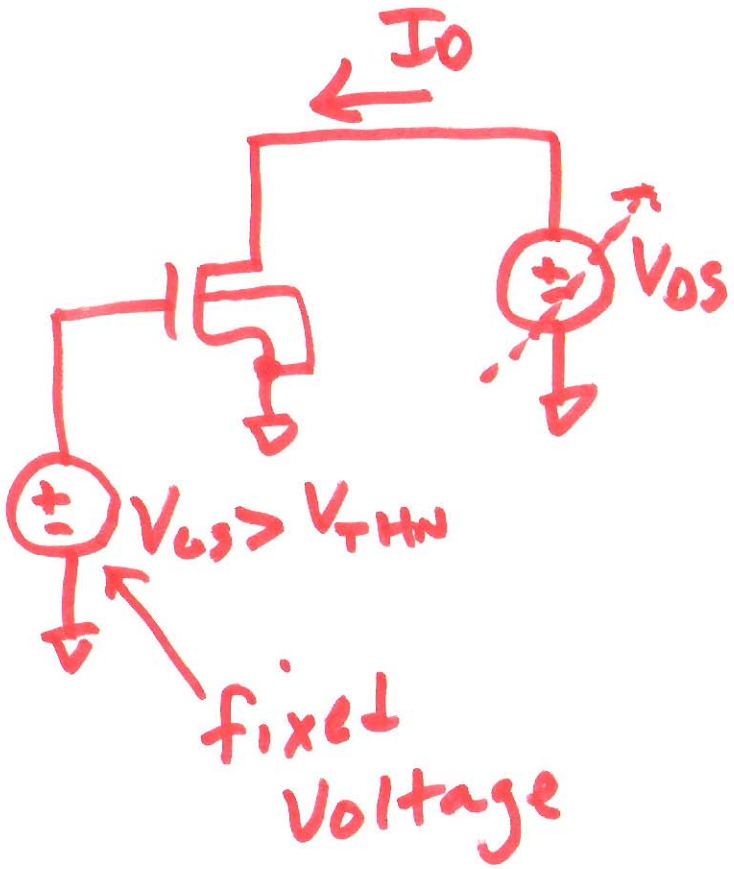
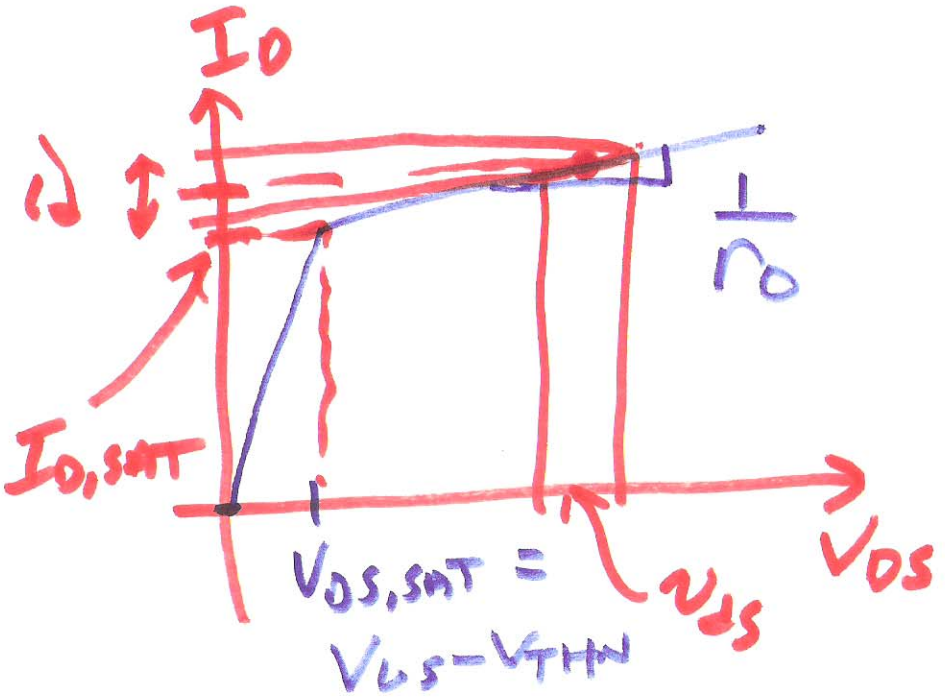
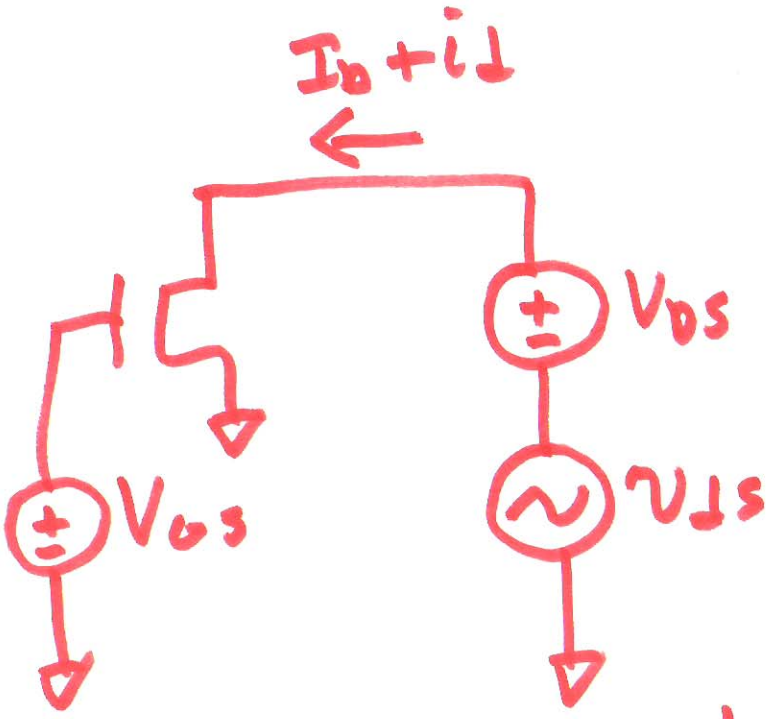
r_o, g_{mb}, V_{THN} v. temp.







