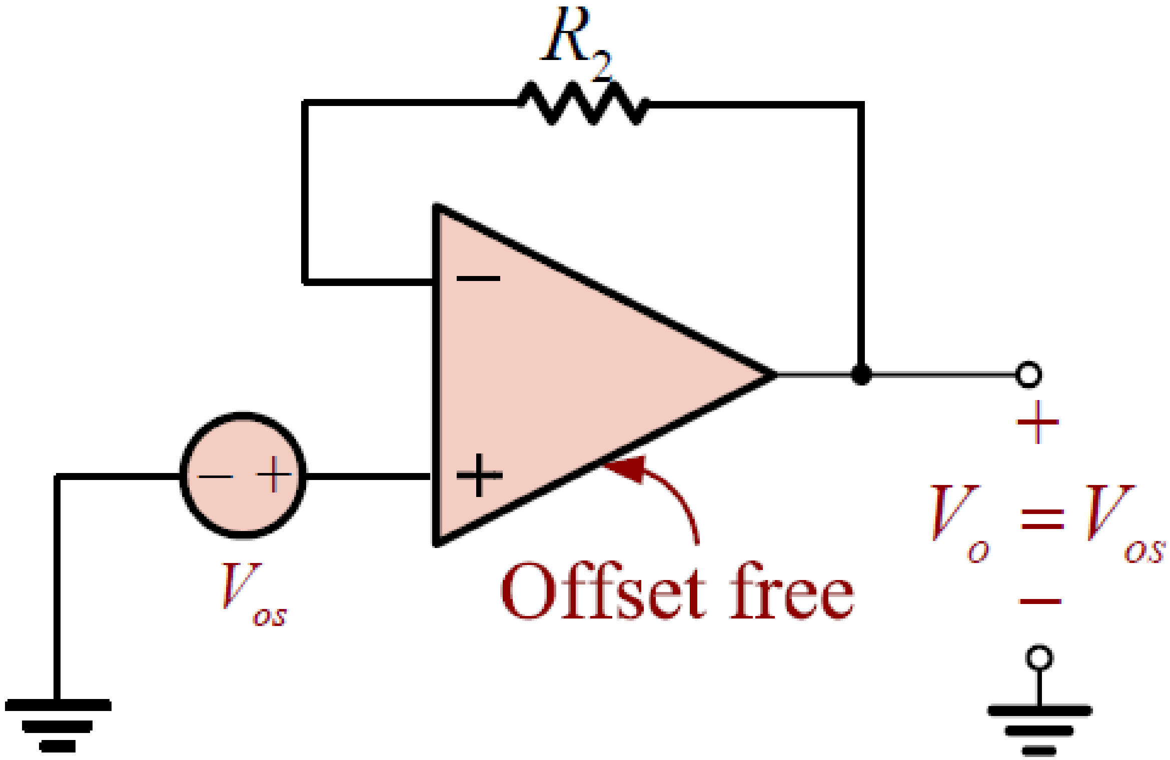




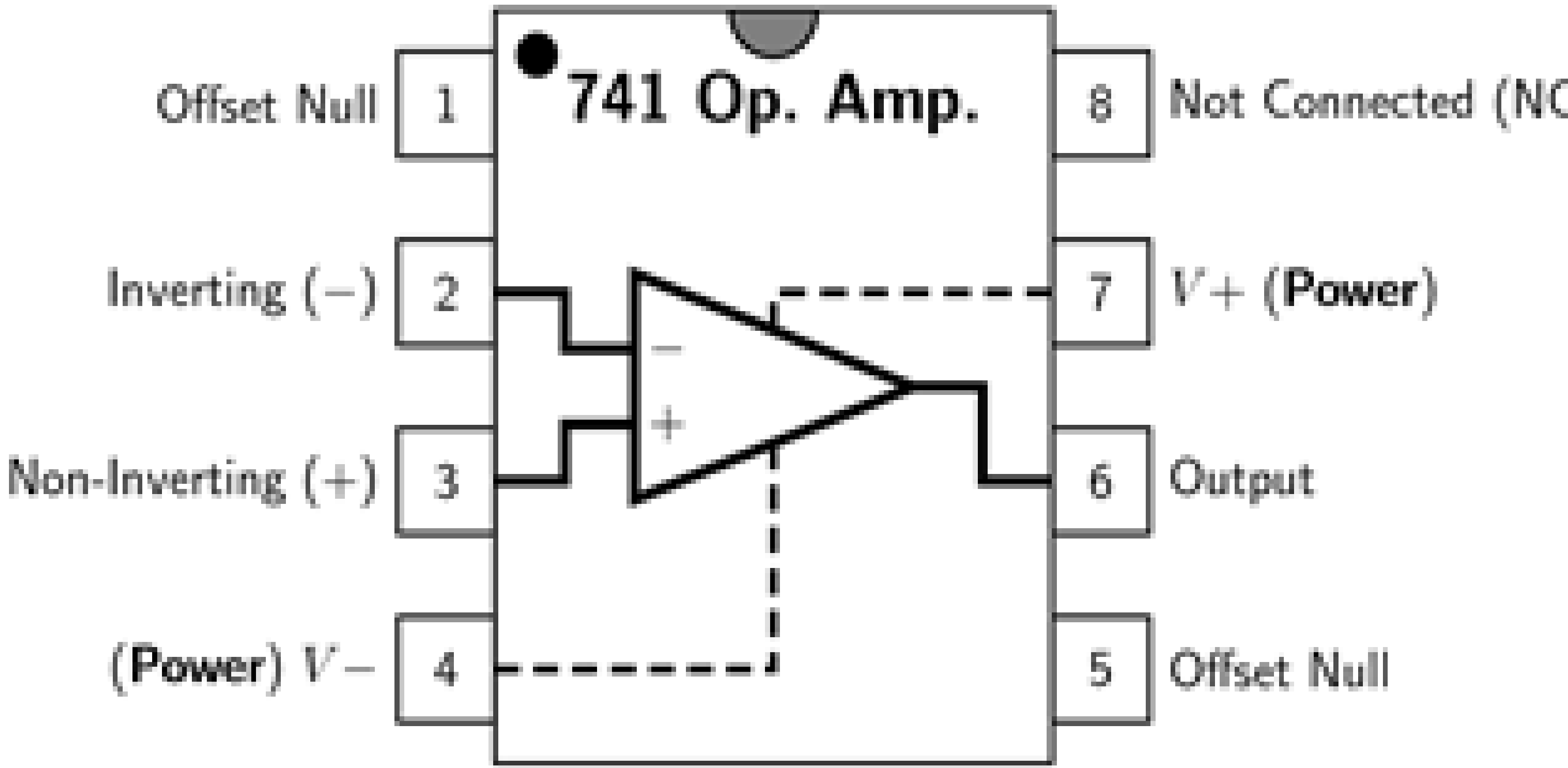
Offset-free op amp

$$V_o = V_{os}\left(1 + \frac{R_2}{R_1}\right)$$

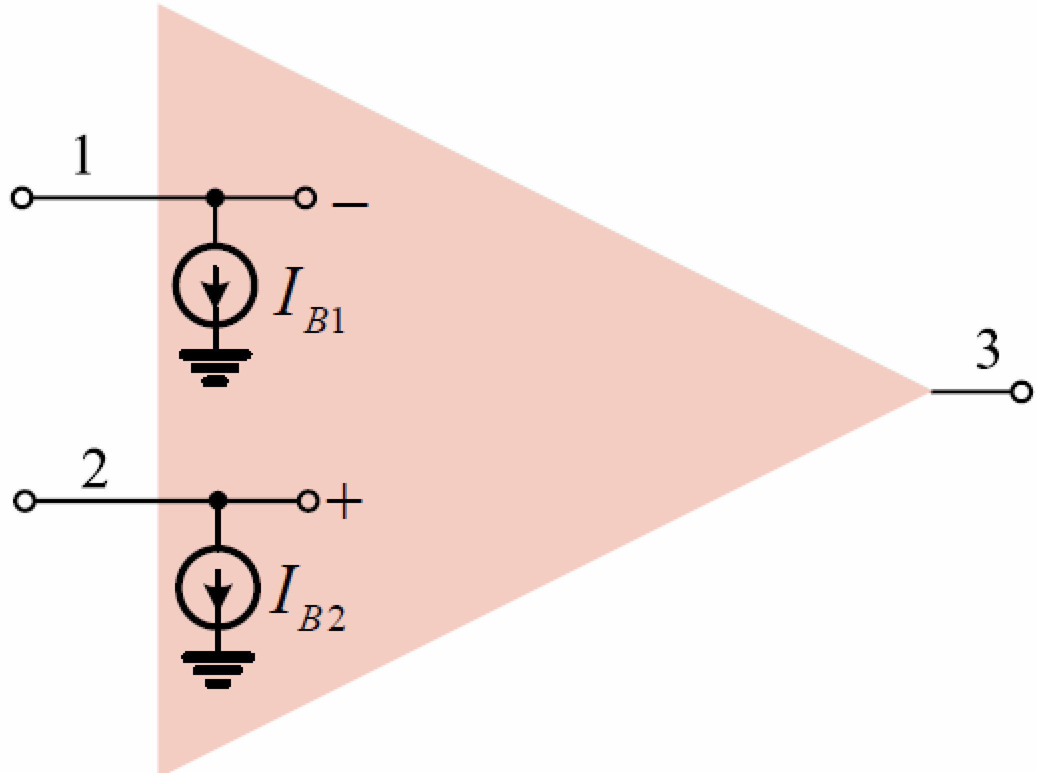




R2
Vos
Offset free
Vo = Vos

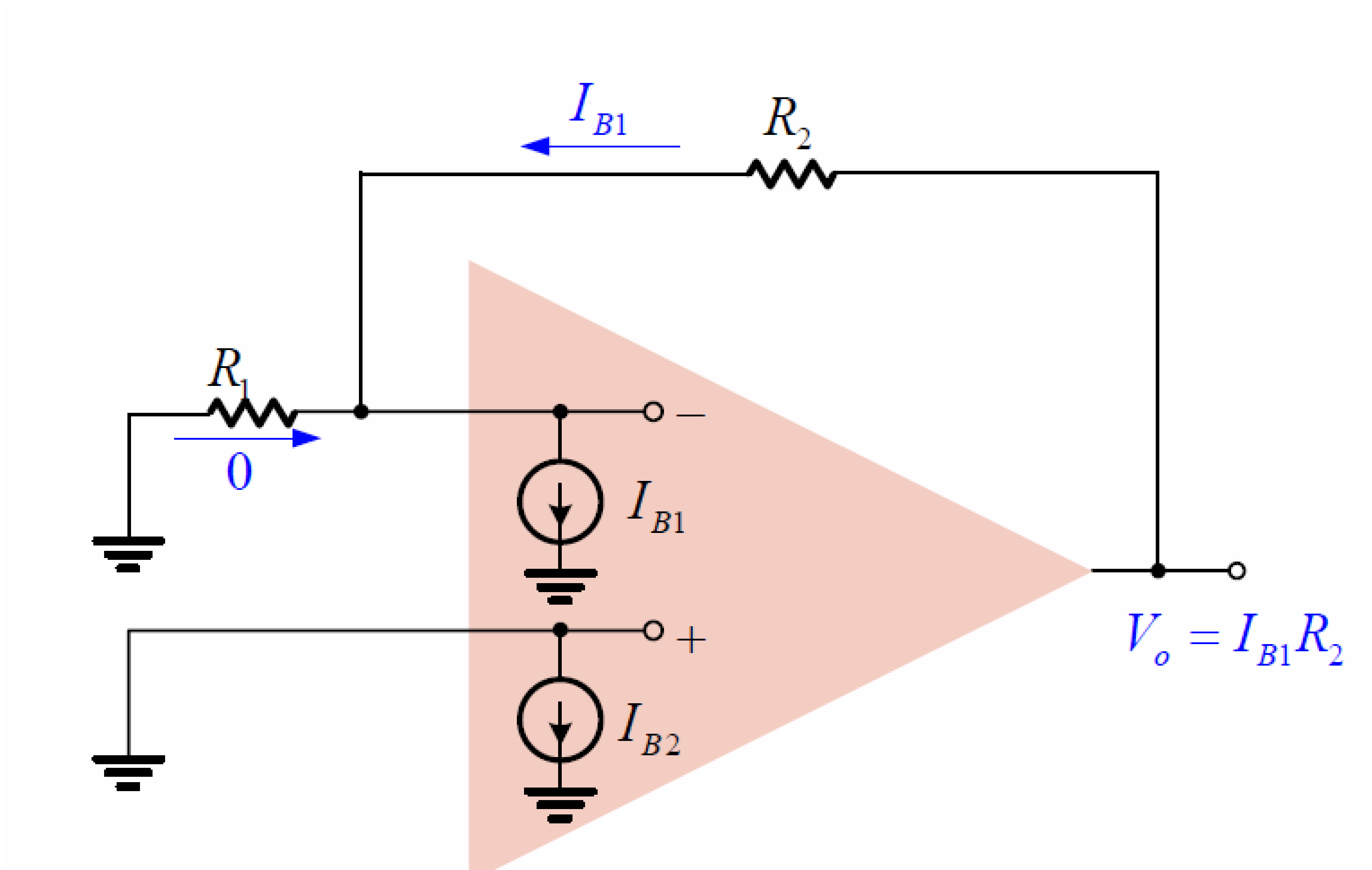

741 Op. Amp.
Offset Null
1
Inverting (−)
2
Non-Inverting (+)
3
(Power) V−
4
8
Not Connected (NC
7
V+ (Power)
6
Output
5
Offset Null

