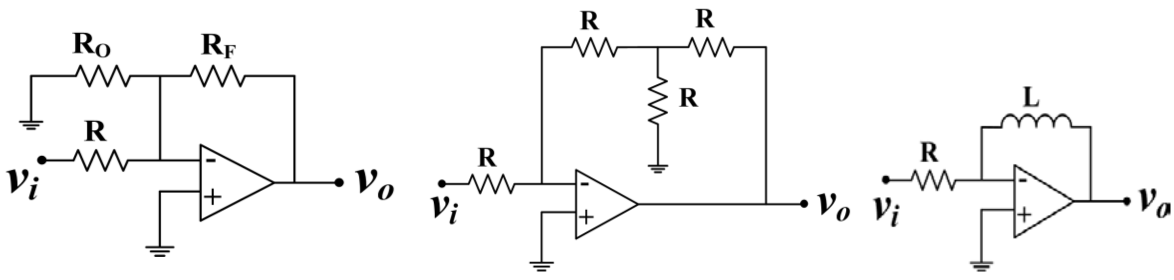
3rd October, 2016

<u>Home Assignment –9</u>

1. For the circuits shown in **Fig. 1**, determine 'v_o' in terms of 'v_i'. Assume that the op-ampsare ideal.



(a)(b) **(c)**

Fig. 1

2. Determine'v_o' in terms of 'v_i' for the difference amplifier, using an ideal op-amp, as shown in **Fig.2,** assuming that both the inputs v_{i1} and v_{i2} are connected to a common input v_i ($v_i = v_{i1} = v_{i2}$). This is known as **common mode gain($A_{cm} = \frac{v_o}{v_i}$)** of this difference amplifier. Also, calculate generalized expression for 'v_o' in terms of 'v_{i1}' and 'v_{i2}'. Show that if $\frac{R_2}{R_1}$is chosen be equal to$\frac{R_4}{R_3}$, then A_{cm} becomes zero and differential mode gain **($A_{dm} = \frac{v_o}{v_{i2} - v_{i1}}$)** becomes $\frac{R_2}{R_1}$.Now assuming that the resistor ratio $\frac{R_2}{R_1}$is 1% less than $\frac{R_4}{R_3}$, determine the **common mode rejection ratio(CMRR)** of the circuit in dB. The values of **R_3**and **R_4** are 10 kΩ and 100 kΩ respectively.

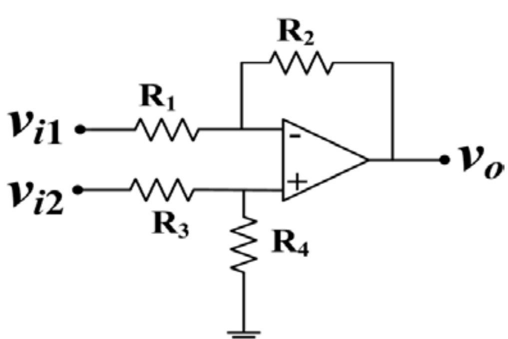


Fig. 2

3. Design an ideal op-amp to produce the output v_o=2v_{i1}+3v_{i2}– 4(v_{i3}+5v_{i4}). All the input signals are in phase. Resistor values must be in between 1 kΩ and 100 kΩ.

4. For the circuit shown in **Fig.3,**if v_i=1V, determine v_o and all the branch currentsi_1, i_2, i_o and i_L, assuming the op-amp to be ideal. Repeat the same for v_i =-1 V. Also, determine the amount of current supplied (or sunk) by the op-amp output in each case.

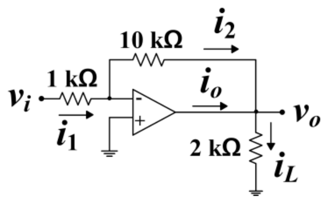


Fig. 3

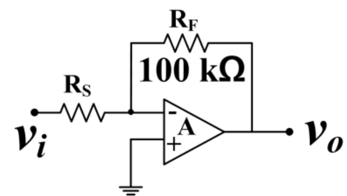


Fig. 4

5. An inverting op-amp shown in **Fig.4**has to be designed to have a gain of -50. However the **open loop gain** of the op-amp is 200. If $\mathbf{R_F}$ = 100kΩ, determine the value of $\mathbf{R_S}$.

