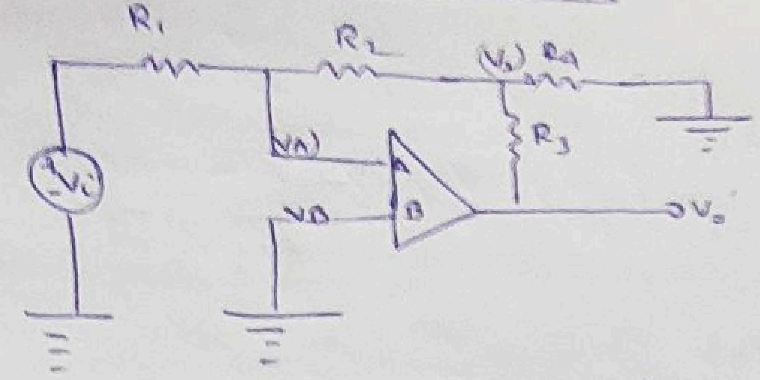
Tutorial-02

(a)



To find signs lets short all the Independent voltage sources.

Here $V_B = 0$.

$$\frac{V_A - 0}{R_1} + \frac{V_A - V_x}{R_2} = 0 \qquad \Rightarrow \frac{V_x - V_o}{R_3} + \frac{V_x - 0}{R_4} + \frac{V_x - V_A}{R_2} = 0$$

By solving the above 2 Equations

$$V_A = \frac{V_o}{R_3 + \frac{(R_1+R_2)R_4}{R_1+R_2+R_4}} \cdot \frac{R_4}{(R_1+R_2+R_4)} \cdot R_1$$

So V_A is a +ve value. and $V_B = 0$.

$\therefore$ B = +ve and A = -ve [For -ve Feedback]

$\Rightarrow$ we can apply the virtual short

So $V_A = V_B = 0$

$$\Rightarrow \frac{V_i}{R_1} = \frac{0 - V_2}{R_2} = \frac{V_2 - 0}{R_4} + \frac{V_2 - V_o}{R_3} \quad \text{[Current direction]}$$

$$\Rightarrow V_2 = -\frac{R_2}{R_1} \cdot V_i$$

$$\text{So } \frac{V_i}{R_1} = \frac{1}{R_4}\left(\frac{-R_2 V_i}{R_1}\right) + \frac{1}{R_3}\left(-\frac{R_2}{R_1} V_i\right) - \frac{V_o}{R_3}$$

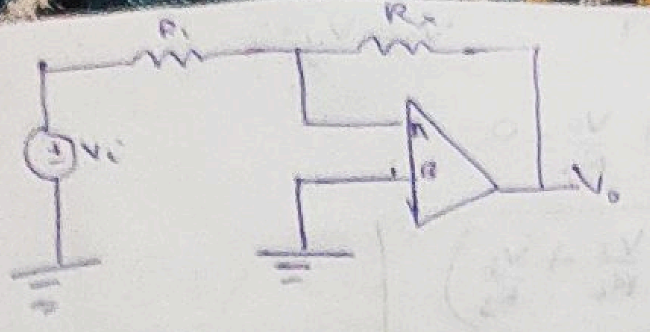
$$\Rightarrow V_i\left[\frac{1}{R_1} + \frac{R_2}{R_1 R_4} + \frac{R_2}{R_1 R_3}\right] = -\frac{V_o}{R_3}$$

$$\Rightarrow V_i \cdot \left(\frac{R_3 R_4 + R_2 R_3 + R_2 R_4}{R_1 \cancel{R_3} R_4}\right) = -\frac{V_o}{\cancel{R_3}}$$

$$\Rightarrow \frac{V_o}{V_{in}} = -\left(\frac{R_3 R_4 + R_2 R_3 + R_2 R_4}{R_1 R_4}\right)$$

$$\boxed{\frac{V_o}{V_{in}} = -\left(\frac{R_2 + R_3}{R_1} + \frac{R_2 R_3}{R_1 R_4}\right)}$$

(b)



$$\frac{V_A - V_o}{R_x} + \frac{V_A - 0}{R_1} = 0 \quad \Rightarrow V_A = \frac{R_1 V_o}{R_1 + R_x} \qquad V_B = 0$$

$\therefore$ A = −ve and B = +ve

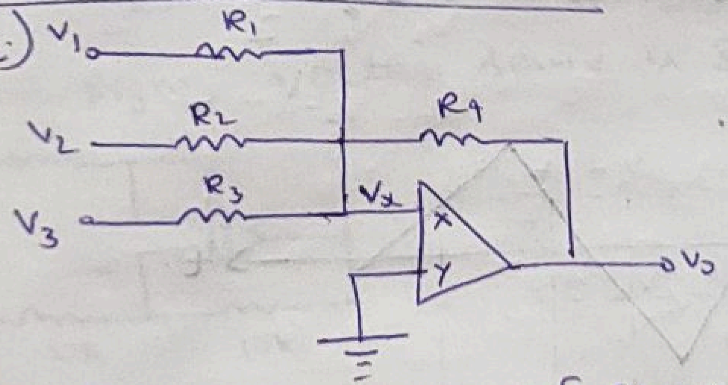
By virtual Short

$\Rightarrow V_A = V_B = 0$ and $\frac{V_A - V_i}{R_1} + \frac{V_A - V_o}{R_x} = 0$

$\Rightarrow \frac{V_o}{V_{in}} = -$ But $V_A = 0$

$\Rightarrow -\frac{V_i}{R_1} - \frac{V_o}{R_x} = 0 \quad \Rightarrow \boxed{\frac{V_o}{V_{in}} = -\frac{R_x}{R_1}}$

(2.)



For Signs:- $V_1 = V_2 = V_3 = 0$ [Short Independent voltage Sources]

$$\frac{V_x - 0}{R_1} + \frac{V_x - 0}{R_2} + \frac{V_x - 0}{R_3} + \frac{V_x - V_o}{R_4} = 0.$$

$$\Rightarrow V_x\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right] = \frac{V_o}{R_4}.$$

V_x is +ve quantity.

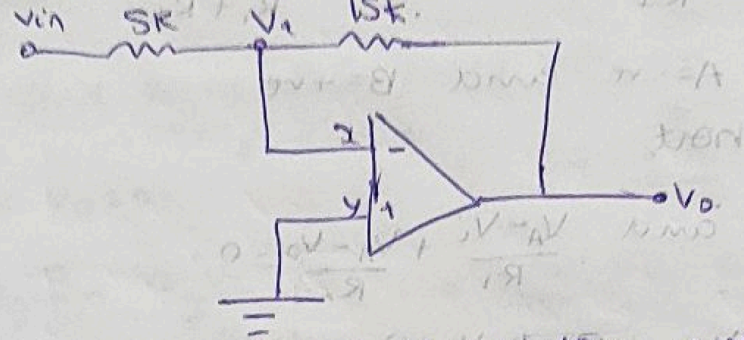
$\therefore$ X = −ve and Y = +ve

By virtual short $V_x = V_y = 0$.

$$\therefore \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_o}{R_A} = 0.$$

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

(3.)



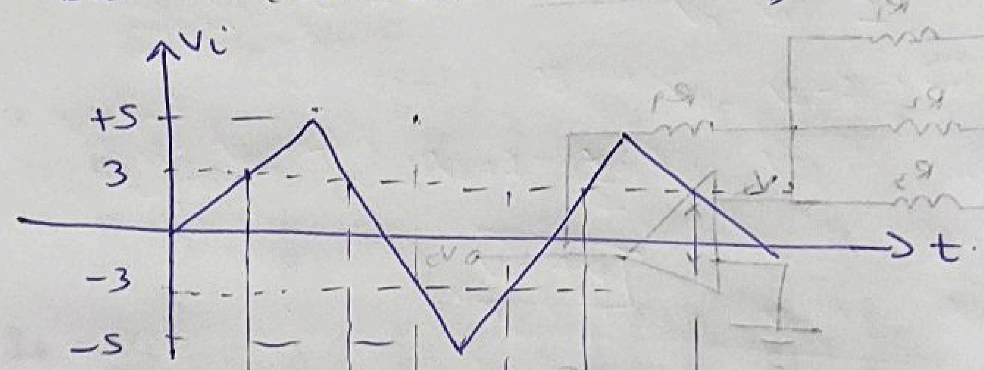
It is -ve feedback system, we can apply the virtual short,

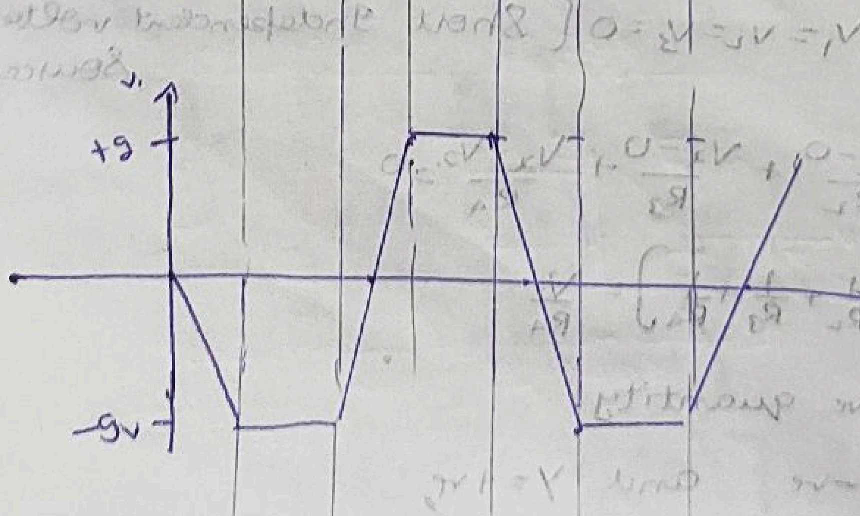
$\therefore V_x = 0$

$$\frac{V_{in} - 0}{5K} = \frac{0 - V_o}{15K} \Rightarrow \frac{V_i}{5K} + \frac{V_o}{15K} = 0.$$

