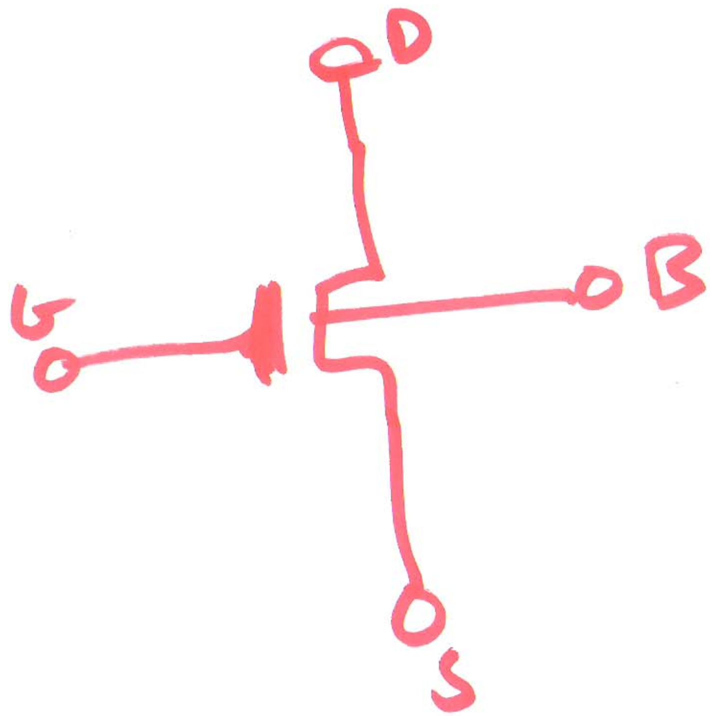
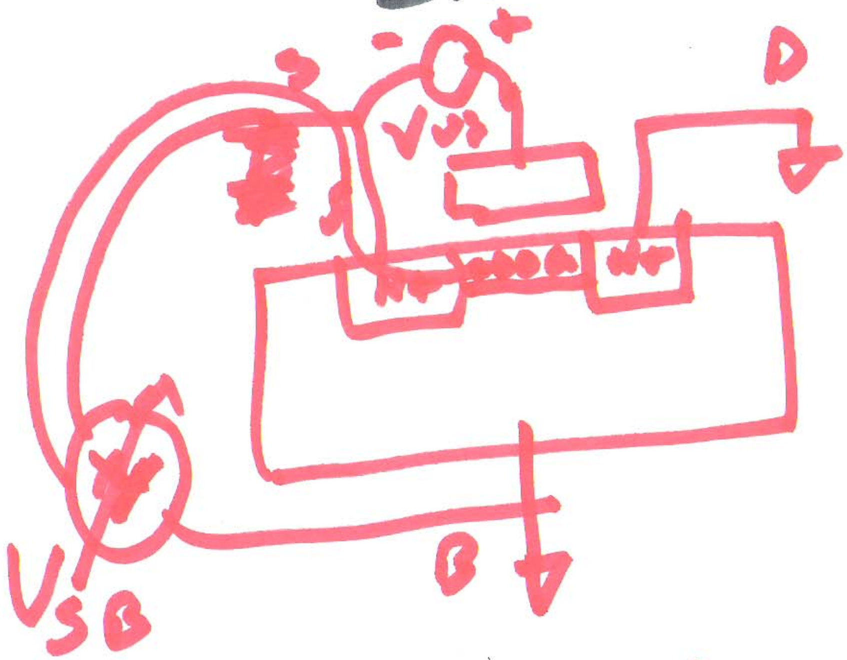
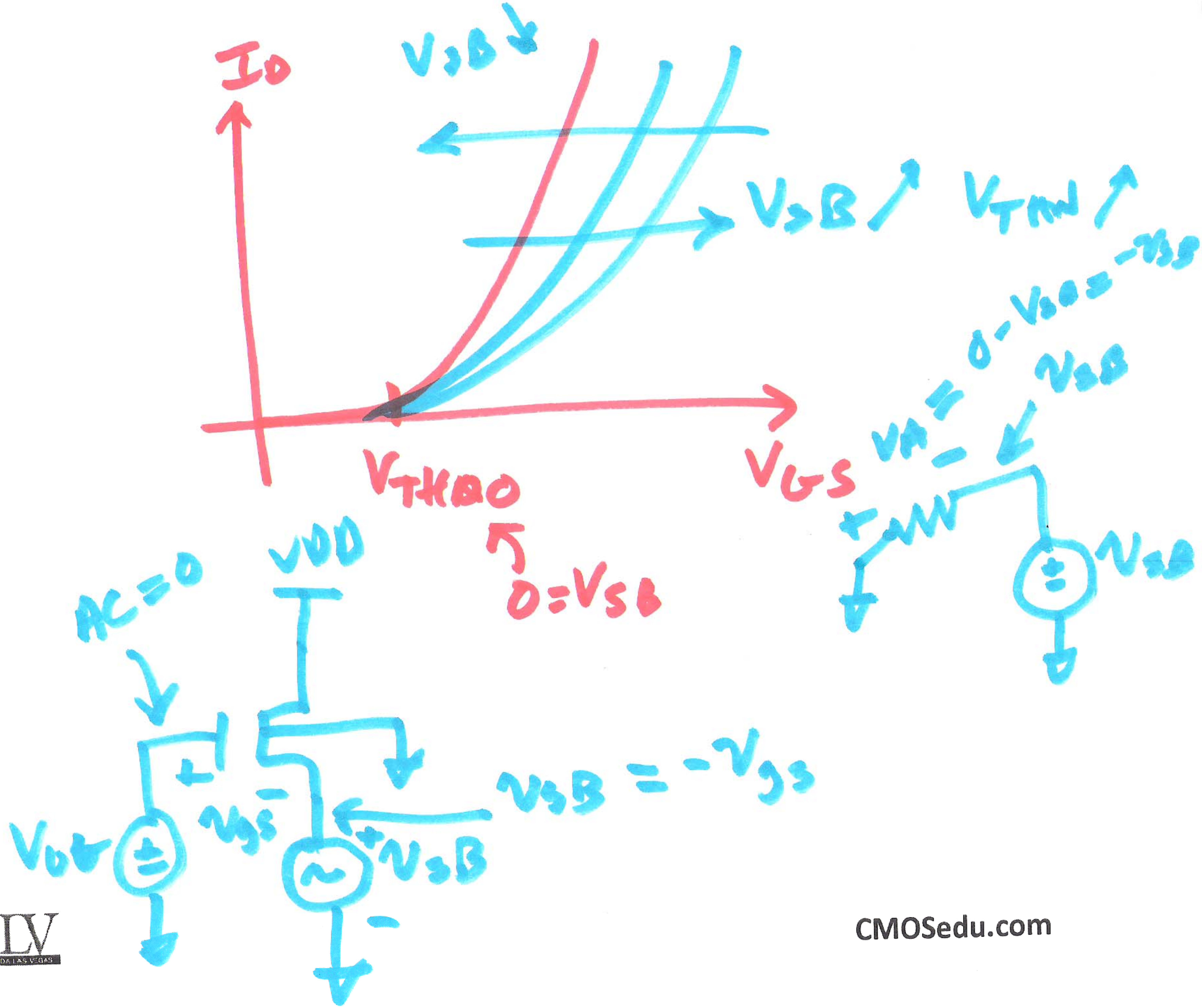
EE 420 / ECG 620

