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→ AC Analysis of BJT with active load :-

$g_{m1} = \frac{I_{C1}}{V_T} = 19.82\,mA/V$, $g_{m2} = \frac{I_{C2}}{V_T} = 19.82\,mA/V$, $g_{m3} = \frac{I_{C3}}{V_T} = 19.82\,mA/V$, $g_{m4} = \frac{I_{C4}}{V_T} = 19.8\ldots$

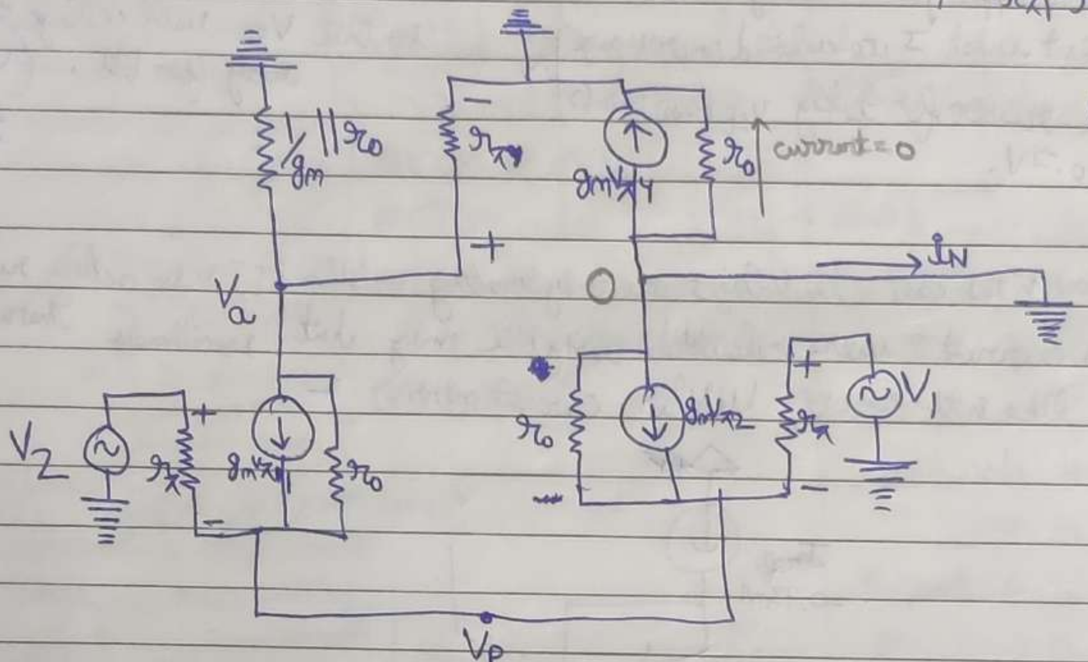
$r_{o1} = \frac{V_A}{I_{C1}} = \frac{100}{512.425\times10^{-3}} = 195.15\,k\Omega$, $r_{o2} = \frac{V_A}{I_{C2}} = \frac{100}{512.425\times10^{-3}} = 195.15\,k\Omega$, $r_{o3} = \frac{V_A}{I_{C3}} = \frac{100}{512.425\times10^{-3}} = 195.15\,k\Omega$, $r_{o4} = \frac{V_A}{I_{C4}} = \frac{100}{512.425\times10^{-3}} = 195.15\,k\Omega$

$\therefore r_{o1} = r_{o2} = r_{o3} = r_{o4} = r_o$

$\therefore g_{m1} = g_{m2} = g_{m3} = g_{m4} = g_m$

$r_\pi = \frac{\beta}{g_m} = 10.09\,k\Omega$

$\therefore r_{\pi1} = r_{\pi2} = r_{\pi3} = r_{\pi4}$




Apply Norton's Theorem

$$\frac{V_2 - V_p}{r_\pi} + g_m(V_2 - V_p) + \frac{V_a - V_p}{r_o} + g_m(V_1 - V_p) + \frac{(0 - V_p)}{r_o} + \frac{(V_1 - V_p)}{r_\pi} = 0$$

$$i_N = g_m(V_a - 0) + g_m(V_1 - V_p) + \frac{(0 - V_p)}{r_o}$$

$$g_m(V_2 - V_p) + \frac{V_a - V_p}{r_o} + \frac{V_a - 0}{\left(\frac{1}{g_m} \| r_o\right)} + \frac{V_a - 0}{r_\pi} = 0$$

$$V_a\left[\frac{1}{r_o} + \frac{1}{r_L} + \frac{1}{r_\pi}\right] = V_p\left[\frac{1}{r_o} + g_m\right] - g_m V_2$$