6. For the circuit shown in **Fig. 5**, calculate the output voltage (v_o). Assume all op-amps are ideal.

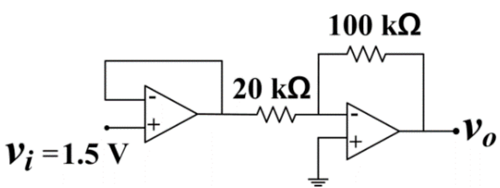


Fig. 5

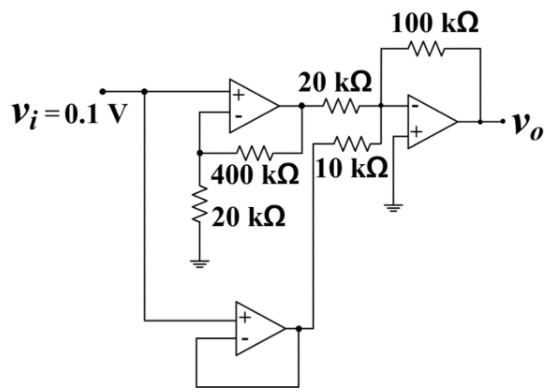


Fig. 6

7. For the circuit shown in **Fig. 6**, calculate the output voltage (v_o). Assume all op-amps are ideal.

8. For the circuit shown in **Fig. 7**, sketch $v_o(t)$ if $v_i(t) = \mathbf{5\ sin(100\pi t)}$. Now, instead of grounding the point **'P'** connect it to (a) -3 V and (b) +2 V supply and sketch $v_o(t)$. Assume the op-amp and diode areideal.

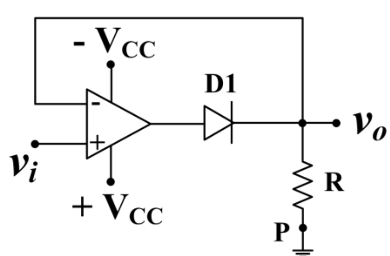
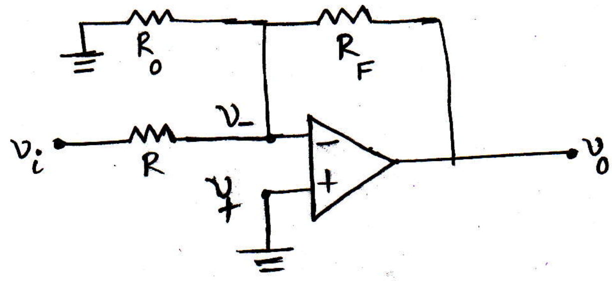
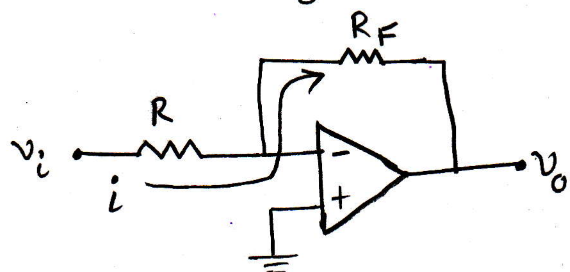


Fig. 7



Since the op-amp is ideal $v_+ = v_- = 0$. Hence no current flows through 'R_0'.

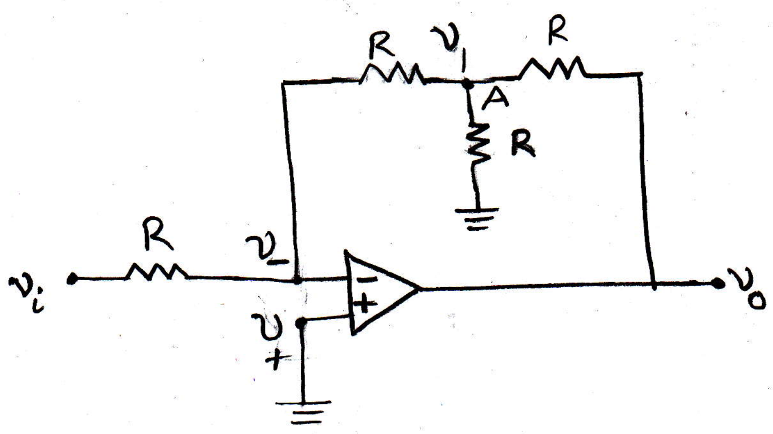
Then we may have the following equivalent circuit.



