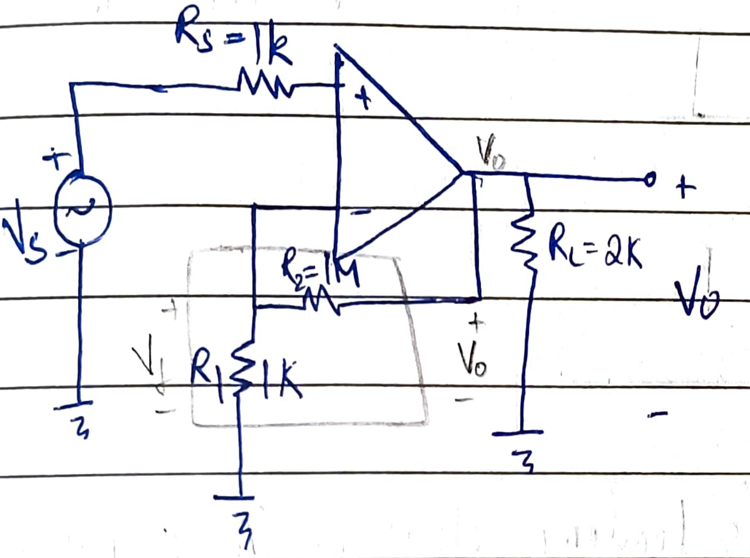
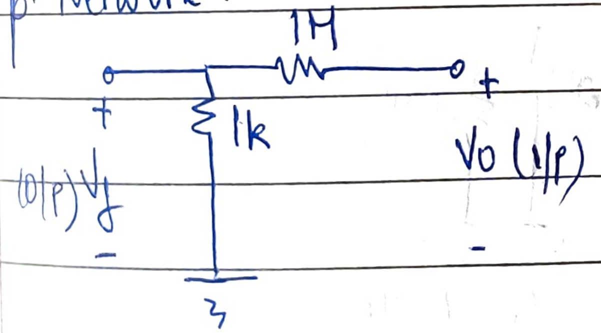
For the given non-inverting voltage series negative feedback amplifier circuit, if $R_i = 100k\Omega$, $R_O = 1k\Omega$, $A_V = 10^4 \times V_i$. Find R_{if}, R_{of}, A_f and the actual R_{in} and R_{out}.

Non-inverting amp is ex. for Voltage series am



[Non-inverting Amp]

β. Network :



$$\beta = \frac{V_f}{V_o}$$

$$V_f = i \times 1k = \frac{V_o \times 1k}{1M + 1k}$$

$$\Rightarrow \frac{V_f}{V_o} = \frac{1k}{1M + 1k} = 0.999m \text{ (or) } 999\mu$$

- Looking from i/p side of amp. if β n/w is connected to 'A' amplifier o/p as shunt, then must remove the β and short it.

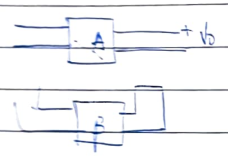
$\boxed{\text{shunt has to be shorted}}$

- O/p of β connected to i/p of A via series ⟶ Open.

Note

- At i/p side of β n/w is connected to 'A' amp o/p as shunt then short it.
- At o/p side of β n/w is connected to A amp, i/p as series then open it.

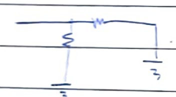
⇒



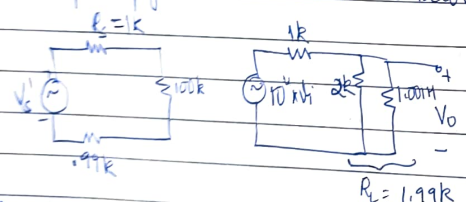
$1k \parallel 1M \approx 999\Omega$

$1k + 1M = 1.001 M\Omega$

⇒



Considering the β's loading effect on 'A' amplifier, the new open loop amplifier circuit will be as below:



$A = \frac{V_0}{V_s'} = \frac{V_0}{V_i} \times \frac{V_i}{V_s'}$

$V_0 = \frac{10^4 V_i \times 1.99k}{2.99k} = 6.655k\, V_i$

$\frac{V_0}{V_i} = 6.655k$

$V_i = \frac{V_s' \times 100k}{1k + 0.99k + 100k} = 0.98 V_s'$

$\Rightarrow \boxed{\frac{V_i}{V_s'} = 0.98}$

$A = 0.98 \times 6.655k = 6.525k$

$1 + A\beta = 1 + (6.525k)(999\mu) = \underline{\underline{7.52}}$

$R_{if} = R_i(1 + A\beta)$

$\Rightarrow R_i = \frac{R_{if}}{1 + A\beta}$

i/p of Amp with loading effect

$R_i = 102k$ $[1k + 1k + 100k]$

$R_{if} = (102k)(7.52) = 767.1k$

$R_{of} = \frac{R_o}{1 + A\beta}$

$R_o = 1k \parallel 1.99k = 665.5\Omega$

$R_{of} = \frac{665.5}{7.52} = 88.5\Omega$

$R_{in}(\text{actual}) = R_{if} - R_s$

$= 767k - 1k$

$\boxed{R_{in}(\text{actual}) = 766k}$

$R_o(\text{actual}) = R_{out} \parallel R_L$

$R_{of} = R_{out(actual)} \parallel R_L$

$R_{of} = R_{out} \parallel R_L$

$88.5 = R_{out} \parallel 2k$

$\boxed{R_{out} = 92.6\Omega}$

Q.2 A voltage amplifier needs 30 mV input to give a certain o/p. When -ve feedback is provided to the amplifier, it needs 2.5V to deliver the same o/p. If the closed loop gain of the amplifier is 38 dB. Find the open loop gain (A), feedback factor and amount of feedback.

Ans

$38 = 20\log(A_{v(CL)})$

$1.9 = \log(A_{v(CL)})$

$(A_v)_{CL} = 10^{1.9} = 79.43$

$V_i = 50mV$; $V_s = 2.5V$

$V_o = V_o$; $V_o = V_o$

$(A_v)_{CL} = \dfrac{(A_v)_{OL}}{1+A\beta}$

$\dfrac{V_o}{V_s} = \dfrac{V_o/V_i}{(1+A\beta)} \Rightarrow (1+A\beta) = \dfrac{V_s}{V_i} = \dfrac{2.5}{50m} = 50$

$\boxed{1+A\beta = 50}$

$(A_v)_{OL} = (79.43)(50) = 3.972k$

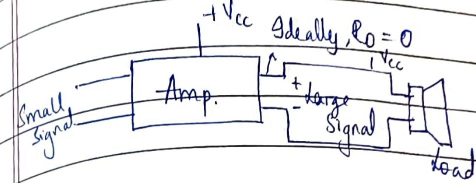
$1+A\beta = 50$

$A\beta = 49$

$\beta = \dfrac{49}{3.972k} = 0.0123$

11/12/24

Power Amplifiers



$P_{(dc)}$ = low [Dissipation should be low].

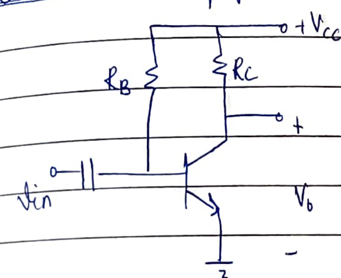
- Power amplifiers are also called as large signal amplifier.