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$$V_a = \frac{V_p\left(\frac{1}{r_o} + g_m\right) - g_m V_2}{\frac{1}{r_o} + \frac{1}{r_e} + \frac{1}{r_\pi}}$$

$$V_a - V_p = \frac{\cancel{\frac{V_p}{r_o}} + V_p g_m - g_m V_2 - \cancel{\frac{V_p}{r_o}} - \frac{V_p}{r_e} - \frac{V_p}{r_\pi}}{\frac{1}{r_o} + \frac{1}{r_e} + \frac{1}{r_\pi}} = \frac{V_p\left(g_m - \frac{1}{r_\pi} - \frac{1}{r_e}\right) - g_m V_2}{\frac{1}{r_o} + \frac{1}{r_e} + \frac{1}{r_\pi}}$$

$$\frac{V_2}{r_\pi} + g_m V_2 - \frac{g_m V_2}{1 + \frac{r_o}{r_e} + \frac{r_o}{r_\pi}} + g_m V_1 + \frac{V_1}{r_\pi} = \frac{V_p}{r_\pi} + g_m V_p - \frac{V_p\left(g_m - \frac{1}{r_\pi} - \frac{1}{r_e}\right)}{1 + \frac{r_o}{r_e} + \frac{r_o}{r_\pi}} + V_p\left(g_m + \frac{1}{r_o} + \frac{1}{r_\pi}\right)$$

$$RHS = V_p\left(\frac{1}{r_\pi} + g_m + \frac{\frac{1}{r_\pi} + \frac{1}{r_e} - g_m}{1 + \frac{r_o}{r_e} + \frac{r_o}{r_\pi}} + g_m + \frac{1}{r_o} + \frac{1}{r_\pi}\right)$$

$$= V_p\left(\frac{2}{r_\pi} + 2g_m + \frac{1}{r_o} + \frac{r_e + r_\pi - g_m r_\pi r_e}{\cancel{r_\pi} r_e} \times \frac{r_e \cancel{r_\pi}}{r_e r_\pi + r_\pi r_o + r_e r_o}\right)$$

take $r_e \approx \frac{1}{g_m}$

$$= V_p\left(\frac{2}{r_\pi} + 2g_m + \frac{1}{r_o} + \frac{\cancel{\frac{1}{g_m}} + \cancel{r_\pi} - \cancel{r_\pi}}{\cancel{\frac{1}{g_m}}} \times \frac{r_e}{r_e r_\pi + r_o\left(r_\pi + \frac{1}{g_m}\right)}\right)$$

$$= V_p\left(\frac{2}{r_\pi} + 2g_m + \frac{1}{r_o} + \frac{1}{r_\pi + r_o + r_o r_\pi g_m}\right) = V_p\left(\frac{2}{r_\pi} + 2g_m + \frac{1}{r_o} + \frac{1}{r_\pi + r_o + r_o r_\pi g_m}\right)$$

$$LHS = V_2 g_m + \frac{V_2}{r_\pi} - \cancel{\quad} \cancel{\quad}(\,) + \left(g_m + \frac{1}{r_\pi}\right)V_1$$

$$LHS = V_2 g_m + V_1 g_m - \frac{g_m V_2 r_\pi}{r_\pi(1 + r_o g_m) + r_o} = g_m(V_1 + V_2) - \frac{g_m r_\pi V_2}{r_o(g_m r_\pi + 1)}$$

$$g_m(V_1 + V_2) - \frac{V_2}{r_o}$$

Spiral

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If $V_2 = -V$ & $V_1 = V$ then $V_p = 0$

$$V_p(42.4) = 19.82V_1 + 19.82V_2 \Rightarrow V_p = 0.467(V_1+V_2)$$

$$V_a = \frac{g_m(V_p - V_2)}{g_m + \frac{1}{r_\pi}} = 0.995(V_p - V_2) = 0.995(0.467V_1 - 0.533V_2)$$

$$V_a = 0.464V_1 - 0.530V_2$$

$$i_N = 19.82 \times (0.464V_1 - 0.53V_2) + 19.82(V_1 - 0.467V_1 - 0.467V_2) - \frac{V_p}{r_o}$$