Since same current flows through 'R' and 'R_F' we can write,

$$v_0 = -\frac{R_F}{R} v_i$$

$$\therefore \boxed{v_0 = -\frac{R_F}{R} v_i}$$



Since the op-amp is ideal, $v_+ = v_- = 0$. Hence, 'v_1' becomes,

$$v_1 = -\left(\frac{v_i}{R}\right) \cdot R = -v_i \quad \text{——— (1)}$$

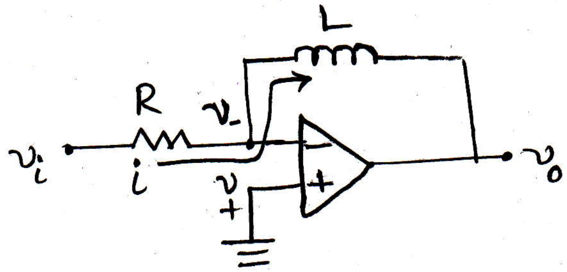
Now apply KCL at node 'A'.

$$\frac{v_1}{R} + \frac{v_1}{R} + \frac{v_1 - v_o}{R} = 0 \quad [\because v_- = 0]$$

$$\Rightarrow \quad 3v_1 - v_o = 0$$

$$\Rightarrow \quad -3v_i = v_o \quad [\because \text{From (1)}]$$

$$\therefore \quad \boxed{v_o = -3v_i}$$



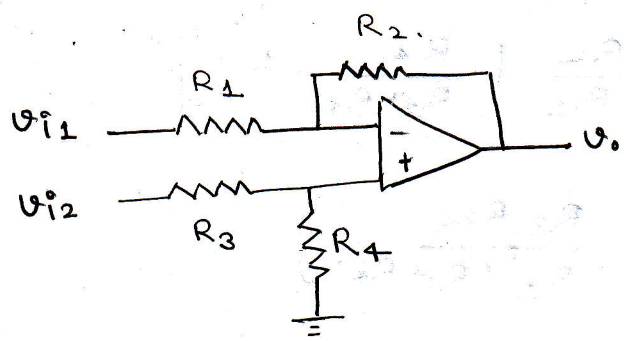
Since the op-amp is ideal $v_+ = v_- = 0$. And same current flows through the resistor, 'R' and inductor, 'L'.

$$i = \frac{v_i}{R}$$

and

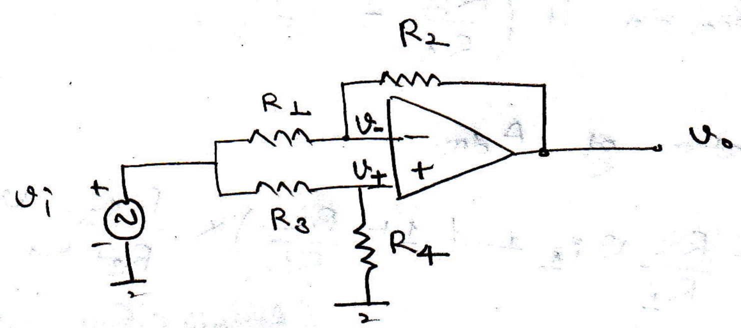
$$v_o = -L\frac{di}{dt} = -L\frac{d}{dt}\left(\frac{v_i}{R}\right)$$

$$= -\frac{L}{R}\frac{dv_i}{dt}$$



i) for determination of Acm. v_{i1} & v_{i2} are tied together to v_i.

So



$$\frac{v_i - v_-}{R_1} = \frac{v_- - v_o}{R_2} \Rightarrow \frac{v_i}{R_1} - v_-\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = -\frac{v_o}{R_2} \quad \text{—(i)}$$

$$v_+ = v_i \times \frac{R_4}{R_3 + R_4} = v_- \quad \text{—(ii)}$$

$\Rightarrow$ Substituting v_- from eq. (ii) to eq. (i)

$$\Rightarrow \frac{v_i}{R_1} - \frac{v_i \times R_4}{R_3 + R_4} \times \frac{R_1 + R_2}{R_1 R_2} = -\frac{v_o}{R_2}.$$

$$\Rightarrow v_o = v_i \left[-\frac{R_2}{R_1} + \frac{R_4}{R_3 + R_4} \times \left(\frac{R_1 + R_2}{R_1}\right) \right]$$

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

$$\Rightarrow v_o = v_i \left[\frac{R_4}{R_3+R_4} + \frac{R_2}{R_1}\left(\frac{R_4}{R_3+R_4} - 1\right)\right]$$

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

$$\Rightarrow A_{cm} = \frac{v_o}{v_i} = \frac{R_4}{R_3+R_4}\left[1 - \frac{R_2}{R_1}\cdot\frac{R_3}{R_4}\right]$$

$$\Rightarrow A_{cm} = 0 \text{ if } \left(\frac{R_2}{R_1} = \frac{R_4}{R_3}\right)$$

ii) Determination of A_{dm}.