$$\underbrace{I_D + i_d}_{i_D} = \frac{\beta_N}{2}\left(V_{GS} - V_{TH}\right)^2 \cdot \left(1 + \lambda\left(\overbrace{V_{DS} + v_{ds}}^{v_{DS}} - V_{DS,SAT}\right)\right)$$

$$\frac{1}{r_o} = \frac{\delta i_D}{\delta V_{DS}} \Bigg|_{\substack{I_D = \text{CONST} \\ V_{DS} = \text{CONST}}} \qquad \left(\underbrace{V_{DS} + v_{ds}}_{v_{DS}} - V_{DS,SAT}\right)$$

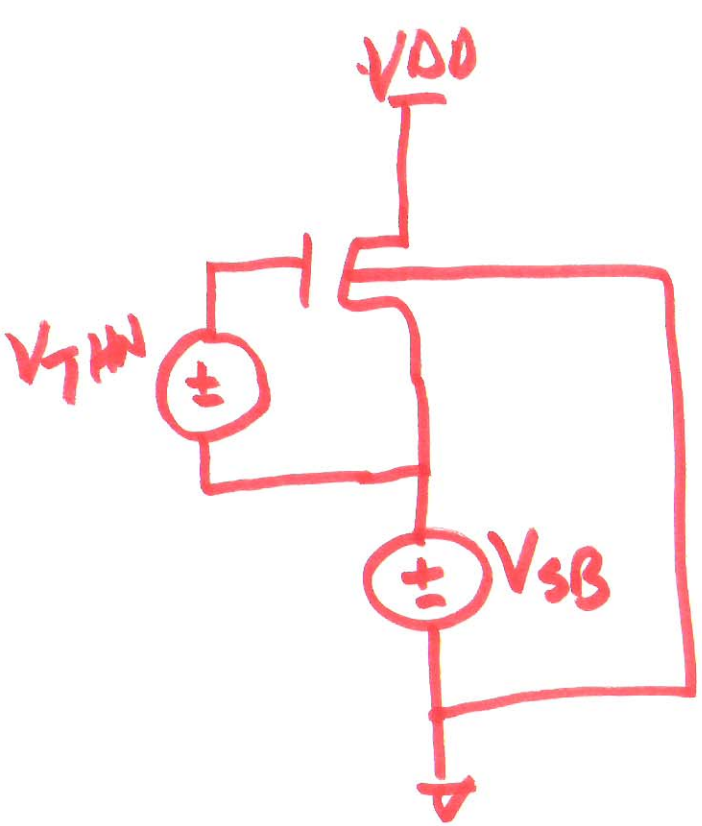
$$r_o = 3.8\,\text{MEG} = \frac{1}{\lambda \cdot 17\mu A}$$