Analog 1/29/14

Lecture 3







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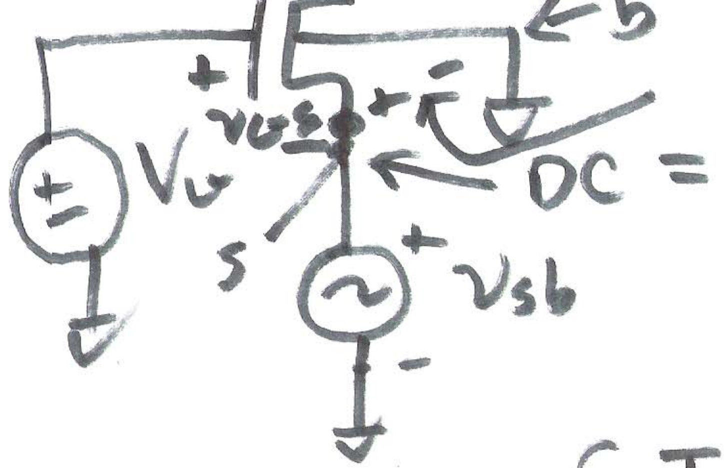


$i_D = I_D + i_d$, $v_{GS} = -v_{sb} + V_G$

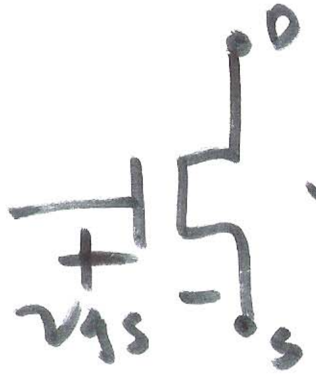
$v_{sb} = v_{sb}$

$$\frac{\partial \left(\frac{I_D + i_d}{i_D}\right)}{\partial v_{SB}} = \frac{\partial \frac{KP}{2}\frac{W}{L}\left(v_{GS} - V_{THN}\right)^2}{\partial v_{sb}}$$