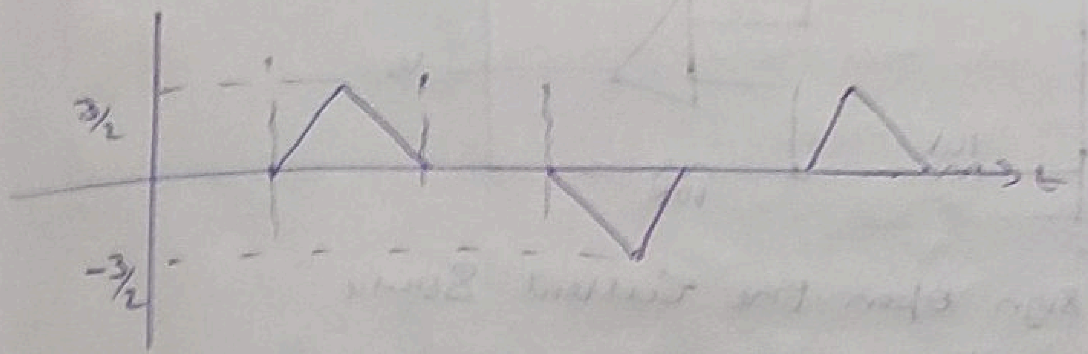
$$\therefore \boxed{V_o = -3V_i}$$

But the saturation is at $\pm 9V$





$$\Rightarrow \frac{V_x - V_{in}}{5K} + \frac{V_x - V_o}{15K} = 0 \quad \Rightarrow V_x = \frac{3V_i + V_o}{4}$$



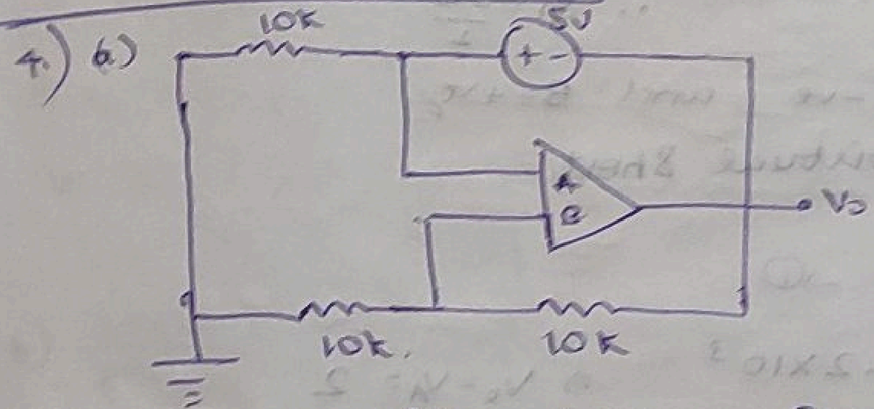
For distortion free output

$$|3V_i| \leq 9V$$

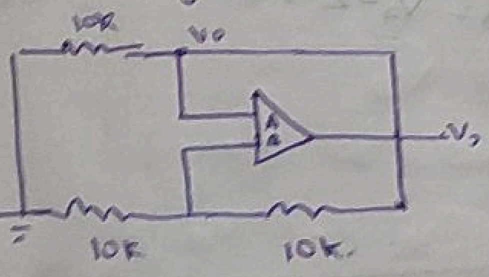
$$|V_i| \leq 3V$$

So Amplitude of the input signal must be less than or Equal to 3

4.) a)



For Signs voltage source is shorted



$$V_A = V_o$$

and $V_B = \left(\frac{V_o}{10K + 10K}\right) \cdot 10K$

$$V_B = \frac{V_o}{2}$$

$\therefore$ A = -ve and B = +ve

By applying virtual short

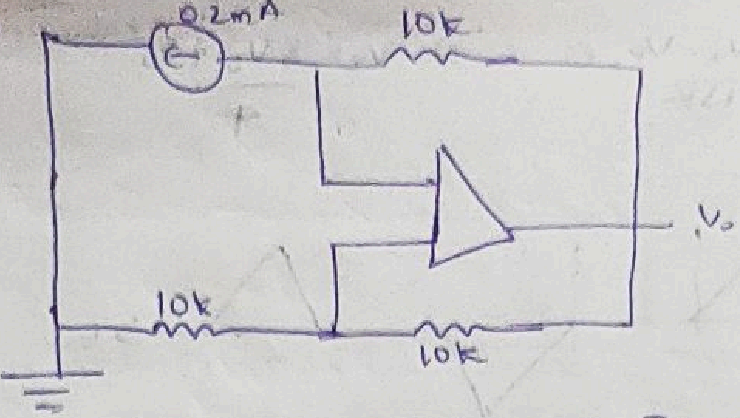
$$V_A = V_B$$

$$V_A = V_B = V_o + 5$$

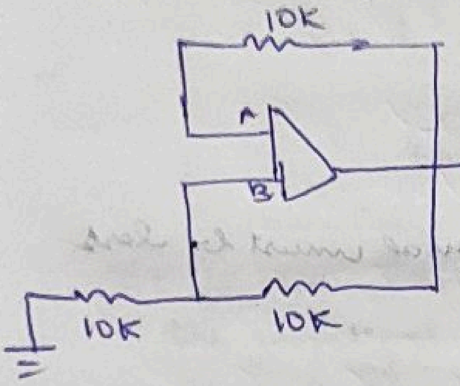
But $V_B = \frac{V_o}{2}$

$\therefore V_o = V_o + 5 \quad \Rightarrow \boxed{V_o = -10V}$

(4) (b)



For sign open the current source.



$V_B = \frac{V_o}{20k} \cdot 10k = \frac{V_o}{2}$.

$\frac{V_A - V_o}{10k} = \frac{V_o}{20k}$ (current flowing must be same)

$\therefore V_A = \frac{3V_o}{2}$

$\therefore A = -ve$ and $B = +ve$

By applying virtual short,

$V_B = \frac{V_o}{2} \rightarrow (1)$

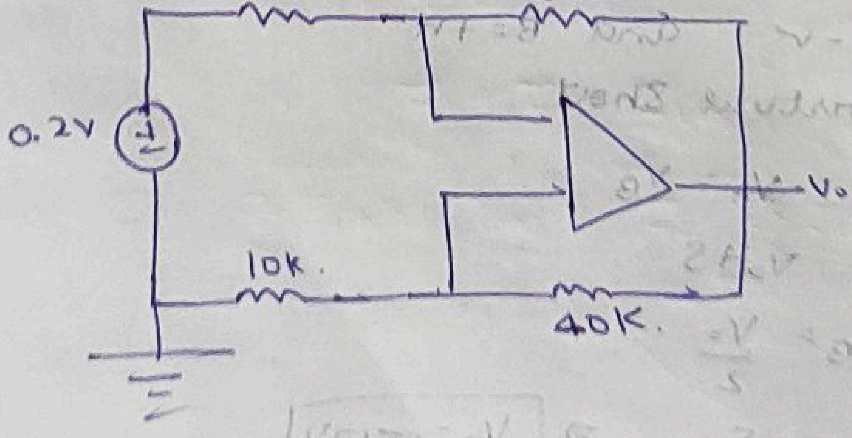
$\Rightarrow \frac{V_o - V_A}{10k} = 0.2 \times 10^{-3}$ $\Rightarrow V_o - V_A = 2$.

$V_A = V_o - 2 \rightarrow (2)$

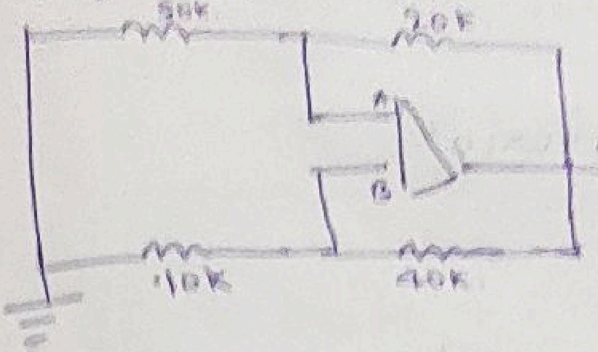
$V_A = V_B \Rightarrow V_o - 2 = \frac{V_o}{2}$

$\Rightarrow \boxed{V_o = 4V}$

(5.) (a)



For finding the sign



$$V_A = \left(\frac{V_o}{20K + 50K}\right) \times 50K = \frac{5V_o}{7}$$

$$V_B = \frac{V_o}{(10+40)K} \cdot 10K = \frac{V_o}{5}$$

$\therefore$ A = -ve and B = +ve

By applying virtual short $V_A = V_B$

$$\frac{0.2 - V_A}{50K} = \frac{V_A - V_o}{20K} \rightarrow ①$$

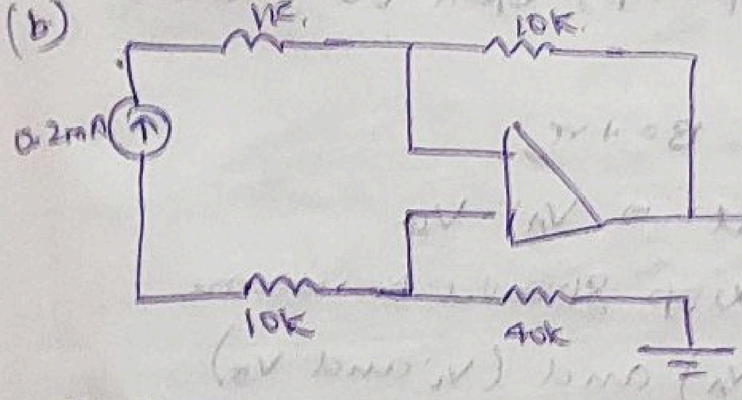
$$\frac{V_o - V_B}{40K} = \frac{V_B - 0}{10K} \rightarrow ②$$