A → $\eta = 25\%$

B → $\eta = 78\%$

C → $\eta = 50\%$

Class A Power Amplifier

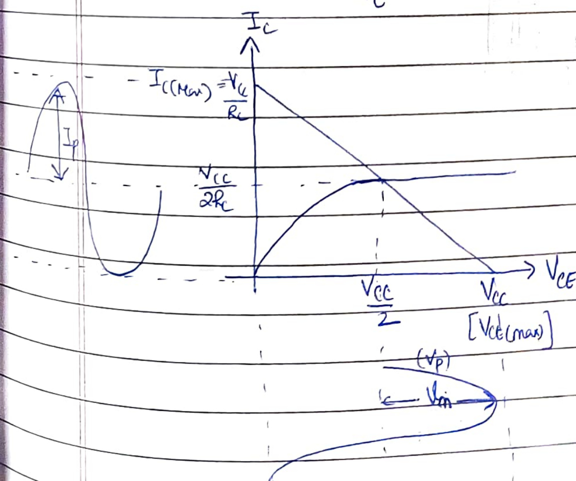


O/P Loop Eq:

$V_{CC} - I_C R_C - V_{CE} = 0$

$V_{CE(max)} = V_{CC}$ [when $I_C = 0$]

$I_{C(Max)} = \dfrac{V_{CC}}{R_C}$ [when $V_{CE} = 0$]



$\boxed{V_m = \dfrac{V_{CC}}{2}}$

$V_{DC} \simeq V_{CC}$

- DC dissipation should be minimised.

$$\eta = \frac{P_o(ac)}{P_{in}(dc)}$$

$$= \frac{V_{rms} \times I_{rms}}{V_{DC} \times I_{DC}}$$

$$= \frac{\frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}}{V_{CC} \times \frac{V_{CC}}{2R_C}}$$

$$= \frac{\frac{V_{CC}}{2\sqrt{2}} \times \frac{V_m}{R_C\sqrt{2}}}{\frac{V_{CC}^2}{2R_C}} = \frac{\frac{V_{CC}}{2\sqrt{2}} \times \frac{V_{CC}}{2\sqrt{2}R_C}}{\frac{V_{CC}^2}{2R_C}}$$

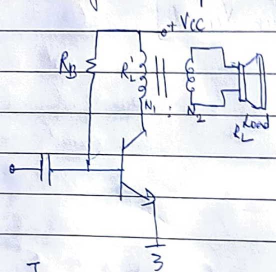
$$= \frac{\frac{1}{(2\sqrt{2})^2}}{\frac{1}{2}}$$

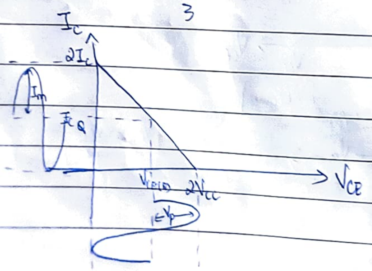
$$= \frac{1}{4\times 2} \times 2 = \frac{1}{4} = 0.25$$

$$= 25\%$$

Efficiency is less:
i) For -ve part, BJT is off.
ii) For +ve part, dissipation might be high if both max values given.

Class A transformer coupled amplifier





R_L' offers low impedance as transformers have low impedance in general → No dissipation

$$\eta = \frac{P_o(ac)}{P_{in}(dc)}$$

$$= \frac{V_{rms} \times I_{rms}}{V_{DC} \times I_{DC}}$$

$$= \frac{\frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}}{V_{CC} \times I_C}$$

$$\cancel{= \frac{V_m}{\sqrt{2}} \times V_m}$$

$$= \frac{\frac{V_{CC}}{\sqrt{2}} \times \frac{I_C}{\sqrt{2}}}{V_{CC} \times I_C} = \frac{1}{2} = 0.5$$

$$= 50\%$$

Calculation of R_L'

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

$$V_1 = \left(\frac{N_1}{N_2}\right) V_2$$

$$I_1 = \left(\frac{N_2}{N_1}\right) I_2$$

$$\Rightarrow \frac{V_1}{I_1} = \left(\frac{N_1}{N_2}\right) V_2 \times \left(\frac{N_1}{N_2}\right) \times \frac{1}{I_2}$$

$$\frac{V_1}{I_1} = \left(\frac{N_1}{N_2}\right)^2 \left(\frac{V_2}{I_2}\right)$$

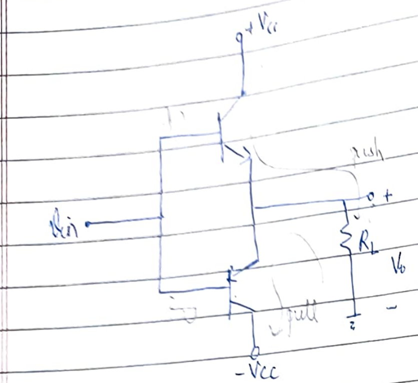
$$\frac{V_1}{I_1} = \left(\frac{N_1}{N_2}\right)^2 R_L \Rightarrow R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L$$

$$\boxed{R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L}$$

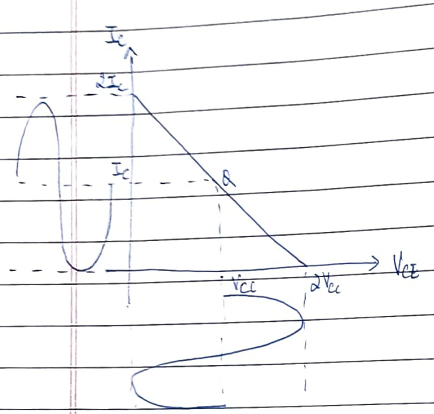
$$R_L = R_L' \left(\frac{N_2}{N_1}\right)^2$$

Advantage: R_C is removed which reduces dissipation.

Class B Power Amplifier



(push-pull configuration)



$$\eta = \frac{P_{o(ac)}}{P_{in(dc)}}$$

$$= \frac{V_{rms} \times I_{rms}}{V_{DC} \times I_{DC}}$$

$$= \frac{V_{rms} \times I_{rms}}{V_{cc} \times I_c}$$

$$= \frac{V_m/\sqrt{2} \times I_m/\sqrt{2}}{V_{cc} \times I_c}$$

$$= \frac{V_m/\sqrt{2} \times V_m/\sqrt{2}R_L}{V_{cc} \times I_c}$$

$$= \frac{V_{cc}/\sqrt{2} \times V_{cc}/\sqrt{2}R_L}{V_{cc} \times \cancel{V_{cc}/R_L} \frac{2I_m}{\pi}}$$

$$P_{o(ac)} = \frac{V_{cc}^2}{2R_L} = \frac{V_p \times V_c}{2R_L}$$

$$P_{in(dc)} = \frac{2V_{cc}^2}{\pi R_L} = \frac{2V_p \times V_c}{\pi R_L}$$

$$= \frac{\frac{V_{cc}}{\sqrt{2}} \times \frac{V_{cc}}{\sqrt{2}R_L}}{V_{cc} \times \frac{2}{\pi}\left[\frac{V_{cc}}{R_L}\right]}$$

$$= \frac{V_{cc}^2}{2R_L} \times \frac{\pi R_L}{2V_{cc}^2}$$

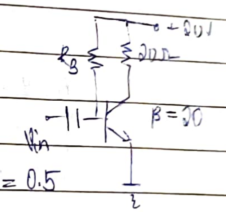
$$= \frac{\pi}{4} = 0.785$$

$$= 78.5\%$$

28/24

Q.1 For a Class-A power amp. $V_{cc} = 20V$, $R_C = 20\Omega$. Find R_B if the o/p current varies by $\pm 250mA$ for the applied input voltage, find the circuit efficiency.

