FET EQUATION SHEET

$$I_D = \frac{1}{2}k_n' \frac{W}{L}\left(v_{GS1} - V_t\right)^2 = \frac{1}{2}k_n' \frac{W}{L}V_{OV}^2 \text{ (nMOS)},\ I_D = \frac{1}{2}k_p' \frac{W}{L}\left(v_{GS1} - V_t\right)^2 = \frac{1}{2}k_p' \frac{W}{L}V_{OV}^2 \text{ (pMOS)}$$

$$g_m = \frac{I_D}{V_{OV}/2} = \frac{2I_D}{V_{OV}}\ ; \qquad r_o = \frac{|V_A|}{I_D}$$

The NMOS differential pair

$v_{id} = v_{G1} - v_{G2}$

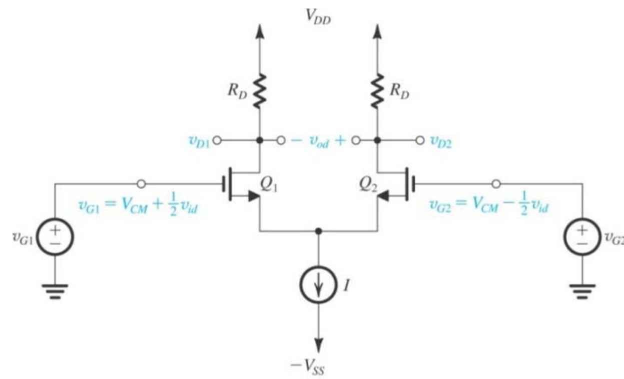
$$i_{D1} = \frac{I}{2} + \left(\frac{I}{V_{OV}}\right)\left(\frac{v_{id}}{2}\right)\sqrt{1-\left(\frac{v_{id}/2}{V_{OV}}\right)^2} \simeq \frac{I}{2} + \left(\frac{I}{V_{OV}}\right)\left(\frac{v_{id}}{2}\right)$$

$$i_{D2} = \frac{I}{2} - \left(\frac{I}{V_{OV}}\right)\left(\frac{v_{id}}{2}\right)\sqrt{1-\left(\frac{v_{id}/2}{V_{OV}}\right)^2} \simeq \frac{I}{2} - \left(\frac{I}{V_{OV}}\right)\left(\frac{v_{id}}{2}\right)$$

$$V_{CM\max} = V_t + V_D = V_t + V_{DD} - \frac{I}{2}R_D$$

$$V_{CM\min} = -V_{SS} + V_{CS} + V_{GS}$$

$$A_d \equiv \frac{v_{od}}{v_{id}} = \frac{v_{o2} - v_{o1}}{v_{id}} = g_m\left(R_D \parallel r_o\right)$$



(a)

Input offset voltage due to differences in load resistances: $V_{OS} = \frac{V_O}{A_d} = \left(\frac{V_{OV}}{2}\right)\left(\frac{\Delta R_D}{R_D}\right)$

Input offset voltage due to differences in device dimensions: $V_{OS} = \left(\frac{V_{OV}}{2}\right)\left(\frac{\Delta(W/L)}{(W/L)}\right)$

Input offset voltage due to differences in threshold voltage: $V_{OS} = \Delta V_t$

RMS, or typical, total input offset voltage: $V_{OS} = \sqrt{\left(\frac{V_{OV}}{2}\frac{\Delta R_D}{R_D}\right)^2 + \left(\frac{V_{OV}}{2}\frac{\Delta(W/L)}{(W/L)}\right)^2 + \left(\Delta V_t\right)^2}$

The active loaded NMOS differential pair

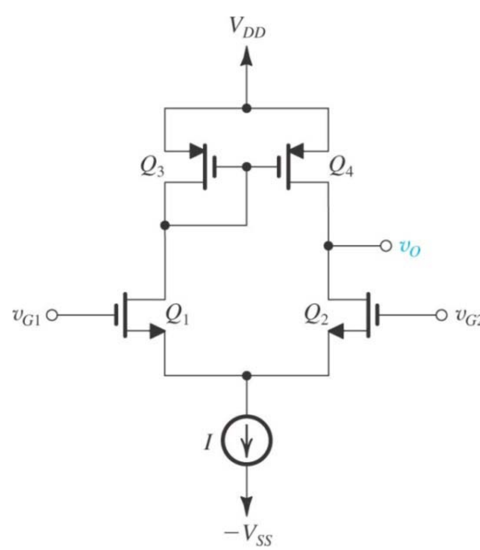
$$G_m \equiv \frac{i_o}{v_{id}} = g_{m1,2}$$