$$i_N = 19.82[0.464V_1 - 0.53V_2 + 0.533V_1 - 0.467V_2] - (V_p \times 0.0051)$$

$$i_N = 19.82[0.997V_1 - 0.997V_2] - 0.0024(V_1 + V_2)$$

$$i_N = 19.76V_1 - 19.76V_2 - 0.0024V_1 - 0.0024V_2$$

$$i_N = 19.76(V_1) - 19.76V_2 = 19.76(V_1 - V_2)$$

$$\frac{i_N}{V_1 - V_2} = 19.76 = G_m = \text{Overall transconductance} \simeq 19.82 \simeq g_m$$

$$R_o = r_{o2} \| r_{o4} = r_o \| r_o = \frac{r_o}{2} = 97.57\,k\Omega$$

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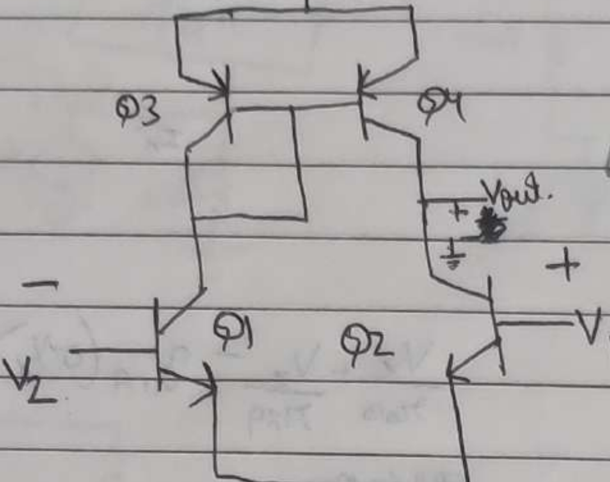
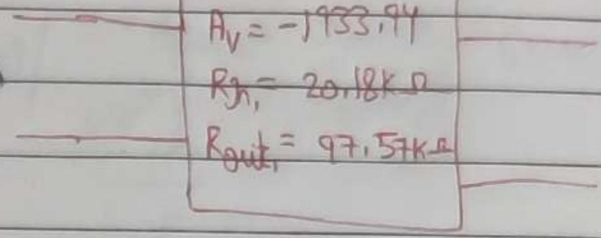
AC Analysis of stage 1

⇙




$$A_V = \frac{V_{out}}{V_2 - V_1} = \frac{V_{out}}{-(V_1 - V_2)} = \frac{g_m r_o}{2}$$

$$A_V = \frac{V_{out}}{V_1 - V_2} = -\frac{g_m r_o}{2} = -1933.94$$

Later $R_{in}$/out $R_{out}$ is done.

$R_{in_1} = R_{id} = 2 \times r_{\pi} = 2 \times 10.09 = 20.18\,k\Omega$ } doubtful, confirm it.

