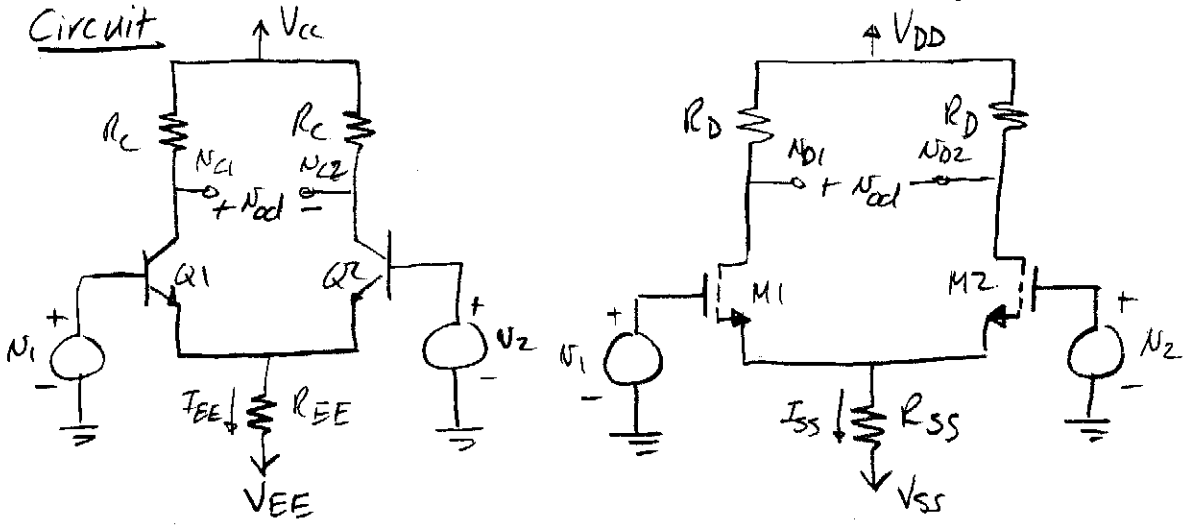
LECTURE 23

Differential Amplifiers

Amplifiers that amplify the difference between two voltages and reject the average of the two voltages.

Circuit



DC Analysis (Assume $N_1 = N_2 = 0$)

$$I_{EE} = \frac{V_{EE} - V_{BE}}{R_{EE}} \qquad I_{SS} = \frac{V_{SS} - V_{GS}}{R_{SS}}$$

$$I_E = \frac{I_{EE}}{2}, \quad I_C = \alpha I_E \qquad I_{DS} = \frac{I_{SS}}{2}$$

$$I_B = \frac{I_C}{\beta_F} \qquad V_D = V_{DD} - I_{DS} R_D$$

$$V_C = V_{CC} - I_C R_C$$

Example:

$V_{DD} = 5V$, $V_{SS} = -5V$, $R_{SS} = 10K$, $R_C = 10K$, $k_n = 1mA/V^2$, $V_{TN} = 1V$

$$V_{SS} = V_{GS} + I_{SS} R_{SS} = V_{GS} + 2 I_{DS} R_{SS}$$

$$V_{SS} = V_{GS} + 2 R_{SS} \frac{1}{2} k_n (V_{GS} - V_T)^2 = V_{GS} + 10 (V_{GS} - 1)^2$$

$$\therefore \quad V_{GS}^2 - 2V_{GS} + \tfrac{1}{10} V_{GS} + .5 = V_{GS}^2 - 1.9 V_{GS} + 0.5 = 0$$

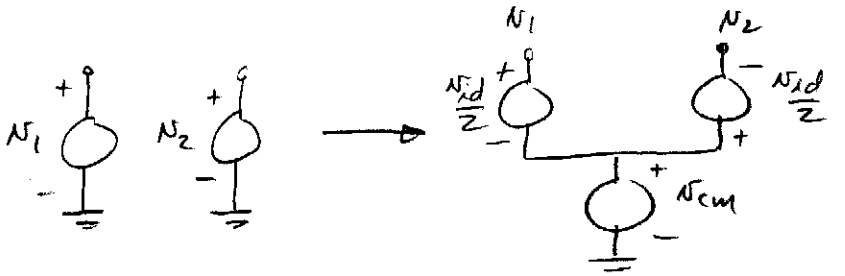
$$V_{GS} = 0.95 \pm 0.634 = 1.584V$$

$$\therefore \quad I_{DS} = \frac{1mA/V^2}{2}(0.584)^2 = \underline{170.8\,\mu A}$$

