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ECE 3050-Fall 2004 Date 9/15/04

Quiz #3: Ideal op amps and/or Bode plots

Comment on bulk-source aspects of MOS SS. model–
It should be developed using v_{BS} rather than v_{SB} (although there should be no difference at the end)

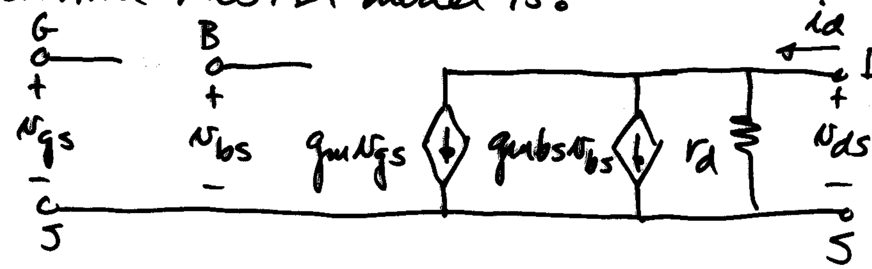
$$V_{TN} = V_{TO} + \gamma\sqrt{2\phi_F - v_{BS}} - \gamma\sqrt{2\phi_F}$$

$$g_{mbs} = \left.\frac{\partial i_D}{\partial v_{BS}}\right|_Q = \left.\left(\frac{\partial i_D}{\partial V_{TN}}\right)\left(\frac{\partial V_{TN}}{\partial v_{BS}}\right)\right|_Q = (-g_m)\left(\frac{-\gamma}{\sqrt{2\phi_F - V_{BS}}}\right)$$

Normally, $V_{BS} < 0$ (the bulk-source diode would be forward-biased otherwise)

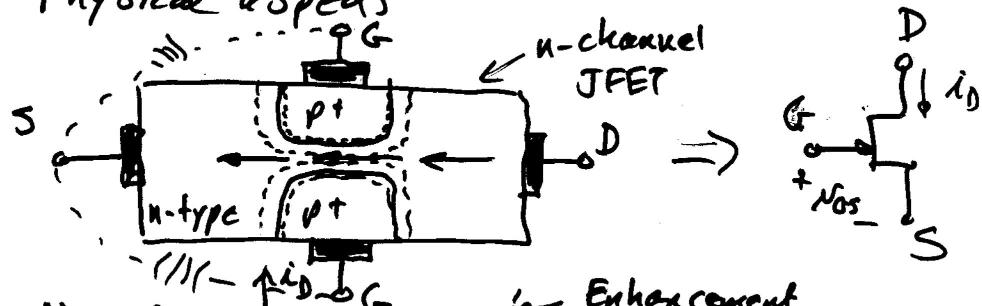
$$\therefore\ g_{mbs} = \frac{g_m\gamma}{\sqrt{2\phi_F + |V_{BS}|}} = m\gamma \quad \left(m \approx \frac{1}{10}\right)$$

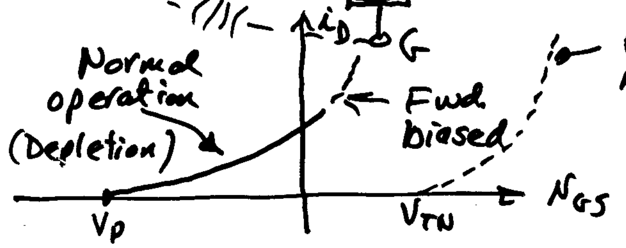
4-terminal MOSFET model is:



JFET Small Signal Model

Physical aspects





$$i_D = I_{DSS}\left[1 - \frac{v_{GS}}{V_P}\right]^2 (1 + \lambda v_{DS})$$

$v_{DS} \geq v_{GS} - V_P$ (saturation)

Small signal model -

$$i_D = f(v_{GS}, v_{DS}) \longrightarrow i_d = k_1 v_{gs} + k_2 v_{ds} = g_m v_{gs} + g_o v_{ds}$$

$$g_m = \frac{i_d}{v_{gs}}\Big|_{v_{ds}=0} \cong \frac{\partial i_D}{\partial v_{GS}}\Big|_Q = -\frac{2I_{DSS}}{V_P}\left(1-\frac{V_{GS}}{V_P}\right)(1+\lambda V_{DS})$$