Ans

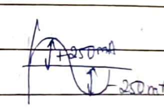


$$20 - I_B R_B - V_{BE} = 0$$

$$R_B = \frac{20 - 0.7}{I_B}$$

For Class-A amp.: $I_{CQ} = \frac{V_{cc}}{2R_C} = \frac{20}{2 \times 20} = 0.5$

$$\beta = \frac{I_c}{I_B} \Rightarrow I_B = \frac{0.5}{20} = 25mA$$



$$R_B = \frac{20 - 0.7}{25m} = 772\Omega$$

$$\eta = \frac{P_{o(ac)}}{P_{in(dc)}} = \frac{V_{rms} \times I_{rms}}{V_{DC} \times I_{DC}} = \frac{0.625}{10} = 0.0625 \times 100\% = 6.25\%.$$

$$P_{o(ac)} = V_{rms} \times I_{rms} = I_{rms}^2 \times R_C = \left(\frac{I_m}{\sqrt{2}}\right)^2 \times R_C = \left(\frac{250m}{\sqrt{2}}\right)^2 \times 20 = 0.625W$$

$$P_{in(dc)} = V_{DC} \times I_{DC} = V_{CC} \times I_{CQ} = \cancel{4}\ 20 \times 0.5 = 10W.$$

Q.2 If the trans ratio is 2:1 and R_L is 4Ω. What is the V_{cc} min to get 4W of power $[P_{o(ac)}]$ a) What is the I_{CQ} for $V_{cc} = 11.31V$? b) When $V_{cc} = 18V$ and $R_L = 4\Omega$, find the $P_{o(ac)}$ (max).

Ans $\cancel{P_{o(ac)} = V_{rms} \times I_{rms}}$

$$\cancel{= V_{cc} \times I_{CQ} = V_{rms}^2}$$

$$P_{o(ac)} = V_{rms} \times I_{rms}$$

$$= V_{cc} \times I_{CQ}$$

$P_o(ac) = \frac{V_{cc} \times V_{cc}}{2R_L'}$

$P_o(ac) = \frac{(V_{cc})^2}{2R_L'}$

$R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L = (2)^2 \times 4 = 16\Omega$

$4W = \frac{(V_{cc})^2}{32} \Rightarrow (V_{cc})^2 = 4 \times 32$

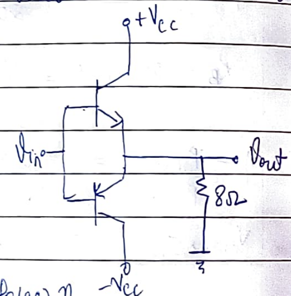
$V_{cc} = 11.31V$

a) $I_{cc} = \frac{V_{cc}}{R_L'} = \frac{11.31}{16} = 0.707A$

b) $V_{cc} = 18V$ & $R_L = 4\Omega$

$P_o(ac)_{max} = \frac{V_{cc}^2}{2R_L'} = \frac{18^2}{2 \times 16} = 10.125W$

Q.3 A class-B power amplifier is given. What is the V_{cc} min to get 20 W of power to 8Ω load.



Ans $P_o(ac) = \frac{V_{cc}^2}{2R_L}$

$V_{cc}^2 = 2R_L P_o(ac)$

$V_{cc}^2 = 2 \times 8 \times 20 = 320$

$V_{cc} = 17.88V$

If the i/p is 10V peak, find $P_{in}(dc)$, $P_o(ac)$, η.

$V_m = 10V$

$P_{in}(dc) = V_{cc} \times \frac{2V_m}{\pi R_L}$

$= 17.88 \times \frac{2 \times 10}{\pi \times 8} = 14.228W$

$P_o(ac) = \frac{V_{cc}^2}{2R_L} \rightarrow Max$] If V_p given, then replace V_{cc} with V_p

Practically, $V_{cc} = V_m = V_p$

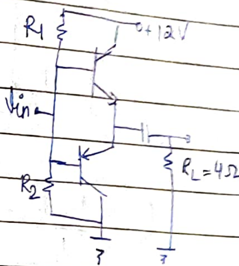
$P_o(ac) = \frac{V_p^2}{2R_L} = 6.25W$

$\eta = \frac{P_o}{P_{in}} = \frac{6.25}{14.228} = 43.9\%$

To understand better, $P_o(ac) = \frac{18^2}{2 \times 8} = 20.25$

$\eta = \frac{20.25}{14.228} = 142\%$

Q.4 For the given circuit, $V_B = 6V$ [when $R_1 = R_2$]. Find the max. AC o/p power.



Ans $V_p = V_B = 6V$

$P_o(ac)\,max = \frac{V_{cc}^2}{2R_L} = \frac{(V_p)^2}{2R_L} = \frac{6^2}{2 \times 4} = 4.5W$

c) If 3V is given at i/p what is $P_o(ac)$?

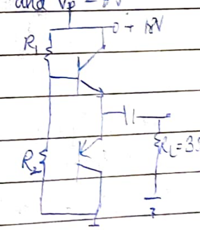
$P_o = \frac{V_p^2}{2R_L} = \frac{3^2}{2 \times 4} = \frac{9}{8} = 1.125W$

~~$P_{in}(ac)\,max = \frac{2V_p \times V_{cc}}{\pi R_L} =$~~

$P_{in}(dc) = \frac{2 \times V_p \times V_c}{\pi R_L} = \frac{2 \times 3 \times 6}{\pi \times 4} = 2.864W$

$\eta = \frac{1.125}{2.864} = 39.27\%$

b) For the same circuit, $V_{cc} = 18V$, and $R_L = 3\Omega$ and $V_p = 6V$. Find $P_o(Max)$, $P_{in}(dc)$; $P_o(ac)min$, η?



Ans $P_o(ac)\,max = \frac{V_{cc}^2}{2R_L} = \frac{9^2}{2 \times 3} = 13.5W$

$P_o(ac)\,min = \frac{V_p^2}{2R_L} = \frac{6^2}{2 \times 3} = 6W$

$P_{in}(dc) = \frac{2 \times V_p \times V_{cc}}{\pi R_L} = \frac{2 \times 9 \times 6}{\pi \times 3} = \cancel{22.92W}$ 11.46W

$\eta = \frac{P_o(ac)\,min}{P_{in}(dc)} = \frac{6}{11.46} = 52.356\%$

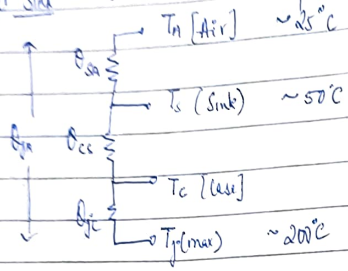
Power dissipation in each transistor:

$P_d(each)_{Tr} = \frac{P_{dc} - P_{ac}}{2} = \frac{11.46 - 6}{2} = 2.73W$

Class A → Transistor always in active
Class B → High efficiency
Class AB → Combines both

11/3/24

Heat Sink → Material used to dissipate heat generated to the ambient air.