Input bias current

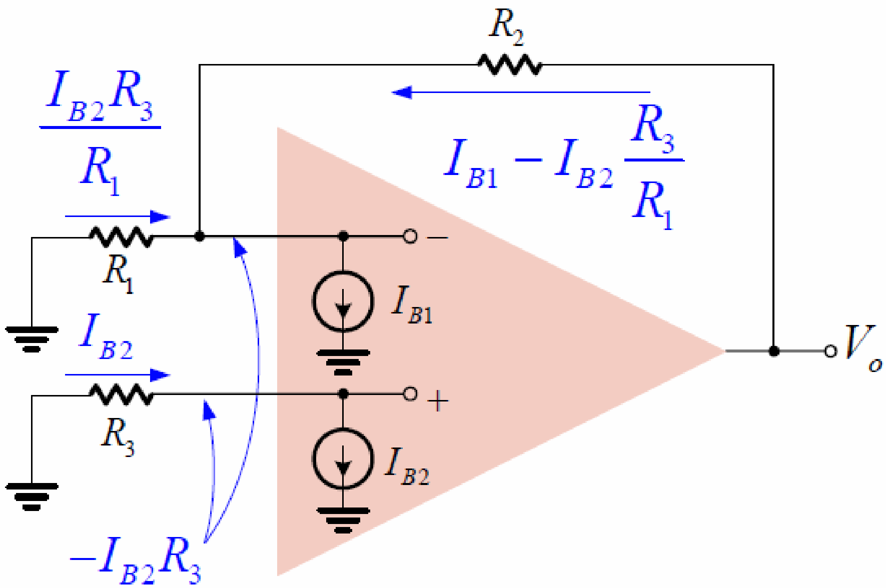


$$I_B = \frac{I_{B1} + I_{B2}}{2}$$

Offset current $$I_{OS} = \left| I_{B1} - I_{B2} \right|$$



I_{B1}
R_2
R_1
0
$-$
I_{B1}
$+$
I_{B2}
$V_o = I_{B1}R_2$



$$V_O = -I_{B2}R_3 + R_2\left(I_{B1} - I_{B2}R_3 / R_1\right)$$

Consider first case $I_B = I_{B1} = I_{B2}$, which results in

$$V_O = I_B\left[R_2 - R_3\left(1 + R_2 / R_1\right)\right]$$

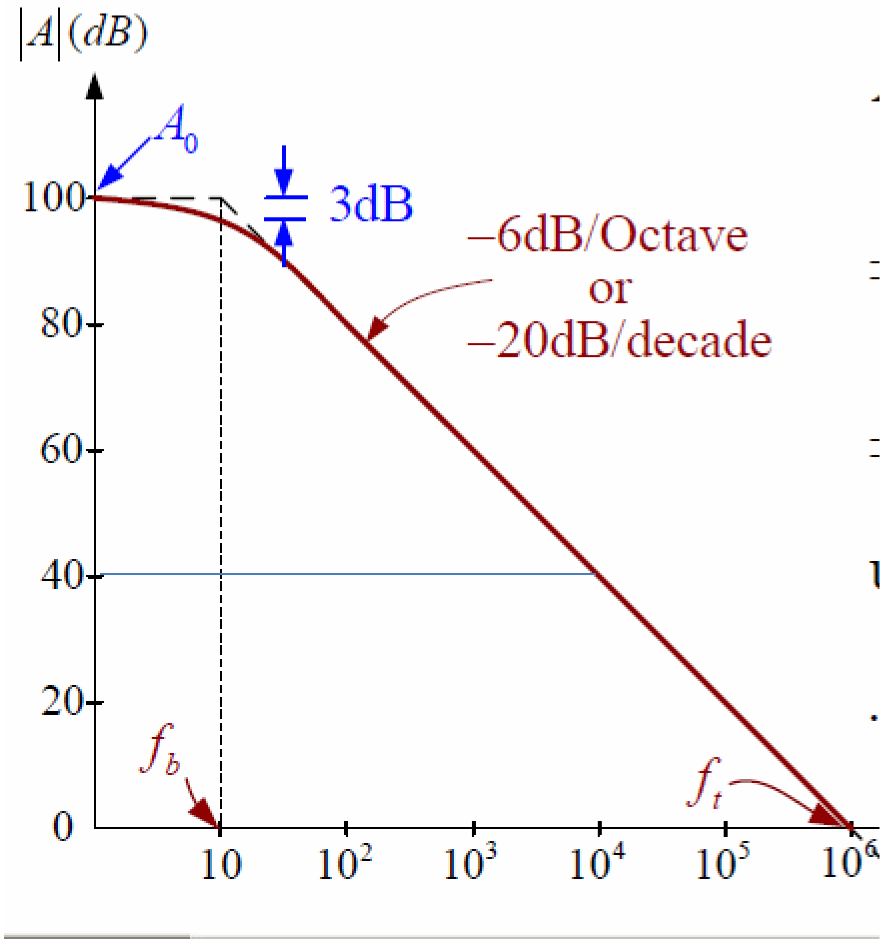
Thus we can reduce V_O to zero by selecting R_3 such that

$$R_3 = \frac{R_2}{\left(1 + R_2 / R_1\right)} = \frac{R_1R_2}{R_1 + R_2} = R_1 // R_2$$

Effect of Finite Open-Loop Gain and Bandwidth on Circuit Performance

Unity gain bandwidth

$$f_1 = A_{VD} f_C$$



$$A(s) = \frac{A_0}{1 + (s/\omega_b)} = \frac{A_0}{1 + (j\omega/\omega_b)}$$

$$\Rightarrow A(j\omega) \simeq \frac{A_0\omega_b}{j\omega}$$

$$\Rightarrow \left|A(j\omega)\right| = \frac{A_0\omega_b}{\omega}$$

unity gain frequency $\omega_t = A_0\omega_b$

$$\therefore A(j\omega) = \frac{\omega_t}{j\omega} \Rightarrow \left|A(j\omega)\right| = \frac{\omega_t}{\omega} = \frac{f_t}{f}$$

Slew rate

Slew rate = maximum rate at which amplifier output can change in volts per microsecond (V/μs)

$$\boxed{SR = \frac{\Delta V_o}{\Delta t} \text{ V}/\mu\text{s}} \quad \text{with } t \text{ in } \mu\text{s}$$

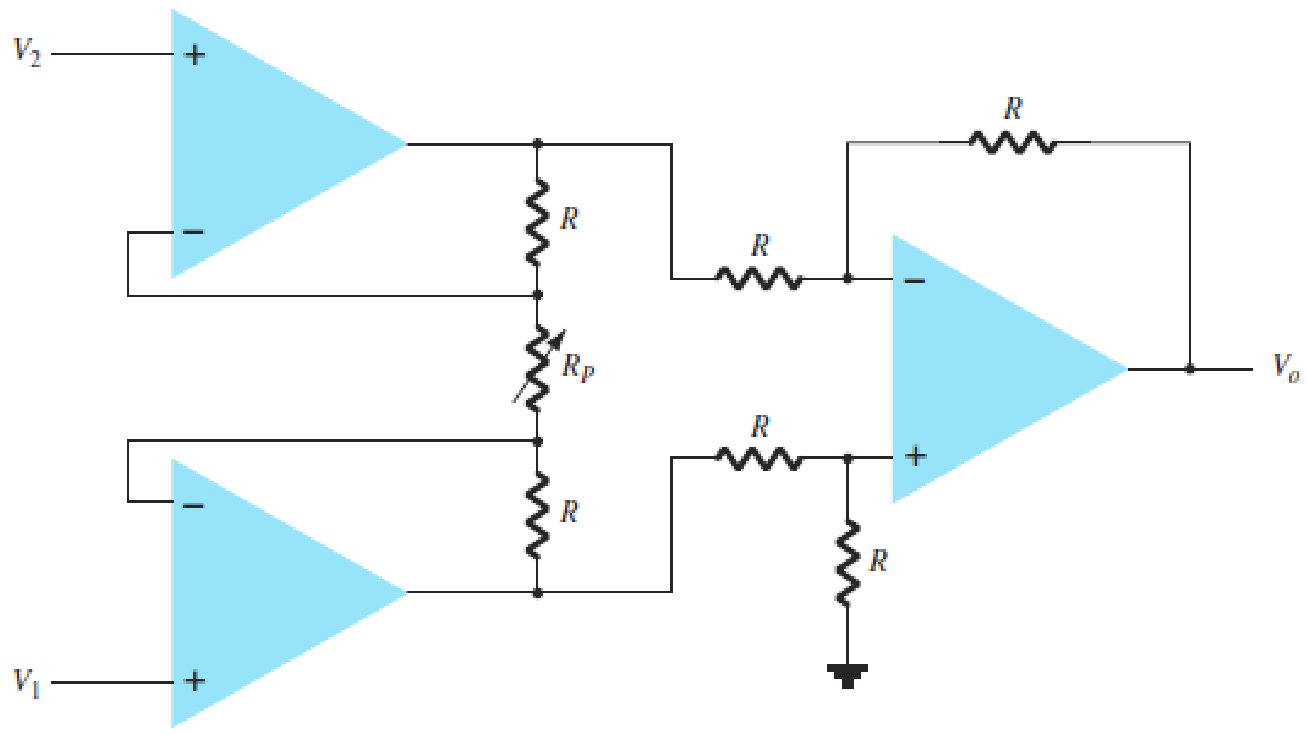
Maximum Signal Frequency

$$2\pi f K \leq \text{SR}$$
$$\omega K \leq \text{SR}$$

$$f \leq \frac{\text{SR}}{2\pi K} \qquad \text{Hz}$$

$$\omega \leq \frac{\text{SR}}{K} \qquad \text{rad/s}$$

A Superior Circuit: The Instrumentation Amplifier



001910701014
Abhijit Deogharia
6:34 PM
001910701024
Ayan Biswas
6:34 PM
001910701012 - AYAN BISWAS
arindam majee
6:34 PM
001910701006
Arijit Saha
6:34 PM
001910701019
Sarit Roy Chaudhury
6:34 PM
001910701096
sagar sarkar
6:34 PM
001910701041
Shubham singh
6:34 PM
001910701008
Snehasish Roy
6:34 PM
Snehasish Roy 001910701013
Asini Praveen Rao

OP-AMPS WITH NEGATIVE FEEDBACK

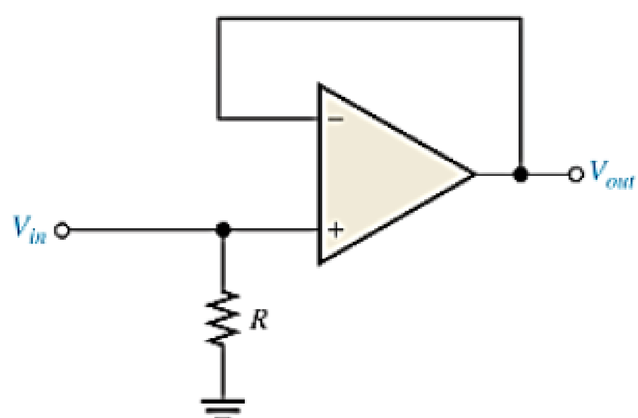
- An op-amp can be connected using negative feedback to stabilize the gain and increase frequency response.
- The closed-loop voltage gain is the voltage gain of an op-amp with external feedback.
- The closed-loop voltage gain is determined by the external component values and can be precisely controlled by them.