$\Rightarrow V_o = 5V_B = 5V_A$

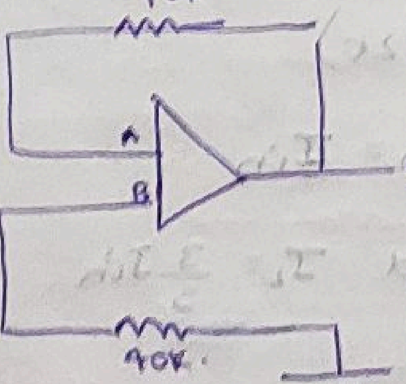
$\Rightarrow 0.4 - 2V_A = 5V_A - 5V_o$

$\Rightarrow \boxed{V_o = -0.11V}$

(b)



For sign



$\therefore$ A = -ve
B = +ve

By virtual short

$V_A = V_B$

$\Rightarrow V_B - 0 = -0.2\times10^{-3}\times40\times10^{3}$

$V_B = -8V$.

and $V_A = -8V$

But $V_A - V_0 = 10\times10^3 \times 0.2\times10^{-3}$

$\Rightarrow V_A - V_0 = 2$

$\Rightarrow V_0 = V_A - 2$

$\boxed{V_0 = -10V}$

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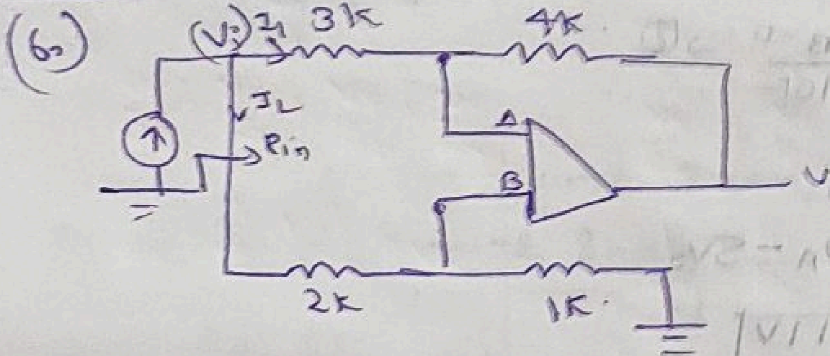
(6)



For signs of the opamp, open the current source.

$\therefore$ A = −ve and B = +ve

By virtual short $\Rightarrow V_A = V_B$

So voltage drop should be same between (V_i and V_A) and (V_i and V_B)

$I_1(3k) = I_2(2k)$

and $I_1 + I_2 = I_{in}$

So $I_1 = \frac{2}{5} I_{in}$ and $I_2 = \frac{3}{5} I_{in}$

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and $\frac{V_B - 0}{1k} = I_2 (1k)$

$\Rightarrow V_B = \frac{3}{5} I_{in} (10^3)$

$$\boxed{V_B = V_A = 600 I_{in}} \rightarrow (1)$$

$\frac{V_A - V_o}{4k} = I_1 \Rightarrow V_A - V_o = 4 \times 10^3 \times I_1$

$\Rightarrow 600 I_{in} - V_o = 4 \times 10^3 \times \frac{2}{5} I_{in} = 1600 I_{in}$

$$\boxed{V_o = -1000 I_{in}}$$

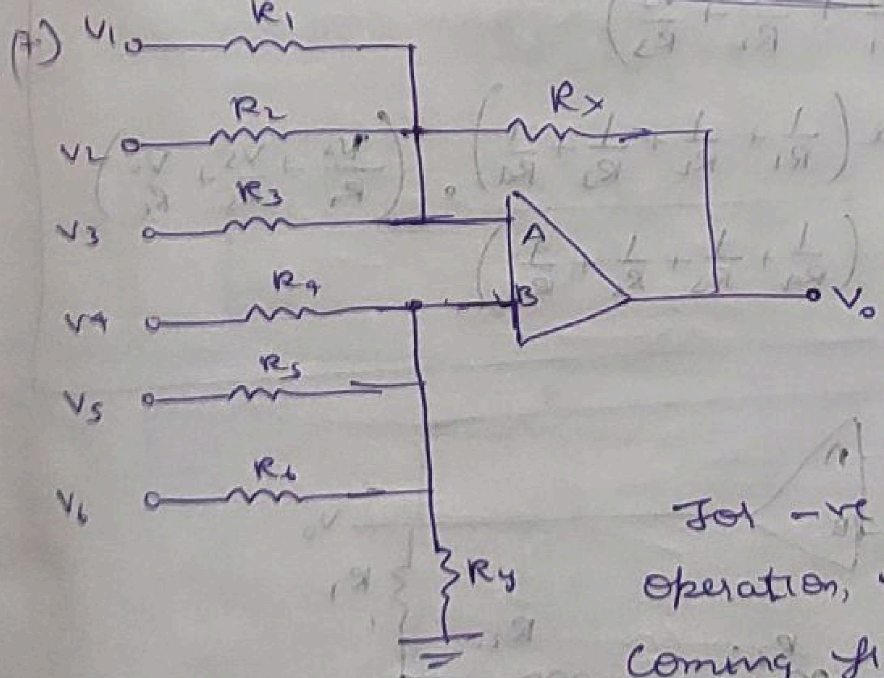
$\Rightarrow V_i - V_A = 3 \times 10^3 \times \frac{2}{5} \times I_{in}$

$\Rightarrow V_i = 600 I_{in} + 1200 I_{in}$

$$\boxed{V_i = 1800 I_{in}}$$

$R_{in} = \frac{V_{in}}{I_{in}} = \frac{1800 I_{in}}{I_{in}} = \underline{\underline{1800\,\Omega}}$

(7.)



For -ve feedback operation, the only feedback coming from V_o should go to A terminal of opamp.

$\therefore$ A = -ve and B = +ve.

By virtual short $V_A = V_B$

$$\frac{V_1 - V_A}{R_1} + \frac{V_2 - V_A}{R_2} + \frac{V_3 - V_A}{R_3} + \frac{V_o - V_A}{R_x} = 0$$

and

$$\frac{V_4 - V_B}{R_4} + \frac{V_5 - V_B}{R_5} + \frac{V_6 - V_B}{R_6} + \frac{0 - V_B}{R_y} = 0$$

$$\Rightarrow \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_o}{R_x} = V_A\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_x}\right)$$

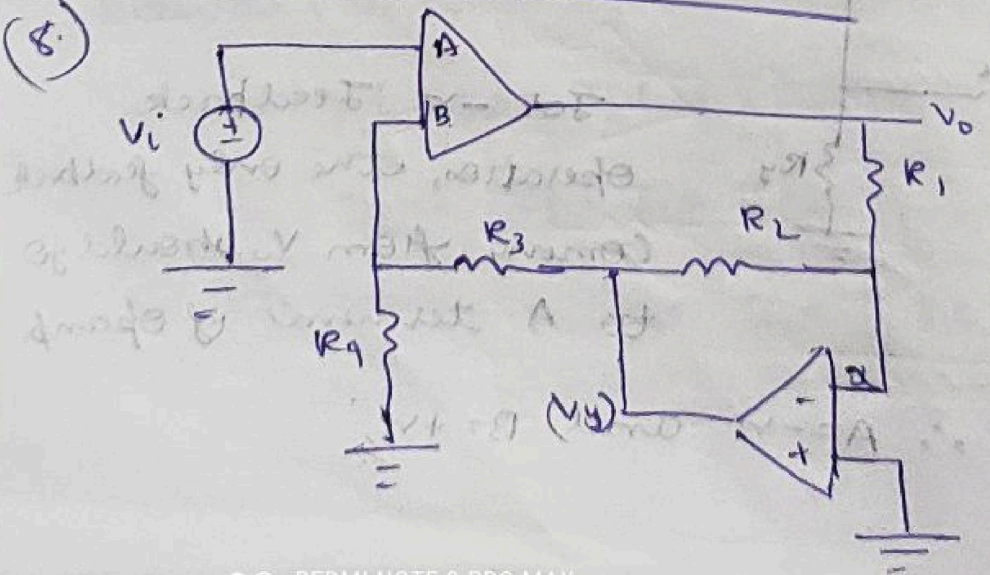
and $$\frac{V_4}{R_4} + \frac{V_5}{R_5} + \frac{V_6}{R_6} = V_B\left(\frac{1}{R_4} + \frac{1}{R_5} + \frac{1}{R_6} + \frac{1}{R_y}\right)$$

But $V_A = V_B$ [virtual short]

$$\therefore \frac{\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_o}{R_x}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_x}} = \frac{\frac{V_4}{R_4} + \frac{V_5}{R_5} + \frac{V_6}{R_6}}{\frac{1}{R_4} + \frac{1}{R_5} + \frac{1}{R_6} + \frac{1}{R_y}}$$

$$\boxed{\Rightarrow V_o = -R_x\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right) + R_x \frac{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right)}{\left(\frac{1}{R_4} + \frac{1}{R_5} + \frac{1}{R_6} + \frac{1}{R_y}\right)} \cdot \left(\frac{V_4}{R_4} + \frac{V_5}{R_5} + \frac{V_6}{R_6}\right)}$$

(8.)