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

(Applying Superposition principle by considering v_{i1} and v_{i2} individually)

$$\Rightarrow \text{so if } \frac{R_2}{R_1} = \frac{R_4}{R_3}.$$

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

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

$$\Rightarrow v_o = -\frac{R_2}{R_1} v_{i1} + \frac{R_4}{R_3} v_{i2} = +\frac{R_2}{R_1}(v_{i2} - v_{i1})$$

for $\left(\frac{R_2}{R_1} = \frac{R_4}{R_3}\right)$

$$\Rightarrow A_{dm} = \frac{v_o}{v_{i2} - v_{i1}} = \frac{R_2}{R_1}.$$

$$\because \frac{R_4}{R_3} = \frac{100\,k\Omega}{10\,k\Omega} = 10$$

so $\frac{R_2}{R_1} = 9.9$ (1% less than $\frac{R_4}{R_3}$)

$$\Rightarrow A_{cm} = \frac{1}{1 + \frac{1}{10}} \times \left(1 - \frac{9.9}{10}\right) = 9.09 \times 10^{-3}$$

$$\left[\because A_{cm} = \frac{1}{1 + \frac{R_3}{R_4}}\left(1 - \frac{R_2}{R_1}\cdot\frac{R_3}{R_4}\right)\right]$$

(Determination of A_{dm})

$\Rightarrow v_o = -9.9 v_{i1} + (1 + 9.9) \times \frac{1}{1 + \frac{1}{10}} \times v_{i2}$

$v_o = -9.9 v_{i1} + 10.9 \times \frac{10}{11} v_{i2}$

$v_o = -9.9 v_{i1} + 9.909 v_{i2}$

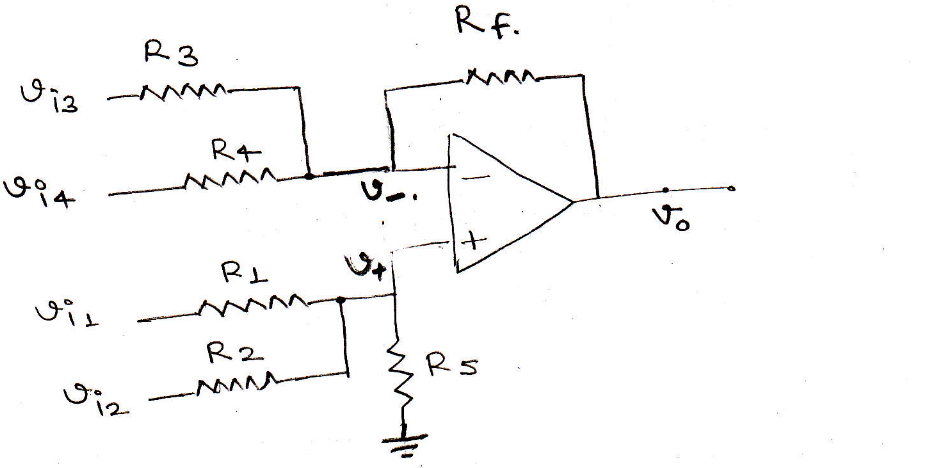
$v_o \simeq 9.9 (v_{i2} - v_{i1})$

$\Rightarrow A_{dm} \simeq 9.9$

$CMRR = 20 \log_{10} \left(\frac{A_{dm}}{A_{cm}} \right)$

$= 60.7 dB$

$\because$ $v_o = 2v_{i1} + 3v_{i2} - 4(v_{i3} + 5v_{i4})$
For implementation of v_o from given set of inputs ($v_{i1}, v_{i2}, v_{i3}, v_{i4}$) of OPAMPS are inverting & non-inverting configurations required



Applying superposition theorem,

$$\frac{v_o}{v_{i3}} = -\frac{R_F}{R_3} = -4 \text{ with } v_{i1} = v_{i2} = v_{i4} = 0 \text{ and}$$

$$\frac{V_o}{v_{i4}} = -\frac{R_F}{R_4} = -20 \text{ with } v_{i1} = v_{i2} = v_{i3} = 0$$

Thus, $\frac{R_F}{R_3} = 4$ and $\frac{R_F}{R_4} = 20$

Choosing $R_4 = 1\,K$, will lead to $R_F = 20K$ and $R_3 = 5K$.