$\theta_{JC} = \frac{T_j - T_C}{P_D} = °C/W$ $\qquad R = \frac{V_1 - V_2}{I}$

$\theta_{JA} = \theta_{SA} + \theta_{CS} + \theta_{JC}$

Q.1 A power transistor for which $T_j(max) = 200°C$ can dissipate $P_{D(max)} = 50W$. Find θ_{JA} at Ambient temperature $T_A = 25°C$. Find P_D at $T_A = 50°C$

Ans $\theta_{JA} = \frac{T_j(max) - T_A}{P_{D(max)}} = \frac{200 - \cancel{50}\,25}{50} = \cancel{3.5}\ \frac{175}{50} = 3.5°C/W$

$P_D = \frac{T_j - T_A}{\theta_{JA}} = \frac{200-50}{3.5} = 42.857\ W$

Q.2 If $T_j(max) = 180°C$, $P_D = 25W$ at $30°C$ [T_A]

a) P_D at $55°C$

Ans $\theta_{JA} = \frac{\cancel{180}\ T_j(max) - T_A}{P_D} = \frac{180 - 30}{25} = 6°C/W$

$P_D = \frac{T_j - T_A}{\theta_{JA}} = \cancel{180 - 55°}\ \frac{180° - 55°}{6} = 20.833\ W$

b) $T_C = 70°C$ and $P_D = 50\ W$.

$\theta_{JC} = \frac{T_j(max) - T_C}{P_D} = \frac{180 - 70}{50} = 2.2°C/W$

Unit 5 : Operational Amplifier

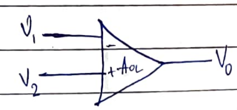
Limitations of Amplifier (BJT, Mosfet)
- Gain is less (A_{OL})
- Bandwidth is low
- Rin is not high (In mosfet it is high)
- Rout is not low

Characteristics of Op-Amp
- Gain is ∞
- Z_{in} is ∞
- Z_o is 0
- BW is ∞
- CMRR is ∞ $\qquad CMRR = \frac{A_d}{A_{CM}}$

If +ve feedback is given → Oscillator
If -ve feedback is given, → Amplifier

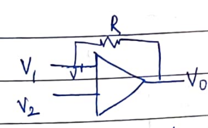
Non-linear Op-Amps ⇒ Comparator, Schmitt Trigger, Precision Rectifier
Linear Op-Amp: Inverting, Non-Inverting, Diff Amp.

Virtual Ground



$V_0 = A_{OL}(V_2 - V_1)$
$V_0 = \infty\,[V_2 - V_1]$
$V_0 = \infty$

If $V_2 - V_1$ is +ve, $V_0 = +\infty$
$V_2 - V_1$ is -ve, $V_0 = -\infty$

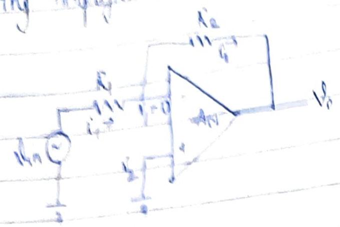


Let $V' = V_2$ ⇒ ~~A_0~~ $V_0 = A_{OL}[V_2 - V']$
$V_0 = \infty \times 0 = 0$

If $V' = V_2 = 0$ ⇒ VG [Virtual Ground]
$V' = V_2 \neq 0$ ⇒ VS [Virtual Short].

* No current goes through Op-Amp as R_{in}
* VG ⇒ $V_2 - V_1 \approx 0$ ... $V_2 = V_1 \neq 0$
* No VG ⇒ $V_2 \neq 0$, $A_{OL} \neq 0$

i) a Inverting Amplifier [Ideal] , $A_{OL} = \infty$, $Z_{in} = \infty$, $V_2 = V_1$



By VG, $V_2 - V_1 = 0$

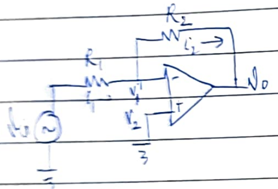
$i_1 = i_2$

$\frac{V_{in}}{R_1} = \frac{-V_0}{R_2}$

$\frac{V_0}{V_{in}} = \frac{-R_2}{R_1} = A_{CL}$

$V_0 = \frac{-R_2}{R_1}(V_{in})$

i) b Inverting Amplifier [Non-Ideal] → $A_{OL} \neq \infty$, $R_{in} = \infty$, $V_2 \neq V_1$



$V_0 = A_{OL}[V_2 - V']$

$= A_{OL}(-V')$

$V' = \frac{-V_0}{A_{OL}}$

Here, $i_1 = i_2$ [$R_{in} = \infty$]

$\frac{V_{in} - V'}{R_1} = \frac{V' - V_0}{R_2}$

$\frac{V_{in} + V_0/A_{OL}}{R_1} = \frac{-V_0/A_{OL} - V_0}{R_2} = -\frac{(V_0 + V_0/A_{OL})}{R_2}$

$R_2\left[V_{in} + \frac{V_0}{A_{OL}}\right] = -R_1\left[V_0 + \frac{V_0}{A_{OL}}\right]$

$V_{in}R_2 = -R_1V_0 - \frac{R_1V_0}{A_{OL}} - \frac{R_2V_0}{A_{OL}}$.

$V_{in}R_2 = -R_1V_0\left[1 + \frac{1}{A_{OL}} + \frac{R_2}{R_1A_{OL}}\right]$

$V_{in}R_2 = -R_1V_0\left[1 + \frac{1}{A_{OL}}\left[1 + \frac{R_2}{R_1}\right]\right]$

$\frac{V_0}{V_{in}} = \frac{-R_2}{R_1\left[1 + \frac{1}{A_{OL}}\left(1 + \frac{R_2}{R_1}\right)\right]}$

$\frac{V_0}{V_{in}} = \frac{-R_2/R_1}{1 + \left(\frac{1 + R_2/R_1}{A_{OL}}\right)}$ //

Input Impedance of Inverting Amplifier

$R_{in} = \frac{V_{in}}{i_1}$

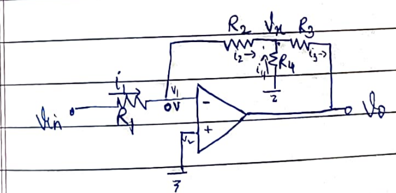
$i_1 = \frac{V_{in} - 0}{R_1}$

$\frac{V_{in}}{i_1} = R_1$

Here, $Z_{in} = R_1 \| \infty = R_1$

~~Here~~ To increase Z_{in}, if $R_1 \uparrow$, then gain reduces.

Thus, R_2 is increased.



By VG, $V = 0$

$i_1 = \frac{V_{in}}{R_1}$, $i_2 = \frac{-V_x}{R_2}$, $V_x = -i_2R_2$; $i_4 = \frac{0 - V_x}{R_4} = \frac{V_{in}R_2}{R_1R_4}$

$i_1 = i_2 \Rightarrow \frac{V_{in}}{R_1} = \frac{-V_x}{R_2} \Rightarrow V_x = \frac{-V_{in}R_2}{R_1}$

~~$\Rightarrow \frac{V_{in}}{R_1} = i_2R_2$~~ $i_3 = i_2 + i_4$

$\Rightarrow i_3 = \frac{V_{in}}{R_1} + \frac{V_{in}R_2}{R_1R_4}$

$V_x - V_0 = i_3 R_3$

$V_0 = V_x - i_3 R_3$

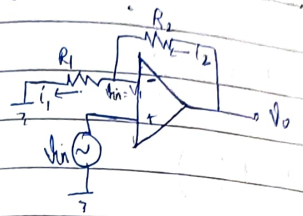
$$V_0 = -\frac{V_{in} R_2}{R_1} - R_3\left[\frac{V_{in}}{R_1} + \frac{V_{in} R_2}{R_1 R_4}\right]$$

$$V_0 = -V_{in}\left[\frac{R_2}{R_1} + \frac{R_3}{R_1} + \frac{R_2 R_3}{R_1 R_4}\right]$$

$$\frac{V_0}{V_{in}} = -\frac{R_2}{R_1}\left[1 + \frac{R_3}{R_2} + \frac{R_3}{R_4}\right]$$

