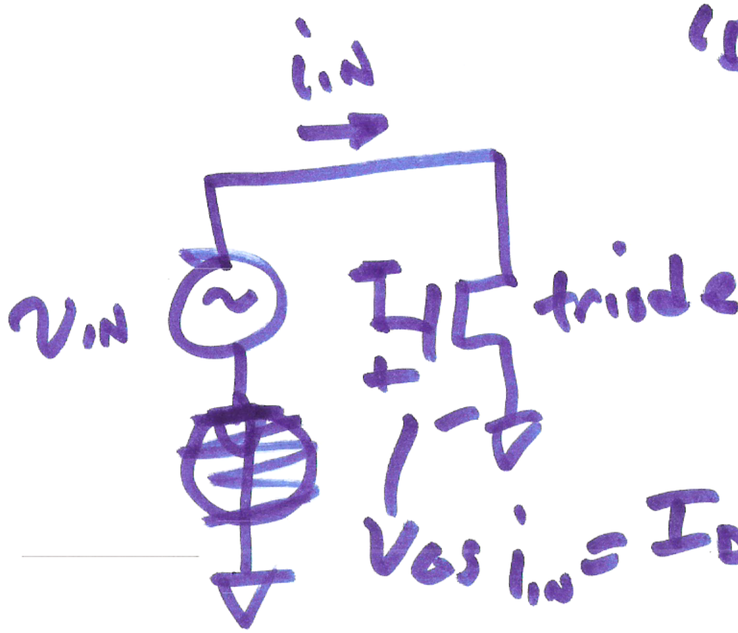
$$i_D = \beta\left((V_{GS} - V_{THN})v_{DS} - \frac{v_{DS}^2}{2}\right)$$



