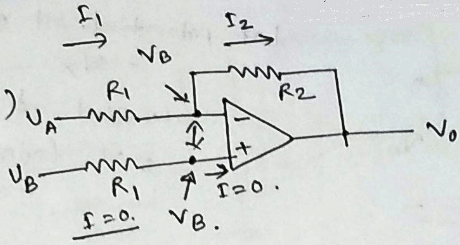
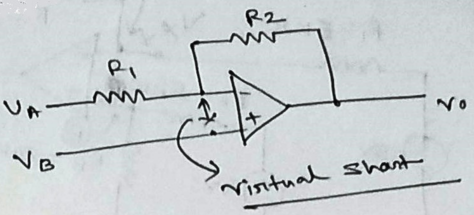
1 (i)



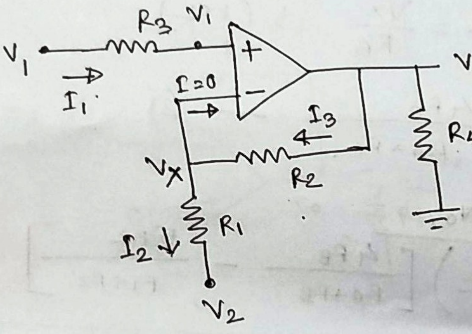


Same as

$$\frac{V_A - V_B}{R_1} = \frac{V_B - V_0}{R_2} \quad ; (\text{as } I_1 = I_2)$$

$$V_0 = \left(1 + \frac{R_2}{R_1}\right) V_B - \frac{R_2}{R_1} V_A$$

1 (ii)



as, $I_1 = I = 0$.

$V_x = V_1$ (virtual short).

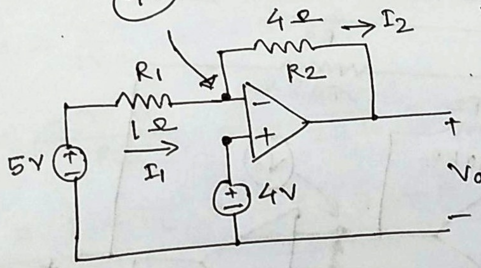
$I_2 = I_3$

$$\therefore \frac{V_x - V_2}{R_1} = \frac{V_0 - V_x}{R_2}$$

$$\therefore V_0 = \frac{V_x R_2 - V_2 R_2 + V_x R_1}{R_1}$$

$$\therefore V_0 = \left(1 + \frac{R_2}{R_1}\right) V_1 - \frac{R_2}{R_1} V_1$$

1 (iii)

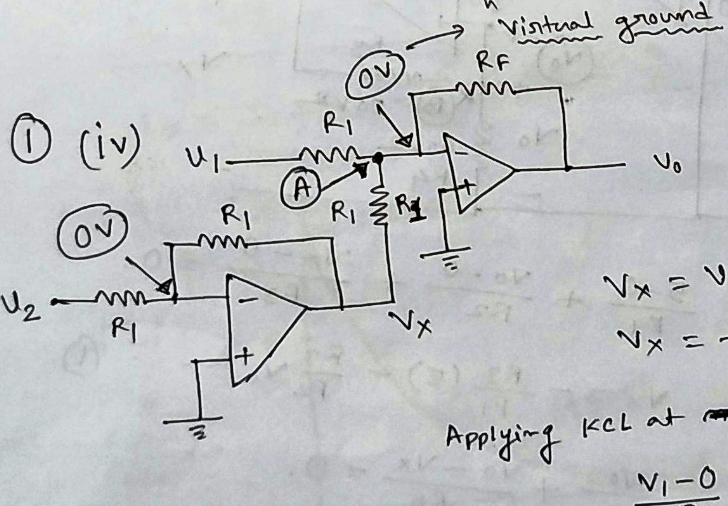


as, $I_1 = I_2$.