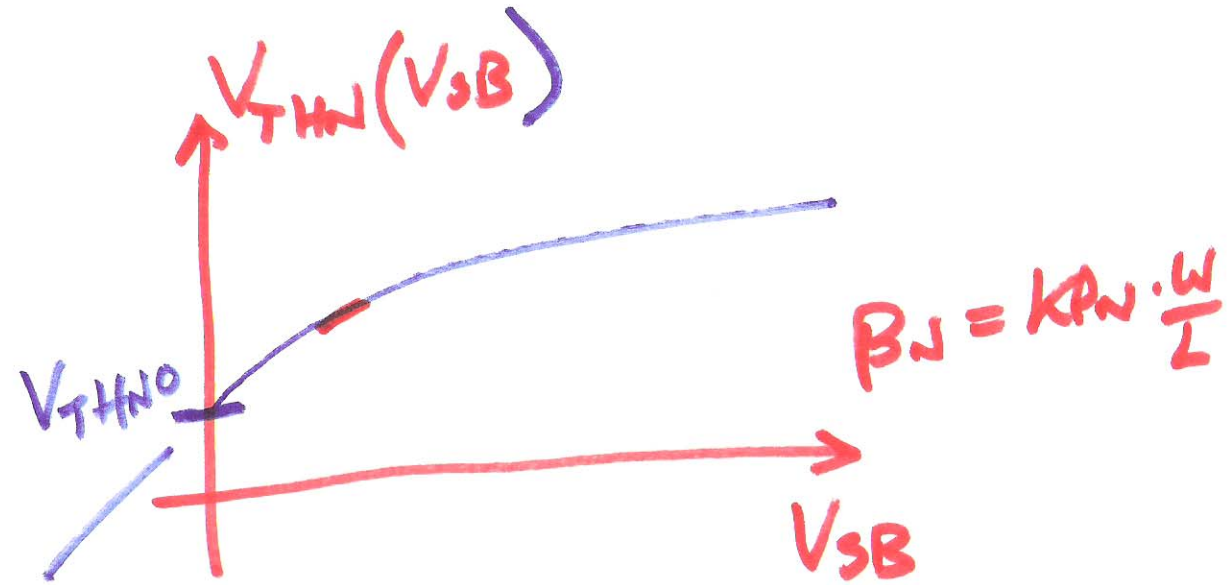
$$= \frac{\beta_N}{2}\left(V_{GS} - V_{TH}\right)^2 \cdot \lambda = I_{DSAT} \cdot \lambda$$