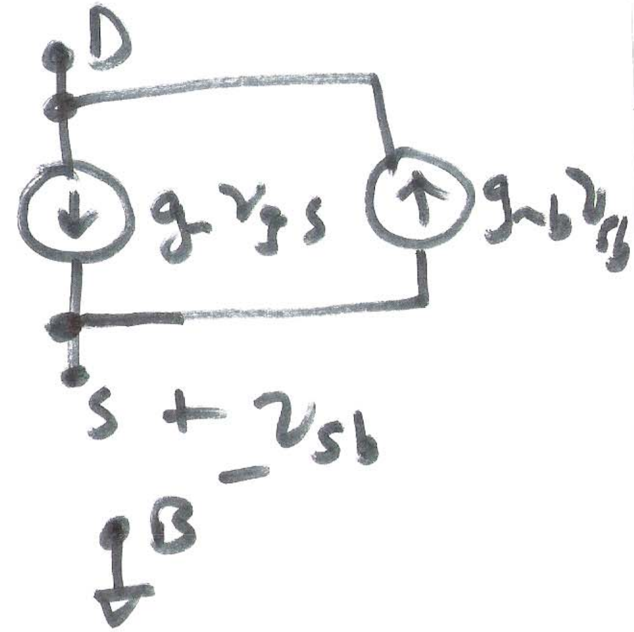
$I_D = \text{CONST}$
$V_{GS} = \text{CONST}$