→ The input impedance is increased.

ii) a Non-Inverting Amplifier [Ideal] [$R_{in} = \infty$, $A_{OL} = \infty$]



$V_1 = V_{in}$ [VS]

Virtual Short

$i_2 = i_1$ [$R_{in} = \infty$]

$$\frac{V_0 - V_{in}}{R_2} = \frac{V_{in}}{R_1}$$

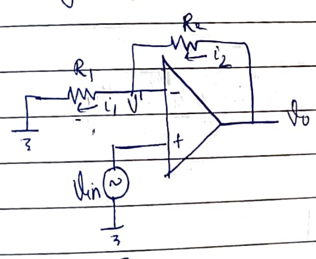
$$\frac{V_0}{R_2} = \frac{V_{in}}{R_1} + \frac{V_{in}}{R_2} \cancel{= V_{in}\left(\frac{R_1 R_2}{R_1 + R_2}\right)}$$

$$\frac{V_0}{R_2} = V_{in}\left(\frac{R_1 + R_2}{R_1 R_2}\right)$$

$$\frac{V_0}{V_{in}} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

$$\frac{V_0}{V_{in}} = A_{CL} = 1 + \frac{R_2}{R_1}$$

ii) b Non-Inverting Amplifier [Non-Ideal] [$R_{in} = \infty$, $A_{OL} \neq \infty$]



$$\frac{V_0}{A_{OL}} = V_{in} - V' \Rightarrow V' = V_{in} - \frac{V_0}{A_{OL}}$$

$V_0 = A_{OL}[V_{in} - V']$

$V' = i_1 R_1$

$i_1 = i_2$

$$\frac{V'}{R_1} = \frac{V_0 - V'}{R_2}$$

$$\frac{V_{in} - \frac{V_0}{A_{OL}}}{R_1} = \frac{V_0 - V_{in} + \frac{V_0}{A_{OL}}}{R_2}$$

$\frac{0}{V_0} = \frac{0}{1}$ * When i/p is given ... terminal, then $Z_{in} = \infty$

$$R_2\left(V_{in} - \frac{V_0}{A_{OL}}\right) = R_1\left(V_0 - V_{in} + \frac{V_0}{A_{OL}}\right)$$

$$V_{in}R_2 - \frac{V_0 R_2}{A_{OL}} = R_1 V_0 - R_1 V_{in} + \frac{V_0 R_1}{A_{OL}}$$

$$V_{in}(R_2 + R_1) = V_0\left(R_1 + \frac{R_1}{A_{OL}} + \frac{R_2}{A_{OL}}\right)$$

$$\frac{V_0}{V_{in}} = \frac{R_2 + R_1}{R_1 + \frac{R_1}{A_{OL}} + \frac{R_2}{A_{OL}}} = \frac{R_2 + R_1}{R_1 + \frac{1}{A_{OL}}(R_1 + R_2)}$$

$$\frac{V_0}{V_{in}} = \frac{\cancel{R_1}\left[1 + \frac{R_2}{R_1}\right]}{\cancel{R_1}\left[1 + \frac{1}{R_1 A_{OL}}(R_1 + R_2)\right]}$$

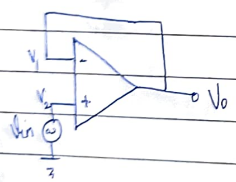
$$\frac{V_0}{V_{in}} = \frac{1 + R_2/R_1}{1 + \frac{1}{A_{OL}}\left[1 + \frac{R_2}{R_1}\right]}$$

$$\boxed{\frac{V_0}{V_{in}} = \frac{1 + R_2/R_1}{1 + \frac{1 + R_2/R_1}{A_{OL}}}}$$

Input Impedance:

$\frac{V_{in}}{i_{in}} = R_{in} = \infty$ [Practically & Ideally]

iii) a Voltage Follower [Ideal]



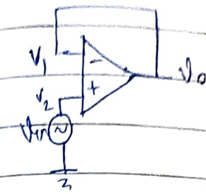
$R_1 = \infty$
$R_2 = 0$

$V_0 = A_{OL}[V_2 - V_1]$

$$V_0 = \left(1 + \frac{R_2}{R_1}\right)V_{in} \Rightarrow V_0 = \left[1 + \frac{0}{\infty}\right]V_{in}$$

$\boxed{V_0 = V_{in}}$ $A_V = 1$

iii) b Voltage follower [Non-Ideal]



$$V_0 = A_{OL}[V_2 - V_1]$$
$$V_0 = A_{OL}[V_2 - V_0]$$
$$V_0 + V_0 A_{OL} = V_2 A_{OL}$$
$$V_0(1 + A_{OL}) = V_{in} A_{OL}$$
$$\boxed{\frac{V_0}{V_{in}} = \frac{A_{OL}}{1 + A_{OL}}}$$

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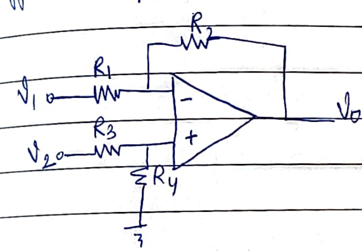
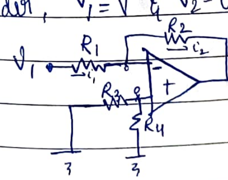
iv) Difference Amplifier



Ideally, $V_0 = A[V_{id}]$
$= A[V_2 - V_1]$
$V_0 = A_d V_{id}$ → A)

Practically, $V_0 = A_d V_{id} + A_{cm} V_{icm}$ → B)

1. Differential i/p
Applying Superposition theorem
Case I
Consider, $V_1 = V$ & $V_2 = 0V$.



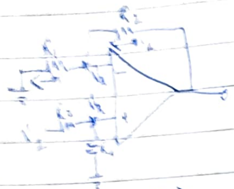
$[A_{OL} = \infty,\ R_{in} = \infty]$

$i_1 = i_2$

$\frac{V_1}{R_1} = -\frac{V_{01}}{R_2}$

$V_{01} = -\left(\frac{R_2}{R_1}\right)V_1 \rightarrow ①$

Case II $V_1 = 0,\ V_2 = V$



By VS, V_x at ~~Non~~ Inverting Terminal,

$V_{02} = V_x\left(1 + \frac{R_2}{R_1}\right)$

$V_x = \frac{V_2 \times R_4}{R_3 + R_4}$ [Voltage division]

$i_1 = i_2$

$\frac{V_x}{R_1} = \frac{V_{02} - V_x}{R_2}$

$\frac{R_2}{R_1} = \frac{V_{02}}{V_x} - 1$

$\frac{R_2}{R_1} = \frac{V_{02}(R_3 + R_4)}{V_2 R_4} - 1$

$\frac{R_2 + R_1}{R_1} = \frac{V_{02}(R_3 + R_4)}{V_2 R_4}$

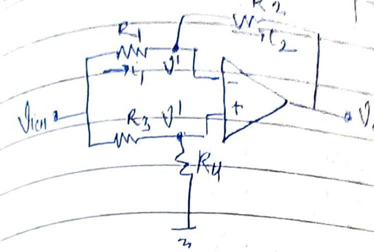
$V_{02} = \frac{V_2 R_4}{R_3 + R_4}\left(\frac{R_1 + R_2}{R_1}\right)$