Op-Amp Parameters (4)
Slew Rate

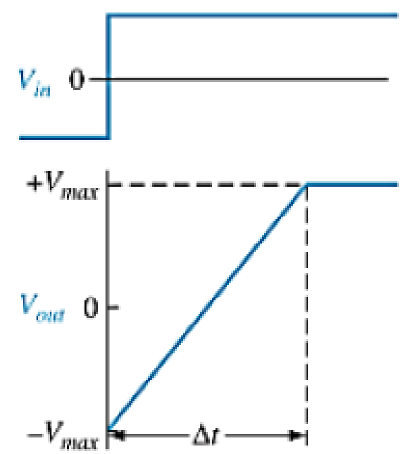
- The maximum rate of change of the output voltage in response to a step input voltage is the slew rate of an op-amp.
- The slew rate is dependent upon the high-frequency response of the amplifier stages within the op-amp.

$$\text{Slew rate} = \frac{\Delta V_{out}}{\Delta t}$$

- **Slew-rate measurement**



(a) Test circuit



(b) Step input voltage and the resulting output voltage

INSTRUMENTATION AMPLIFIERS

- Instrumentation amplifiers are commonly used in environments with high common-mode noise such as in data acquisition systems where remote sensing of input variables is required.
- The main purpose of an instrumentation amplifier is to amplify small signals that may be riding on large common-mode voltages.
- The key characteristics are high input impedance, high common-mode rejection, low output offset, and low output impedance.

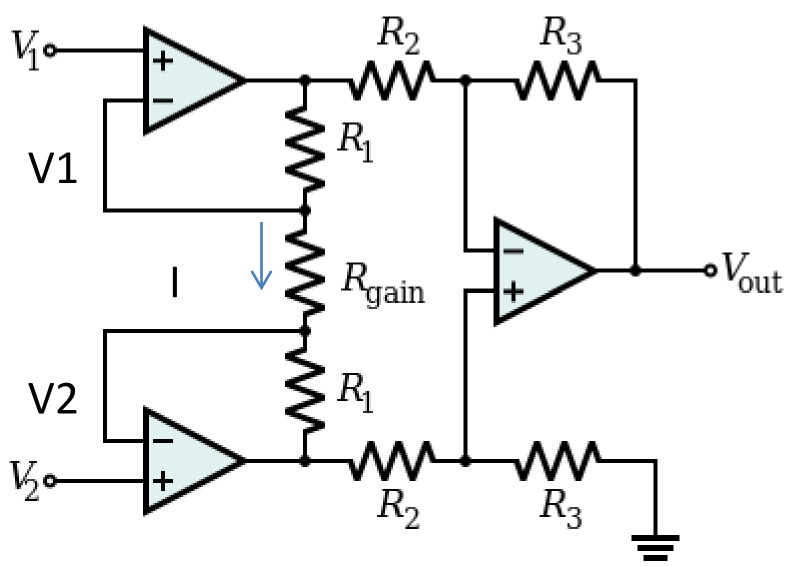
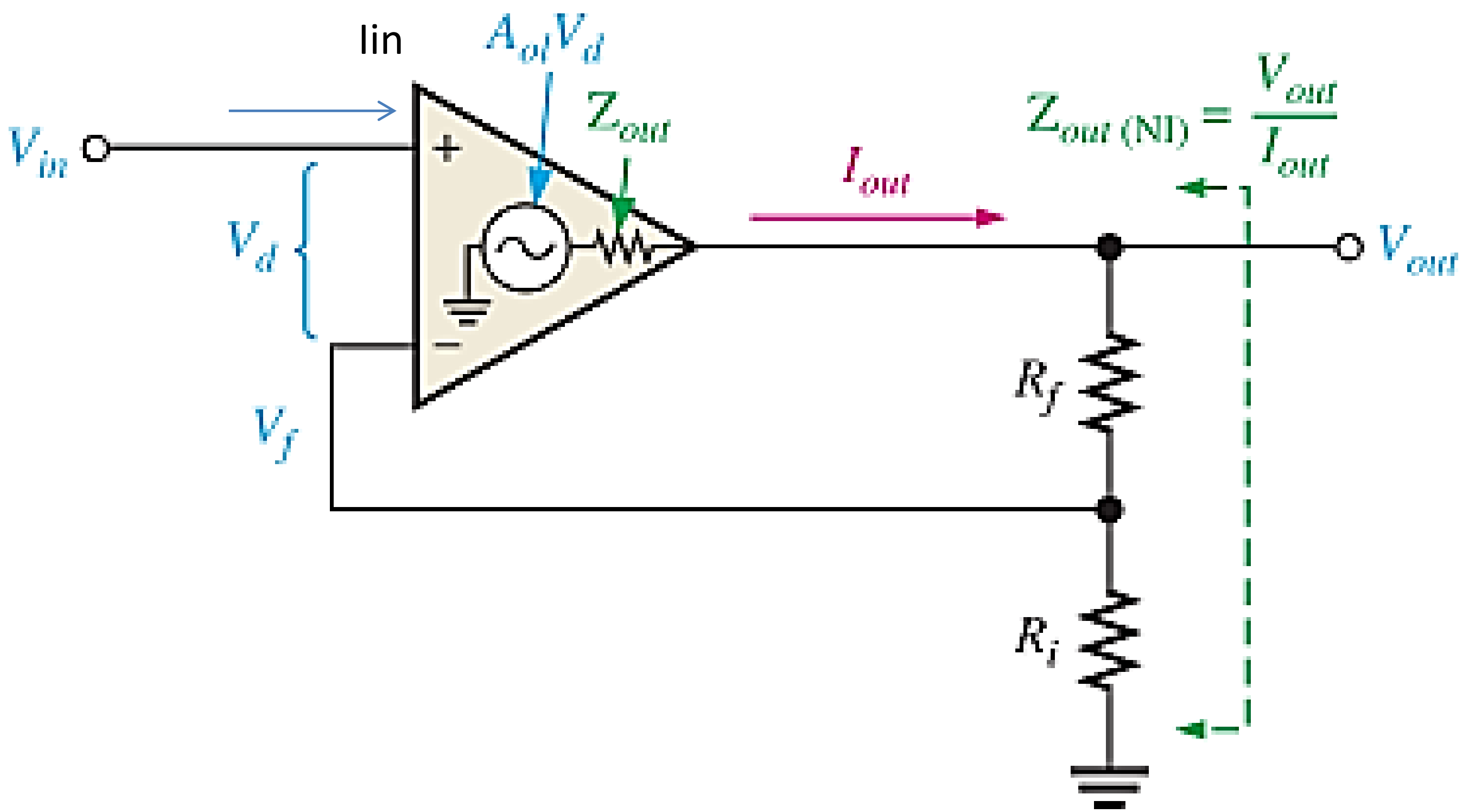


Fig. The basic instrumentation amplifier using three op-amps.

Ref: Floyd

$I = (Vo1-Vo2)/(R1+Rgain+R1)$ ………………………(1)
$I = (Vo1-Vo2)/(2R1+Rgain)$
Since no current is flowing to the input of the op-amps 1 & 2, the current I between the nodes G and H can be given as,
$I = (VG-VH) / Rgain = (V1-V2) / Rgain$………………………(2)
Equating equations 1 and 2,
$(Vo1-Vo2)/(2R1+Rgain) = (V1-V2)/Rgain$
$(Vo1-Vo2) = (2R1+Rgain)(V1-V2)/Rgain$ ………………………(3)
The output of the difference amplifier is given as,
$Vout = (R3/R2) (Vo1-Vo2)$
Therefore, **$(Vo1 – Vo2) = (R2/R3)Vout$**
Substituting **$(Vo1 – Vo2)$** value in equation 3, we get
$(R2/R3)Vout = (2R1+Rgain)(V1-V2)/Rgain$
i.e. **$Vout = (R3/R2)\{(2R1+Rgain)/Rgain\}(V1-V2)$**

$$Acl=R3/R2 (1+2R1/Rgain)$$



Vd=IinZin   Zin-input impedance of op-amp in open loop condition

$$Z_{out(NI)} = \frac{Z_{out}}{1 + A_{ol}B}$$

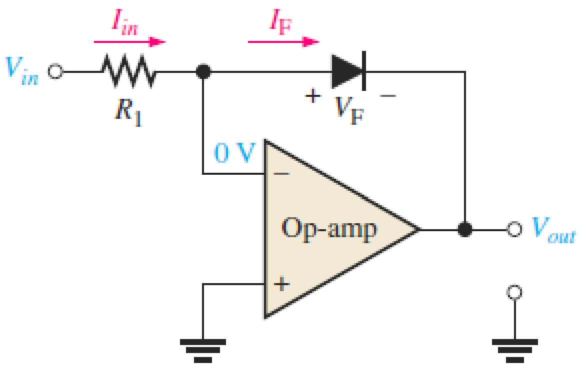
vin-vf=vd

vf=Bvo ;   B=Ri/Ri+Rf; vout=Aolvd

Vin=IinZin(1+BAol)

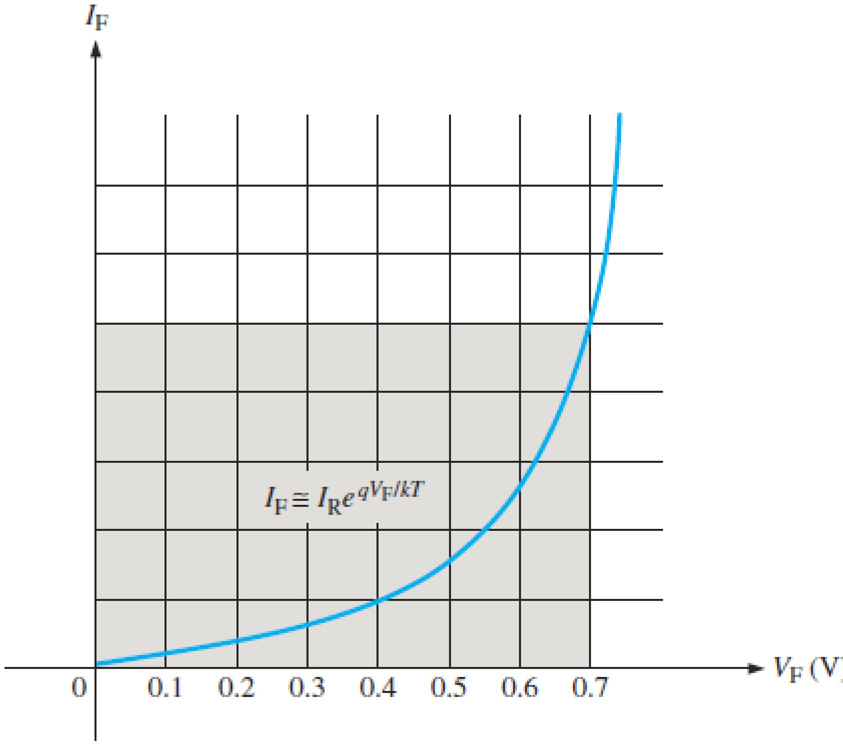
Zin(NI)=Vin/Iin=Zin(1+BAol)

Logarithmic amplifier



$$V_{out} = -V_F$$

$$I_F = I_{in} = \frac{V_{in}}{R_1}$$



As you can see on the graph, the diode curve is nonlinear. Not onl curve nonlinear, it is logarithmic and is specifically defined by the fo

$$I_F \cong I_R e^{qV_F/kT}$$

where I_R is the reverse leakage current, q is the charge on an electron, k is Boltzmann's constant, and T is the absolute temperature in Kelvin. From the previous equation, the diode forward voltage, V_F, can be determined as follows. Take the natural logarithm (*ln* is the logarithm to the base *e*) of both sides.

$$\ln I_F = \ln I_R e^{qV_F/kT}$$

The ln of a product of two terms equals the sum of the ln of each term.

$$\ln I_F = \ln I_R + \ln e^{qV_F/kT} = \ln I_R + \frac{qV_F}{kT}$$

$$\ln I_F - \ln I_R = \frac{qV_F}{kT}$$

The difference of two ln terms equals the ln of the quotient of the terms.

$$\ln\left(\frac{I_F}{\quad}\right) = \frac{qV_F}{\quad}$$

$$V_{out} = -\left(\frac{kT}{q}\right)\ln\left(\frac{V_{in}}{I_R R_1}\right)$$

The **antilogarithm** of a number is the result obtained when the base is raised to a power equal to the logarithm of that number. To get the antilogarithm, you must take the exponential of the logarithm (antilogarithm of $x = e^{\ln x}$).