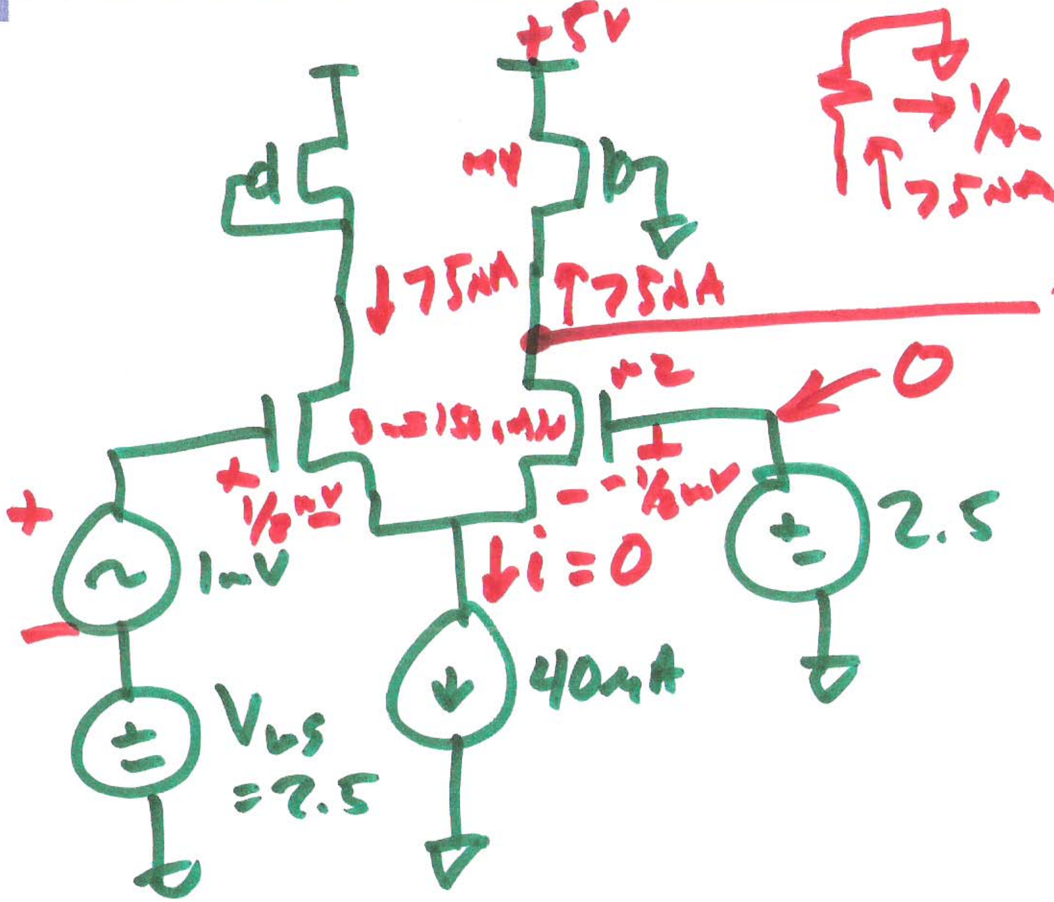

$$i_{IN} = I_D + i_d = \beta\left((V_{GS} - V_{THN})\cdot v_{in} - \frac{v_{in}^2}{2}\right)$$

$$r_{IN}^{-1} = \frac{\delta i_{in}}{\delta v_{in}} = \beta\left((V_{GS} - V_{THN}) - v_{in}\right)$$

$$v_{in} \ll V_{GS} - V_{THN} \ast$$

$$r_{IN}^{-1} \approx \beta(V_{GS} - V_{THN}) = g_m$$

1)




$$v_{d24} = 75nA \cdot \frac{1}{g_m}$$

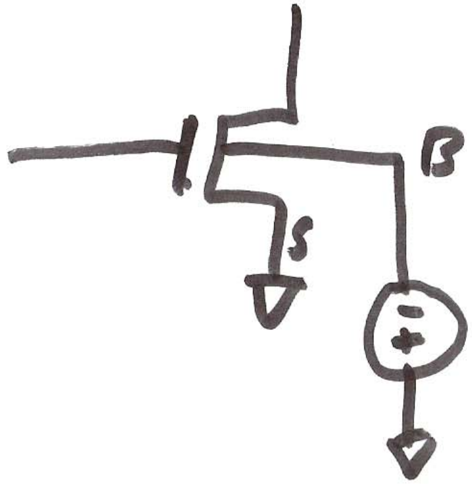
$$r_{CH} = \frac{1}{40mA/V \cdot \frac{30}{2}(5-.8)}$$

$$= 407\Omega$$

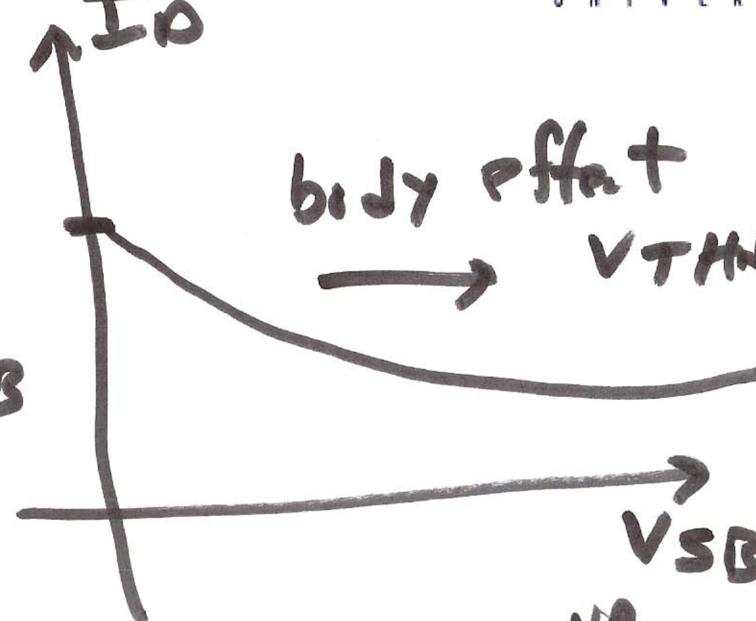
$$v_{d24} = 75n \cdot 407\Omega$$

$$\approx \underline{30mV}$$

2)