$$\therefore \frac{5-4}{1} = \frac{4 - V_0}{4}$$

$$\therefore V_0 = 0.$$

1 (iv)



$$V_x = V_2 \times \left(-\frac{R_1}{R_1}\right)$$

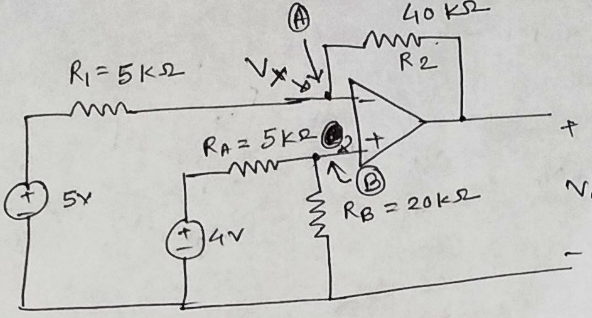
$$V_x = -U_2$$

Applying KCL at node A,

$$\frac{V_1 - 0}{R_1} + \frac{V_x - 0}{R_1} = \frac{0 - V_0}{R_F}$$

$$\therefore V_0 = -\frac{R_F}{R_1}(V_1 - V_2)$$

1 (v)



Let potential at node (A) $= V_x$

So, potential at node (B) $= V_x$ (virtual short).

At, node (A), $\dfrac{5 - V_x}{R_1} = \dfrac{V_x - V_o}{R_2}$ (KCL)

$$\therefore V_x = \left(\frac{R_2}{R_1 + R_2}\right) \cdot 5 + \left(\frac{R_1}{R_1 + R_2}\right) V_o \quad \text{— (1)}$$

At, node (B), $\dfrac{4 - V_x}{R_A} = \dfrac{V_x}{R_B}$; (KCL)

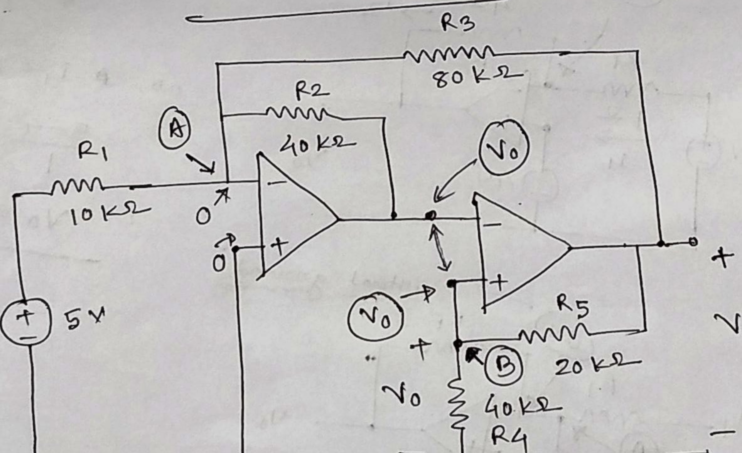
$$\therefore V_x = \frac{4 R_B}{R_A + R_B} \quad \text{— (2)}$$

From, (1) & (2), Find V_o.

$$V_o = \left(\frac{R_1 + R_2}{R_1}\right)\left[\frac{4 R_B}{R_A + R_B} - \frac{5 R_2}{R_1 + R_2}\right]$$

$V_o = -11.2$ V. (value).

1 (vi)



At node (A), $\dfrac{5 - 0}{R_1} + \dfrac{V_o - 0}{R_2} + \dfrac{V_x - 0}{R_3} = 0.$

$$\therefore V_x = -\frac{R_3}{R_1}(5) - \frac{R_3}{R_2} V_o \quad \text{---- (1)}$$

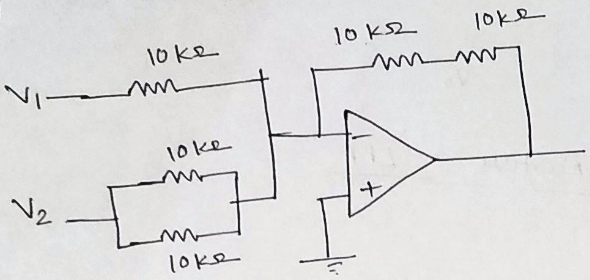
At node (B), $\dfrac{V_o}{R_4} + \dfrac{V_o - V_x}{R_5} = 0.$

$$V_x = V_o\left(1 + \frac{R_5}{R_4}\right) \quad \text{--- (2)}$$

From (1) and (2), find V_o.

$V_o = -11.43$ V.