An antilog amplifier is formed by connecting a transistor (or diode) as the input element as shown in Figure 14–33. The exponential formula still applies to the base-emitter *pn* junction. The output voltage is determined by the current (equal to the collector current) through the feedback resistor.

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

The characteristic equation of the *pn* junction is

$$I_C = I_{EBO} e^{qV_{BE}/kT}$$

Substituting into the equation for V_{out},

$$V_{out} = -R_f I_{EBO} e^{qV_{BE}/kT}$$

As you can see in Figure 14–33, $V_{in} = V_{BE}$.

$$V_{out} = -R_f I_{EBO} e^{qV_{in}/kT}$$

The exponential term can be expressed as an antilogarithm as follows:

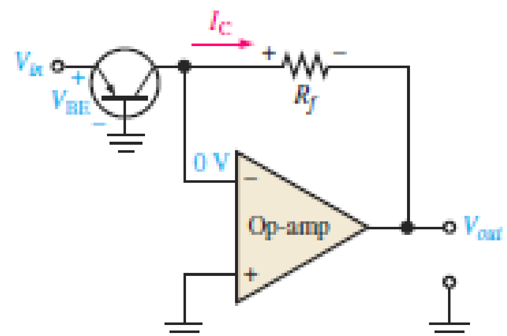
$$V_{out} = -R_f I_{EBO} \text{antilog}\left(\frac{V_{in}q}{kT}\right)$$

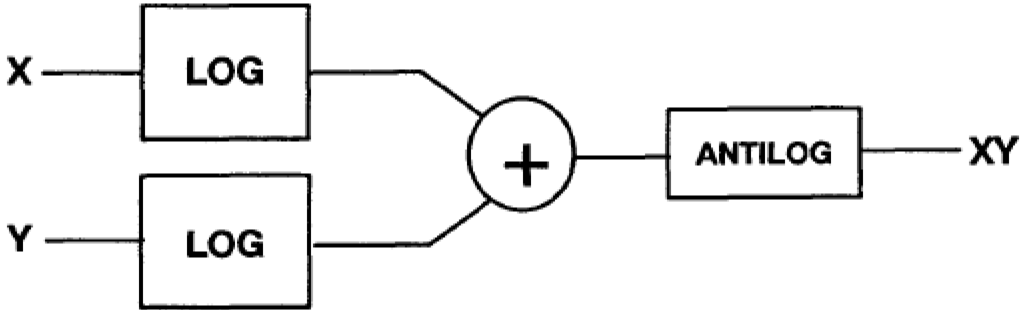
Since kT/q is approximately 25 mV,

$$\mathbf{V_{out} = -R_f I_{EBO} \textbf{antilog}\left(\frac{V_{in}}{25\ mV}\right)}$$

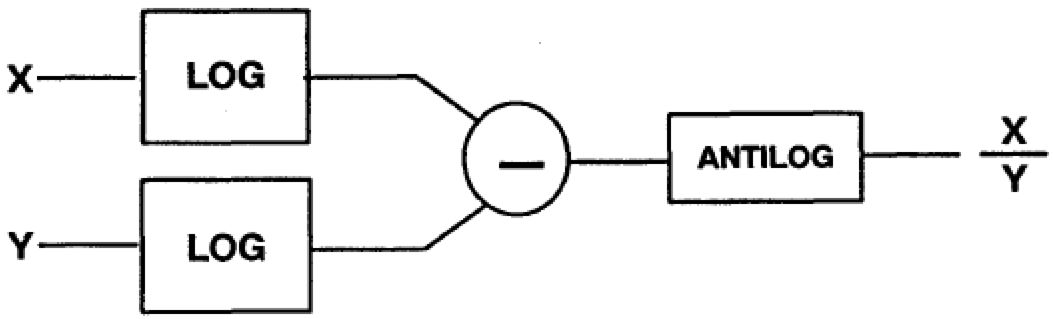
▶ FIGURE 14–33

A basic antilog amplifier.