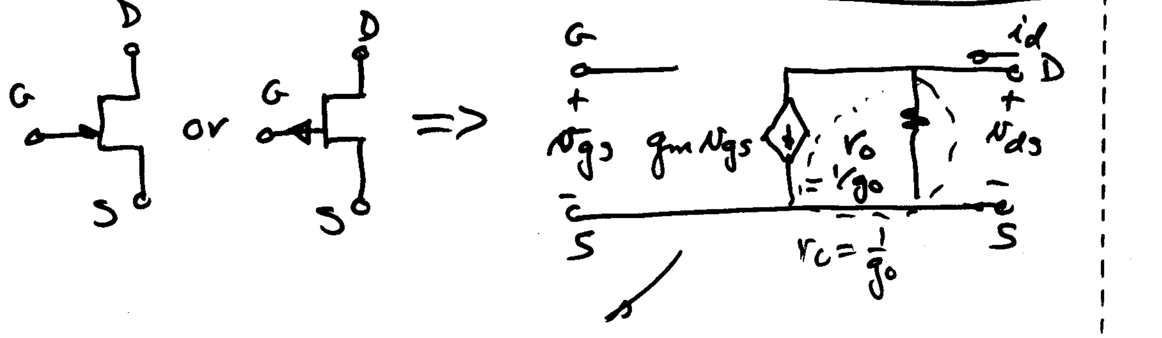
$$g_m = -\frac{2I_{DSS}}{V_P^2}(V_P - V_{GS})(1+\lambda V_{DS}) = \frac{2I_{DSS}}{V_P^2}(V_{GS}-V_P)(1+\lambda V_{DS})$$

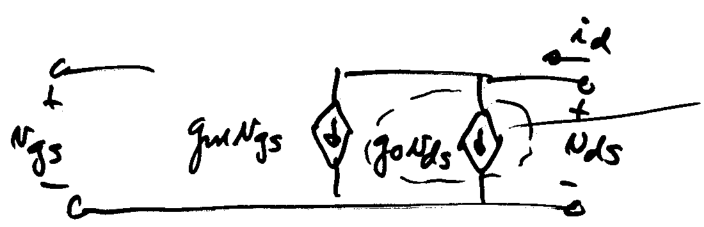
$$I_D = \frac{I_{DSS}}{V_P^2}(V_P - V_{GS})^2(1+\lambda V_{DS}) = \frac{I_{DSS}}{V_P^2}(V_{GS}-V_P)^2(1+\lambda V_{DS})$$

$$|V_{GS}-V_P| = \sqrt{\frac{I_D V_P^2}{I_D(1+\lambda V_{DS})}}$$

$$g_m = \frac{2I_{DSS}}{V_P^2}(1+\lambda V_{DS})\sqrt{\frac{I_D V_P^2}{I_D(1+\lambda V_{DS})}} = \frac{2}{|V_P|}\sqrt{I_D I_{DSS}(1+\lambda V_{DS})}$$

$$\boxed{g_m \approx \frac{2}{|V_P|}\sqrt{I_D I_{DSS}}} \qquad \boxed{g_o = \frac{\partial i_D}{\partial v_{DS}}\Big|_Q = \frac{\lambda I_D}{1+\lambda V_{DS}} \approx \lambda I_D}$$