2

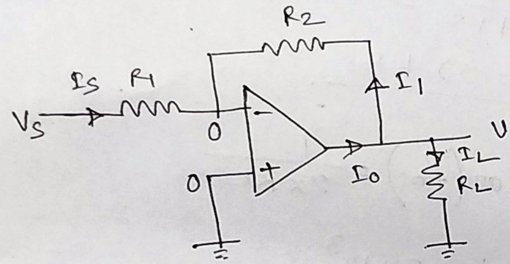


$$V_0 = -20\left(\frac{V_1}{10} + \frac{V_2}{10 \parallel 10}\right)$$

(Small correction in the question)

$$\underline{V_0 = -2V_1 - 4V_2}.$$

3



$$\left.\begin{array}{l} R_2 = 27\,k\Omega \\ R_1 = 3\,k\Omega. \end{array}\right\} \quad R_L = 1\,k\Omega.$$

$V_s = 1\,V.$

$$V_0 = -\frac{R_2}{R_1} V_s = -\frac{27}{3} \cdot 1 = -9\,V$$

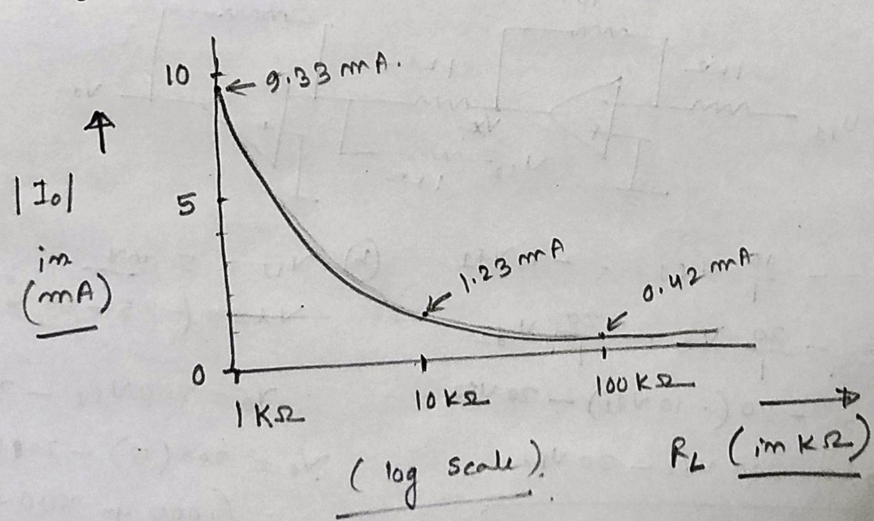
$$I_L = -\frac{9\,V}{1\,k\Omega} = -9\,mA.$$

$$I_1 = \frac{-9-0}{R_2} = -\frac{9\,V}{27\,K} = -0.33\,mA.$$

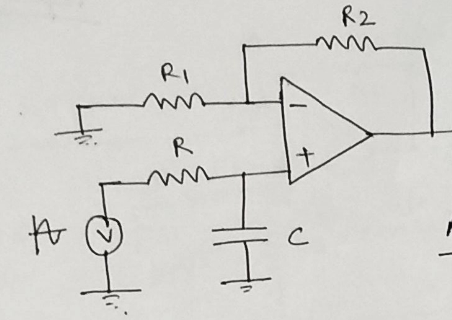
$$\underline{I_0 = I_1 + I_L = -9.33\,mA.}$$

$$\underline{I_s = -I_1 = 0.33\,mA.}$$

$$I_0 = I_1 + I_L = \left(-0.33 - \frac{9}{R_L}\right) \text{ in } mA.$$



(4)



Active 'LPF'

$R_1 = 1\,k\Omega$, $C = 0.2\,\mu F$

pass-band gain = 100 = gain of the non-inverting amplifier.

$$A = \left(1 + \frac{R_2}{R_1}\right) = 100$$

$$\therefore 1 + \frac{R_2}{1\,k\Omega} = 100$$

$$\therefore R_2 = 99\,k\Omega.$$

Cut-off frequency (f_T) or (f_c) $= \dfrac{1}{2\pi RC}$

$$\therefore \frac{1}{2\pi RC} = 2\times10^3$$

$$\therefore R = 398\,\Omega.$$

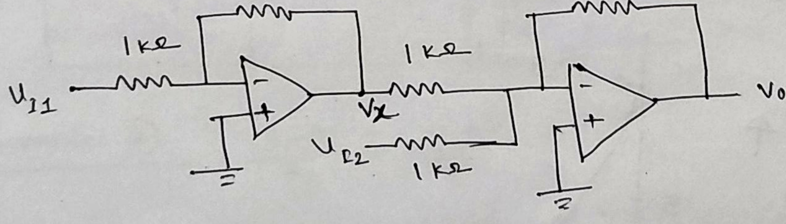
(5) Differential gain = 100 = A_d

Common mode gain $(A_c) = \dfrac{V_{out}}{V_{in}} = \dfrac{0.01}{1} = 10^{-2}$

$$\therefore \text{So, } CMRR = \frac{A_d}{A_c} = \frac{100}{10^{-2}} = 10^4$$

$$\therefore (CMRR)_{dB} = 20\log\left|\frac{A_d}{A_c}\right| = 80\text{ dB.}$$

(6) (a)