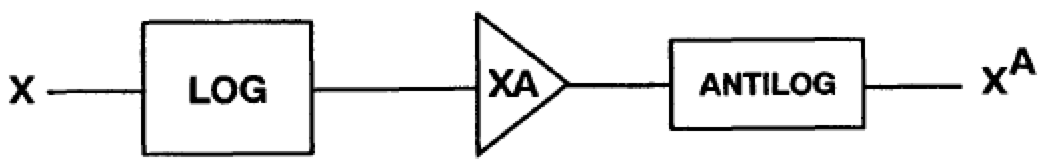




MULTIPLICATION



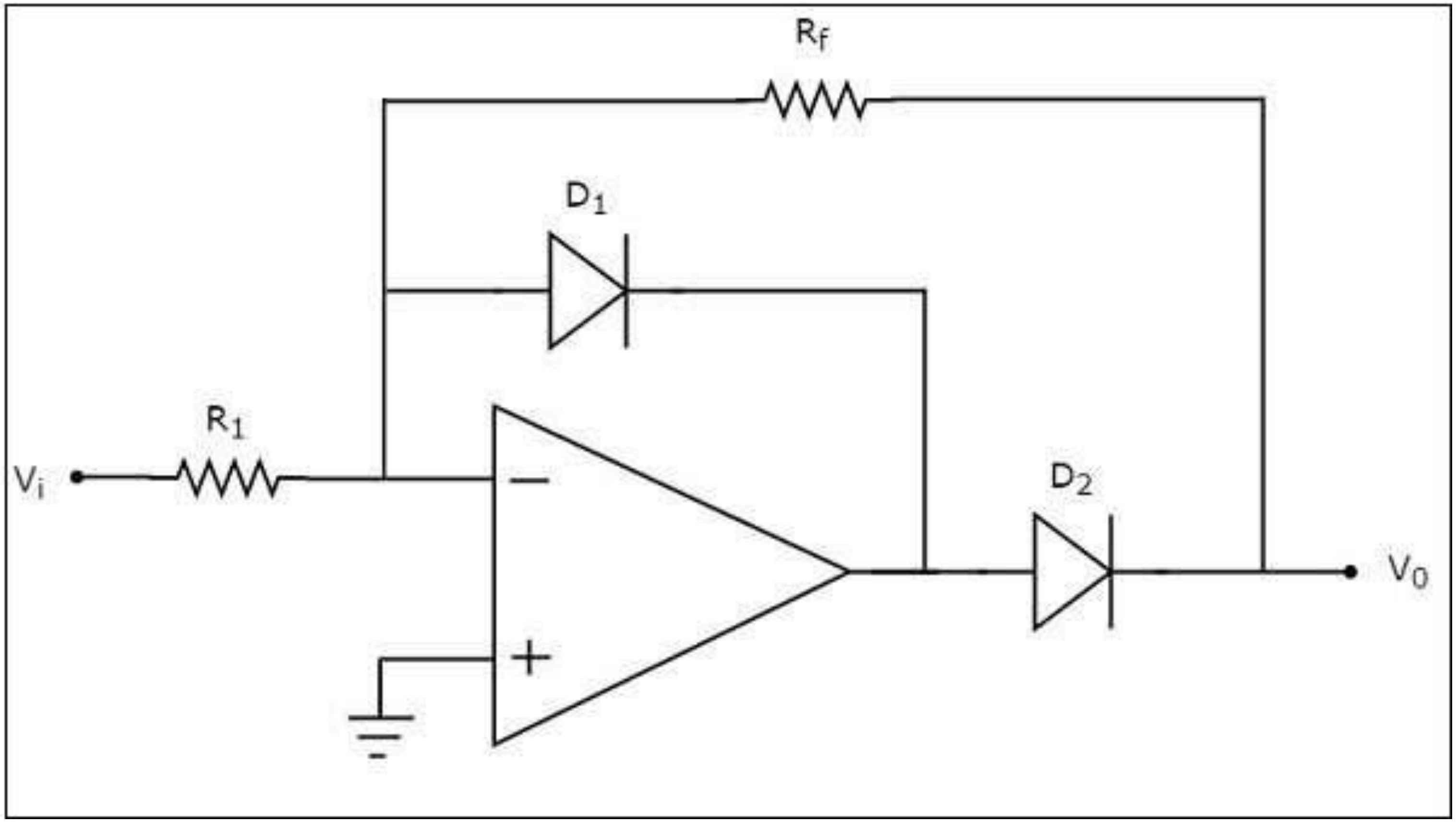
DIVISION

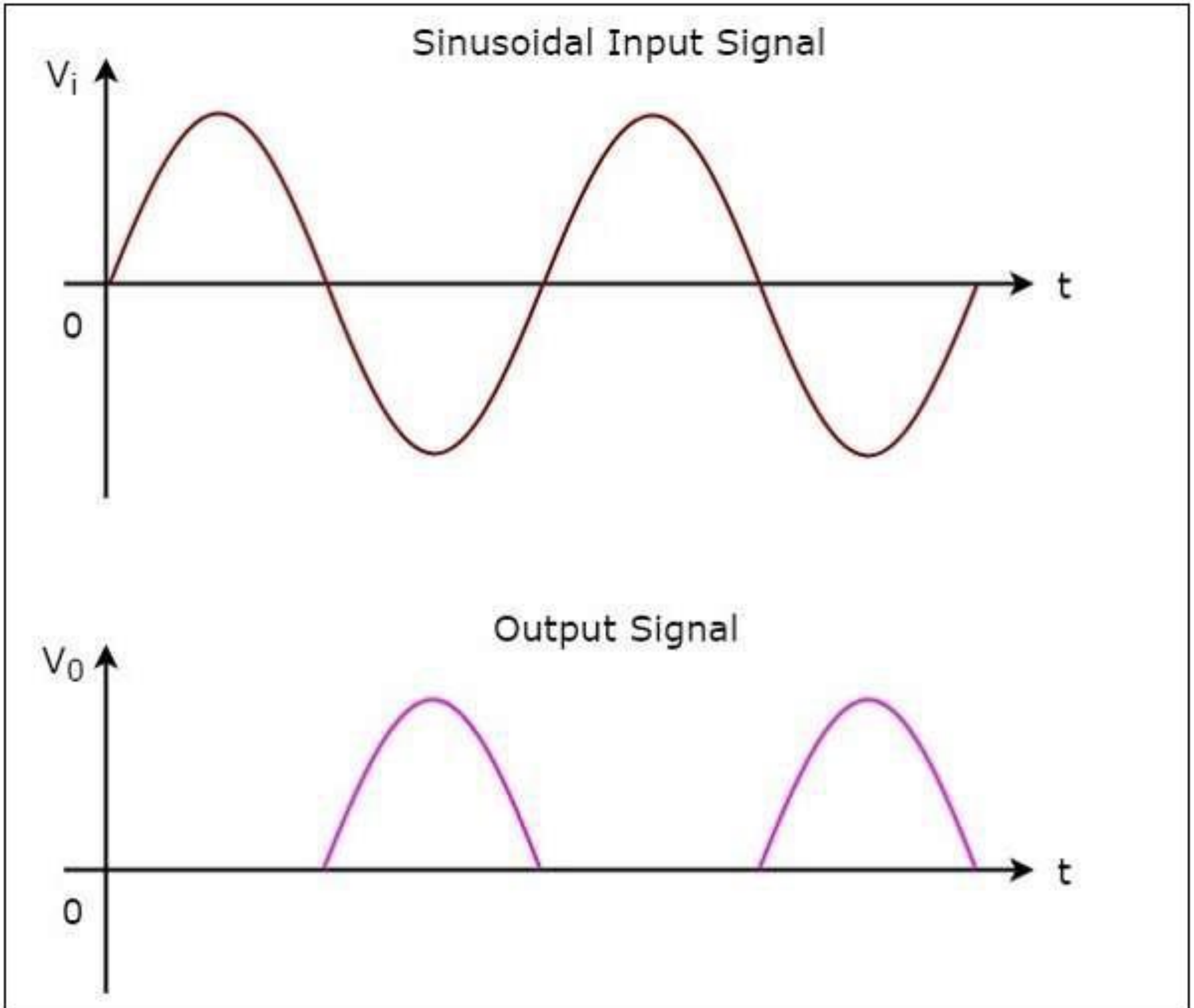


RAISING TO A POWER A

Trans-resistance amplifier → current dependent voltage source
$R=V_{out}/I_{in}$

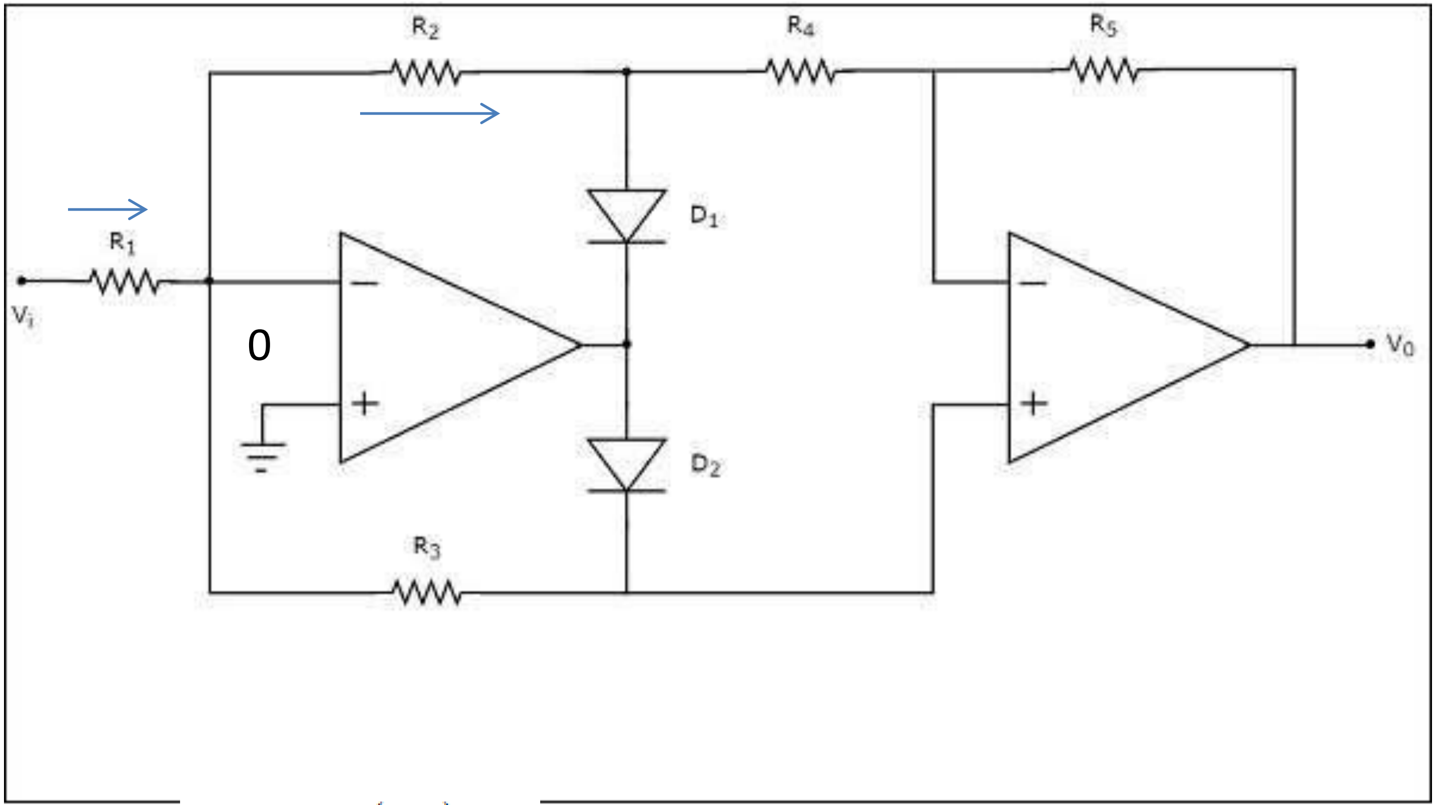
Half-wave rectifier



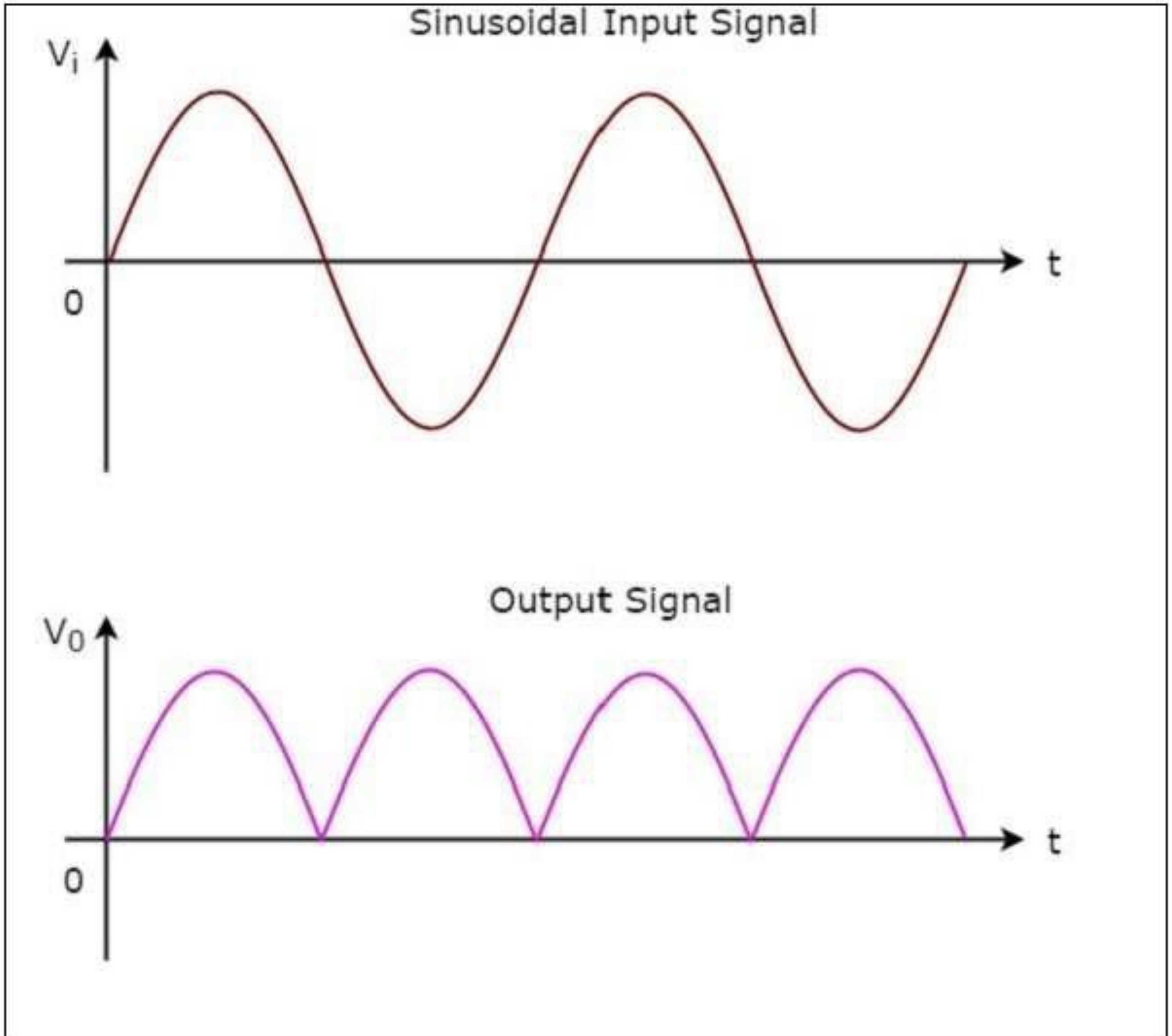


Sinusoidal Input Signal
V_i
t
0
Output Signal
V_0
t
0

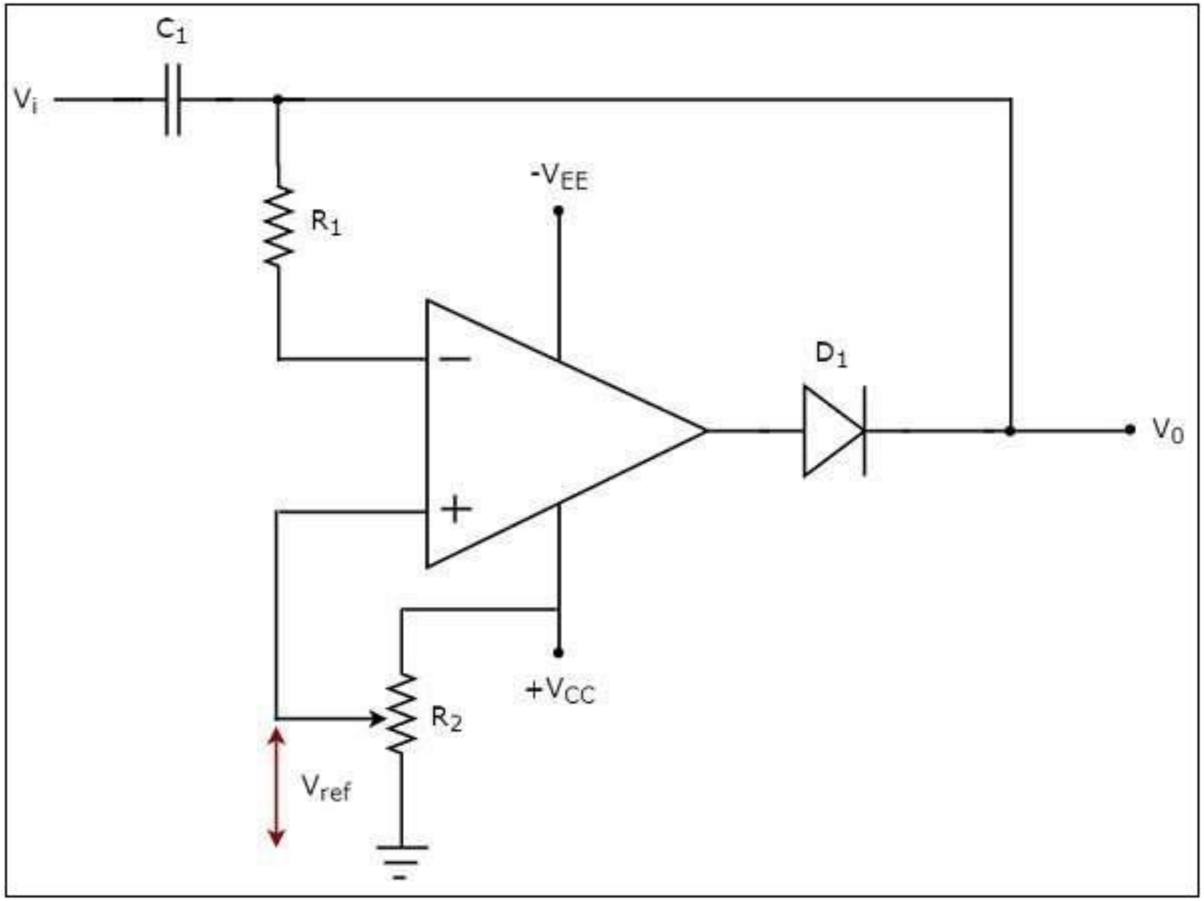
Vo+=viR2/R1 R5/R4
Vo-=-viR3/R1(1+R5/R4)