Now, considering V_{i1} with $U_{i2} = U_{i3} = V_{i4} = 0$,

$$V_+ = V_{i1} \times \frac{R_2 \| R_5}{R_1 + R_2 \| R_5} = V_{i1} \times \frac{(R_2 R_5)/(R_2+R_5)}{R_1 + \frac{R_2 R_5}{R_2 + R_5}}$$

$$= V_{i1} \times \frac{R_2 R_5}{R_1 R_2 + R_1 R_5 + R_2 R_5}$$

$$= V_{i1} \times \frac{R''}{R_1}$$

$R'' = R_1 \| R_2 \| R_5$ ---- (i)

Now, $$\frac{v_o}{v_+} = 1 + \frac{R_F}{R_3 \| R_4} = 1 + \frac{\cancel{20}^{4} \times 6}{\cancel{5} \times 1}$$

$$= 25$$

$$\Rightarrow \frac{V_o \times R_1}{V_{i1} \times R''} = 25 \Rightarrow \frac{V_o}{V_{i1}} = \frac{25 \times R''}{R_1}$$

$\because \frac{v_o}{v_{i1}} = 2 \Rightarrow \frac{25 \times R''}{R_1} = 2$

$\Rightarrow \frac{R''}{R_1} = \frac{2}{25} = 0.08$

$\Rightarrow R_1 = 12.5 R''$ ------ (ii)

considering v_{i2} with $v_{i1} = v_{i3} = v_{i4} = 0$

we obtain,

$v_+ = v_{i2} \times \frac{R_1 \| R_5}{R_2 + R_1 \| R_5} = v_{i2} \times \frac{R''}{R_2}.$

$\Rightarrow v_o = \left(1 + \frac{R_F}{R_3 \| R_4}\right) \times \frac{R''}{R_2} \times v_{i2}.$ $\quad \because \frac{v_o}{v_{i2}} = 3.$

$\Rightarrow \left(1 + \frac{20K \times 6K}{5K}\right) \times \frac{R''}{R_2} = 3.$

$\Rightarrow 25 \times \frac{R''}{R_2} = 3 \Rightarrow \frac{R''}{R_2} = \frac{3}{25} = 0.12$

$\Rightarrow R_2 = 8.33\ R''$ — (iii)

from eq. (i) & (ii) $\quad R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2} = \frac{12.5 R'' \times 8.33 R''}{12.5 R'' + 8.33 R''}$

$\Rightarrow R_1 \| R_2 = 5 R''$ $\quad \because$ from eq. (i) $R'' = R_1 \| R_2 \| R_5.$

$\Rightarrow R'' = 5R'' \| R_5 \Rightarrow R'' = \frac{5R'' R_5}{5R'' + R_5} \Rightarrow 5R'' + R_5 = 5R_5$

$\Rightarrow R_5 = 1.25 R''.$ — (iv)

$\because$ All the resistor have to be in range of 1kΩ - 100kΩ

$\therefore$ from eq. (ii) & (iii) R_1 is lager than R_2.

So choose $R_1 = 100\,k\Omega$

$\therefore$ from eq (ii)

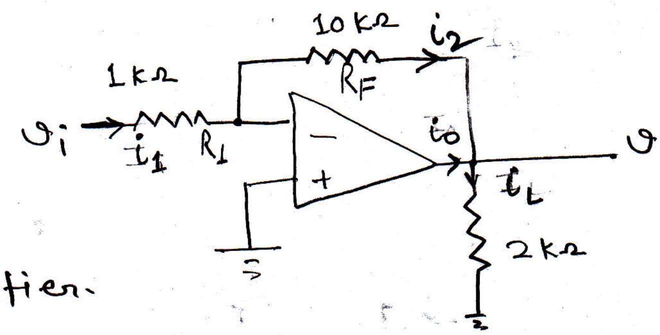
$\Rightarrow R'' = \dfrac{R_1}{12.5} = 8\,k\Omega.$

from eq. (iii)

$\Rightarrow R_2 = 66.64\,k.$

& from eq. (iv)

$\Rightarrow R_5 = 1.25 \times 8\,k\Omega = 10\,k\Omega.$



∵ This is an inverting amplifier & for an inverting amplifier.

