Thus:

$$\boxed{CMRR = \frac{(1+\beta) R_E}{(R_s + h_{ie})} \cong \frac{R_E}{\left(\frac{R_s}{\beta} + h_{ib}\right)}}$$

c) Differential Mode input resistance:

$$R_d = \frac{V_d}{(i_{s1} - i_{s2})} = \left.\frac{V_{s1}}{i_{s1}}\right|_{\substack{V_{s2}=0 \\ R_{s1}=R_{s2}=0}}$$

Since $i_{s1} = i_{b1}$ we obtain from the SFG

$$R_d \cong h_{ie} \frac{\Delta}{\left[1 + (1+\beta)\frac{R_E}{h_{ie}}\right]} = h_{ie} \frac{[h_{ie} + 2(1+\beta) R_E]}{[h_{ie} + (1+\beta) R_E]}$$

$$\boxed{R_d \cong 2 h_{ie} \frac{R_E + \frac{1}{2} h_{ib}}{R_E + h_{ib}} \cong 2 h_{ie} \left(1 - \frac{1}{2}\frac{h_{ib}}{R_E}\right)}$$

d) Summary $\left(\frac{R_s}{\beta} << h_{ib}\right)$

$$A_{cm} \cong -\frac{1}{2} \frac{R_C}{R_E} \frac{1}{\left(1 + \frac{1}{2}\frac{h_{ib}}{R_E}\right)} \cong -\frac{1}{2}\frac{R_C}{R_E}$$

$$A_d \cong \frac{1}{2} \frac{R_C}{h_{ib}} \frac{1}{\left(1 + \frac{1}{2}\frac{h_{ib}}{R_E}\right)} = \frac{1}{2}\frac{R_C}{h_{ib}}$$

$$CMRR \cong \frac{R_E}{h_{ib}}$$

$$R_d \cong 2 h_{ie} \frac{1}{\left(1 + \frac{1}{2}\frac{h_{ib}}{R_E}\right)} \cong 2 h_{ie}$$

e.g. $R_C = R_E = 4.7 k\Omega$

$h_{ib} \cong 30\Omega$

$\beta = 100$

$\Downarrow$

$A_{cm} \cong -0.5$

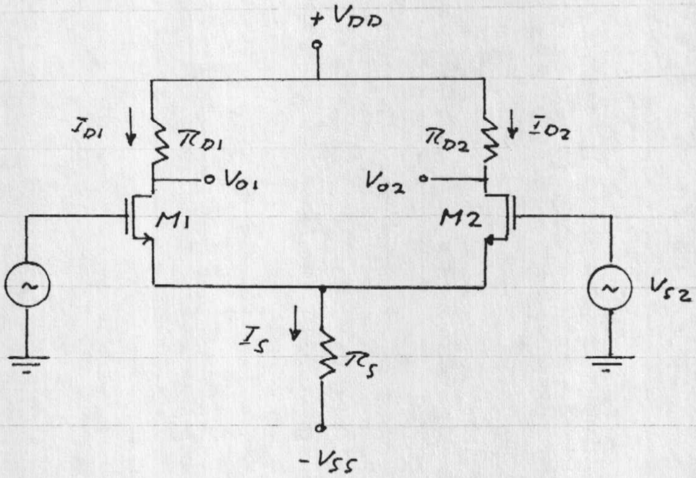
$A_d \cong 78$

$CMRR = 157$

$R_d \cong 6 k\Omega$

4.2 MOSFET Differential Amplifier

Basic Configuration



assumption: M1 and M2 are matched

4.2.1 DC Considerations

Recall: MOSFET in saturation (forward active mode)

$$\left| I_D \cong \underbrace{\frac{1}{2} \frac{W}{L} \mu C_{ox}}_{K} (V_{GS} - V_t)^2 \right| \quad (V_{DS} > [V_{GS} - V_t] = V_{DSsat})$$

from differential amplifier:

$$\left| I_{D1} = I_{D2} = \frac{1}{2} I_S \right|$$

$$\left| V_{GS1} = V_{GS2} = V_{CM} + V_{SS} - I_S R_S \right|$$

Note: Transconductance parameter for ac model

$$\left| g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{W}{L} \mu C_{ox} (V_{GS} - V_t) = \sqrt{2 \frac{W}{L} \mu C_{ox} I_D} \right|$$