$$V_{01} = -\left(\frac{R_2}{R_1}\right) V_i$$



Sinusoidal Input Signal
Vi
t
0
Output Signal
V0
t
0

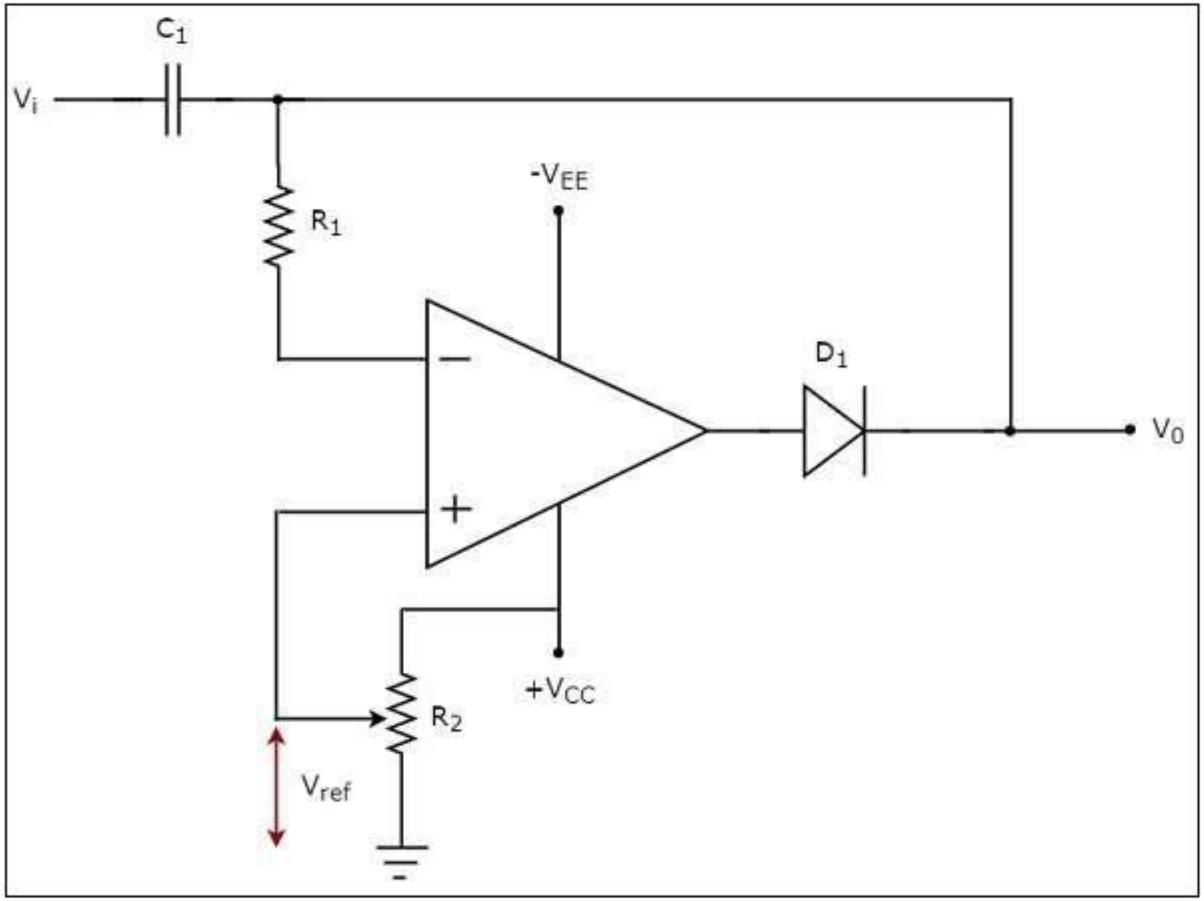


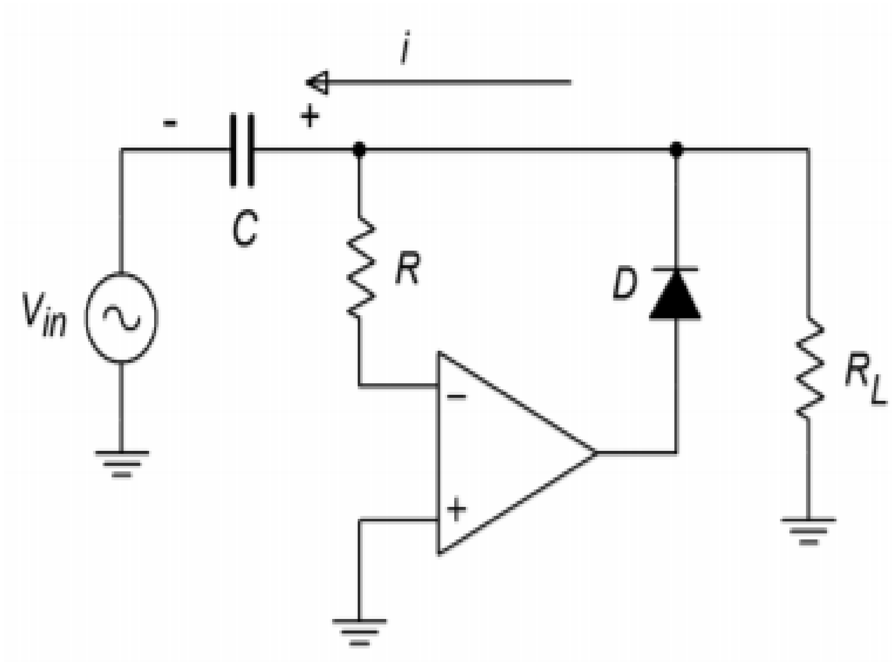
C1
Vi
R1
-VEE
D1
V0
R2
+VCC
Vref

2:15 PM
001910701012
Sagnik Banerjee
2:15 PM
001910701015
sagar sarkar
2:15 PM
001910701041
Arijit Saha
2:15 PM
001910701019
Utso Majumder
2:15 PM
001910701070
You
2:15 PM
\G1 join at 3:15 pm
Tandeep Singh
2:15 PM
001910701002
Snehasish Roy
2:15 PM
Snehasish Roy 001910701013
Souvik Barman
2:15 PM