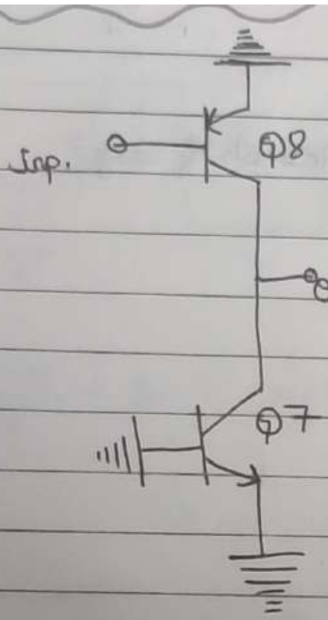
differential input resistance

combine all stages

⇓

# AC analysis of Stage 2

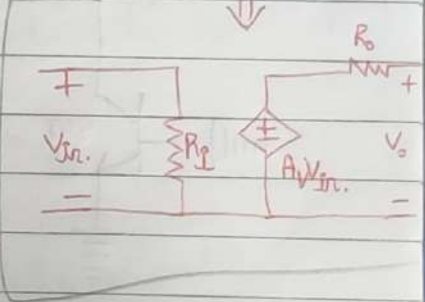
$A_v, R_i, R_o = ?$

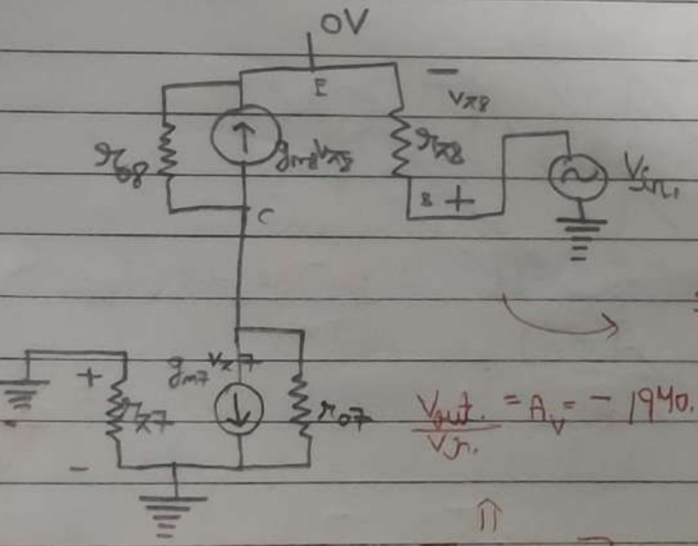


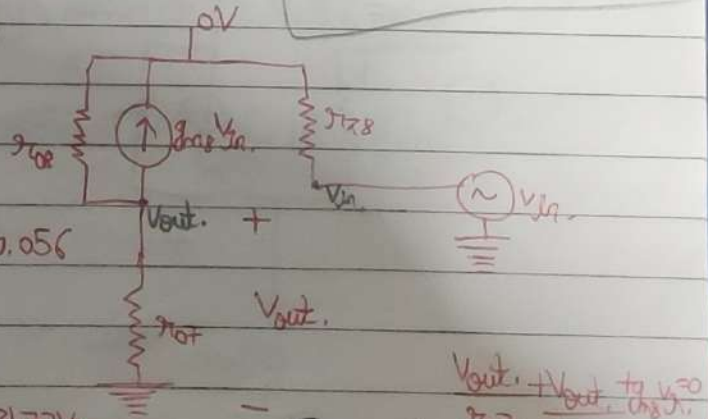

$A_v = -1940.056$
$R_i = 6.3k\Omega$
$R_o = 61.16k\Omega$

* A BJT used as voltage amplifier can be represented as a two port N/w which we studied in Network Theory

⇓




$\frac{V_{out}}{V_{in}} = A_v = -1940.056$

⇑

$V_{out}\left[\frac{1}{122.7}+\frac{1}{121.95}\right] = -31.72V_{in}$

$\frac{V_{out}}{r_{o7}} + \frac{V_{out}}{r_{o8}} + g_{m8}V_{in} = 0$

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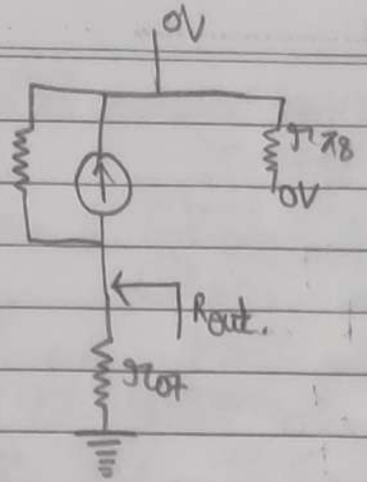
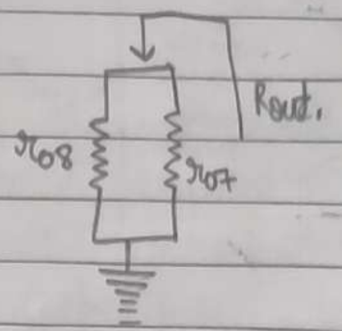
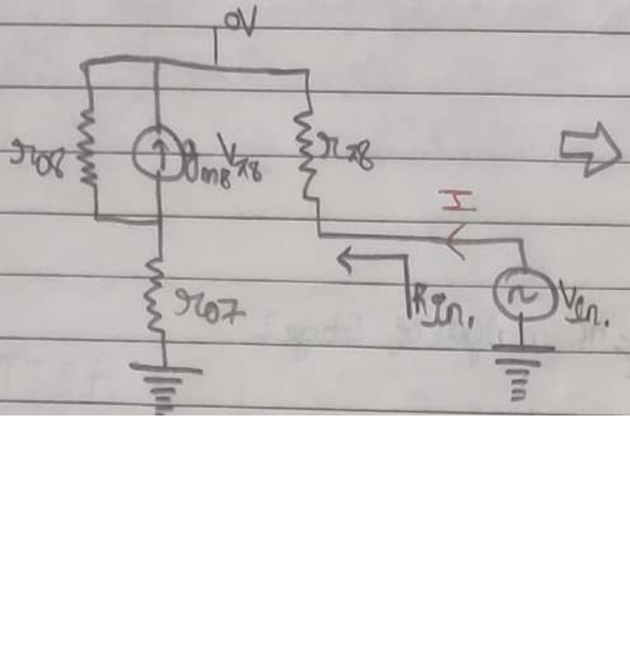