I_{DSAT} ↑ $\underbrace{\qquad\qquad}_{I_{D,SAT}}$

$$\boxed{r_o = \frac{1}{\lambda I_{DSAT}}}$$

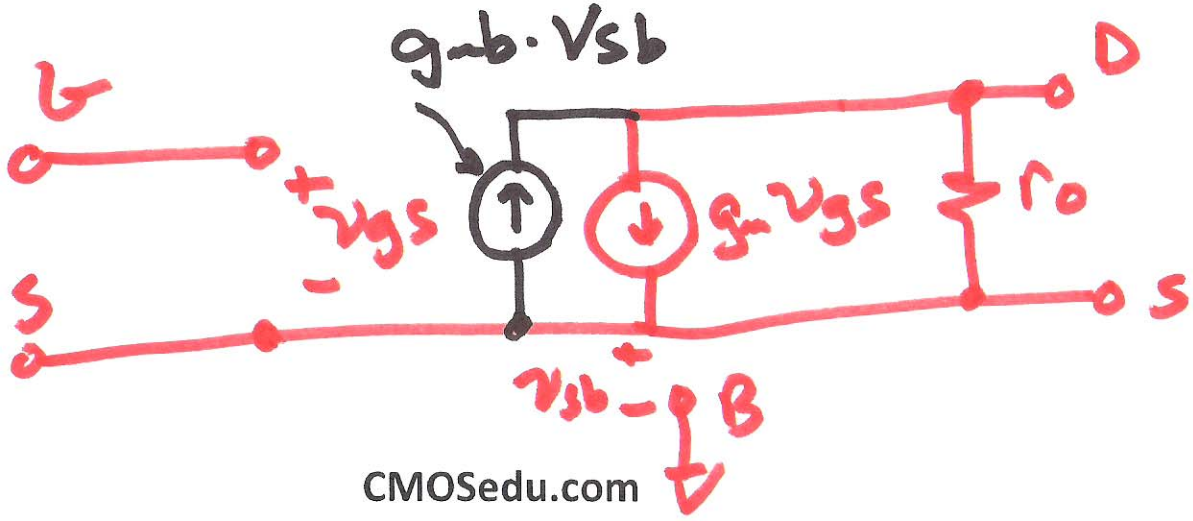
CMOSedu.com





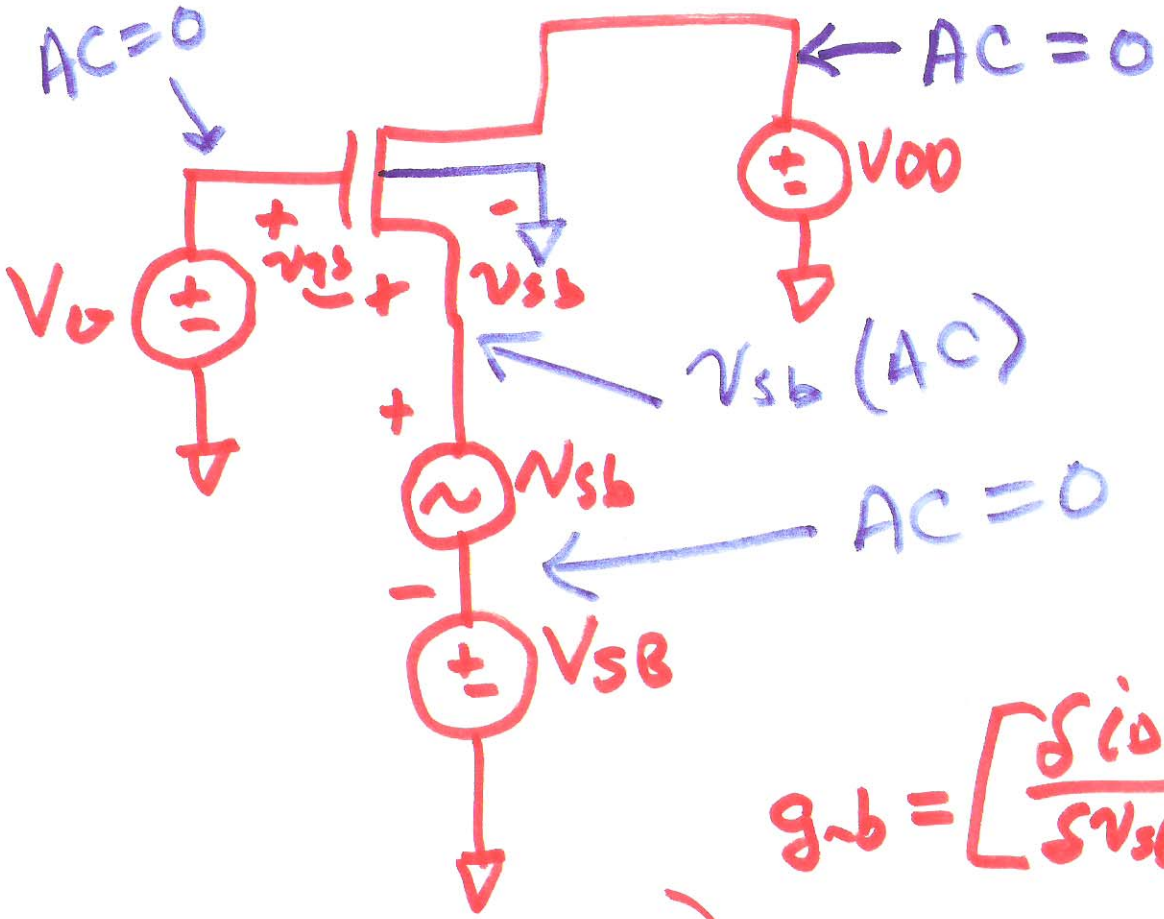
Source shorted to bulk

$$I_D = \frac{\beta_N}{2}\left(V_{GS} - V_{THN}(V_{SB})\right)^2$$



CMOSedu.com

3)



$$g_{mb} = \left[\frac{\delta i_D}{\delta V_{SB}}\right]^{I_D = CONST}_{V_{SB} = CONST}$$

$$v_{sb} = -v_{gs} \quad \Big\} \quad g_{mb} = \frac{\delta}{\delta V_{SB}}\left(\frac{W}{L}\frac{K_{PN}}{2}\left(V_{GS} - V_{THN}\right)^2\right)$$