$\downarrow$

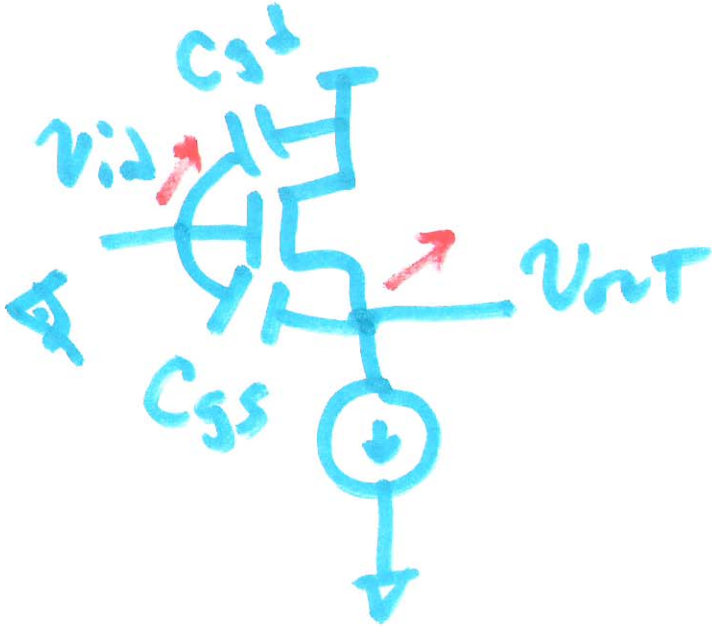
$i_d = -g_{mb} \cdot v_{sb}$

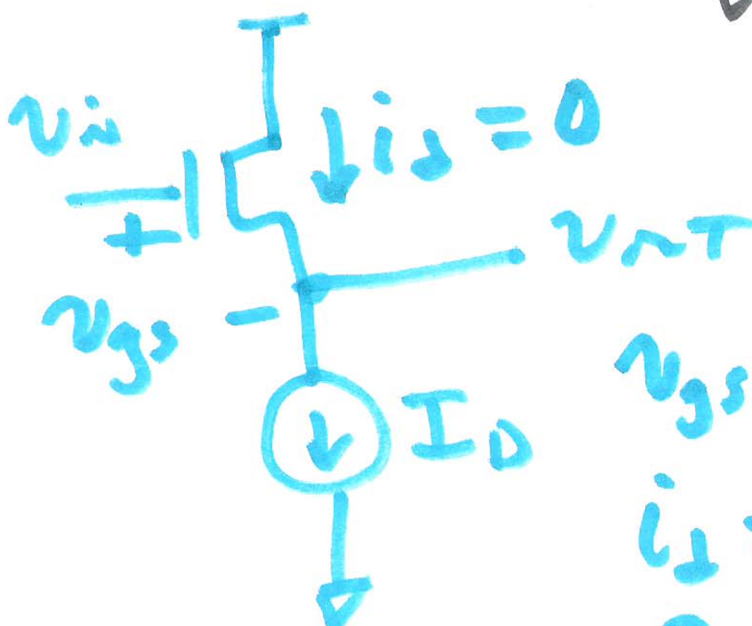


$$\downarrow i_d = g_m v_{gs} - g_{mb} v_{sb}$$



SF → source follower





No body effect

$$v_{gs} = v_{in} - v_{out}$$

$$i_d = g_m v_{gs}$$

$$0 = g_m (v_{in} - v_{out})$$

$$v_{in} = v_{out}$$

$$v_{out}/v_{in} = 1$$

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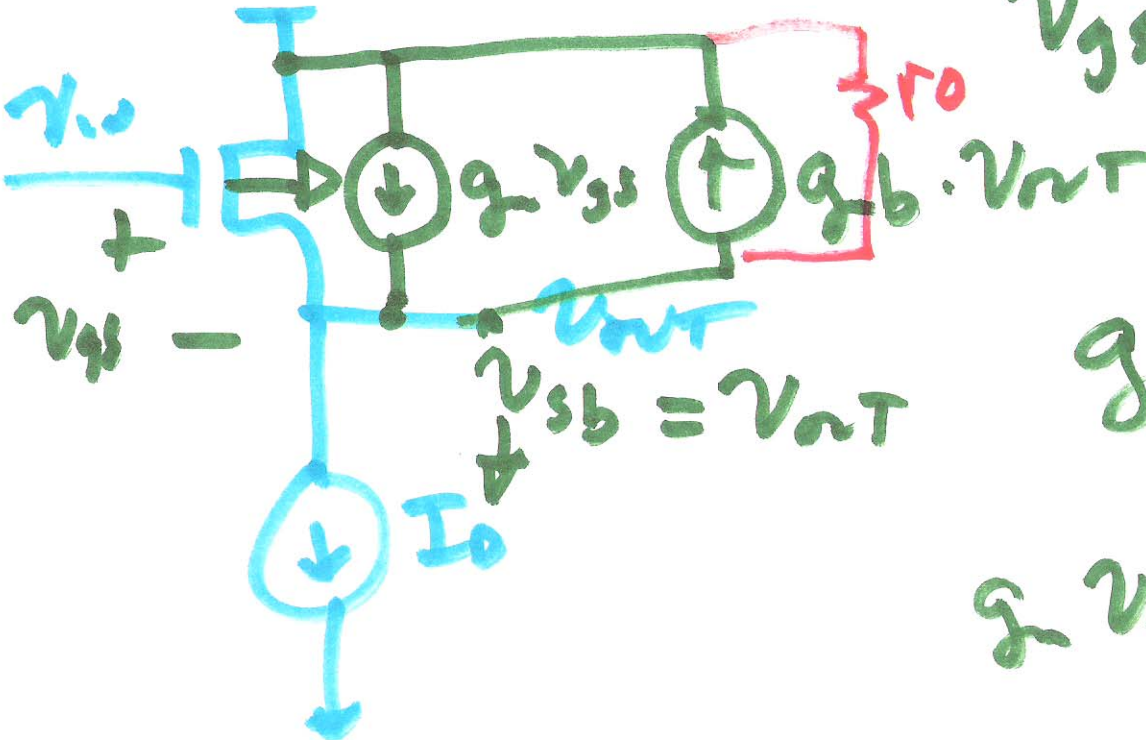