Sign of opamp
By applying virtual short to the lower opamp

So $V_a = 0V$

$\Rightarrow \frac{V_o - 0}{R_1} = \frac{0 - V_y}{R_2} \Rightarrow V_y = \frac{-R_2}{R_1}(V_o)$

[Inverting Amplifier]

$\Rightarrow \frac{V_B - 0}{R_4} + \frac{V_B - V_y}{R_3} = 0$

$$V_B = \frac{R_4 V_y}{R_3 + R_4}$$

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

and $V_A = 0$

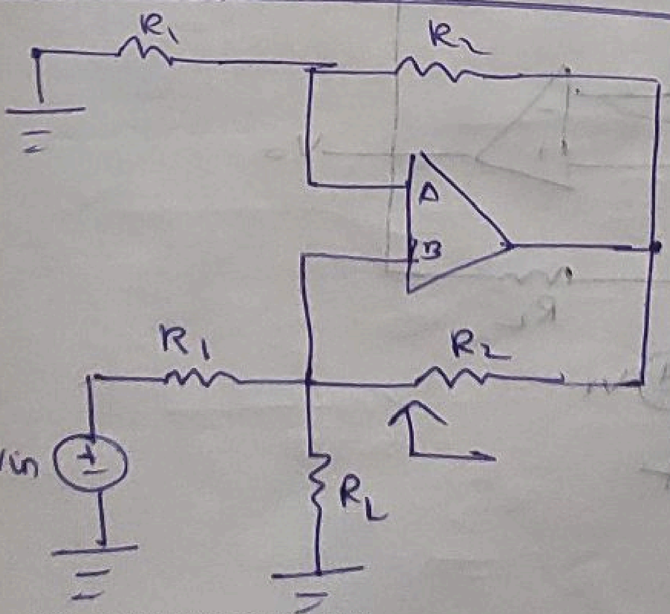
$\therefore$ B = +ve and A = -ve

For applying virtual short $V_A = V_B$.

$$V_A = V_i = \frac{-R_2 R_4}{R_1(R_3+R_4)} V_o$$

$$\Rightarrow \boxed{V_o = -V_i \frac{(R_1)(R_3+R_4)}{R_2 R_4}}$$

(9)



For sign short the voltage sources.

$$V_B = \left(\frac{V_0}{R_2 + \frac{R_1 R_2}{R_1 + R_2}} \right) \frac{R_1 R_L}{R_1 + R_L}$$

$$V_B = \frac{V_0 R_1 R_L}{R_1 R_2 + R_2 R_L + R_1 R_L}$$

and $V_A = \frac{V_0 R_1}{R_1 + R_2}$

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

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

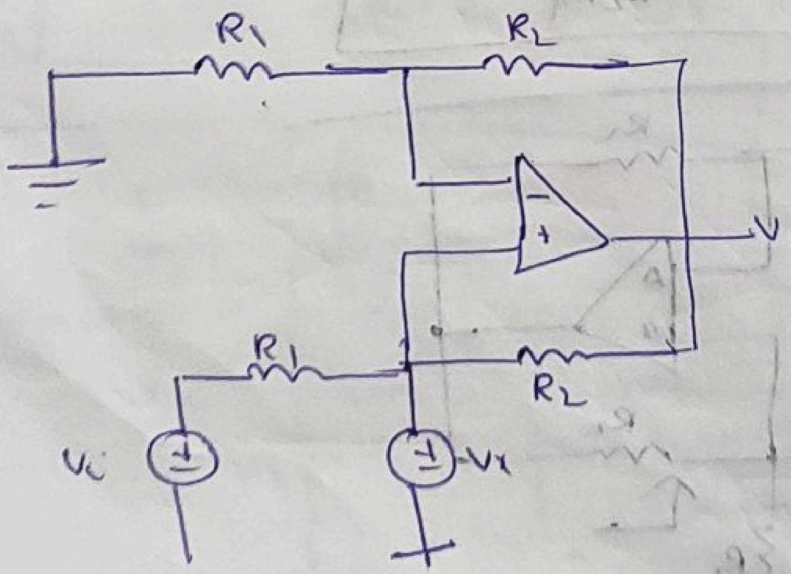
$$= V_0 R_1 \left[\frac{R_1 R_2}{(R_1 + R_2)(R_2 R_1 + R_2 R_L + R_1 R_L)} \right]$$

$\Rightarrow$ +ve

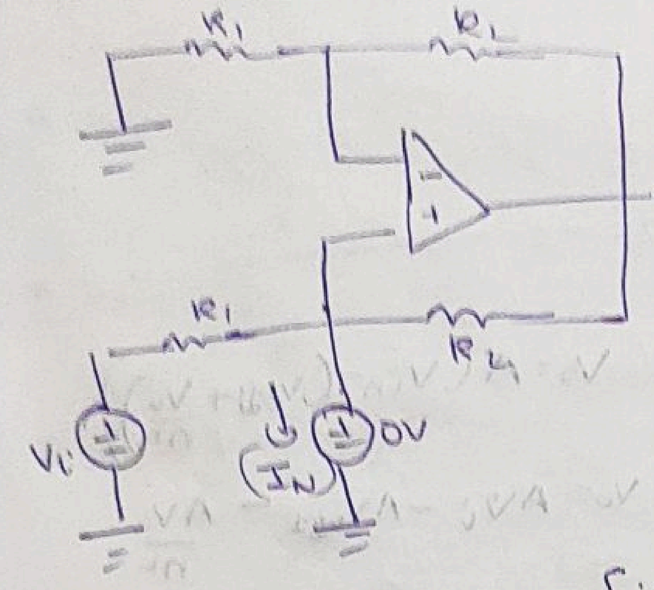
$\therefore$ B = +ve and A = -ve

→ For Norton Equivalent:-

Let's Replace the Resistor R_L with 'V_x' source.



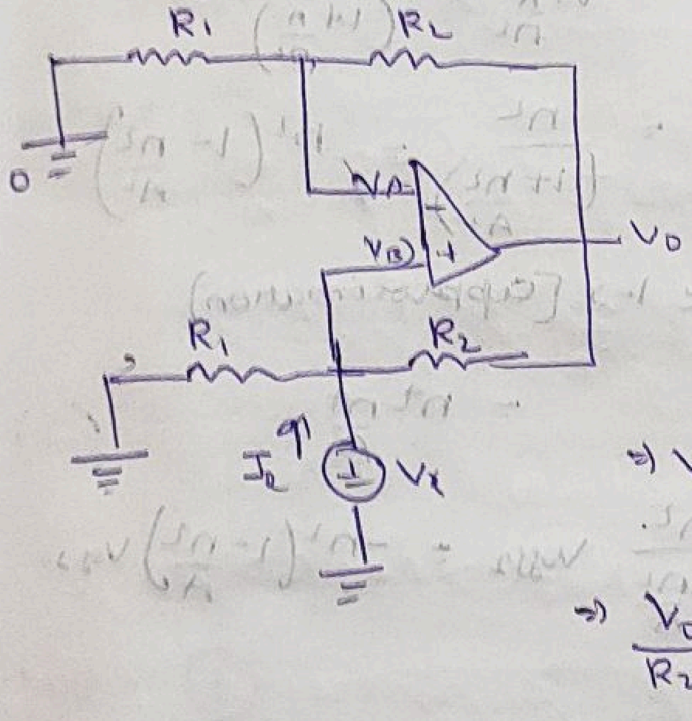
For finding I_N $v_x = 0$.



$$\boxed{I_N = \frac{V_i}{R_1}}$$

$[\because V_o = 0 \text{ and } I_1 = 0]$

To R_{Norton}, $V_i = 0$ and find I_x produced by source v_x.



By virtual short

$V_A = V_x$.

$$\Rightarrow \frac{V_0 - V_A}{R_2} = \frac{V_A}{R_1}$$

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

$$\Rightarrow V_0 = R_2 V_x \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$\Rightarrow I_x = \frac{V_x}{R_1} + \frac{V_x - V_0}{R_2}$$

$$I_x = V_x\left[\frac{1}{R_1} + \frac{1}{R_2} - \left(\frac{1}{R_1} + \frac{1}{R_2}\right)\right]$$

$$I_x = 0 \qquad \therefore (R_N \to \infty)$$

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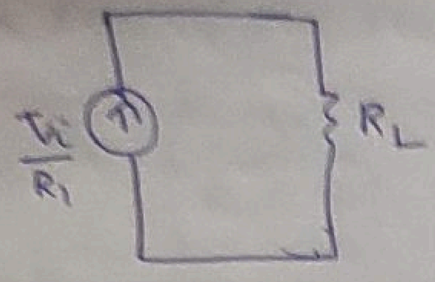
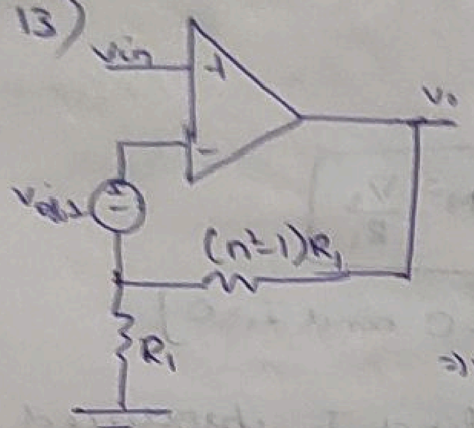


13)



$$V_o = A\left(V_{in} - \left(V_{off} + \frac{V_o}{n^2}\right)\right)$$

$$\Rightarrow V_o = AV_i - AV_{off1} - \frac{AV_o}{n^2}$$

$$\Rightarrow V_o\left(1+\frac{A}{n^2}\right) = AV_i - AV_{off1}$$

$$\Rightarrow V_o = \frac{AV_i}{1+\frac{A}{n^2}} - \frac{AV_{off1}}{\left(1+\frac{A}{n^2}\right)}$$

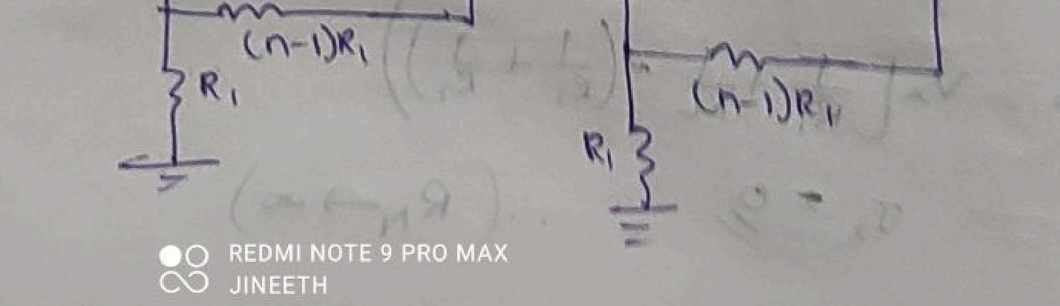
Close loop gain $= \frac{A}{1+\frac{A}{n^2}} = \frac{n^2}{\left(1+\frac{n^2}{A^2}\right)} = n^2\left(1-\frac{n^2}{A^2}\right)$

