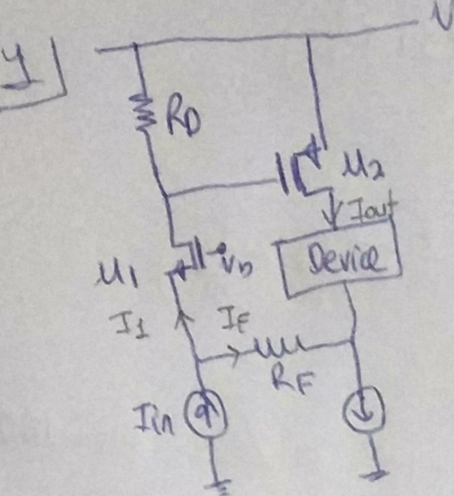
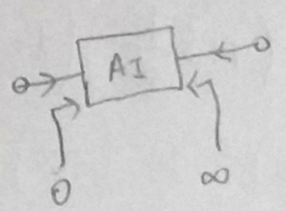
EHB 335E HW6

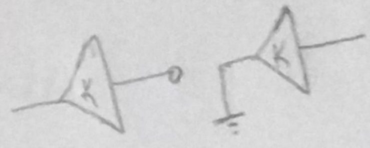
1)



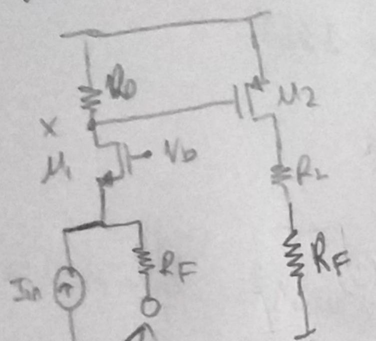
Sense : Current
Return : Current
⇒ CL Amplifier ⇒ Shunt-Series Amplifier



⇒



When we break the loop, the new circuit is



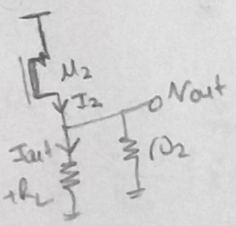
open there

since $\lambda_1 = 0$, and DC current source is open in AC analysis

$v_x = I_{in} R_D$ (All current flows into the transistor)

However $\lambda_2 \neq 0$

$$V_{out} = -g_{m2}\left[(R_L+R_F) \parallel r_{O2}\right] v_x$$



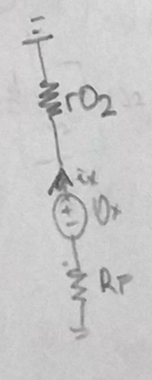
$$I_2 = \frac{V_{out}}{\left[(R_L+R_F) \parallel r_{O2}\right]} = -g_{m2} v_x$$

$$I_{out} = \frac{r_{O2}}{R_F+R_L+r_{O2}} I_2 = -\frac{g_{m2} r_{O2}}{R_F+R_L+r_{O2}} v_x$$

Simple Current Division

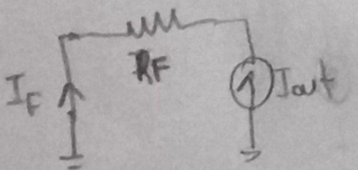
$$\Rightarrow A_I = \frac{I_{out}}{I_{in}} = -\frac{g_{m2} r_{O2} R_D}{R_F+R_L+r_{O2}}$$

$$\Rightarrow R_{in} = \frac{1}{g_{m1}} \quad ; \quad R_{out} =$$



$$\Rightarrow \frac{v_x}{i_x} = R_{out} = r_{O2} + R_F$$

Let us determine K-factor



$$\Rightarrow K = \frac{I_F}{I_{out}} = -1 \Rightarrow$$

$$A_{I,CL} = \frac{A_I}{1+KA_I} = \frac{-\frac{g_{m2} r_{O2} R_D}{R_F+R_L+r_{O2}}}{1+(-1)\left(-\frac{g_{m2} r_{O2} R_D}{R_F+R_L+r_{O2}}\right)}$$

- $$A_{I,CL} = -\frac{g_{m2} r_{O2} R_D}{R_F+R_L+r_{O2}+g_{m2} r_{O2} R_D}$$

- $$R_{in,CL} = \frac{R_{in}}{1+KA_I} = \frac{1/g_{m1}}{1+\frac{g_{m2} r_{O2} R_D}{R_F+R_L+r_{O2}}}$$

- $$R_{out,CL} = (1+KA_I) R_{out} = \left(1+\frac{g_{m2} r_{O2} R_D}{R_F+R_L+r_{O2}}\right)\left[r_{O2}+R_F\right]$$