$$v_{gs} = v_{in} - v_{out}$$

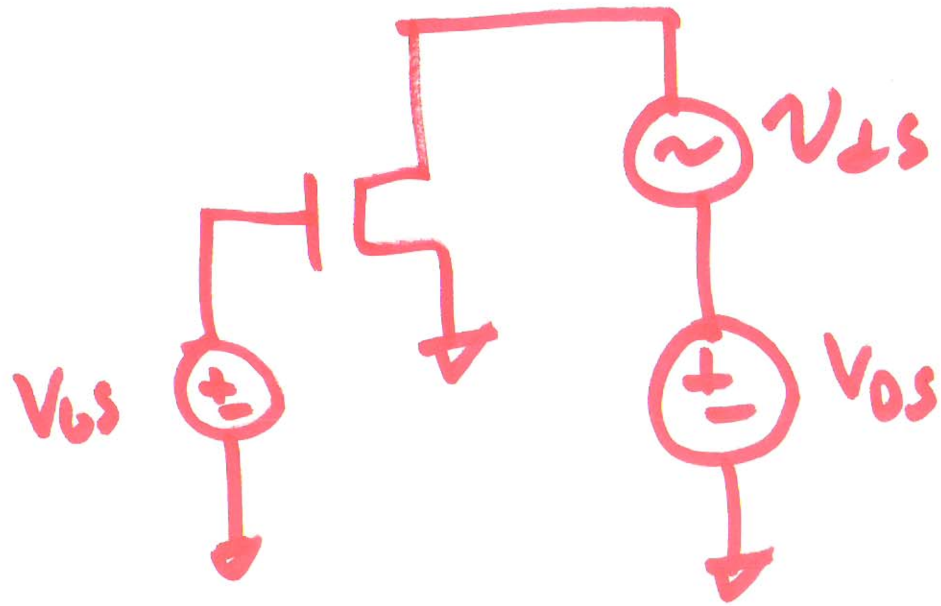
$$g_m v_{gs} = g_{mb}(v_{out})$$

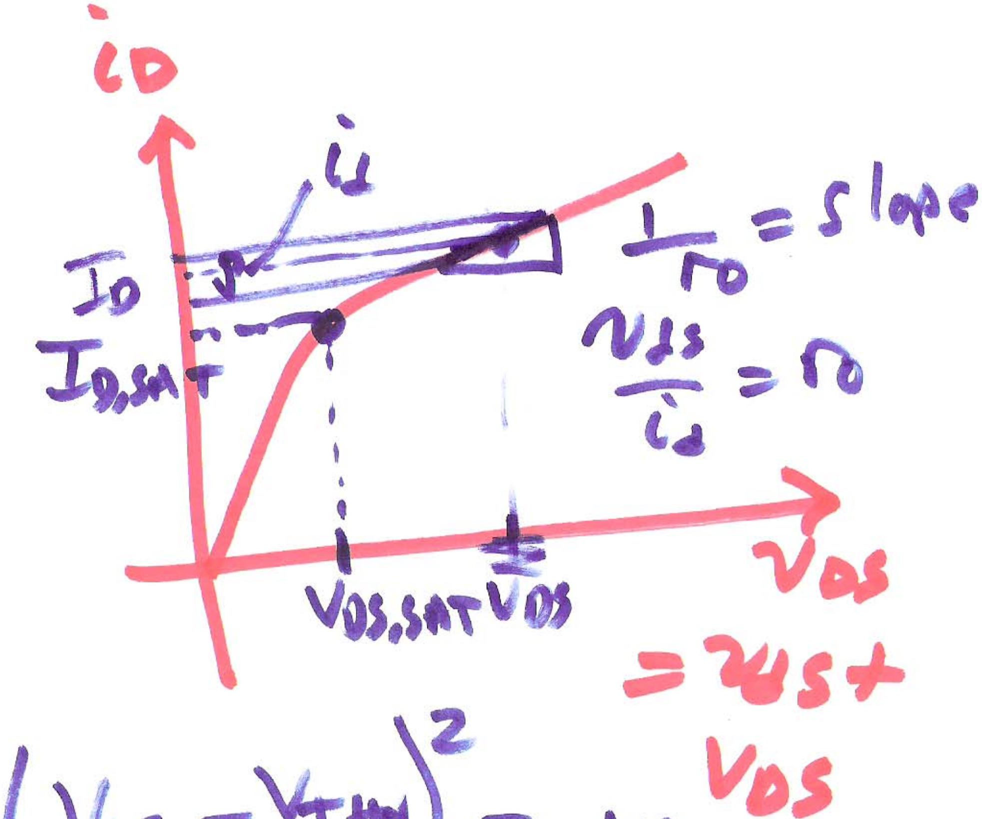
$$g_m v_{in} - g_m v_{out} = g_{mb} v_{out}$$

$$g_m v_{in} = v_{out}(g_m + g_{mb})$$

$$\underline{\underline{.71}} \simeq \frac{1}{1.4} = \frac{v_{out}}{v_{in}} = \frac{g_m}{g_m + g_{mb}}$$

$$g_{mb} = 0.4 g_m$$





$$I_{D,SAT} = \frac{KP}{2}\frac{W}{L}\left(V_{GS} - V_{THN}\right)^2 = \frac{KP}{2}\frac{W}{L}V_{DS,SAT}^2$$

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

$$I_D = I_{D,SAT}\left(1 + \lambda\left(V_{DS} - V_{DS,SAT}\right)\right)$$

$$V_{DS} \geq V_{DS,SAT}$$

$$\frac{1}{r_o} = \frac{\delta \quad i_d + I_D}{\delta v_{DS}}\Bigg|_{\substack{I_D = CONST \\ V_{DS} = CONST}} = \frac{\delta}{\delta v_{DS}}\left(I_{D,SAT}\left(1 + \lambda\left(V_{DS} + v_{DS} - V_{DS,SAT}\right)\right)\right)$$