$$\frac{1}{R_{out.}} = \frac{1}{r_{o8}} + \frac{1}{r_{o7}}$$

$$R_{out.} = \frac{r_{o8} r_{o7}}{r_{o8}+r_{o7}} = 61.16\,K\Omega$$

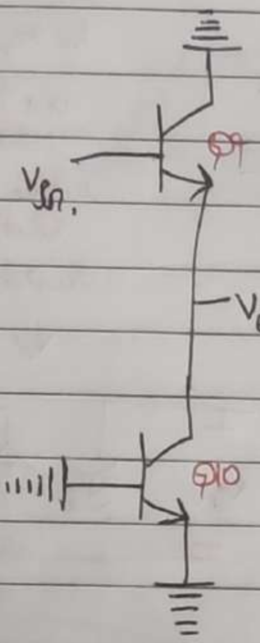



$$\frac{V_{in.}}{I} = R_{in.}$$

$\Rightarrow \quad I r_{\pi 8} = V_{in.}$

$\therefore R_{in.} = r_{\pi 8} = 6.3\,K\Omega$

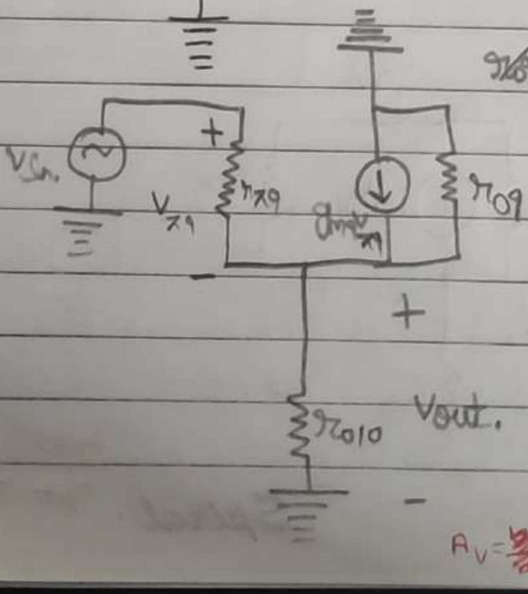
# AC Analysis of Stage 3

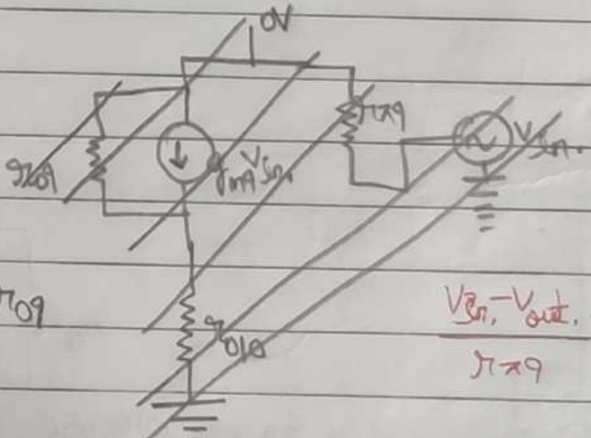



$A_V = 1$

$R_{in} = 20576.13\ K\Omega$

$R_o = 0.031\ K\Omega$




$$\frac{V_{in} - V_{out}}{r_{\pi 9}} + g_{m9}(v_{in} - v_{out}) + \frac{(0 - v_{out})}{r_{o9}} = \frac{V_{out}}{r_{o10}}$$

$$V_{in}\left[\frac{1}{r_{\pi 9}} + g_{m9}\right] = V_{out}\left[\frac{1}{r_{o10}} + \frac{1}{r_{o9}} + g_{m9} + \frac{1}{r_{\pi 9}}\right]$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{32.58}{32.57} = 0.9997 \simeq 1$$