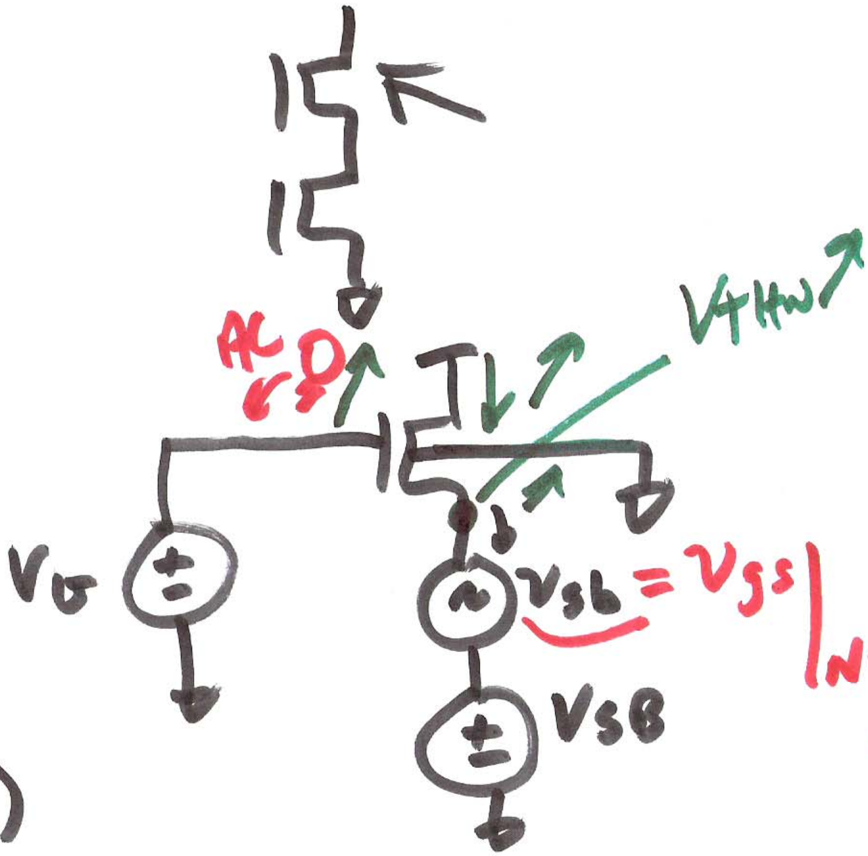

$V_{SB} = V_S - V_B$




body effect → $V_{THN}\nearrow$

up

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




$v_{sb} = v_{gs}$

Neglect $g_m$

$$i_D = i_d + I_D = \frac{\beta}{2}\left(V_{GS} + v_{gs} - V_{THN}\right)^2$$

Assume doesn't vary with $v_{sb}$

($v_{gs}$ does gives $g_m$)