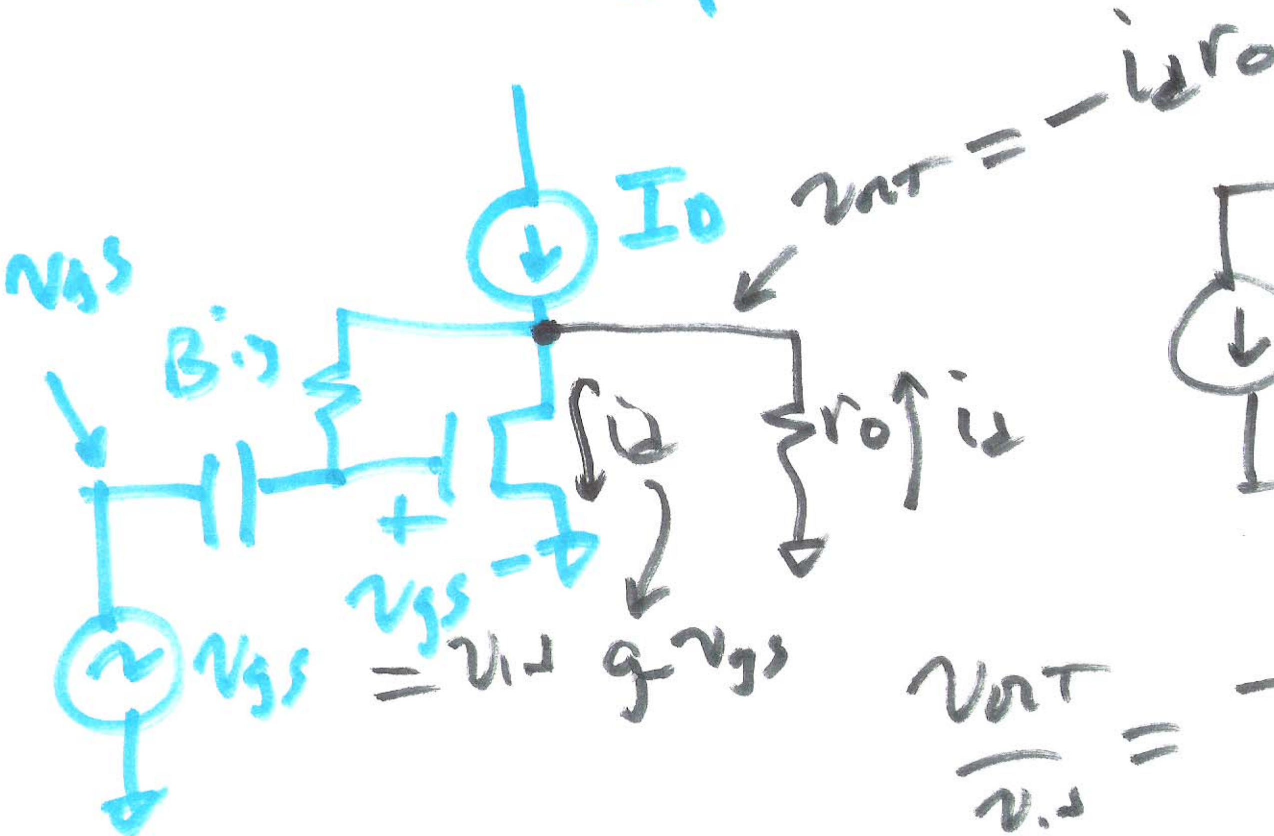
$$= I_{D,SAT}\,\lambda\left(\frac{V_{DS} + v_{ds}}{v_{DS}} - \cancelto{0}{V_{DS,SAT}}\right)$$

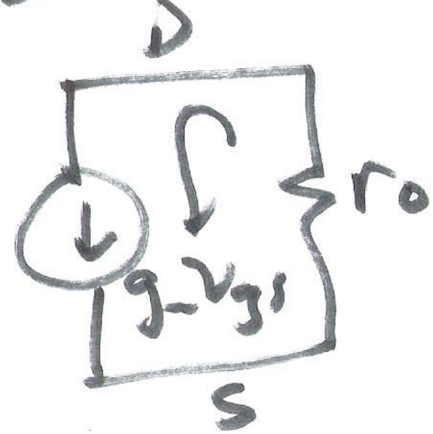
$$V_{DS} \gg v_{ds}$$

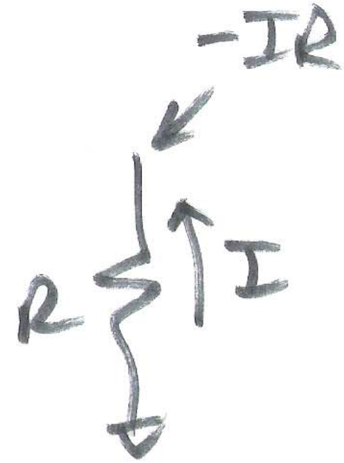
$$\frac{1}{r_o} = \lambda I_{D,SAT}$$

$$\boxed{r_o = \frac{1}{\lambda I_{D,SAT}}}$$

Open-CKT gain







$$\frac{v_{out}}{v_{id}} = -\frac{i_d r_o}{v_{gs}} = -g_m r_o$$

$$|A_{open\ ckt}| = \boxed{g_m r_o}$$

$$g_m r_o = \sqrt{2KP \cdot \frac{W}{L} \cdot I_D} \cdot \frac{1}{\lambda I_D}$$

$$g_m r_o \propto \frac{1}{\sqrt{I_D}}$$

$I_D \uparrow$ gain, $g_m r_o \downarrow$

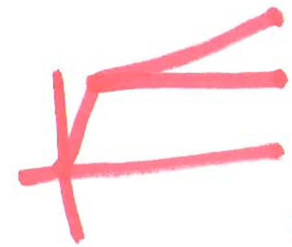
for subthreshold $g_m = \frac{I_D}{n \cdot V_T}$