2) $A_0 = 10^4 \ (\frac{V}{V})$

$f_1 = 10^5 \ Hz$

$f_2 = 3.16 \times 10^5 \ Hz$

$f_3 = 10^6 \ Hz$

$$\Rightarrow A(s) = \frac{A_0}{\left(1+\frac{jf}{f_1}\right)\left(1+\frac{jf}{f_2}\right)\left(1+j\frac{f}{f_3}\right)}$$

$$A(s) = \frac{10^4}{\left(1+j\frac{f}{10^5}\right)\left(1+j\frac{f}{3.16\times10^5}\right)\left(1+j\frac{f}{10^6}\right)}$$

$$\underline{\angle A(s)} = -\left[\tan^{-1}\left(\frac{f}{10^5}\right) + \tan^{-1}\left(\frac{f}{3.16\times10^5}\right) + \tan^{-1}\left(\frac{f}{10^6}\right)\right]$$

we want a phase margin of 45°, $PM = \angle A(s) + 180^\circ \Rightarrow \angle A(s) = PM - 180^\circ$

$$\Rightarrow \angle A(s) = 45^\circ - 180^\circ = -135^\circ$$

$$\Rightarrow \left[\tan^{-1}\left(\frac{f_1}{10^5}\right) + \tan^{-1}\left(\frac{f_1}{3.16\times10^5}\right) + \tan^{-1}\left(\frac{f_1}{10^6}\right)\right] = 135^\circ$$

By using Wolfram Alpha we find $f_1 \approx 3.16 \times 10^5 \ Hz$

$$A(jw_1) = \frac{10^4}{\left(1+j\frac{3.16\times10^5}{10^5}\right)\left(1+j\frac{3.16\times10^5}{3.16\times10^5}\right)\left(1+j\frac{3.16\times10^5}{10^6}\right)} \Rightarrow |A(jw_1)| = 2034.25 \ (\frac{V}{V})$$

$|A(jw_1)| \ (dB) = 20\log_{10}(2034.25) \approx 66.17 \ dB$ (open-loop gain)

Since at gain-crossover frequency loop gain is 0 dB. We can calculate β -

$\beta_{(dB)} \approx -66.17 \ dB \Rightarrow 20\log_{10}\beta = -66.17 \Rightarrow \beta = 10^{-\frac{66.17}{20}} \approx 4.91 \times 10^{-4}$

Then, we can calculate the closed-loop gain by the formula $A_f = \frac{A_0}{1+KA_0}$

$$\Rightarrow A_{f0} = \frac{10^4}{1+(4.91\times10^{-4})(10^4)} = \frac{10^4}{5.91} = 1.69 \times 10^3 \ (\frac{V}{V})$$

$$\Rightarrow A_{f0\,(dB)} = 20\log(1.69\times10^3) = 64.56 \ dB$$

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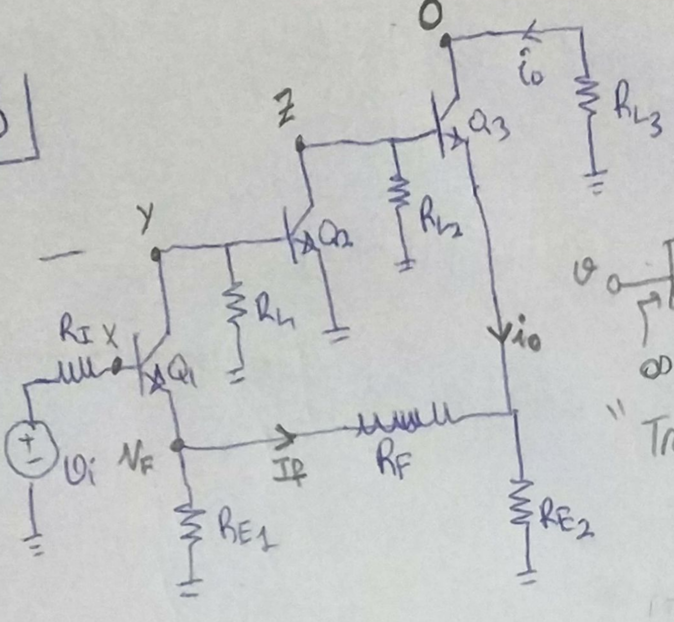
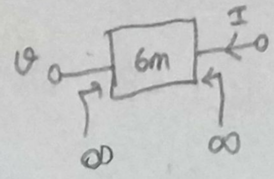
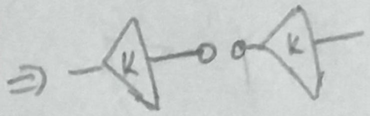


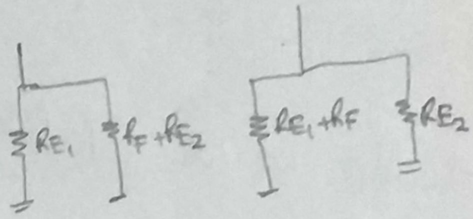
→ we are sensing current

→ and returning voltage (v_{be} subtractor)