$I_{SS} = 341.6\mu A$ $\qquad V_D = 5 - 10(0.1708) = 3.29V$

$V_S = -1.584V \rightarrow V_{DS} = \underline{4.876} \rightarrow$ saturated

AC Analysis of the Differential Amplifier

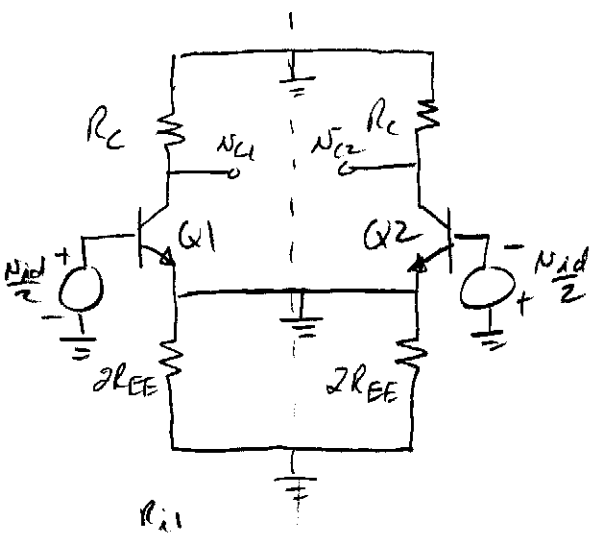


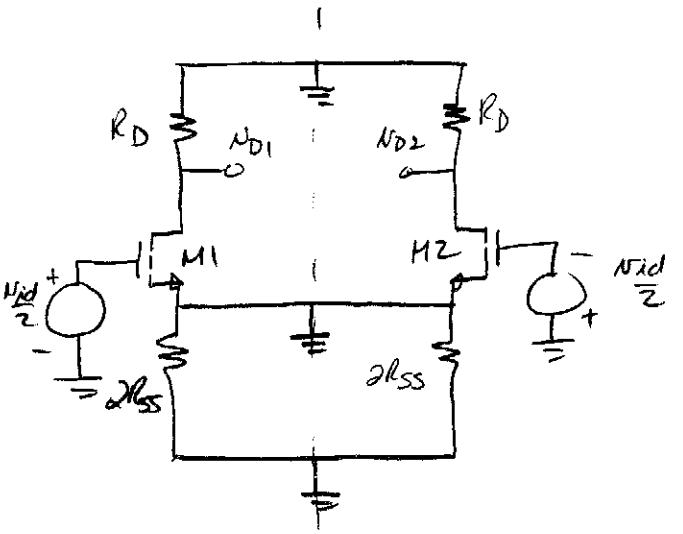
Differential-mode input: $v_{id} = v_1 - v_2$

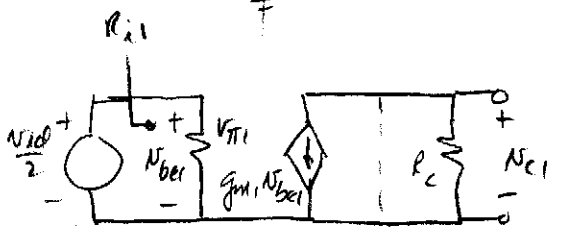
Common mode input: $v_{cm} = \frac{v_1 + v_2}{2}$

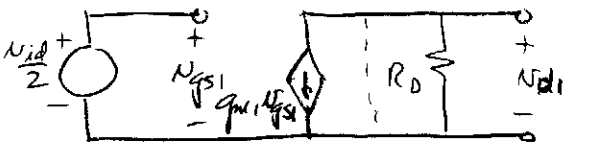
$\therefore \quad v_1 = \frac{v_{id}}{2} + v_{cm}$ and $v_2 = -\frac{v_{id}}{2} + v_{cm}$

Differential mode Half Circuit—









$v_{c1} = -g_{m1} R_C \frac{v_{id}}{2}$

$v_{d1} = -g_m R_D v_{gs1} = -g_m R_D \frac{v_{id}}{2}$

$\therefore A_{vd} = \frac{v_{c1}}{v_{id}} = \underline{\underline{-\frac{g_{m1} R_C}{2}}}$ $\quad \frac{v_{od}}{v_{id}} = \underline{\underline{g_{m1} R_C}}$ $\quad \therefore A_{vd} = \frac{v_{d1}}{v_{id}} = \underline{\underline{-\frac{g_m R_D}{2}}}$ $\quad \frac{v_{od}}{v_{id}} = \underline{\underline{g_m R_D}}$

$R_{i1} = r_{\pi 1}$

$R_{id} = \frac{v_{id}}{i_b} = \frac{v_{id}}{v_{id}/2 / r_\pi} = \underline{\underline{2 r_\pi}}$

$R_{id} = \underline{\underline{\infty}}$

$R_{od} = \underline{\underline{2(R_C \| r_o)}}$

$R_{od} = \underline{\underline{2(R_D \| r_o)}}$