V_T ← Thermal voltage $.026\,mV$, $\frac{kT}{q}$

$g_m r_o$ independent of I_D

$$g_m r_o = \sqrt{2KP\cdot\frac{W}{L}\cdot I_D}\cdot\frac{1}{\lambda\cdot\frac{KP}{2}\frac{W}{L}(V_{GS}-V_{THN})^2}$$

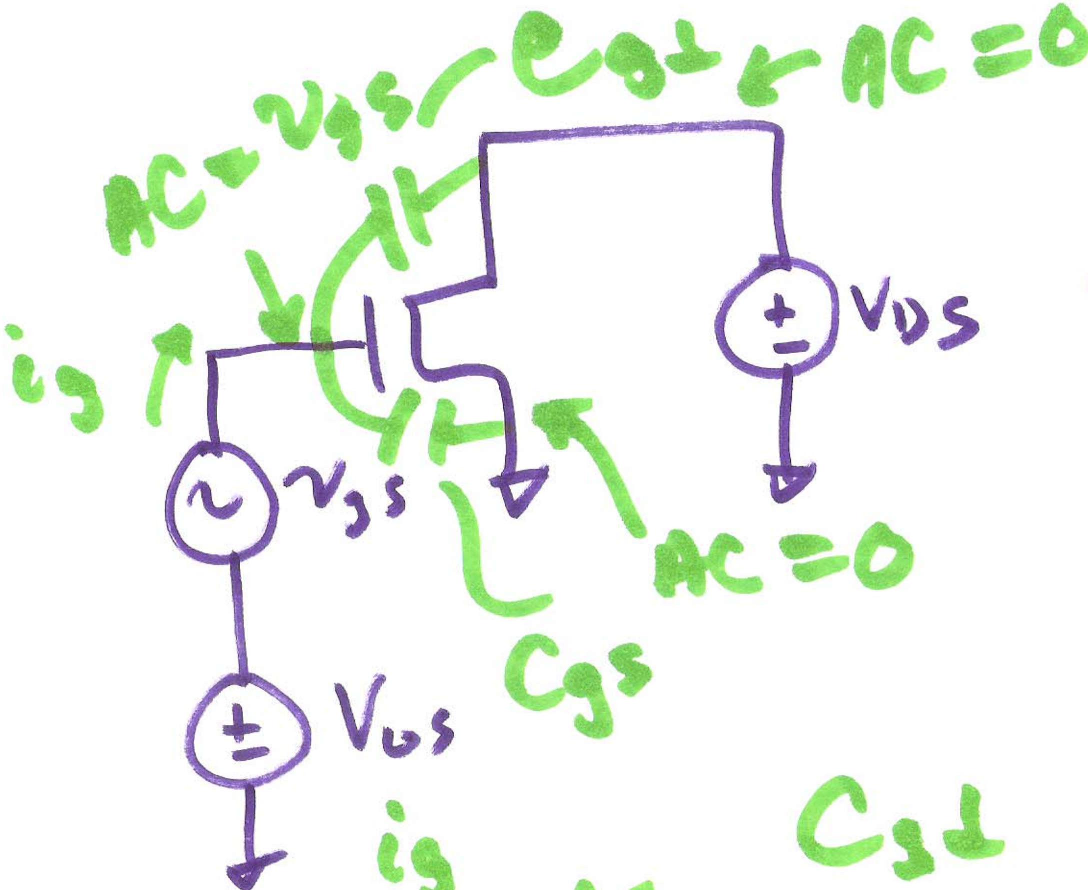
$$= \frac{KP\cdot\frac{W}{L}(V_{GS}-V_{THN})}{\lambda\frac{KP}{2}\cdot\frac{W}{L}(V_{GS}-V_{THN})^2}$$