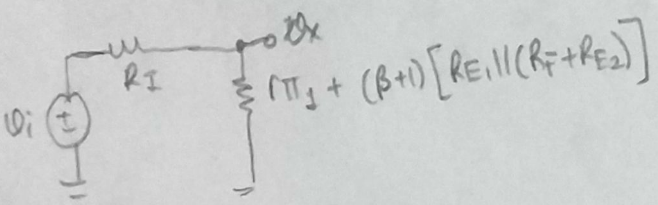


"Transconductance Amplifier"



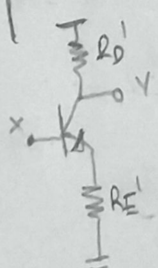
$$\frac{i_o}{v_i} = \frac{v_x}{v_i}\cdot\frac{v_y}{v_x}\cdot\frac{v_z}{v_y}\cdot\frac{i_o}{v_z}$$ ⇒ Let's calculate these gains seperately

$$\frac{v_x}{v_i} = \frac{(\beta+1)\left[R_{E1}\,||\,(R_F+R_{E2})\right]+r_{\pi 1}}{(\beta+1)\left[R_{E1}\,||\,(R_F+R_{E2})\right]+r_{\pi 1}+R_I}$$



"Voltage Divider"

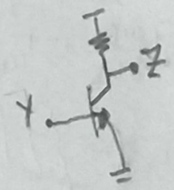
$$\frac{v_y}{v_x} = -\frac{g_{m1}\left[R_{L1}\,||\,r_{\pi 2}\right]}{1+g_{m1}\left[R_{E1}\,||\,(R_F+R_{E2})\right]}$$



$R_E' = R_{E1}\,||\,(R_F+R_{E2})$

$R_D' = R_{L1}\,||\,r_{\pi 2}$

"Emitter Degenerated CE stage with $g_m' = \frac{g_m}{1+g_m R_E'}$"



"Simple CE stage"

$$\frac{v_z}{v_y} = -g_{m2}\left\{R_{L2}\,||\left[r_{\pi 3}+(\beta+1)\left[(R_{E1}+R_F)\,||\,R_{E2}\right]\right]\right\}$$

"emitter degenerated CE stage"

$$\frac{i_o}{v_z} = \frac{g_{m3}}{1+g_{m3}\left[(R_{E1}+R_F)\,||\,R_{E2}\right]}$$

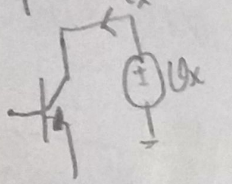
Then, the open loop gain $G_{m,OL}$ (We have assumed that collector and emitter currents are the same for Q3)

$$G_{m,OL} = \underbrace{\frac{(\beta+1)\left[R_{E1}\,||\,(R_F+R_{E2})\right]+r_{\pi 1}}{(\beta+1)\left[R_{E1}\,||\,(R_F+R_{E2})\right]+r_{\pi 1}+R_I}}_{\frac{v_x}{v_i}}\cdot\underbrace{\frac{g_{m1}\left[R_{L1}\,||\,r_{\pi 2}\right]}{1+g_{m1}\left[R_{E1}\,||\,(R_F+R_{E2})\right]}}_{\frac{v_y}{v_x}}\cdot\underbrace{g_{m2}\left\{R_{L2}\,||\left[r_{\pi 3}+(\beta+1)\left[(R_{E1}+R_F)\,||\,R_{E2}\right]\right]\right\}}_{\frac{v_z}{v_y}}\cdot\underbrace{\frac{g_{m3}}{1+g_{m3}\left[(R_{E1}+R_F)\,||\,R_{E2}\right]}}_{\frac{i_o}{v_z}}$$

→ We can calculate open-loop input resistance simply by looking into the base of the Q1. That is,

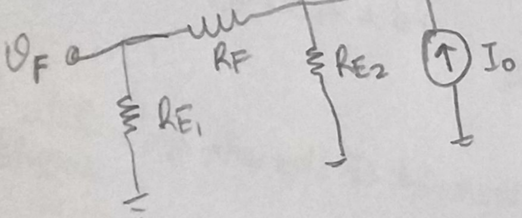
$$R_{in,OL} = r_{\pi 1} + (\beta+1)\left[(R_F+R_{E2}) \,||\, R_{E1}\right]$$

→ Also, we can calculate the Rout by adding a test source in series to the output.



$$\Rightarrow R_{out,OL} = \frac{v_x}{i_x} = \infty$$

→ Now, we can calculate the feedback factor **K** in order to find closed-loop parameters



$$\Rightarrow K = \frac{v_f}{I_o} = \frac{R_{E2}}{R_{E1}+R_{E2}+R_F} \cdot R_{E1}$$

→ CLOSED-LOOP PARAMETERS

- $G_{m,CL} = \dfrac{G_{m,OL}}{1 + K\,G_{m,OL}}$

- $R_{in,CL} = R_{in,OL}\left(1 + K \cdot G_{m,OL}\right)$

- $R_{out,CL} = R_{out,CL}\left(1 + K \cdot G_{m,OL}\right)$