$$\Rightarrow \frac{v_o}{v_i} = -\frac{R_F}{R_1} = -\frac{10K}{1K} = -10.$$

a). $v_o = -10V$ if $v_i = +1V$

$$i_1 = \frac{v_i}{R_1} = \frac{1}{1K} = 1mA.$$

$\Rightarrow i_2 = i_1 = 1mA$

$$\Rightarrow i_L = \frac{v_o}{2K} = -\frac{10}{2K} = -5mA.$$

$\Rightarrow ∵ i_o + i_2 = i_L \Rightarrow i_o = -5mA - 1mA = -6mA$

∴ Op-Amp is sinking current.

b) if $v_i = -1V$ $v_o = 10V$

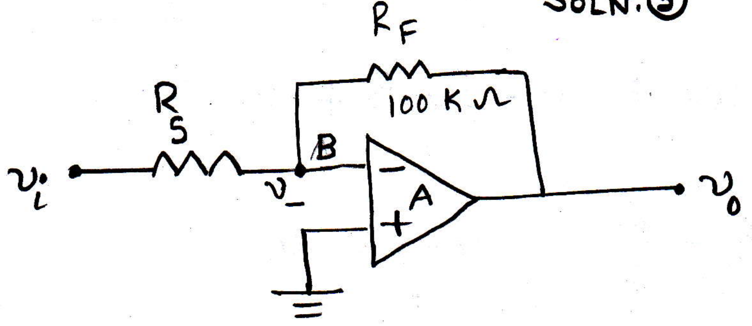
$$∴ i_1 = \frac{v_i}{R_1} = -\frac{1}{1K} = -1mA.$$

$\Rightarrow i_2 = i_1 = -1mA.$

$$\Rightarrow i_L = \frac{v_o}{2K} = \frac{10}{2K} = 5mA.$$

$\Rightarrow i_o = i_L - i_2 = 5mA + 1mA = 6mA.$

∴ Op-Amp is supplying current.



given

open loop gain , $A = 200$

desired gain, $\frac{v_o}{v_i} = -50 \Rightarrow v_o = -50\, v_i$ — ①

But from the figure,

$$A = -\frac{v_o}{(v_- - 0)} = 200 \Rightarrow v_o = -200\, v_- \quad — ②$$

Applying KCL at node "B, we get

$$\frac{v_- - v_i}{R_S} + \frac{v_- - v_o}{R_F} = 0$$

$$\Rightarrow v_-\left(\frac{1}{R_S} + \frac{1}{R_F}\right) = \frac{v_o}{R_F} + \frac{v_i}{R_S}$$

$$\Rightarrow v_-(R_S + R_F) = v_o R_S + v_i R_F$$

$$= v_o R_S - \frac{v_o}{50} R_F \quad [\because \text{From ①}]$$

$$\Rightarrow v_-(R_S + R_F) = \left(R_S - \frac{R_F}{50}\right) v_o$$

$$= \left(R_S - \frac{R_F}{50}\right) \times (-200\, v_-) \quad [\because \text{From ②}]$$

$$\Rightarrow R_S + 100\,K = -200\, R_S + \left(\frac{200}{50} \times 100\,k\right)$$

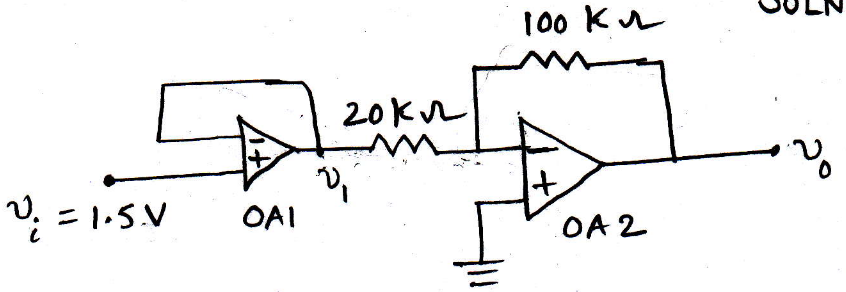
$$\Rightarrow R_S + 100\,K = -200\,R_S + 400\,k$$