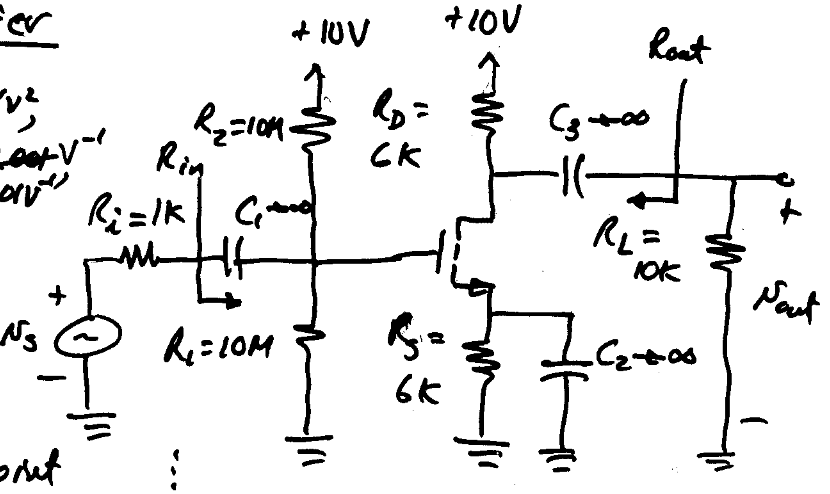




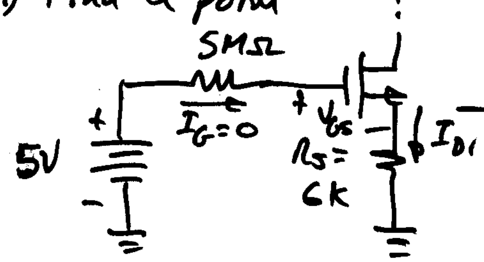
$$\frac{v}{i} = \frac{v_{ds}}{g_o v_{ds}} = \frac{1}{g_o}$$

NMOS Amplifier

If $K_N = 0.5\,mA/V^2$, $V_{TN} = 1V$ and $\lambda = \cancel{0.001}\ 0.01V^{-1}$ find $\frac{v_{out}}{v_{in}}$, R_{in} and R_{out}.



a.) Find Q point



$$\left.\begin{array}{l} 5 = V_{GS} + I_D\, 6K \\ I_D = \frac{K_N}{2}(V_{GS} - V_{TN})^2 \end{array}\right\}$$

$$V_{GS}^2 - \frac{5}{3}V_{GS} - \frac{2}{3} = 0$$

$$V_{GS} = \frac{5}{6} \pm 1.667 = \underline{2V}$$

$$I_D = \frac{0.5mA}{V^2}(2-1)^2 = \underline{0.5mA}$$

$V_{DS} = 10 - I_D 6k = 4V \rightarrow$ Check sat. $V_{DS} \geq V_{GS} - V_{TN}$

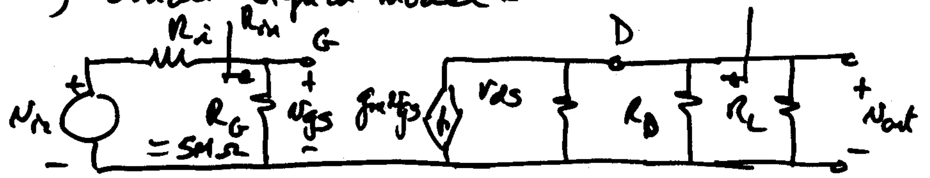
$4 \geq 2 - 1 = 1$

b.) Small signal model parameters

$$g_m = \sqrt{2K_N I_D(1+\lambda V_{DS})} = \sqrt{2 \cdot \tfrac{1}{2} \cdot \tfrac{1}{2} \cdot (1.04)} = \underline{0.721mS}$$

$$r_{ds} = r_o = \frac{V_{DS} + \frac{1}{\lambda}}{I_D} = \frac{4 + 100}{1/2} = \underline{208k\Omega}$$

c.) Small signal model -



$R_{in} = R_G = R_1 \| R_2 = \underline{5M\Omega}$ $\quad R_{out} = r_{ds} \| R_D = 6k \| 208k = \underline{5.834k\Omega}$

$$\frac{v_{out}}{v_{in}} = \left(\frac{v_{out}}{v_{gs}}\right)\left(\frac{v_{gs}}{v_{in}}\right) = \left[-g_m(r_{ds}\|R_D\|R_L)\right]\left[\frac{R_G}{R_i + R_G}\right] = (-2.13)(0.999)$$

$$= \underline{-2.13\ V/V}$$