$$V_x = -\frac{10}{1}V_{I1} = -10V_{I1}$$

$$V_o = -\frac{20}{1}V_x - \frac{20}{1}V_{I2}$$

$$= -20(-10V_{I1}) - 20V_{I2}$$

$$\therefore V_o = 200V_{I1} - 20V_{I2}$$

(b) $V_{I1} = 5\text{ mV}.$

$V_{I2} = (-25 - 50\sin\omega t)\text{ mV}$

$$\therefore V_o = 200V_{I1} - 20V_{I2}$$

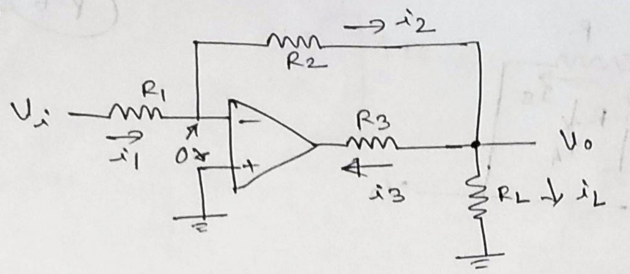
$$V_o = 200(5) - 20(-25 - 50\sin\omega t)$$

$$= (1000 + 500 + 1000\sin\omega t)\text{ mV}$$

$$V_o = (1.5 + \sin\omega t)\text{ V.}$$

Q-5

7



$$i_1 = \frac{V_i}{R_1} \;;\; i_2 = \frac{0 - V_o}{R_2}$$

$$i_1 = i_2$$

$$\therefore \frac{V_i}{R_1} = -\frac{V_o}{R_2}$$

$$\therefore V_o = -\frac{R_2}{R_1} V_i$$

$$i_L = \frac{V_o}{R_L}$$

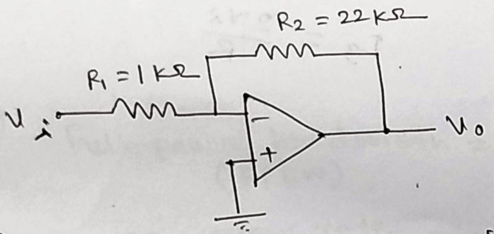
again, $i_2 = i_3 + i_L$

$$\therefore \frac{V_i}{R_1} = i_3 + \frac{V_o}{R_L}$$

$$\therefore \frac{V_i}{R_1} = i_3 - \frac{R_2}{R_1 R_L} V_i$$

$$\therefore i_3 = \frac{V_i}{R_1}\left(1 + \frac{R_2}{R_L}\right)$$

8



(a) Considering the op-amp as ideal, the gain is $= -\frac{R_2}{R_1} = -\frac{22}{1} = -22$

(b) Actual gain $= -\frac{R_2}{R_1} \times \frac{1}{\left[1 + \frac{1}{A_{od}}\left(1 + \frac{R_2}{R_1}\right)\right]}$; [We have derive this in the class]

where, A_{od} = open-loop gain.

$$= -22 \times \frac{1}{1 + \frac{1}{5\times10^3}(1+22)}$$

$$= -21.9$$

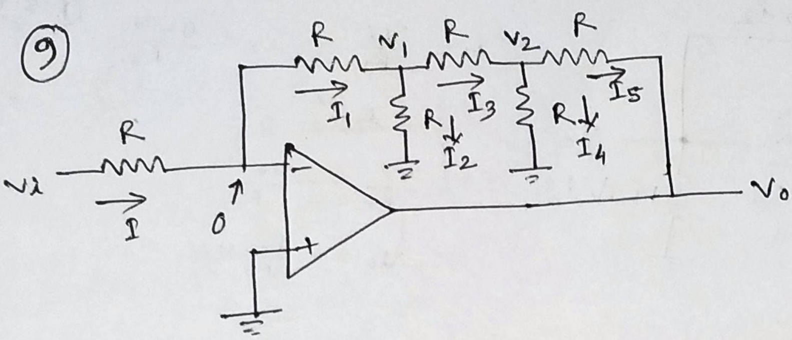
(c) Gain $= -22 \pm 0.2\% = -22 \pm 0.044 = \begin{matrix} -21.956 \checkmark \\ -22.044 \ (\times) \end{matrix}$

$$\therefore -21.956 = -22 \times \frac{1}{1 + \frac{1}{A_{od}} \times 23}$$

$$\therefore 23/A_{od} = 1.002 - 1$$

$$\therefore A_{od} = 11.4 \times 10^3$$

(9)