$V_{02} = \frac{V_2 R_4}{R_3 + R_4}\left(1 + \frac{R_2}{R_1}\right) \rightarrow ②$

$V_0 = V_{01} + V_{02}$

$$\boxed{V_0 = -\left(\frac{R_2}{R_1}\right)V_1 + \frac{V_2 R_4}{R_3 + R_4}\left(1 + \frac{R_2}{R_1}\right)} \rightarrow ③$$

Common Mode Op. [Both the inputs are the same]



$V_{iCM} = \frac{V_1 + V_2}{2}$

$V' = iR_4$

$V' = \frac{V_{iCM} \times R_4}{R_3 + R_4}$

$i_1 = i_2$ [$\because R_{in} = \infty$]

$\frac{V_{iCM} - V'}{R_1} = \frac{V' - V_0}{R_2}$

$i_1 = \frac{V_{iCM} - \frac{V_{iCM} R_4}{R_3 + R_4}}{R_1} = \frac{V_{iCM}(R_3 + R_4) - V_{iCM} R_4}{R_1(R_3 + R_4)}$

$i_1 = \frac{V_{iCM}}{R_1}\left[\frac{R_3}{R_3 + R_4}\right] = i_2$

~~$V_0 = V'$~~

$V' - V_0 = i_2 R_2$

$V_0 = V' - i_2 R_2$

$= \frac{V_{iCM} R_4 R_1}{R_1(R_3 + R_4)} - \frac{V_{iCM}}{R_1}\left[\frac{R_3 R_2}{R_3 + R_4}\right]$

$V_0 = \frac{V_{iCM}}{R_1(R_3 + R_4)}\left[R_4 R_1 - R_3 R_2\right]$

$$\boxed{V_0 = \frac{V_{iCM}(R_4 R_1 - R_3 R_2)}{R_1(R_3 + R_4)}}$$

$V_0 = \frac{V_{iCM} R_4}{(R_3 + R_4) R_4 R_1}\left[R_4 R_1 - R_3 R_2\right]$

$V_0 = V_{iCM}\frac{R_4}{R_3 + R_4}\left[1 - \frac{R_3 R_2}{R_1 R_4}\right] \rightarrow ④$ $A_{CM} = \frac{R_4}{R_3 + R_4}\left[1 - \frac{R_3 R_2}{R_1 R_4}\right]$

$\frac{R_2 R_3}{R_1 R_4} = 1 \rightarrow$ Then ④ tends to Zero.

$\Rightarrow R_2 R_3 = R_1 R_4 \rightarrow ⑤$

$$\boxed{\frac{R_1}{R_2} = \frac{R_3}{R_4}}$$

$\frac{R_2}{R_1} = \frac{R_4}{R_3}$

Due to tolerance, this condition won't be satisfied

Applying ⑤ on ④

$V_0 = 0 \rightarrow$ For V_{ICM} [Common Mode Signal]

Applying ⑤ on ③

$$V_0 = -\left(\frac{R_2}{R_1}\right)V_1 + \frac{V_2 R_4}{R_3+R_4}\left(1+\frac{R_2}{R_1}\right)$$

$$= -\left(\frac{R_4}{R_3}\right)V_1 + \frac{V_2 R_4}{R_3+R_4}\left(1+\frac{R_4}{R_3}\right)$$

$$= -\left(\frac{R_4}{R_3}\right)V_1 + \frac{V_2 R_4}{\cancel{R_3+R_4}}\left(\frac{\cancel{R_3+R_4}}{R_3}\right)$$

$$= V_2\left(\frac{R_4}{R_3}\right) - V_1\left(\frac{R_4}{R_3}\right)$$

$$V_0 = \frac{R_4}{R_3}(V_2 - V_1)$$

$$V_0 = \frac{R_2}{R_1}(V_2 - V_1) = \frac{R_2}{R_1}(V_{id})$$

$\left[\frac{R_2}{R_1} \neq \frac{R_4}{R_3}\right]$

When the conditions are not satisfied, substitute $V_1 = V_{ICM} - V_{id}/2$; $V_2 = V_{ICM} + V_{id}/2$ in ③

Hence, $A_{CM} = \frac{-R_2}{R_1} + \frac{R_4}{R_3+R_4}\left(1+\frac{R_2}{R_1}\right)$

$$A_d = \frac{1}{2}\left\{\frac{R_2}{R_1} + \frac{R_4}{R_3+R_4}\right\}\left[1+R_2/R_1\right]$$

$V_{id} = V_2 - V_1$ $\quad V_{id} = -V_1 + V_2$

$V_{icm} = \frac{V_1+V_2}{2}$ $\Rightarrow 2V_{ICM} = V_1 + V_2$

$V_2 = V_{ICM} + \frac{V_{id}}{2}$; $V_1 = V_{ICM} - \frac{V_{id}}{2}$

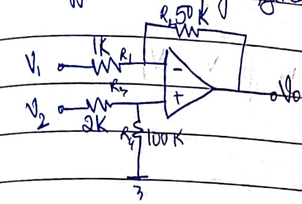
$\boxed{Z_{in} = R_1 + R_2}$ (Input Impedance).

Input Impedance of Diff-Ampl:

i) Diff I/P: $\frac{V_{in}}{i_{in}} = R_{in} = R_1 + R_3$

ii) Common Mode I/P: $\frac{V_{in}}{i_{in}} = (R_3 + R_4) \parallel \left(\frac{R_1(R_3+R_4)}{R_3}\right)$

Q.1 For a given difference amplifier, find A_d, A_{CM}, CMRR. [Ideal] Also find A_d, A_{CM} and CMRR when resistors have 1% tolerance. [Practical]



Ans Here, $\frac{R_2}{R_1} = \frac{R_4}{R_3}$

$\frac{50k}{1k} = \frac{100k}{2k} = 50$

$A_{CM} = 0$; $CMRR = \frac{A_d}{A_{CM}} = \infty$; $A_d = \frac{R_2}{R_1} = 50$

$V_0 = \frac{R_2}{R_1}(V_2 - V_1) \Rightarrow A_d = \frac{V_0}{V_2 - V_1} = 50$

$R_2 R_3 = +1\%$

$R_1 R_4 = -1\%$

New Values: $R_2 = 50.5\,k\Omega$ $\quad \frac{50.5k}{0.99k} + \frac{99k}{2.02k}$

$R_3 = 2.02\,k\Omega$

$R_1 = 0.99\,k\Omega$ $\quad A_d - 50.98$

$R_4 = 99\,k\Omega$ $\quad A_{CM} = 0.05$

CMRR = 1.019 K = 60.16 dB

$$A_{CM} = \frac{-50.5}{0.99} + \frac{99}{101.02}\left[1 + \frac{50.5}{0.99}\right] = -0.04$$

$$A_d = \frac{1}{2}\left\{\frac{50.5}{0.99} + \frac{99}{101.02}\right\}\left[1 + \frac{50.5}{0.99}\right] = 50.99$$

$$CMRR = \frac{|A_d|}{|A_{CM}|} = \cancel{0.2008}\ 1274.75$$

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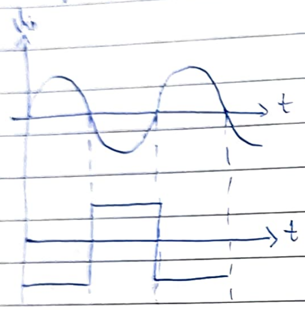
v) Comparator [App^n of Op Amp in Open loop]