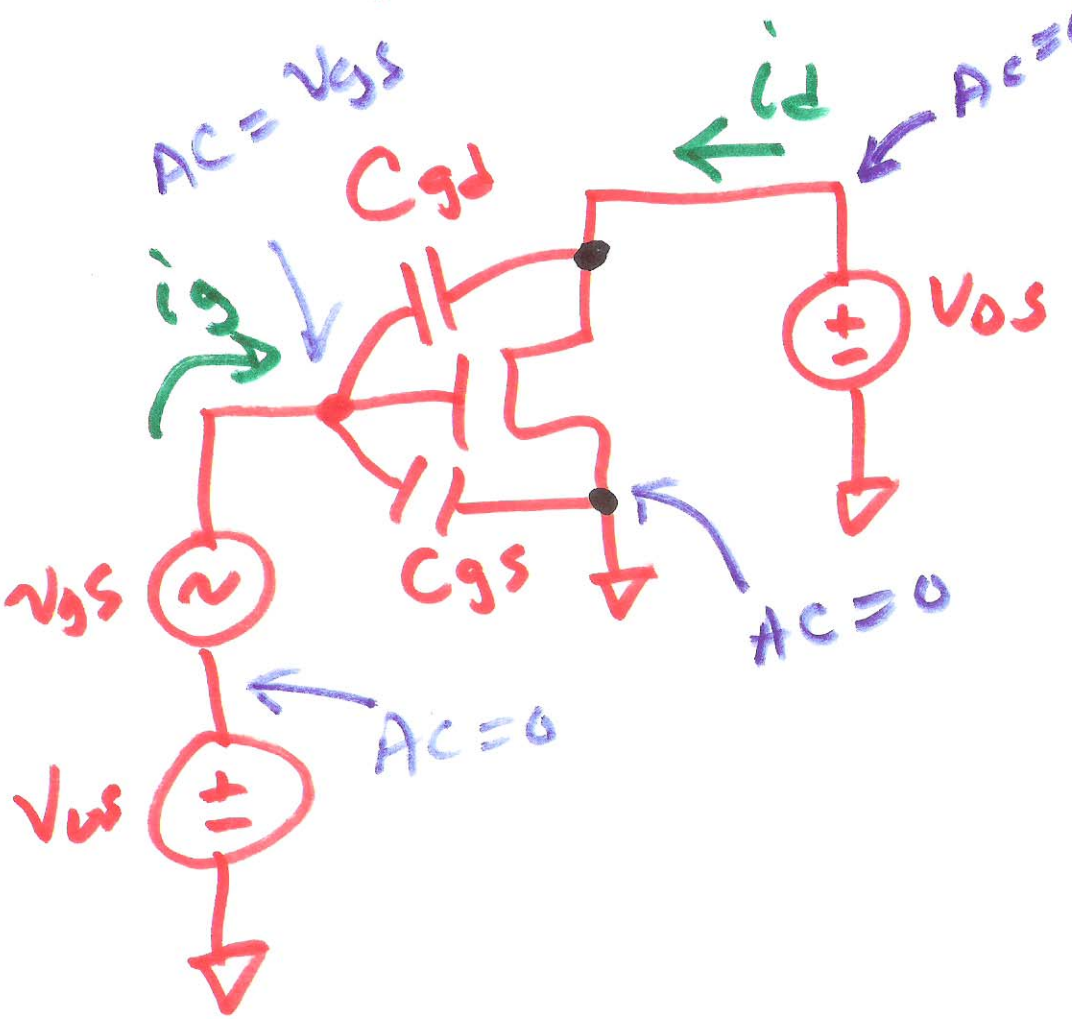
$$g_{mb} = \eta \cdot g_m \qquad g_{mb} = \underbrace{K_{PN}\cdot\frac{W}{L}\left(V_{GS} - V_{THN}\right)}_{g_m}\underbrace{\frac{\delta(-V_{THN})}{\delta V_{SB}}}_{\eta}$$

$0 \rightarrow .4$

4)