$A >> n^2$ $\because \frac{1}{1+x} \simeq 1-x$ [approximation]

$$= n^2 - \frac{n^4}{A}$$

Output DC offset $= \frac{-n^2}{1+\frac{n^2}{A}} \cdot V_{off1} = -n^2\left(1-\frac{n^2}{A}\right)V_{off1}$

(b)



$$V_x = \frac{n}{1+\frac{n}{A}}(V_i - V_{off1})$$

$$\Rightarrow V_o = \frac{n}{1+\frac{n}{A}}(V_x - V_{off2})$$

$$\Rightarrow V_o = \frac{n}{1+\frac{n}{A}}\left(\frac{n}{1+\frac{n}{A}}(V_i - V_{off1}) - V_{off2}\right)$$

$$\Rightarrow V_o = \frac{n^2}{(1+\frac{n}{A})^2} V_i - \frac{n^2}{(1+\frac{n}{A})^2} \cdot V_{off1} - \frac{n}{1+\frac{n}{A}} \cdot V_{off2}$$

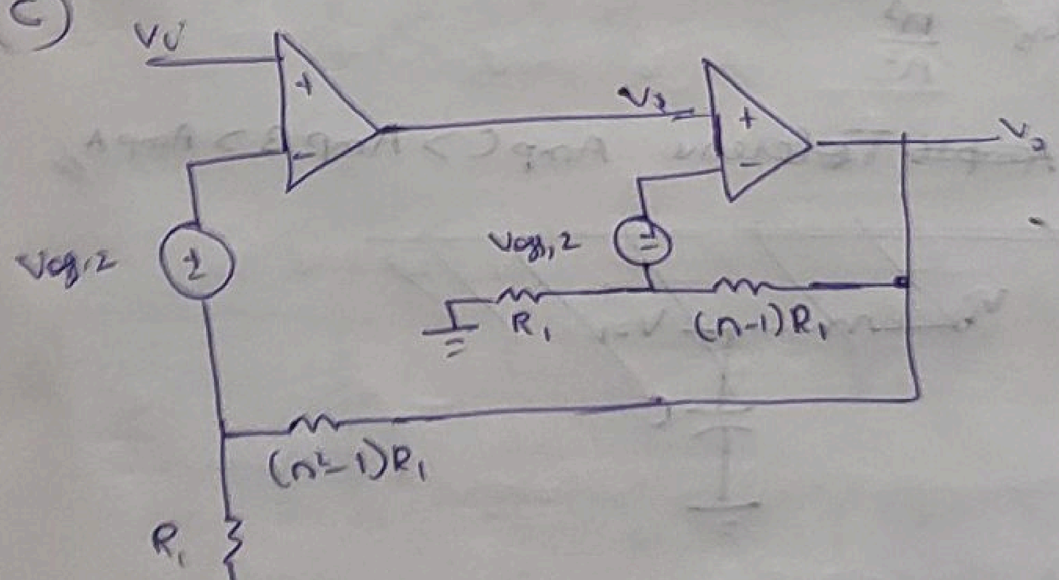
• Close loop gain = $\frac{n^2}{(1+\frac{n}{A})^2} = n^2\left(1-\frac{n}{A}\right)^2$

$$G_L = n + \frac{n^4}{A^2} - \frac{2n^3}{A} \quad \text{[Binomial Expansion]}$$

output DC offset $= \frac{-n^2}{(1+\frac{n}{A})^2} V_{off1} - \frac{n}{(1+\frac{n}{A})} \cdot V_{off2}$

$$= -\left(n^2 + \frac{n^4}{A^2} - \frac{2n^3}{A}\right) V_{off1} - n\left(1-\frac{n}{A}\right) V_{off2}$$

(c)



$$V_x = A\left(V_i - \frac{V_o}{n^2} - V_{off1}\right)$$

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$$V_o = A\left(V_2 - \frac{V_o}{n} - V_{off,2}\right)$$

$$\Rightarrow V_o = A\left(A\left(V_i - \frac{V_o}{n^2} - V_{off,1}\right) - \frac{V_o}{n} - V_{off,2}\right)$$

$$\Rightarrow V_o\left(1 + \frac{A^2}{n^2} + \frac{A}{n}\right) = A^2 V_i - A^2 V_{off,1} - A V_{off,2}$$

$$\Rightarrow V_o = \frac{A^2}{1 + \frac{A}{n} + \frac{A^2}{n^2}}\left(V_i - V_{off,1}\right) - \frac{A}{\left(1 + \frac{A}{n} + \frac{A^2}{n^2}\right)} V_{off,2}$$

$$\Rightarrow V_o = \frac{n^2}{1 + \frac{n}{A} + \frac{n^2}{A^2}}\left(V_i - V_{off,1}\right) - \frac{\left(\frac{n^2}{A}\right)}{\left(1 + \frac{n}{A} + \frac{n^2}{A^2}\right)} V_{off,2}$$

Close loop gain $= G_3 = n^2\left(1 - \frac{n}{A} - \frac{n^2}{A^2}\right)$

output DC offset =

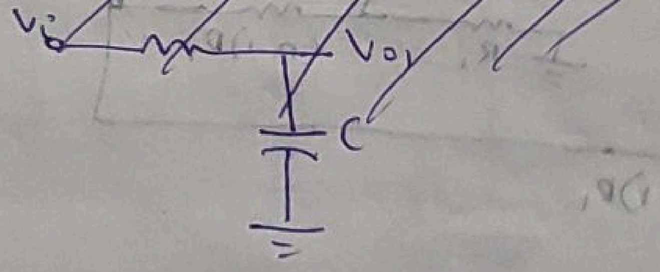
$$-n^2\left(1 - \frac{n}{A} - \frac{n^2}{A^2}\right)V_{off,1} - \frac{n^2}{A}\left(1 - \frac{n}{A} - \frac{n^2}{A^2}\right)V_{off,2}.$$

$\cancel{SG_1 = \frac{n^4}{A^2} \delta A}$ $\cancel{SG_2 = \frac{2n^3}{A^2}\left(1 - \frac{n}{A}\right)\delta A}$

$\cancel{SG_3 = \frac{n^3}{A^2}}$

$\therefore$ ~~Amplifi~~ Tolerence: Amp C > Amp B > Amp A

15.) (a)



In case of $n^2 >> A$

(a) gain $= A\left(1-\frac{A}{n^2}\right) = A - \frac{A^2}{n^2}$

DC offset $= -\left(A - \frac{A^2}{n^2}\right) V_{off,1}$

(b) gain $= A^2\left(1-\frac{A}{n}\right)^2 = A^2 - \frac{2A^3}{n} + \frac{A^4}{n^2}$

DC offset $= -\left(A^2 - \frac{2A^3}{n} + \frac{A^4}{n^2}\right)V_{off,1} - \left(A - \frac{A^2}{n}\right)V_{off,2}$

(c) gain $= A^2\left(1-\frac{A}{n} - \frac{A^2}{n^2}\right)$

DC offset $= -A^2\left(1-\frac{A}{n}-\frac{A^2}{n^2}\right)V_{off,1} - A\left(1-\frac{A}{n}-\frac{A^2}{n^2}\right)V_{off,2}$

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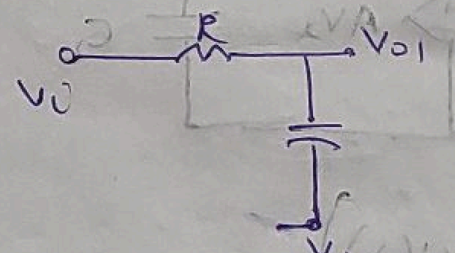
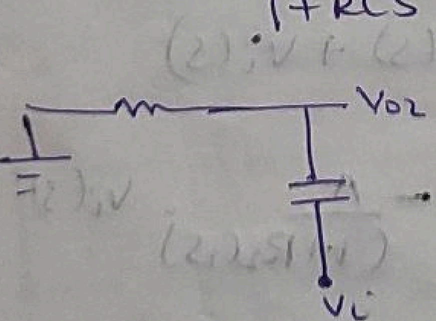
(15) (a)



$$V_{o1}(s) = \left(\frac{V_i(s)}{R+\frac{1}{sC}}\right)\frac{1}{sC}$$

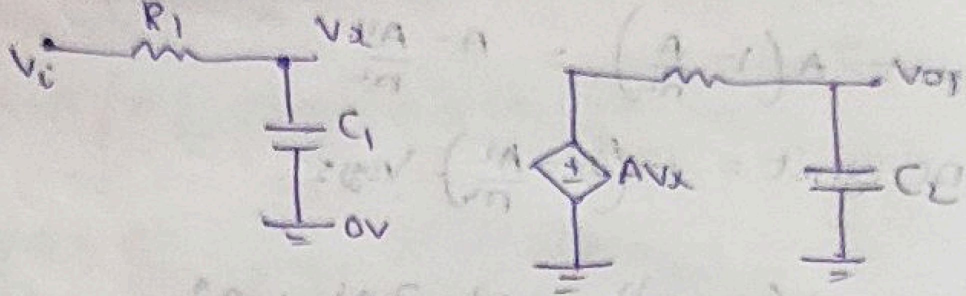
$$H_1(s) = \frac{1}{1+RCs}$$



$$V_{o2}(s) = \left(\frac{V_i(s)}{R+\frac{1}{sC}}\right)\times R$$

$$H_2(s) = \left(\frac{sRC}{1+sRC}\right)$$

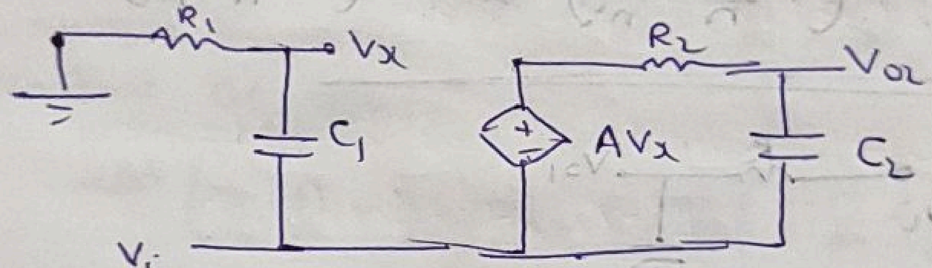
(b.)