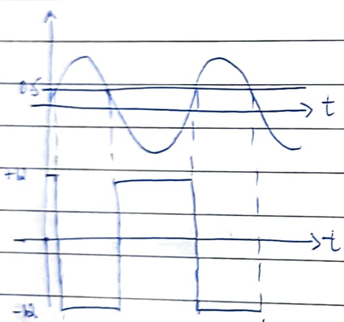
*Inverting Comparator

$V_0 = A_{OL}[V_2 - V_1] \Rightarrow +12$ for $V_2 > V_1$
$= \infty[+12] = +\infty$

$V_0 = A_{OL}[V_2 - V_1] \Rightarrow -12$ for $V_2 < V_1$
$= \infty[-12] = -\infty$



Zero Crossing Detector

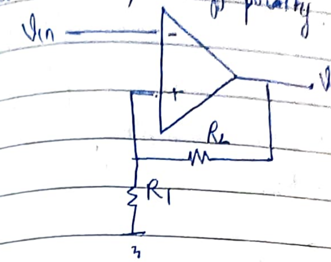


$V_0 = A_{OL}[0.5 - V_1]$
Let $V_1 = 0.3$
$V_0 = A_{OL}[0.5 - 0.3]$
$= 0.2 A_{OL} = 0.2 \times \infty = \infty$

Let $V_1 = 0.6$
$V_0 = \infty[0.5 - 0.6] = -\infty$

vi) Schmitt Trigger

Magnitude is same, but diff polarity



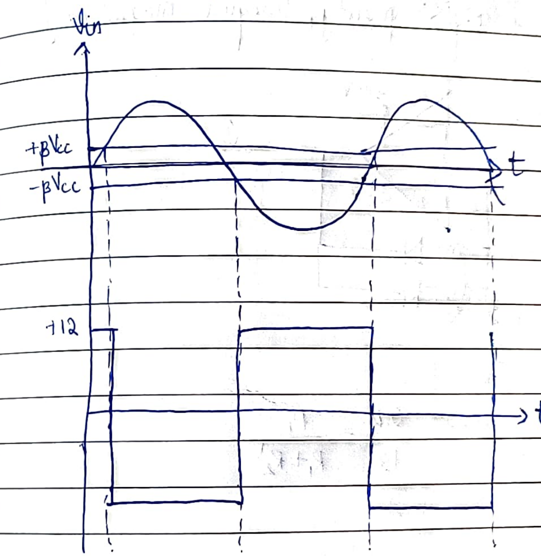
$V_{UTP} = \frac{+V_{sat} R_1}{R_1 + R_2}$

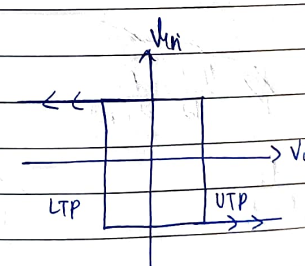
$V_{LTP} = \frac{-V_{sat} R_1}{R_1 + R_2}$

$\frac{V_{UTP}}{+V_{sat}} = \frac{R_1}{R_1 + R_2} = \beta$

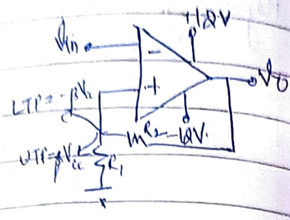
$\Rightarrow V_{UTP} = +V_{sat}\beta \rightarrow$ i)
$V_{LTP} = -V_{sat}\beta \rightarrow$ ii)

Here in 1st section $V_{in} < V_{UTP}$ hence should be in -ve part but this is inverting hence in +ve part.





Q.1 Design a Schmitt Trigger with UTP = +1 and LTP = −1 given that $V_{cc} = 12V$.



Ans $V_{UTP} = \dfrac{+V_{sat} R_1}{R_1+R_2}$

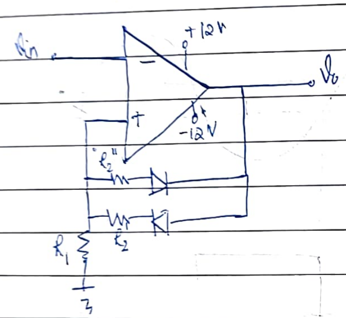
$\dfrac{1}{12} = \dfrac{R_1}{R_1+R_2} \Rightarrow 12R_1 = R_1 + R_2$
$11R_1 = R_2$

$-1 = \dfrac{-V_{sat} R_1}{R_1+R_2} \Rightarrow \dfrac{R_1}{R_1+R_2} = \beta = \dfrac{1}{12}$

Here, $R_1 = 1K$; $R_2 = 11K$.

Q.2 Design a Schmitt Trigger with UTP = +2.4V, LTP = −4.8 V, $V_{cc} = \pm 12V$. [Unequal polarity, Unequal magnitude]

Ans



Ans $V_{UTP} = \dfrac{+12 R_1}{R_1+R_2'} \Rightarrow \dfrac{2.4}{12} = \dfrac{R_1}{R_1+R_2'}$

$\dfrac{1}{5} = \dfrac{R_1}{R_1+R_2'}$

$\dfrac{24^2}{120} = \dfrac{1}{5}$

$\dfrac{48^4}{120_{10}} = \dfrac{2}{5}$

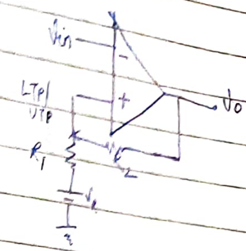
$V_{LTP} = \dfrac{-12 R_1}{R_1+R_2''} = -4.8 \Rightarrow \dfrac{4.8}{12} = \dfrac{R_1}{R_1+R_2''}$

$\dfrac{2}{5} = \dfrac{R_1}{R_1+R_2''} = \dfrac{1}{5/2} = \dfrac{R_1}{R_1+R_2''}$

$\Rightarrow R_1 = 1k\Omega,\ R_2' = 4k\ ;\ R_2'' = 1.5k$

Q.3 Design a Schmitt Trigger for UTP = 2V, LTP = 1V and $V_{cc} = \pm 12V$.
[Magnitude is diff, polarity is same]

Ans ~~$V_{UTP} = \dfrac{+V_{sat} R_1}{R_1+R_2}$~~ , V_{LTP} :



~~$\dfrac{2}{12\,6} = \dfrac{R_1}{R_1+R_2}$~~

~~$\Rightarrow 6R_1 - R_1 = R_2$~~
~~$5R_1 = R_2$~~

$V_{UTP} = I R_1 + V_R$
$V_{UTP} = \dfrac{(12 - V_R) R_1}{R_1+R_2} + V_R$ $\qquad V_{LTP} = \dfrac{(-12-V_R) R_1}{R_1+R_2} + V_R$

Let $\dfrac{R_1}{R_1+R_2} = x$

$\Rightarrow 2 = (12 - V_R)x + V_R \qquad \Rightarrow 1 = (-12-V_R)x + V_R$

$2 = 12x - xV_R + V_R$
$(-)\ 1 = -12x - xV_R + V_R$
$1 = 24x \Rightarrow \boxed{x = \dfrac{1}{24}} = 0.04$

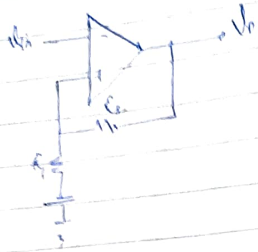
~~$\dfrac{2}{x} = 12 - V_R \Rightarrow 48 = 12 - V_R \Rightarrow \boxed{V_R = -36V}$~~

$2 = 0.5 - \dfrac{V_R}{24} + V_R \Rightarrow 1.5 = V_R\left(1 - \dfrac{1}{24}\right) = V_R\left(\dfrac{23}{24}\right) = \dfrac{3}{2}$

$V_R = \dfrac{36}{23} = 1.565V$

$\dfrac{1}{24} = \dfrac{R_1}{R_1+R_2} \Rightarrow R_1 = 1K ; R_2 = 23K.$

Q.4 UTP = -2V ; LTP = -1V



Have $-V_R$ here.