CMOSedu.com

f_T, transition frequency



$$i_g = \frac{v_{gs}}{1/j\omega(C_{gs}+C_{gd})}$$

$$i_d = g_m v_{gs},\ v_{gs} = \frac{i_d}{g_m}$$

$$i_g = \frac{i_d/g_m}{1/j\omega(C_{gs}+C_{gd})}$$

CMOSedu.com

$$\left|\frac{i_d}{i_g}\right| = \left|\frac{g_m}{j\omega_T(C_{gs}+C_{gd})}\right| = 1$$

$$\omega_T = 2\pi f_T$$

$$f_T = \frac{g_m}{2\pi(C_{gs}+C_{gd})}$$

$$C_{gs} = \frac{2}{3}WLC_{ox}'$$

$$= \frac{2}{3}\cdot W\cdot L\,\frac{\epsilon_{ox}}{t_{ox}}$$

$$g_m = \left(K_{PN}\cdot\frac{W}{L}\right)(V_{GS}-V_{THN})$$

$$\left(\mu_N C_{ox}'\cdot\frac{W}{L}\right)(V_{OVN})$$

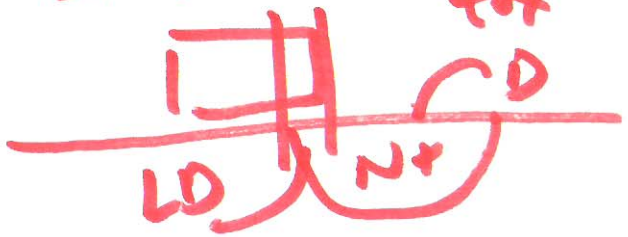
$$\parallel$$

$$\mu_N\cdot\frac{\epsilon_{ox}}{t_{ox}}\cdot\frac{W}{L}\cdot(V_{DS,SAT})$$

Long short

$$C_{gd} = W\cdot L_D\cdot C_{ox}'$$

$$= W\cdot L_D\cdot\frac{\epsilon_{ox}}{t_{ox}}$$



6)

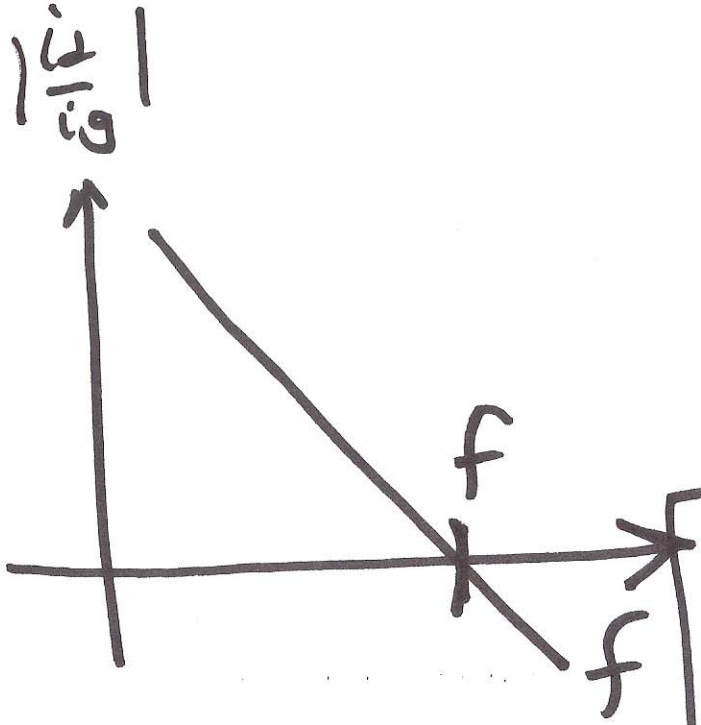
CMOSedu.com

ASSUMING $C_{gs} \gg C_{gd}$

$V_{OS,SAT} = V_{GS} - V_{THN}$

$$f_T \approx \frac{g_m}{2\pi C_{gs}} = \frac{B_n K_{PN} \cdot W/L \, (V_{OVN})}{2\pi \cdot \frac{\epsilon_{ox}}{t_{ox}} \cdot W \cdot L \cdot \frac{2}{3}}$$

$$= \frac{\cancel{\frac{\epsilon_{ox}}{t_{ox}}} \cdot \mu_N \cdot \cancel{\frac{W}{L}} V_{OVN}}{2\pi \cancel{\frac{\epsilon_{ox}}{t_{ox}}} \cdot \cancel{W} \cdot L \cdot \frac{2}{3}}$$



$$f_T = \frac{3\mu_N \cdot V_{OVN}}{4\pi \cdot L^2}$$

NANO-CMOS

$$f_T \propto \frac{V_{OVN}}{L}$$

7)