$$\Rightarrow 200\,R_S + R_S = -100\,K + 400\,K$$

$$\Rightarrow 201\,R_S = 300\,K$$

$$\Rightarrow R_S = \frac{300\,K}{201} = 1.492\ k\Omega$$

$$\therefore \boxed{R_S = 1.492\ k\Omega}$$



if both the op-amps OA1 and OA2 are assumed to be ideal,

then

$$v_1 = v_i = 1.5\ V$$

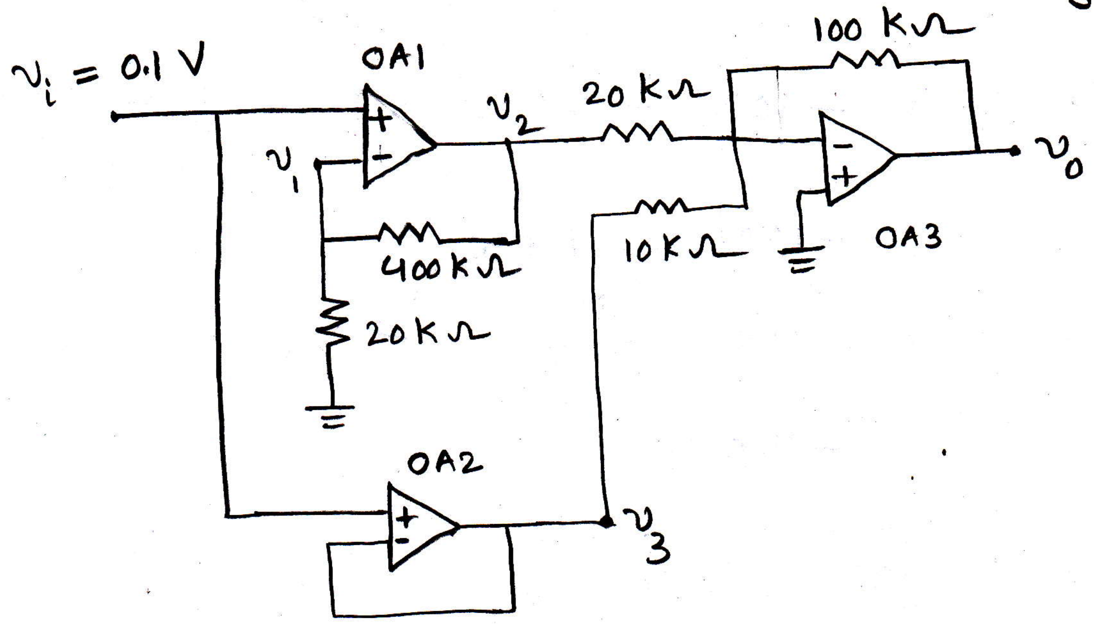
Op-amps are ideal, therefore loading of second op-amp to first op-amp will be minimum. (Input impedance : high Output impedance : very low)

we can write that,

$$v_0 = -\frac{100\ K}{20\ K} \times v_i$$

$$= -5 \times 1.5\ V = -7.5\ V$$

$$\therefore \boxed{v_0 = -7.5\ V}$$



if all the op-amps depicted in the figure, are assumed to be ideal, then

$$v_1 = v_3 = v_i = 0.1 \text{ V} \quad \text{——— (1)}$$

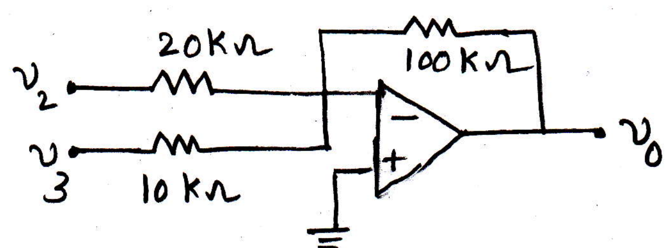
and

$$v_2 = v_1\left[1 + \frac{400K}{20K}\right] = v_1[1+20]$$

$$= 21\, v_i \qquad [\because \text{From (1)}]$$

$$\Rightarrow \quad v_2 = 21\, v_i \quad \text{——— (2)}$$

Now the op-amp OA3, becomes,



$$v_0 = -\left(\frac{100K}{10K}\right)v_3 - \left(\frac{100K}{20K}\right)v_2$$

$$= -10v_3 - 5v_2$$

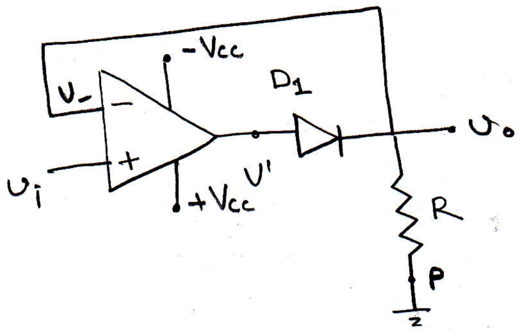
$$\Rightarrow v_o = -10v_i - 5(21v_i) \quad [\because \text{From } 1 \,\&\, 2]$$

$$= -10v_i - 105v_i$$

$$= -115 \times 0.1\,V \quad [\because v_i = 0.1\,V \text{ given}]$$

$$= -11.5\,V$$

$$\therefore \boxed{v_o = -11.5\,V}$$



⇒ consider diode D_1 is not conducting (cut-off).