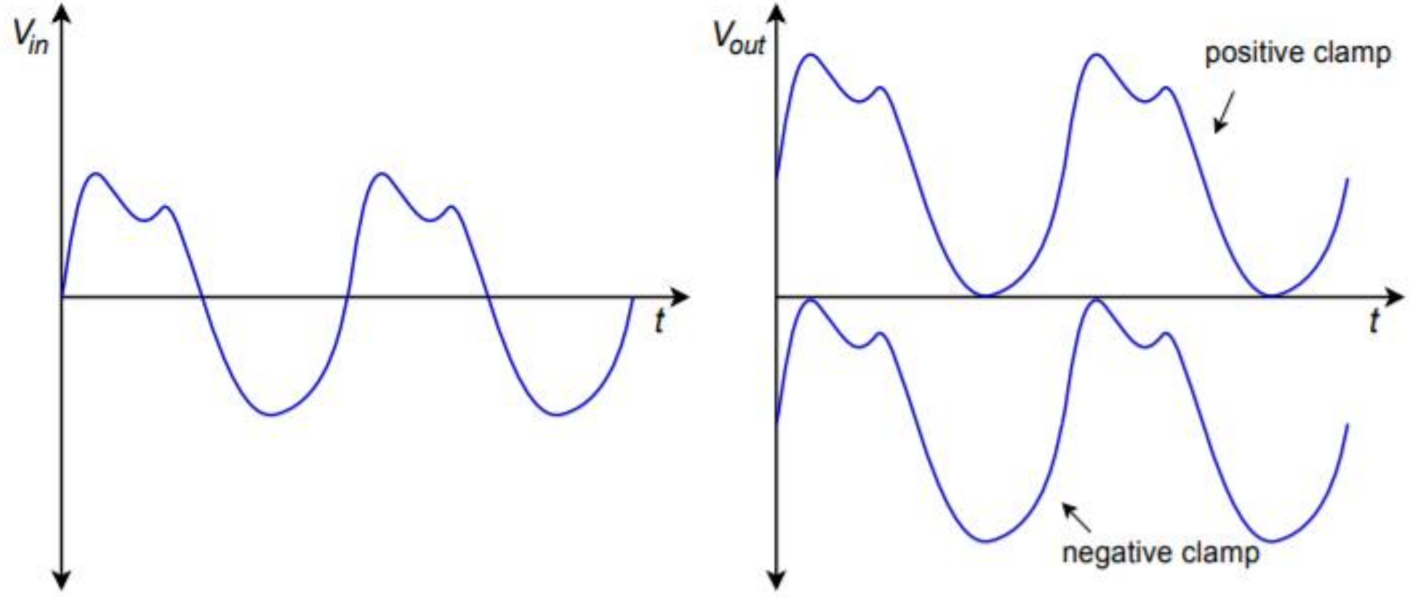
19/01/21

Clampers

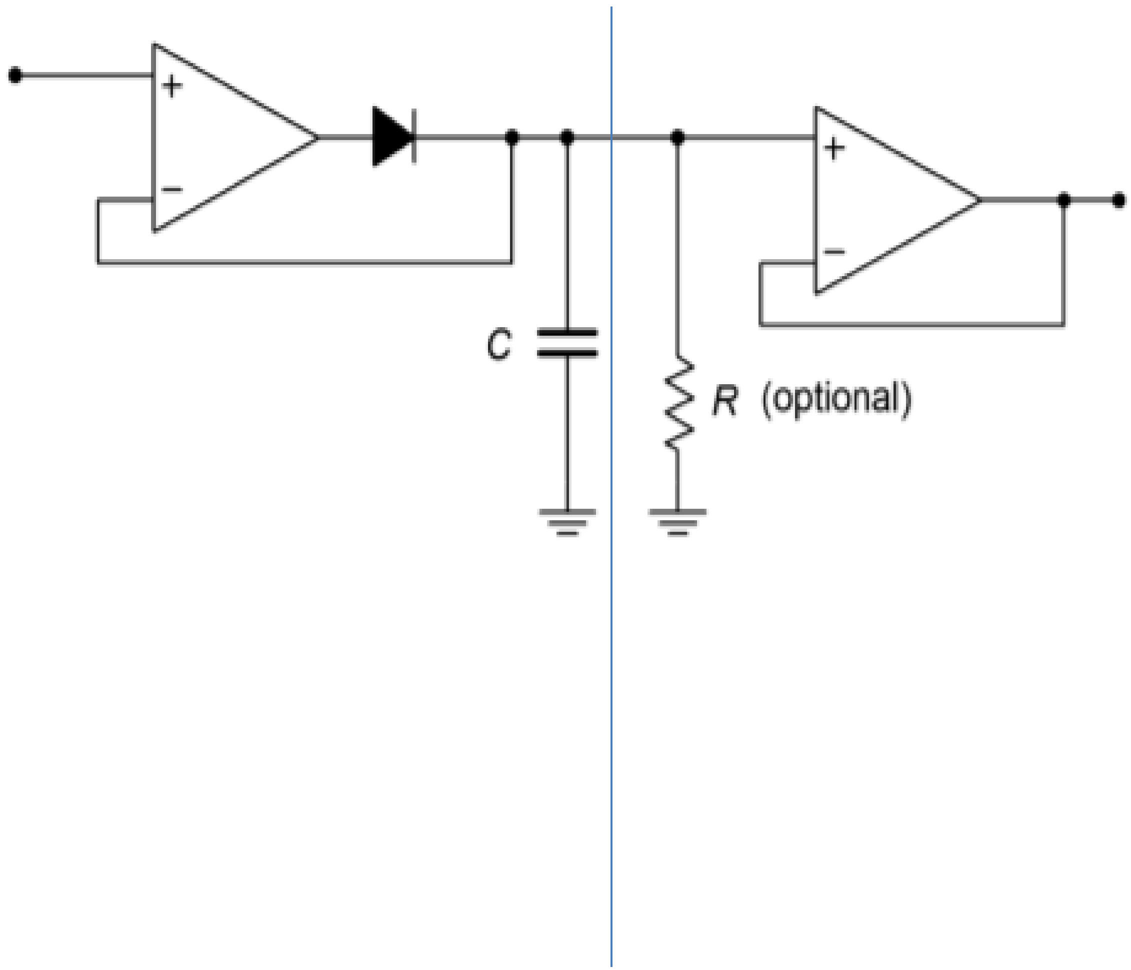




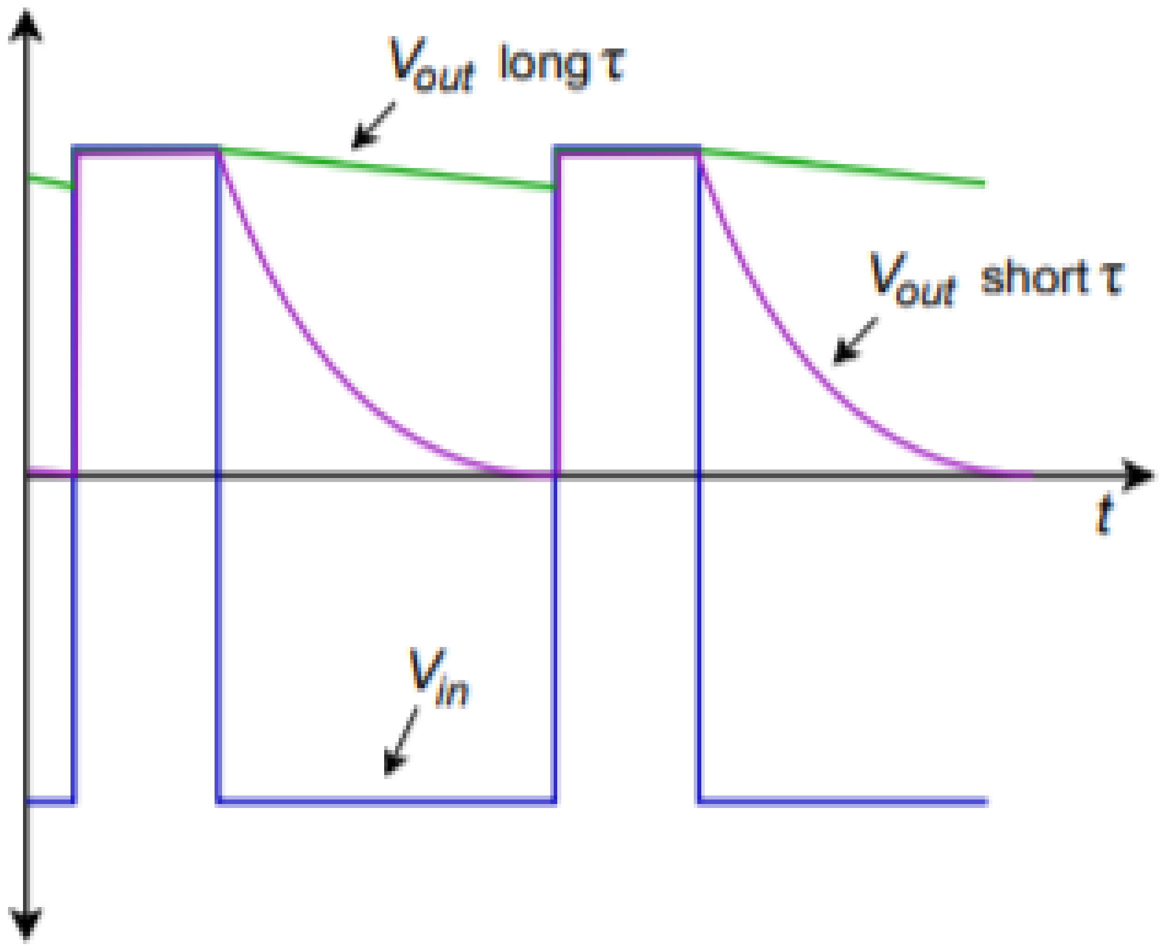
Vout=Vin+|Vp⁻|+Vref



V_{in}
t
V_{out}
positive clamp
t
negative clamp

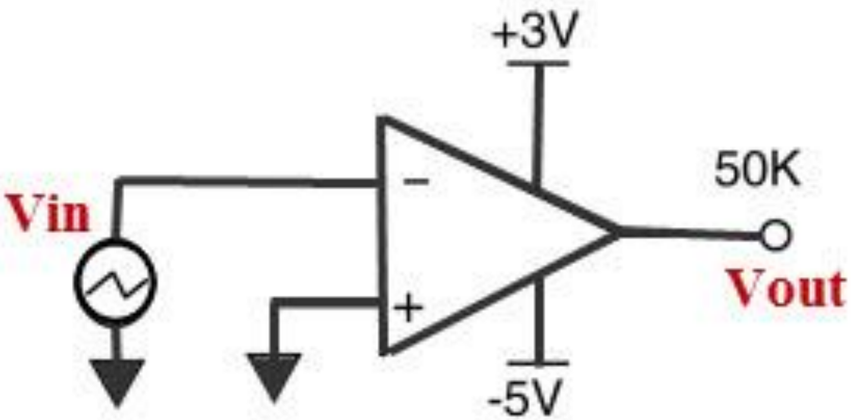


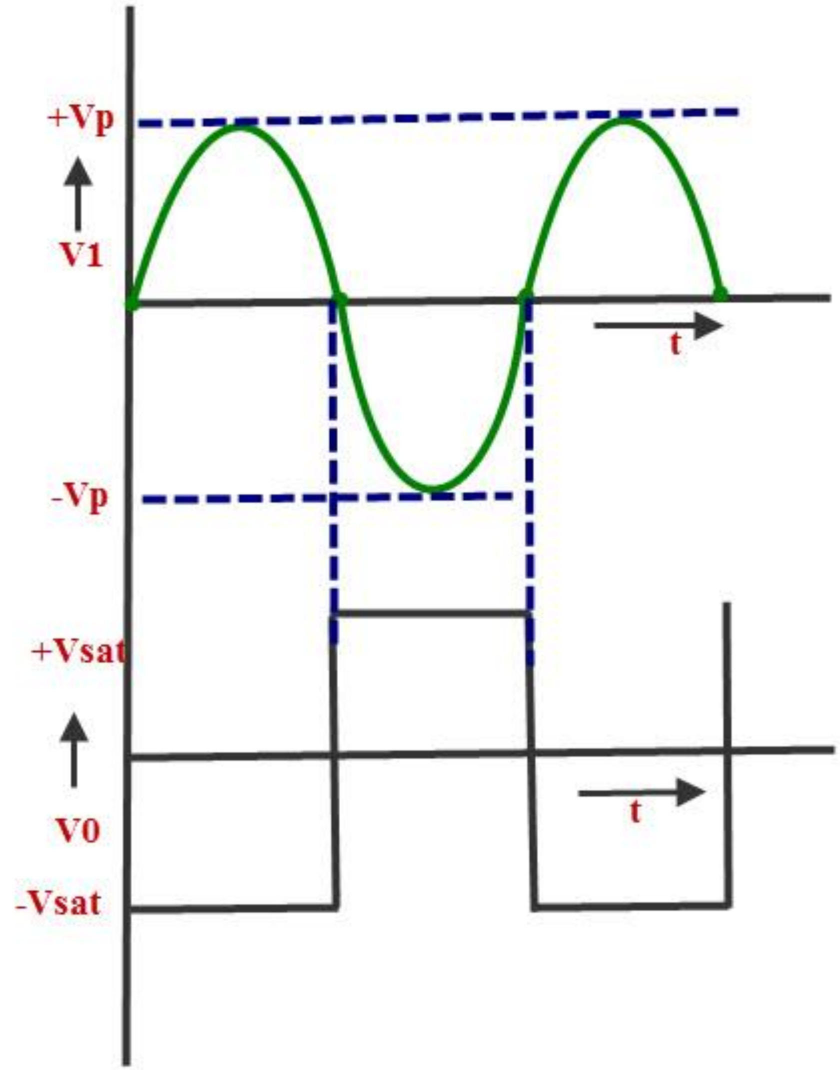
+
−
C
R (optional)