$I = \frac{v_i - 0}{R} = \frac{v_i}{R} = I_1$ $\therefore V_1 = 0 - I_1 R$

$V_1 = -\frac{v_i}{R} \times R = -v_i$

$\therefore I_2 = \frac{V_1}{R} = -\frac{v_i}{R}$; again, $I_1 = I_2 + I_3$

$\therefore I_3 = I_1 - I_2$

$= \frac{v_i}{R} - \left(-\frac{v_i}{R}\right)$

$I_3 = \frac{2v_i}{R}$

$\therefore V_2 = V_1 - I_3 R$

$= -v_i - \frac{2v_i}{R} \times R$

$\therefore V_2 = -3v_i$

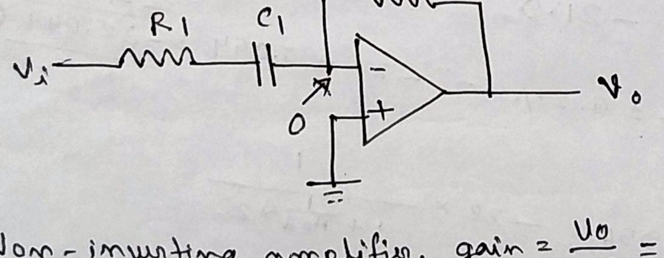
So, $I_4 = \frac{V_2}{R} = -\frac{3v_i}{R}$

$I_5 = I_3 - I_4 = \frac{2v_i}{R} - \left(-\frac{3v_i}{R}\right) = \frac{5v_i}{R}$

$V_o = V_2 - I_5 R = -3v_i - \frac{5v_i}{\cancel{R}} \cdot \cancel{R} = -8v_i$

$\therefore \frac{V_o}{v_i} = -8 = A_V$

(10)

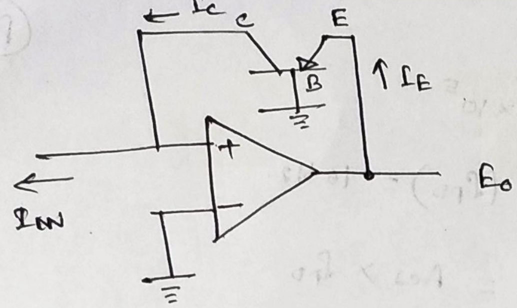


Non-inverting amplifier, gain $= \frac{V_o}{V_i} = -\frac{Z_2}{Z_1}$

$= -\frac{R_2}{R_1 + \frac{1}{j\omega C_1}}$

Gain $= -\frac{R_2 (j\omega C_1)}{R_1 j\omega C_1 + 1}$

(11)



$$\underline{V_{EB} = E_o.}$$

$$I_E = I_{ES} \exp\left(\frac{V_{EB}}{V_T}\right)$$

$I_E \approx I_C$ (β very high)

$\therefore I_C = I_{IN}.$

$$\therefore I_{IN} = I_{ES} \exp\left(\frac{V_{EB}}{V_T}\right)$$

$$\frac{I_{IN}}{I_{ES}} = \exp\left(\frac{E_o}{V_T}\right)$$

$$\therefore \underline{E_o = \frac{KT}{q} \ln\left(\frac{I_{IN}}{I_{ES}}\right)} \; ; \left[V_T = \frac{KT}{q}.\right]$$

(12) Full power bandwidth (FPBW) $= \dfrac{SR}{2\pi V_{o,max}}.$

SR = slew rate

$V_{o,max}$ = peak output voltage

(a) $FPBW = \dfrac{5\, V/\mu s}{2\pi(5)} = \dfrac{\cancel{5}\times 10^6\, V/S}{2\pi \times \cancel{5}} = \underline{159.2\, kHz.}$

(b) $FPBW = \underline{530.78\ kHz.}$

(c) $FPBW = \underline{1.99\ MHz..}$

(13) output peak = 10 V. max. frequency = 12 KHz.

$\therefore$ FPBW = 12 KHz.