Then there will be no current in R.

$\therefore \quad V_o = v_- = 0$

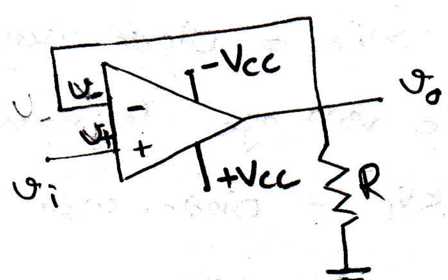
⇒ As $v_i > 0\,V$ (+ve half cycle).

then $V_+ > V_-$ ⇒ $v' = +V_{cc}$

So D_1 will start conducting & equivalent circuit will become:-

∵ This is voltage follower.

$v_o = v_i$

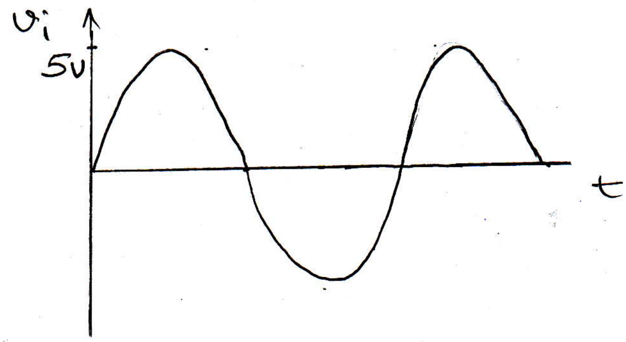


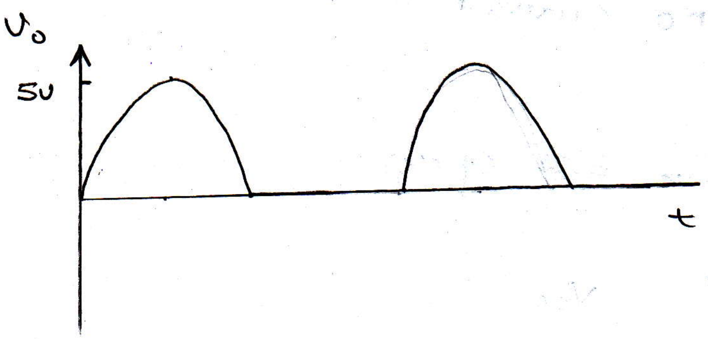
⇒ During -ve half cycle.

$v' =$ output of op-Amp $= -V_{cc}$.

so diode will go in cut-off mode.

⇒ so, no current will flow through R. So $V_o = 0$.



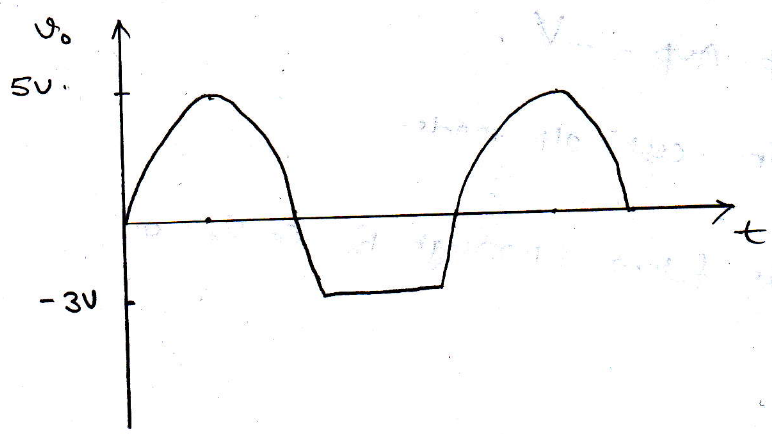


a) if $V_P = -3V$.

when $v_i > V_P$ = Diode will conduct & circuit will become voltage follower. So, $v_o = v_i$

when $v_i < V_P$ = Diode will be in cut-off mode.

So $v_o = V_P = -3V$.



b) if $V_P = +2V$.

when $v_i > V_P$ = Diode will conduct

& $v_o = v_i$

$v_i < V_P$ = Diode will be in cut-off and $v_o = 2V$