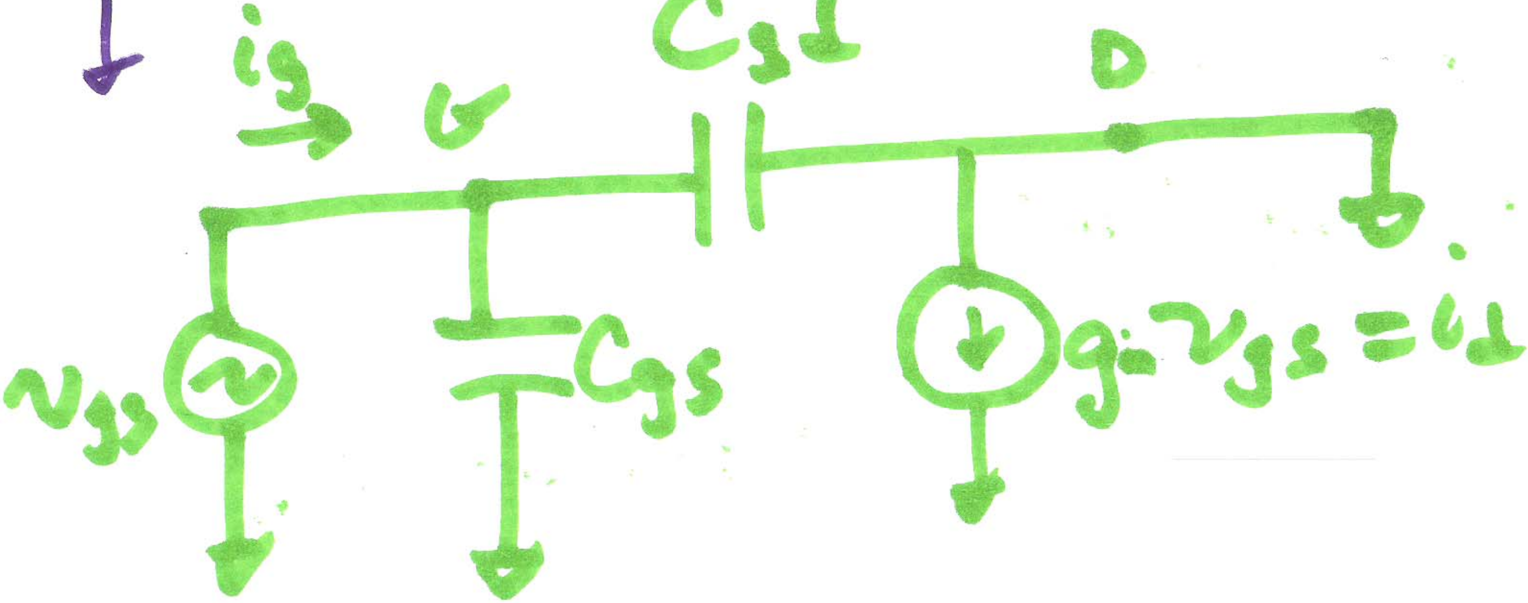
$$\lambda \propto \frac{1}{L}$$

$$g_m r_o \propto \frac{1}{\lambda}$$

$$I_D = \frac{KP}{2}\frac{W}{L_{eff}}(V_{GS}-V_{THN})^2$$



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

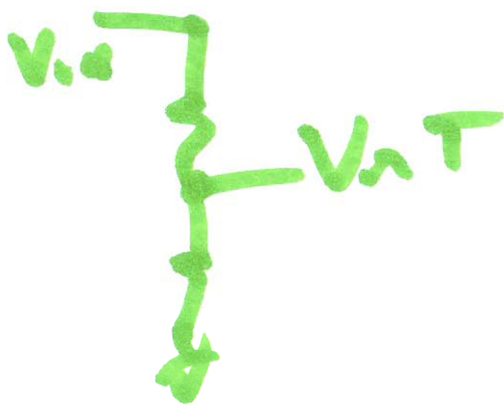


$$i_d = g_m v_{gs} = \frac{g_m \cdot i_g}{j\omega(C_{gd} + C_{gs})}$$

$$1 = \left|\frac{i_d}{i_g}\right| = \frac{g_m}{2\pi f_T (C_{gd} + C_{gs})}$$

$$\left|\frac{i_d}{i_g}\right| = 1 \quad f = f_T$$

← MOSFET transitions from an Amplifier to Attenuator



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

how does I_D or $V_{GS} - V_{THN}$

$V_{GS} - V_{THN}$ → $V_{DS,sat}$, overdrive voltage

$$f_T = \frac{\sqrt{2KP \cdot \frac{W}{L} I_D}}{2\pi(C_{gd} + C_{gs})} \qquad I_D \uparrow \; f_T \nearrow$$

$$= \frac{KP \cdot \frac{W}{L}(V_{GS} - V_{THN})}{2\pi(C_{gs} + C_{gd})} \qquad V_{GS} \uparrow \; f_T \nearrow$$

$$C_{gd} << C_{gs} = \frac{2}{3} W \cdot L \cdot C'_{ox}$$

$$\frac{\varepsilon_{ox}}{t_{ox}}$$

$$KP = \mu_n \cdot C'_{ox}$$

$$f_T \approx \frac{\mu_n C'_{ox} \cdot \frac{W}{L}(V_{GS} - V_{THN})}{2\pi \frac{2}{3} \cdot W \cdot L \cdot C'_{ox}}$$

$$f_T \propto \frac{1}{L^2}$$

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$$G \cdot f_T = g_m r_o f_T$$

$$= \frac{\left[\mu_n C_{ox}' \cdot \frac{W}{L}(V_{GS} - V_{THN})\right]^2}{2\pi \frac{2}{3} C_{ox}' \lambda \cdot \frac{W}{L} \cdot \frac{\mu_n C_{ox}'}{2}(V_{GS} - V_{THN})^2}$$

$$GFT \propto \frac{\mu}{L^2}$$