$$V_x(s) = \frac{1}{1+R_1C_1s} V_i(s)$$

$$V_{o1}(s) = \frac{1}{1+R_2C_2s} \cdot A V_x(s)$$

$$\Rightarrow H_1(s) = \frac{A}{(1+R_1C_1s)(1+R_2C_2s)}$$



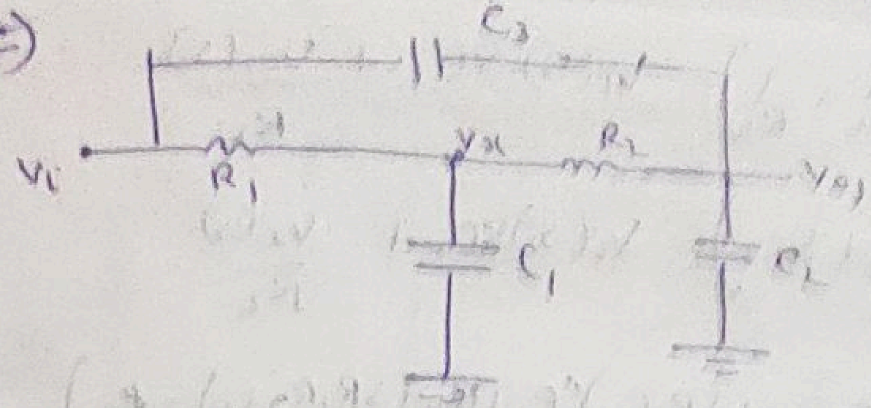
$$V_x(s) = \frac{R_1C_1s}{1+R_1C_1s} (V_i(s))$$

$$\Rightarrow V_{o2}(s) = \frac{1}{1+R_2C_2s} A(V_x(s) - V_i(s)) + V_i(s)$$

$$V_{o2}(s) = \frac{A}{(1+R_2C_2s)} \cdot \frac{R_1C_1s}{(1+R_1C_1s)} \cdot V_i(s) + V_i(s) - \frac{A}{(1+R_2C_2s)} V_i(s)$$

$$H_2(s) = \frac{AR_1C_1s}{(1+R_2C_2s)(1+R_1C_1s)} + 1 - \frac{A}{(1+R_2C_2s)}$$

(c)



$$\Rightarrow V_x(s)\left[\frac{1}{R_1}+sC_1+\frac{1}{R_2}\right)=\frac{V_i}{R_1}+\frac{V_{o1}}{R_2}$$

$$\Rightarrow V_{o1}(s)\left[sC_1+sC_2+\frac{1}{R_2}\right]=V_i sC_3+\frac{V_x(s)}{R_2}$$

$$\Rightarrow V_{o1}(s).\left[sR_2C_1+sR_2C_2+1\right)-sR_2C_3V_i(s)=V_x(s)$$

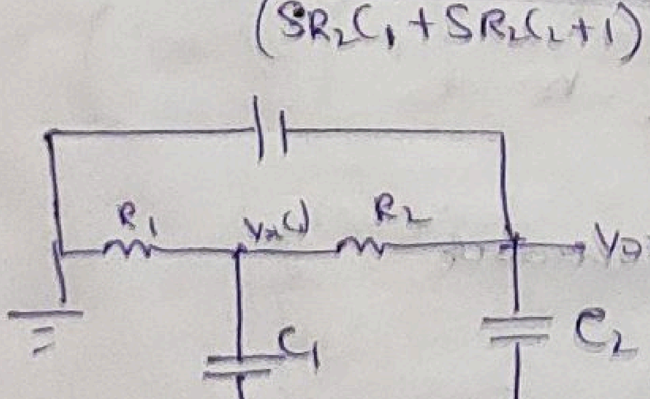
$$\Rightarrow V_{o1}(s)\left[sR_2C_1+sR_2C_2+1\right)\left[\frac{1}{R_1}+sC_1+\frac{1}{R_2}\right]$$

$$-sR_2C_3V_i(s)\left[\frac{1}{R_1}+sC_1+\frac{1}{R_2}\right]=\frac{V_i}{R_1}+\frac{V_{o1}}{R_2}$$

$$\Rightarrow V_{o1}(s)\left(\frac{(sR_2C_1+sR_2C_2+1)(R_1+R_2+R_1R_2sC_1)}{R_1R_2}-R\right)$$

$$=V_i(s)\left[\frac{R_2}{R_1R_2}+\frac{sR_2C_3(R_1+R_2+sR_1R_2C_1)}{R_1R_2}\right.$$

$$\Rightarrow H_1(s)=\frac{R_2+sR_2C_3(R_1+R_2+sR_1R_2C_1)}{(sR_2C_1+sR_2C_2+1)(R_1+R_2+R_1R_2sC_1)-R_1}$$



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$$V_x(S)\left(SC_1 + \frac{1}{R_2} + \frac{1}{R_1}\right) = V_i(S).SC_1 + \frac{V_{o2}(S)}{R_2}$$

$$\Rightarrow V_{o2}(S)\left(\frac{1}{R_2} + SC_3 + SC_2\right) = V_i(S)SC_2 + \frac{V_x(S)}{R_2}$$

$$\Rightarrow V_{o2}(S).\left[\frac{(1+SR_2C_3+SR_2C_2)(R_1+R_2+SR_1R_2C_1) - R_1}{R_1R_2}\right)$$

$$= \frac{SR_2C_2(R_1+R_2+SR_1R_2C_1) + SR_1C_1R_2}{R_2R_1R_2}$$

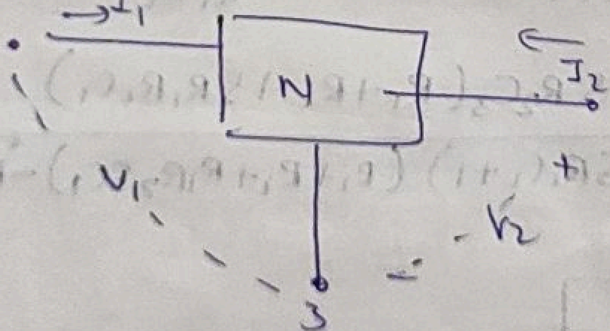
$$H_2(S) = \frac{SC_2R_2(R_1+R_2+SR_1R_2C_1) + SR_1C_1R_2}{(1+SR_2C_3+SR_2C_2)(R_1+R_2+SR_1R_2C_1) - R_1}$$

From above 3 we can Observe that

$$H_1(S) + H_2(S) = 1$$

Generalizaton

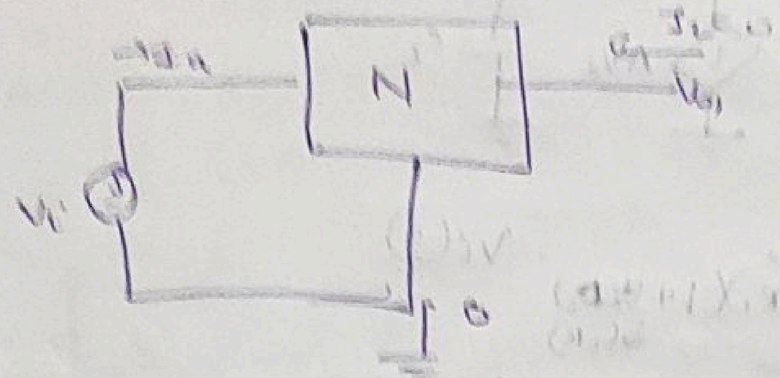
Lets consider a generalised linear network



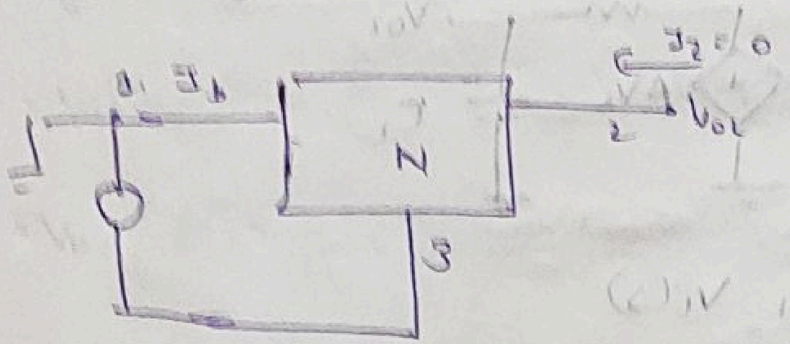
G parameter of the Network

$$\begin{pmatrix} V_2 \\ I_1 \end{pmatrix} = G\begin{pmatrix} V_1 \\ I_2 \end{pmatrix}$$

$I_1 = 0$ (since no source is connected)



$$\begin{pmatrix} V_{01} \\ I_a \end{pmatrix} = G \begin{pmatrix} V_i \\ 0 \end{pmatrix}$$



There is no other independent sources in network. Reversing the excitation gives reverse current.