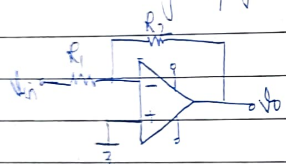
15/3/24

Q.1 a) Design an amplifier to have a gain of -40 and input impedance of 5k using an Op-Amp which is ideal in all aspects except that it has a finite gain of 600.

b) In the designed circuit, what would be the gain if the Op-Amp is replaced by an ideal one.

c) What would be the modification needed to obtain original gain with same input impedance with an ideal Op Amp.

Ans - It is an inverting amplifier



Given, $R_1 = 5k$; $A_{CL} = -40$

WKT, $\dfrac{V_o}{V_{in}} = A_{CL} = \dfrac{-R_2/R_1}{1 + \left[\dfrac{1 + R_2/R_1}{A_{OL}}\right]}$

$$-40 = \frac{-R_2/5k}{1 + \left[\dfrac{1 + R_2/5k}{600}\right]}$$

$$\Rightarrow 40\left[1 + \left(\frac{1 + \frac{R_2}{5k}}{600}\right)\right] = \frac{R_2}{5k}$$

$$\Rightarrow \cancel{40}\left[\frac{600 + 1 + R_2/5k}{\cancel{600}\ \cancel{15}\ 3}\right] = \frac{R_2}{5k}$$

$$601 + \frac{R_2}{5k} = \frac{3R_2}{1000}$$

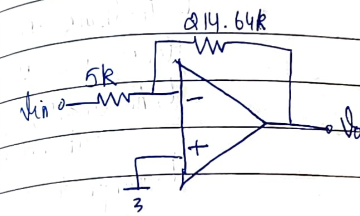
$$601 = \frac{3R_2}{1000} - \frac{R_2}{5000} = R_2\left[\frac{3}{1000} - \frac{1}{5000}\right] = R_2[0.0028]$$

$$R_2 = \frac{601}{0.0028} = 214.64k\Omega$$

$R_2 = 214.64k\Omega$

b) $A_{CL} = \dfrac{+V_o}{V_{in}} = \dfrac{-R_2}{R_1} = \dfrac{-214.64k}{5k} = -42.93$

c)



$R_1 = 5k$

$A_{CL} = -40$

$-40 = \dfrac{-R_2}{5k}$ $\Rightarrow R_2 = 200k\Omega \rightarrow$ It is the required feedback resistance.

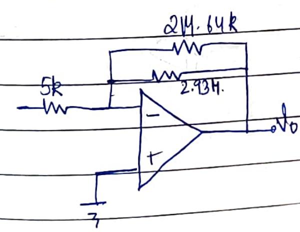
$200k = 214.64k \,||\, R_2'$

$$\frac{1}{200k} = \frac{1}{214.64k} + \frac{1}{R}$$

$R = 2932.24k\Omega$

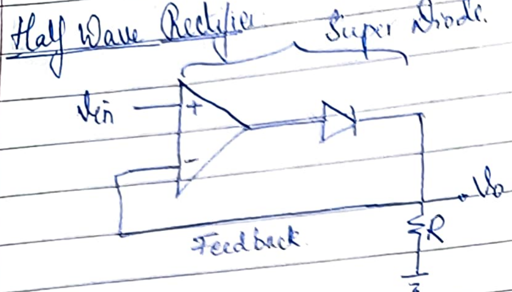
$\boxed{R = 2.932M\Omega}$

Thus, the new circuit is

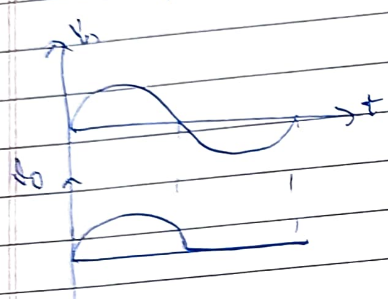


Precision Rectifiers

Half Wave Rectifier



$V_{in} > 0$, O/P $V_o = +ve$, $D_1 \to ON$



$V_{in} < 0$

O/P $\to -ve$; $D_1 \to$ Off

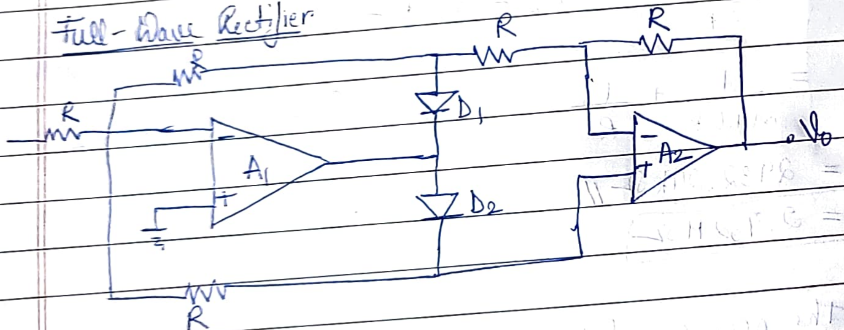
↳ Feedback doesn't exist

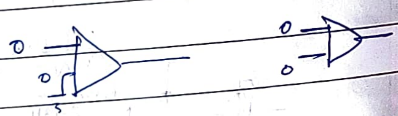
Hence, acts as Comparator

↳ At $V_{in} < 0$, it gets saturated.

↳ Larger Switching time

Full-Wave Rectifier





Case i) $V_{in} > 0$

$A_1 = -ve$

$D_1 = ON$; $D_2 = Off$

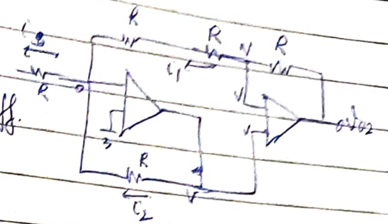
$V_{o1} = \left(-R/R\right) V_{in} = -V_{in}$

O/P of $A_2 = \left(-R/R\right) V_{o1}$

$V_{o2} = -(-V_{in}) = V_{in}$

Case ii) $V_{in} < 0$

A_1 (O/P) $= +ve$; $D_2 = ON$ / $D_1 = Off$.



$i = i_1 + i_2$

$i = \frac{V}{2R} + \frac{V}{R} = \frac{-V_{in}}{R}$

$\Rightarrow \frac{V}{R}\left(\frac{1}{2}+1\right) = -\frac{V_{in}}{R} \Rightarrow V_{in} = \frac{-3V}{2} \Rightarrow V = \frac{-2V_{in}}{3}$

In the 2nd Amplifier, the actual i/p is to +ve (Non-inverting)

$\cancel{V_{o2} = -\left(\frac{R}{2R}\right) V = \frac{-V}{2} = \frac{-1}{2}\left(\frac{-2V_{in}}{3}\right) = \frac{V_{in}}{3}}$

$V_{o2} = \left(1 + \frac{R}{2R}\right) V = \frac{3}{2}\left[\frac{-2}{3} V_{in}\right] = -V_{in}$

Hence, $V_{in} < 0$; $V_{o2} = -(-V_{in}) = V_{in}$ //