$$R_o \equiv \frac{v_x}{i_x} = r_{o2} \parallel r_{o4}$$

$$A_d \equiv \frac{v_{od}}{v_{id}} = G_m R_o = g_m\left(r_{o2} \parallel r_{o4}\right)$$

$$A_{cm} \equiv \frac{v_{od}}{v_{icm}} \simeq -\frac{1}{2g_{m3}R_{SS}}$$

where R_{SS} is the output resistance of the current source



(a)

$$I_C = I_S e^{v_{BE}/V_T} \;;\; \alpha = \beta/(\beta+1) \;; \qquad I_C = \alpha I_E \;; \qquad v_{BE2} = v_{BE1} + V_T \ln\left(\frac{i_{C2}}{i_{C1}}\right)$$

$$g_m = \frac{I_C}{V_T} \;; \qquad r_\pi = \frac{\beta}{g_m} \;; \qquad r_e = \frac{V_T}{I_E} \;; \qquad r_o = \frac{V_A}{I_C}$$

The basic BJT differential-pair configuration

$$v_{id} = v_{B1} - v_{B2}$$

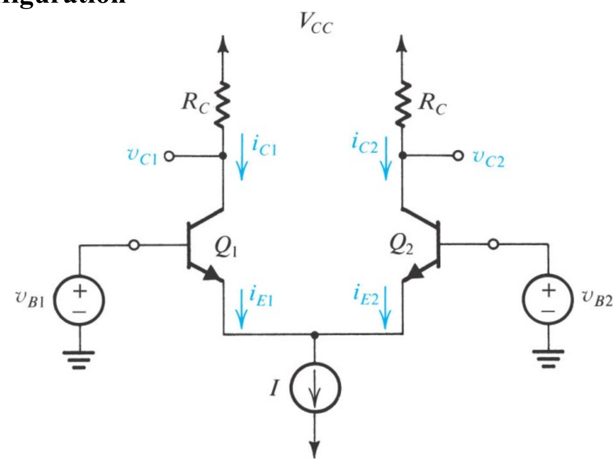
$$i_{E1} = \frac{I}{1+e^{-v_{id}/V_T}}$$

$$i_{E2} = \frac{I}{1+e^{v_{id}/V_T}}$$

$$V_{CM\max} \approx V_C + 0.4 = V_{CC} - \alpha\frac{I}{2}R_C + 0.4$$

$$V_{CM\min} = -V_{EE} + V_{CS} + V_{BE}$$

$$A_d \equiv \frac{v_{od}}{v_{id}} = \frac{v_{o2} - v_{o1}}{v_{id}} = g_m\left(R_C \,\|\, r_o\right)$$



Input offset voltage due to differences in load resistances: $V_{OS} = \dfrac{V_O}{A_d} = V_T\left(\dfrac{\Delta R_D}{R_D}\right)$

Input offset voltage due to differences in device dimensions: $V_{OS} = V_T\left(\dfrac{\Delta I_S}{I_S}\right)$

RMS, or typical, total input offset voltage: $V_{OS} = V_T\sqrt{\left(\dfrac{\Delta R_C}{R_C}\right)^2 + \left(\dfrac{\Delta I_S}{I_S}\right)^2}$

Input offset current: $I_{OS} = \dfrac{I}{2(\beta+1)}\left(\dfrac{\Delta\beta}{\beta}\right) = I_B\left(\dfrac{\Delta\beta}{\beta}\right)$

The active loaded PNP differential pair

$$G_m \equiv \frac{i_o}{v_{id}} = g_m$$

$$R_o \equiv \frac{v_x}{i_x} = r_{o2} \,\|\, r_{o4}$$

$$A_d \equiv \frac{v_{od}}{v_{id}} = G_m R_o = g_m\left(r_{o2} \,\|\, r_{o4}\right)$$

$$A_{cm} \equiv \frac{v_{od}}{v_{icm}} \simeq -\frac{r_{o4}}{\beta_3 R_{EE}}$$

where R_{EE} is the output resistance of the current source