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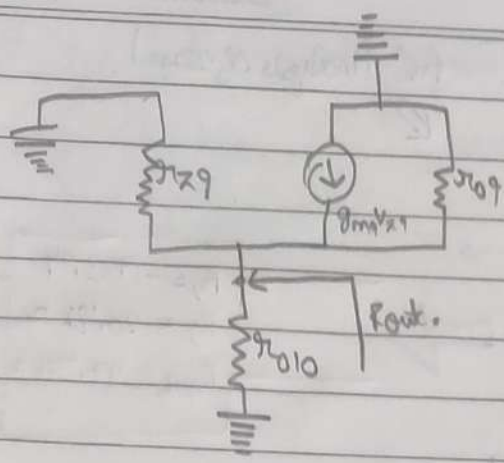
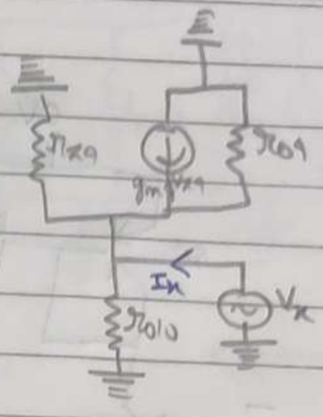
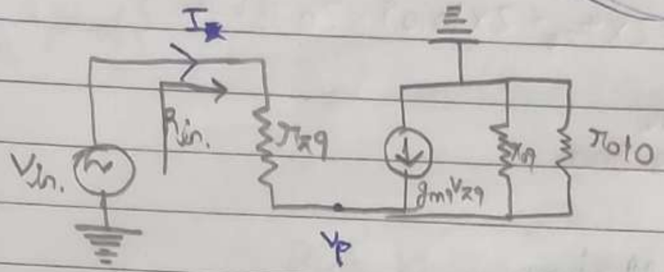



$$\frac{V_x}{r_{o10}} + \frac{V_x}{r_{\pi 9}} - g_{m9}(0 - V_x) + \frac{V_x}{r_{o9}} = I_x$$

$R_{out} = 0.031\ K\Omega$

$$\frac{V_x}{I_x} = R_{out} = \frac{1}{\frac{1}{r_{o10}} + \frac{1}{r_{\pi 9}} + g_{m9} + \frac{1}{r_{o9}}}$$




$$\frac{V_{in}}{I} = R_{in}.$$

$$R_{eq} = \frac{r_{o9} r_{o10}}{r_{o9} + r_{o10}}$$

$$\frac{V_{in} - V_p}{r_{\pi 9}} + g_{m9}(V_{in} - V_p) = \frac{V_p}{R_{eq}} = \frac{V_p(r_{o9} + r_{o10})}{r_{o9} r_{o10}}$$

$$V_{in}\left[g_{m9} + \frac{1}{r_{\pi 9}}\right] = V_p\left[\frac{r_{o9} + r_{o10}}{r_{o9} r_{o10}} + g_{m9} + \frac{1}{r_{\pi 9}}\right] = V_p\left[\frac{1}{r_{o10}} + \frac{1}{r_{o9}} + g_{m9} + \frac{1}{r_{\pi 9}}\right]$$