$V_1 = -V_i$ $\qquad$ $V_2 = V_{02} - V_i$

and $I_b = -I_a$

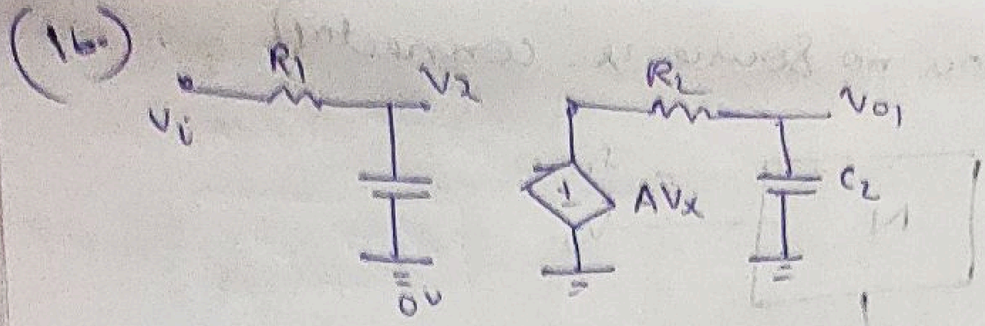
$$\begin{pmatrix} V_{02} \\ -I_a \end{pmatrix} = G \begin{pmatrix} -V_i \\ 0 \end{pmatrix} \rightarrow (2)$$

$$\begin{pmatrix} V_{02} \\ -I_a \end{pmatrix} - \begin{pmatrix} V_i \\ 0 \end{pmatrix} = -\begin{pmatrix} V_{01} \\ I_a \end{pmatrix}$$

$$V_{02}(s) + V_{01}(s) = V_i(s)$$

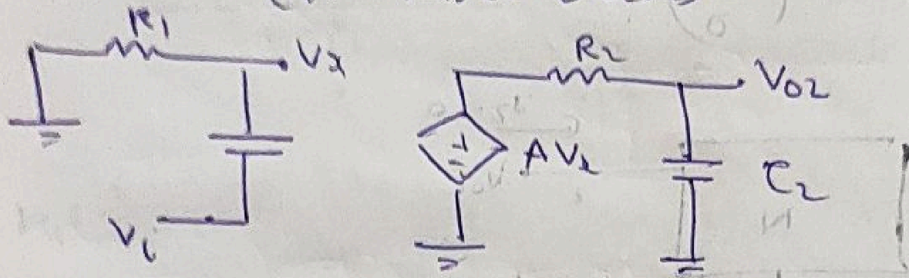
$$\therefore \boxed{H_1(s) + H_2(s) = 1}$$

(1a.)



$$V_{01}(s) = \frac{A}{(1+SC_1R_1)(1+\cancel{SCR}\,SC_2R)} \cdot V_i(s)$$

$$H_1(S) = \frac{A}{(1+SC_1R_1)(1+SC_2R_2)}$$

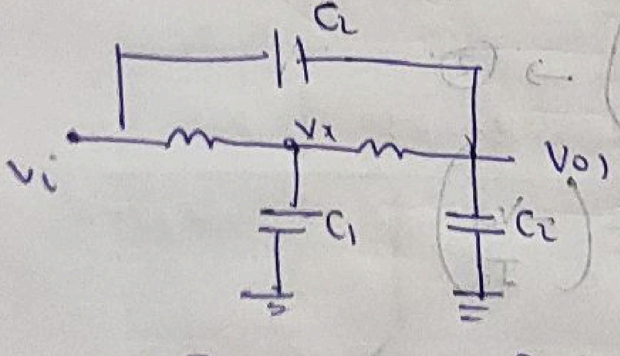


$$V_x(S) = \frac{SC_1R_1 \; V_i(S)}{1+SR_1C_1}$$

$$V_0(2) = \frac{A\,V_x(S)}{1+SR_2C_2}$$

$$H_2(S) = \frac{ASR_1C_1}{(1+SC_1R_1)(1+SC_2R_2)}$$

(b.)

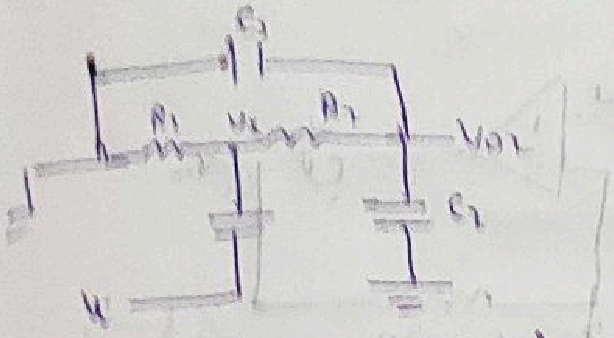


$$V_x(S)\left[SC_1 + \frac{1}{R_1} + \frac{1}{R_2}\right] = SC_1V_i + \frac{V_{01}}{R_2}$$

$$V_{01}(S)\left[SC_2 + SC_3 + \frac{1}{R_2}\right] = SC_3V_i(S) + \frac{V_x}{R_2}$$

$$H_1(s) = \frac{R_1 + sR_1C_3(R_1+R_2+sR_1R_2C_1)}{(sR_2C_1+sR_2C_2+1)(R_1+R_2+sR_1R_2C_1)+R_1}$$

$$H_1(s) = \frac{R_1 + sR_1C_3(R_1+R_2+sR_1R_2C_1)}{(sR_2C_1+sR_2C_2+1)(R_1+R_2+sR_1R_2C_1)-R_1}$$



$$V_x(s)\left(\frac{1}{R_1}+\frac{1}{R_2}+sC_1\right) = V_i sC_1 + \frac{V_{o2}(s)}{R_2}$$

$$V_{o2}\left(sC_2+\frac{1}{R_2}+sC_3\right) = \frac{V_x(s)}{R_2}$$

$$H_2(s) = \frac{sC_1R_1R_2}{(R_1+R_2+sC_1R_1R_2)(1+s(C_2+C_3)R_2)-R_1}$$

$$\cancel{H_1(s)} \quad H_1(s)+H_2(s) \neq 1$$

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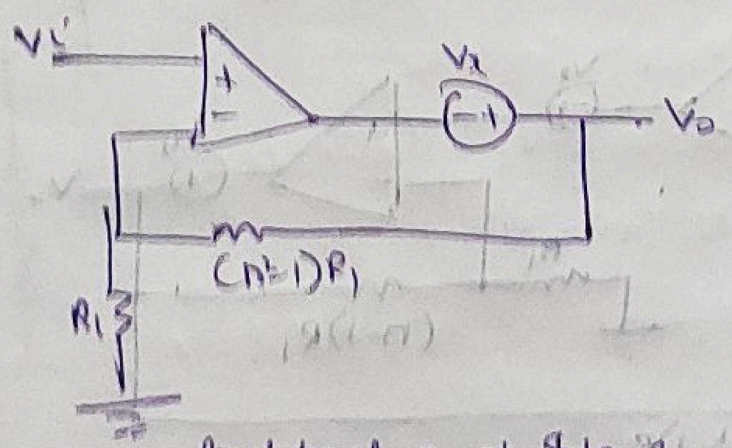
(17)



Negative feed back and Ideal

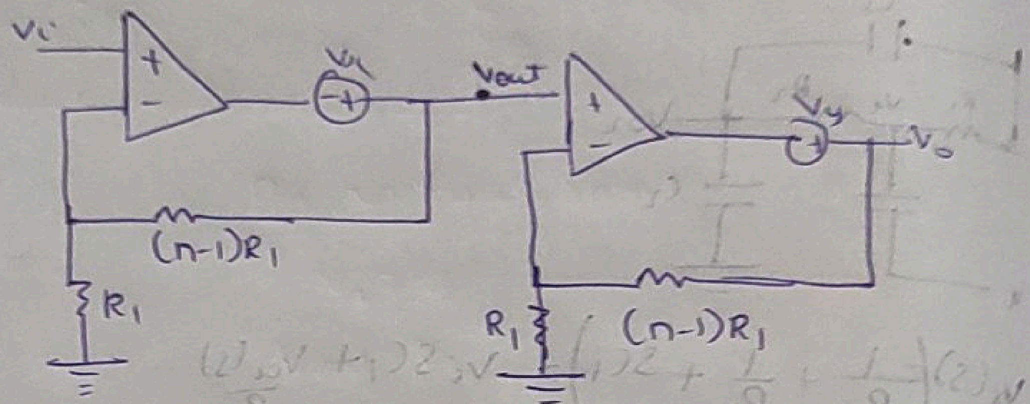
By virtual short

$V_i{}' = V_{i-}$

$$\Rightarrow \frac{V_o - V_i}{(n^2-1)R_1} = \frac{V_i}{R_1}$$ [Current Flowing]

$$\boxed{V_o = n^2 V_i}$$

(b)



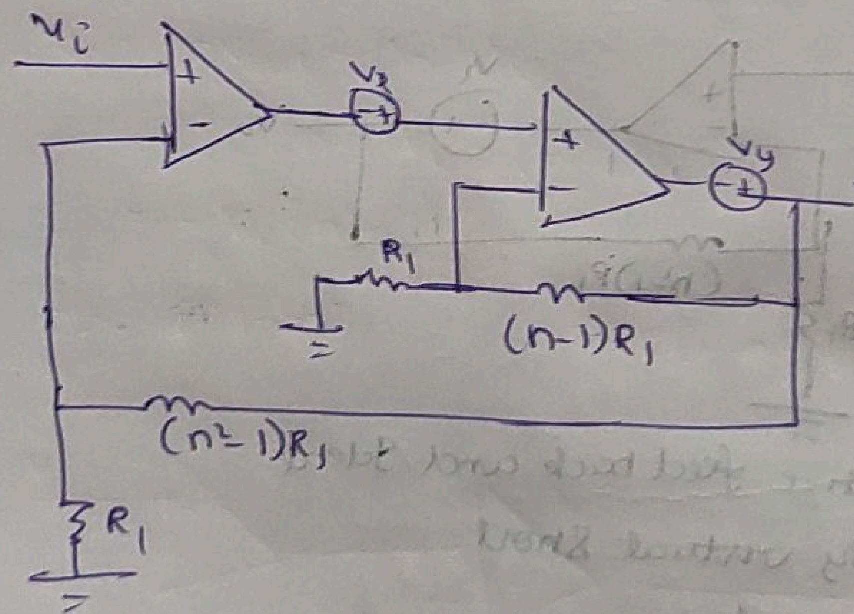
$$V_i = \frac{V_{out}}{n}$$

$$\boxed{V_{out} = nV_i}$$

This will be input for next Op-Amp.