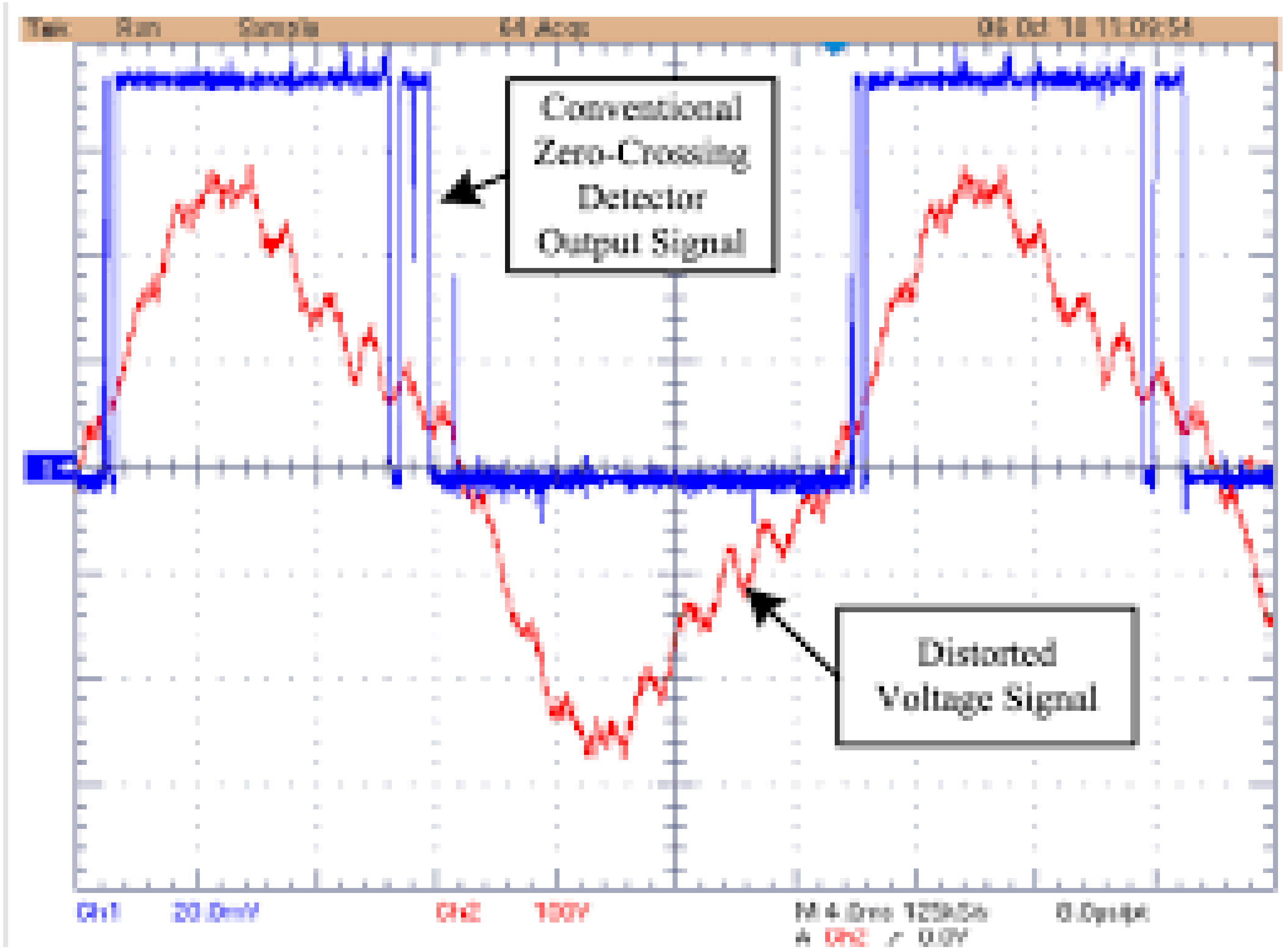


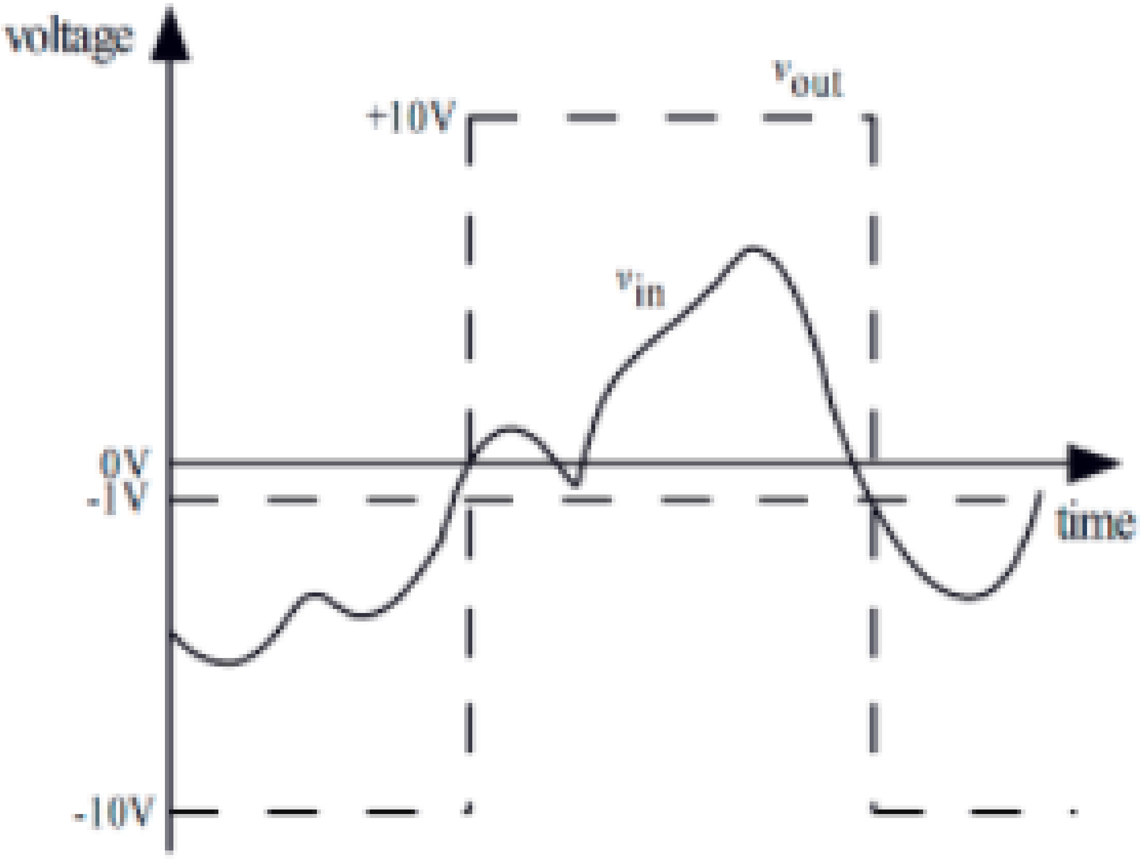
V_{out} long τ
V_{out} short τ
t
V_{in}

Zero crossing detector

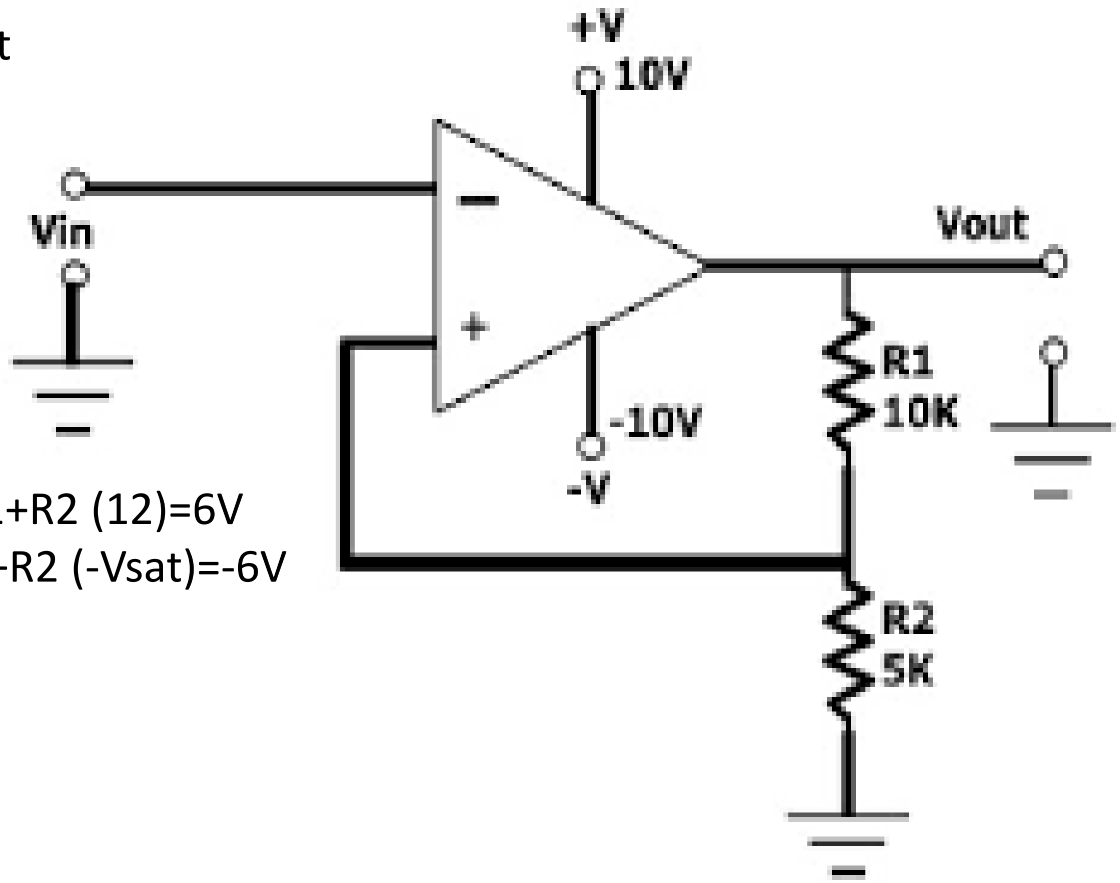




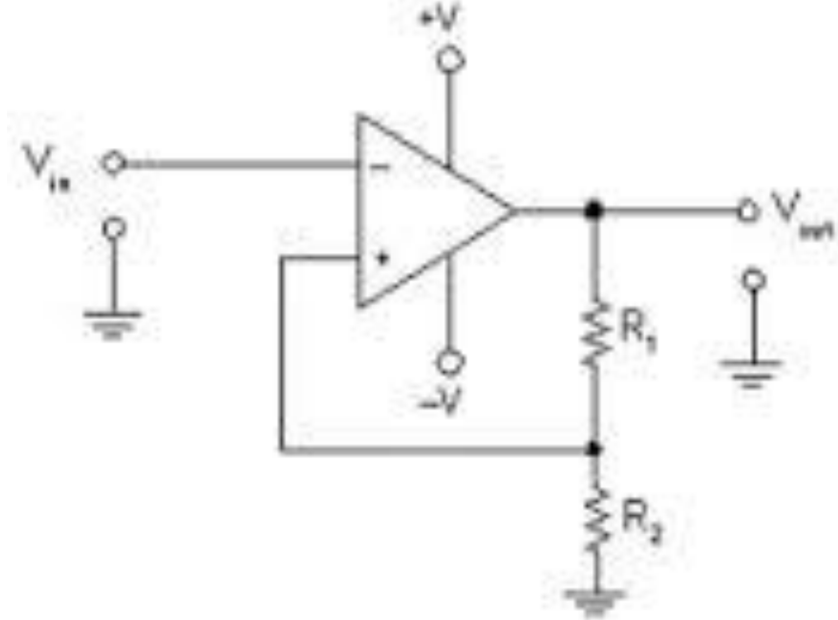

Conventional
Zero-Crossing
Detector
Output Signal
Distorted
Voltage Signal

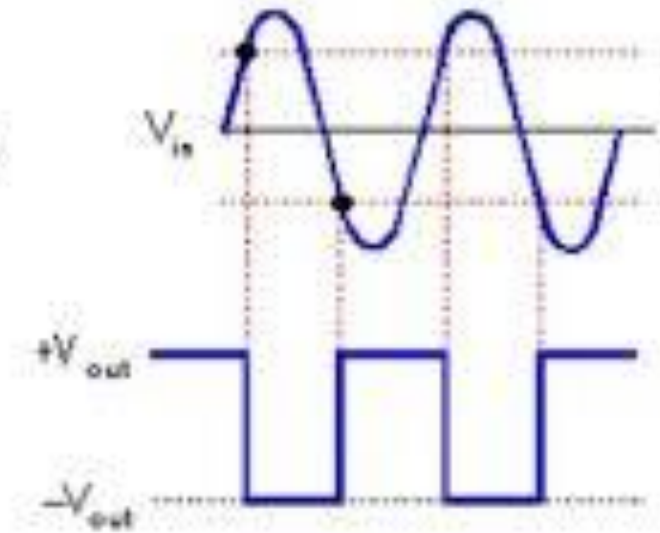

voltage
v_{out}
+10V
v_{in}
0V
-1V
time
-10V

V->V+ vout=-Vsat
V-<V+ vout= Vsat

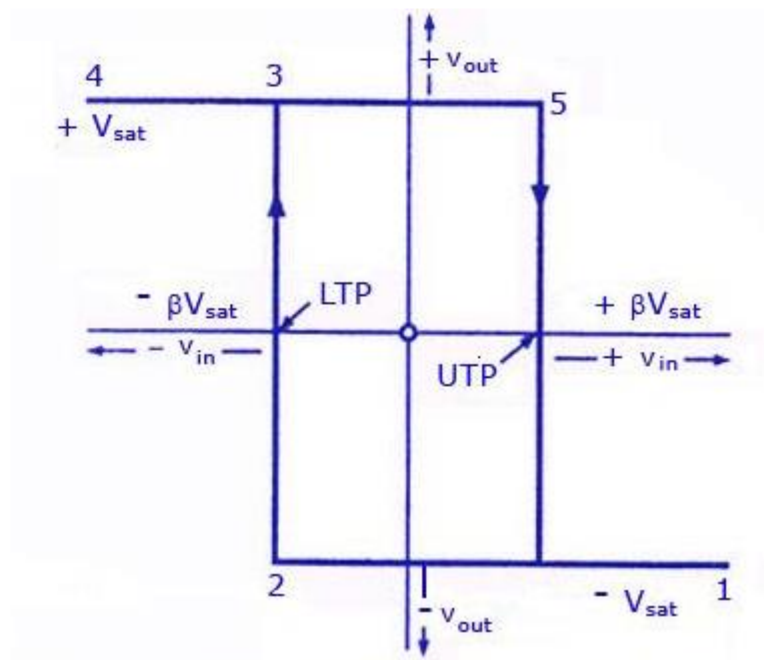


UTP=$Vref^{+}$=R2/R1+R2 (12)=6V
LTP=$Vref^{-}$=R2/R1+R2 (-Vsat)=-6V





Lower trip po



Input Output Characteristics