$$V_{in} \times 32.58 = V_p \times 32.59$$

$$V_p = V_{in} \times 0.9997 = 0.9997 V_{in}.$$

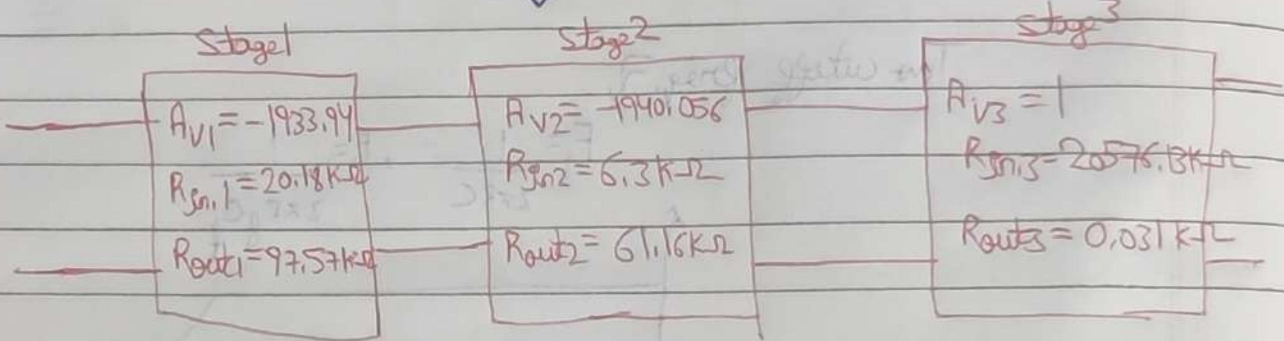
$$\frac{V_{in} - V_p}{r_{\pi 9}} = I \Rightarrow I = \frac{0.0003 V_{in}}{6.17} = 4.86 V_{in} \times 10^{-5}$$

$$R_{in} = \frac{V_{in}}{4.86 V_{in}} = \frac{10^5}{4.86} = 20576.13\ K\Omega$$

P.T.O.

# Combining all stages

$\Downarrow$

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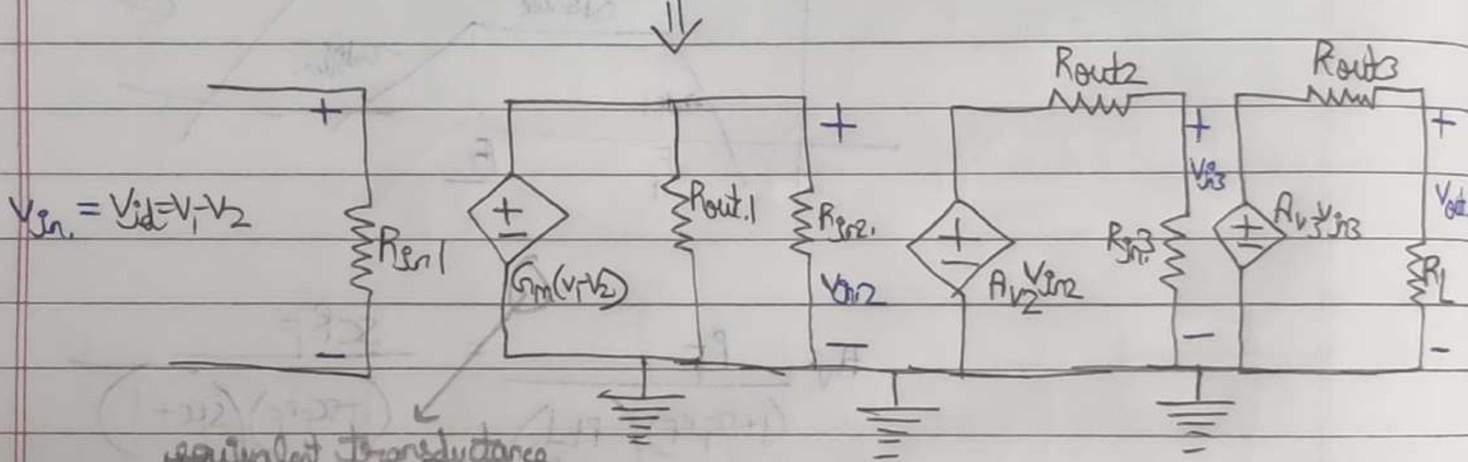


equivalent transconductance of stage1

For open loop gain $R_L \to \infty$ $\therefore$ open circuit on output side

$$A_{OL} = \frac{V_{out}}{V_{in}} = \frac{V_{in2}}{V_{in}} \times \frac{V_{in3}}{V_{in2}} \times \frac{V_{out}}{V_{in3}} = \left[\frac{G_m(V_1-V_2)}{V_{in}} \times (R_{out1} \| R_{in2})\right] \times \left[\frac{R_{in3}}{R_{out2}+R_{in3}} \times \frac{A_{V2}V_{in2}}{V_{in2}}\right] \times \left[\frac{R_L}{R_L+R_{out3}} \times \frac{A_{V3}V_{in3}}{V_{in3}}\right]$$

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$A_{OL} = 19.82 \times 5.92 \times 1940.056 \times 0.997$

$A_{OL} = 226952.4$

$\boxed{A_{OL}\,(\text{In dB}) \simeq 108\,dB}$