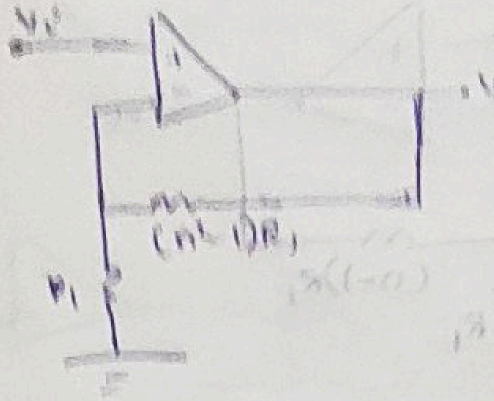
$$\therefore \quad nV_i = \frac{V_o}{n} \Rightarrow \boxed{V_o = n^2 V_i}$$

(c)



$$V_i = \frac{V_o}{n^2} \Rightarrow \boxed{V_o = n^2 V_i}$$ [By virtual short]

(1a)

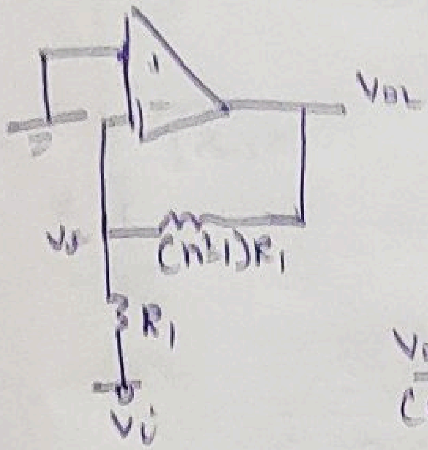


By virtual short

$$\frac{V_{o1}}{n^2} = V_i$$

$$V_{o1} = V_i(n^2)$$

$$\frac{V_{o1}}{V_i} = n^2 = H_1$$



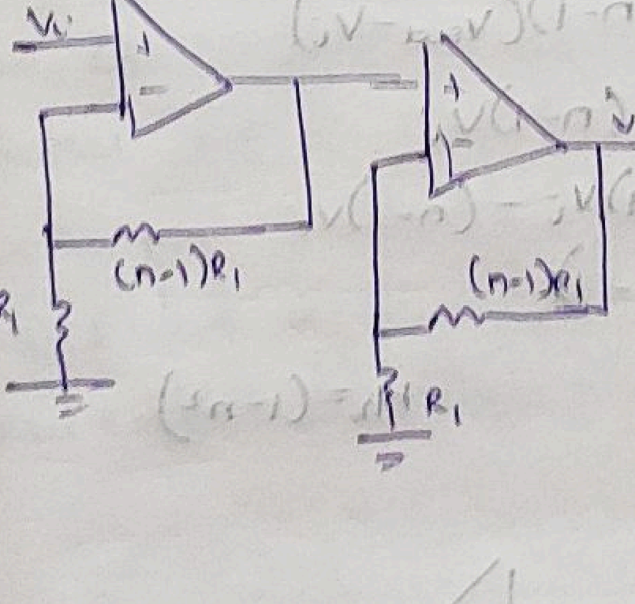
By virtual short

$V_x = 0$

$$\boxed{\frac{V_{o2} - 0}{(n^2-1)R_1} = \frac{0 - V_i}{R_1}}$$

$$\Rightarrow \frac{V_{o2}}{V_1} = -(n^2-1) \quad \therefore H_2 = 1-n^2$$

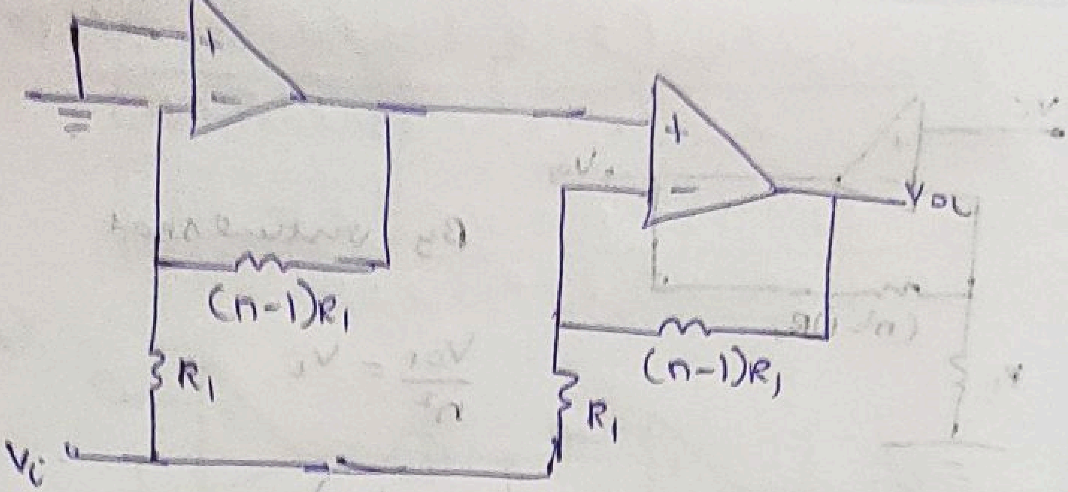
(b)



By virtual short

$V_{o1} = n^2 V_i$

$$\frac{V_{o1}}{V_i} = n^2 = H_1$$



By virtual short

$$V_1 = 0$$

$$V_{out} = V_2.$$

$$\frac{V_{out} - 0}{(n-1)R_1} = \frac{0 - V_i}{R_1}$$

$$\boxed{V_{out} = -(n-1)V_i}$$

$$\frac{V_{o2} - V_{out}}{(n-1)R_1} = \frac{V_{out} - V_i}{R_1}$$

$$\Rightarrow V_{o2} = V_{out} + (n-1)(V_{out} - V_i)$$

$$V_{o2} = nV_{out} - (n-1)V_i$$

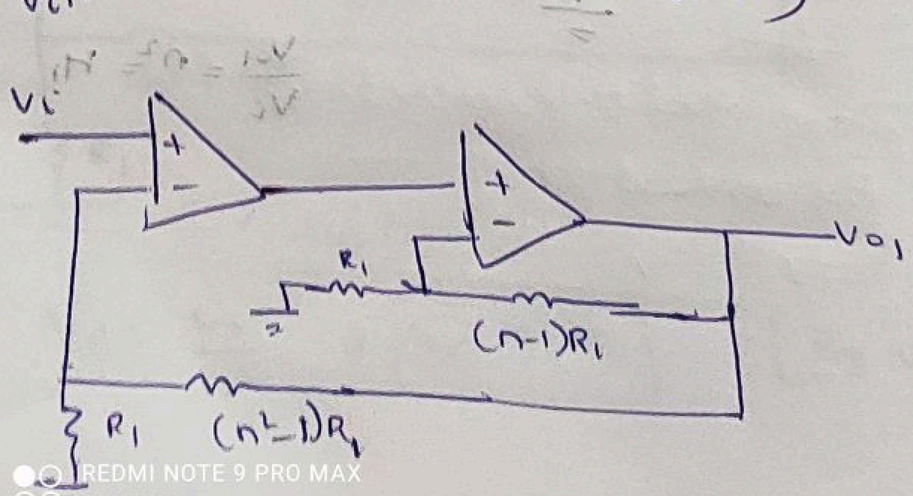
$$= -(n)(n-1)V_i - (n-1)V_i$$

$$= -V_i(n^2 - 1)$$

$$\therefore \frac{V_{o2}}{V_{in}} = 1 - n^2$$

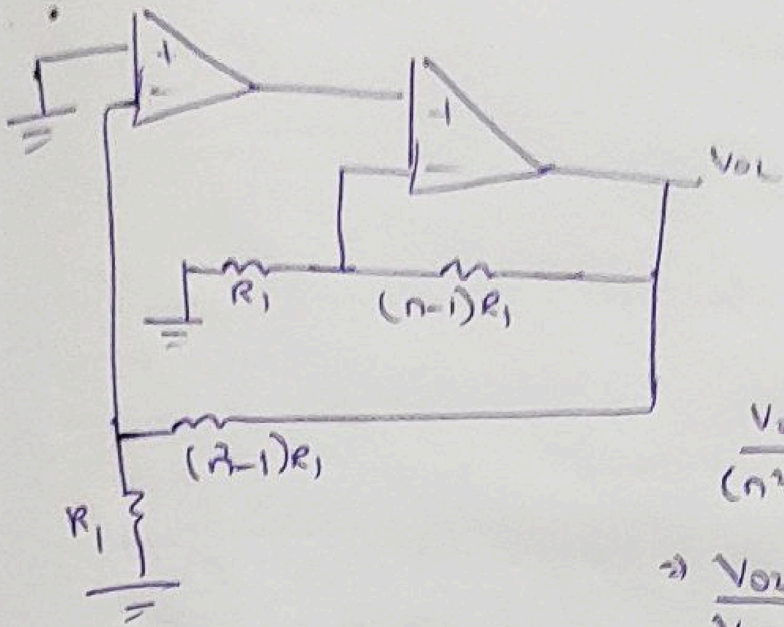
$$H_2 = (1 - n^2)$$

(c)



$\therefore V_o = n^2 V_i$

$H_1 = n^2$



By virtual short

$V_1 = 0V$

$V_2 = V_{out}$

$$\frac{V_{o2} - 0}{(n^2-1)R_1} = \frac{0 - V_i}{R_1}$$

$$\Rightarrow \frac{V_{o2}}{V_i} = (1-n^2)$$

$H_2 = 1 - n^2$.

$\therefore H_1 + H_2 = 1$

If the opamps been operated at finite gain, ckt (c) falls under the catery of 16th problem patter i.e $H_1 + H_2 = 1$.

However the limit of $A \to \infty$ turned it to $H_1 + H_2 = 1$. As the voltage input V_a value doesn't affect the output