If the max. operating freq. is limited by the <u>slew rate</u>, then

$$FPBW = \frac{SR}{2\pi V_{omax}}.$$

$$\therefore SR = FPBW \times 2\pi V_{omax}.$$

$$= 12\times 10^3 \times 2\pi \times 10$$

$$\underline{SR = 0.75\, V/\mu s.}$$

(14)

open-loop gain $(A_{od}) = 2 \times 10^5$

Dominant pole frequency $(f_{PD}) = 10\text{ Hz}$.

$\therefore$ unity-gain bandwidth $= A_{od} \times f_{PD}$

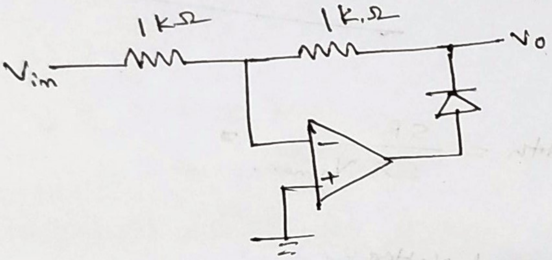
$= 2 \times 10^6$

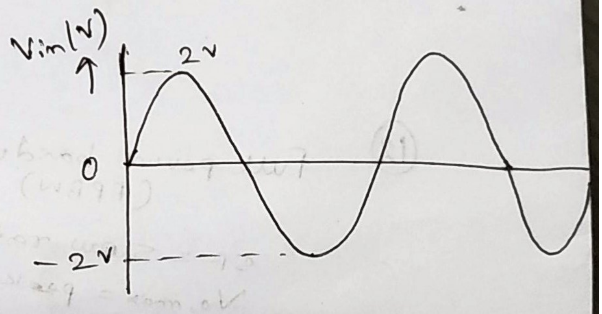
Closed loop gain $(A_{cd}) = 100$

$\therefore$ so, closed loop frequency $= \dfrac{2 \times 10^6}{100} = 2 \times 10^4$

$= 20\text{ KHz}$.

(15)

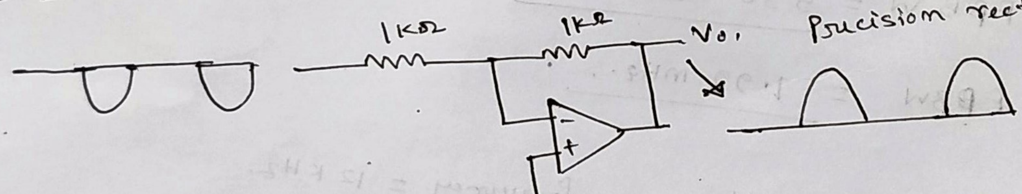




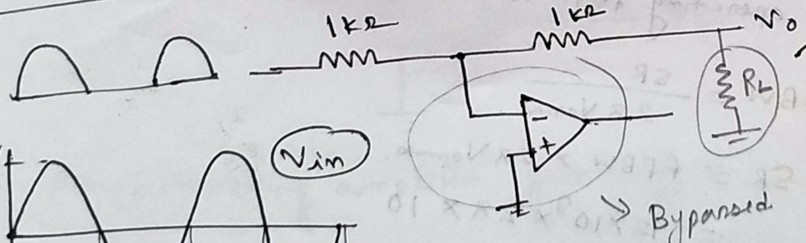
This is an Inverting amplifier with gain = -1

When Vin is negative, Vo is positive, diode in forward bias.

Precision rectifier (inverting).

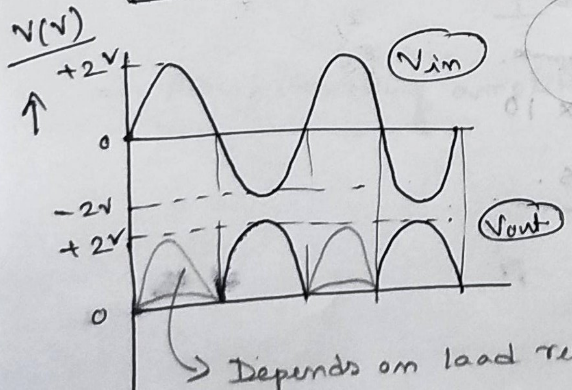


When Vin is positive, diode is OFF.



Depending on RL Vo will change (Voltage divider rule)

Bypassed



Depends on load resistance.

if RL is very high

if RL is low

Vo →