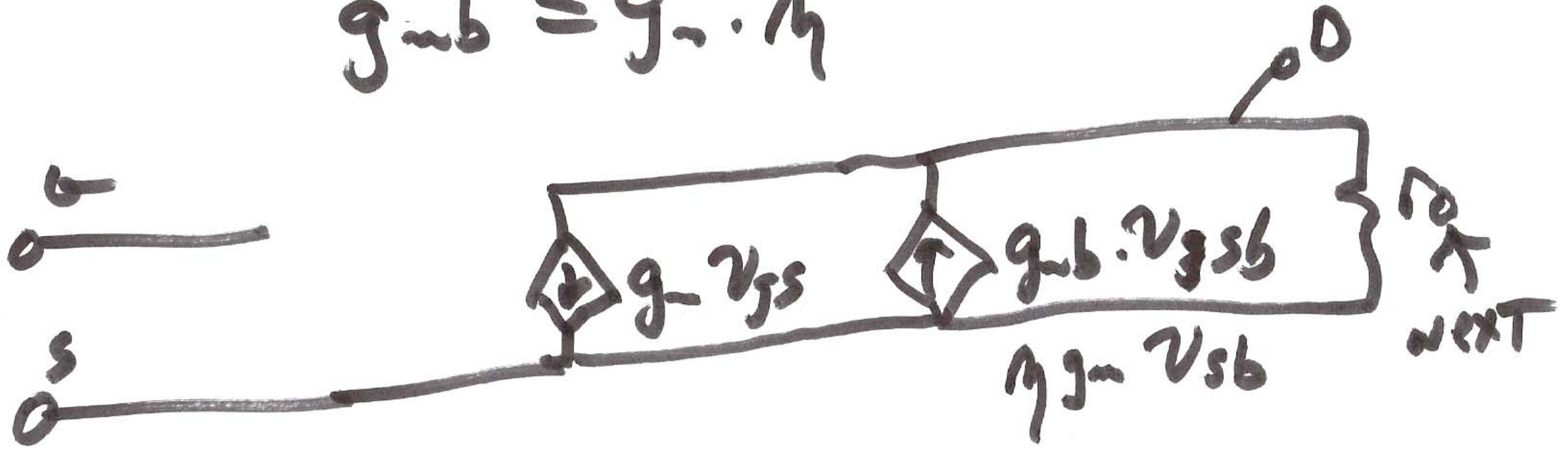
$$g_{mb} = \frac{\delta (I_D + i_d)}{\delta v_{sb}} = \frac{\delta \beta (V_{GS} - V_{THN})^2}{\delta v_{sb}}$$

$g_{mb}$ ← body transconductance

$$g_{mb} = \underbrace{2\beta(V_{GS} - V_{THN})}_{g_m} \underbrace{\left(-\frac{\delta V_{THN}}{\delta v_{sb}}\right)}_{\eta}$$

$$\eta < 1$$

$$g_{mb} = g_m \cdot \eta$$



# source followers

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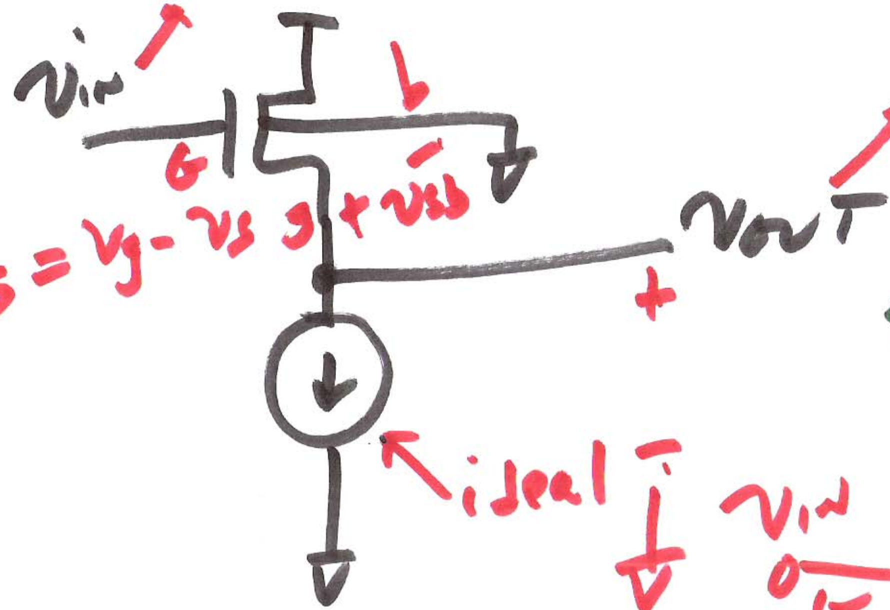
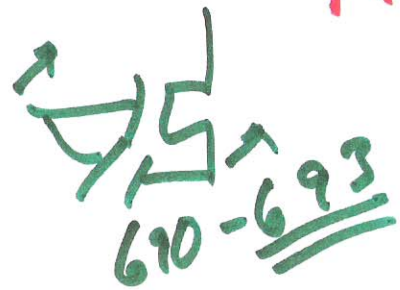
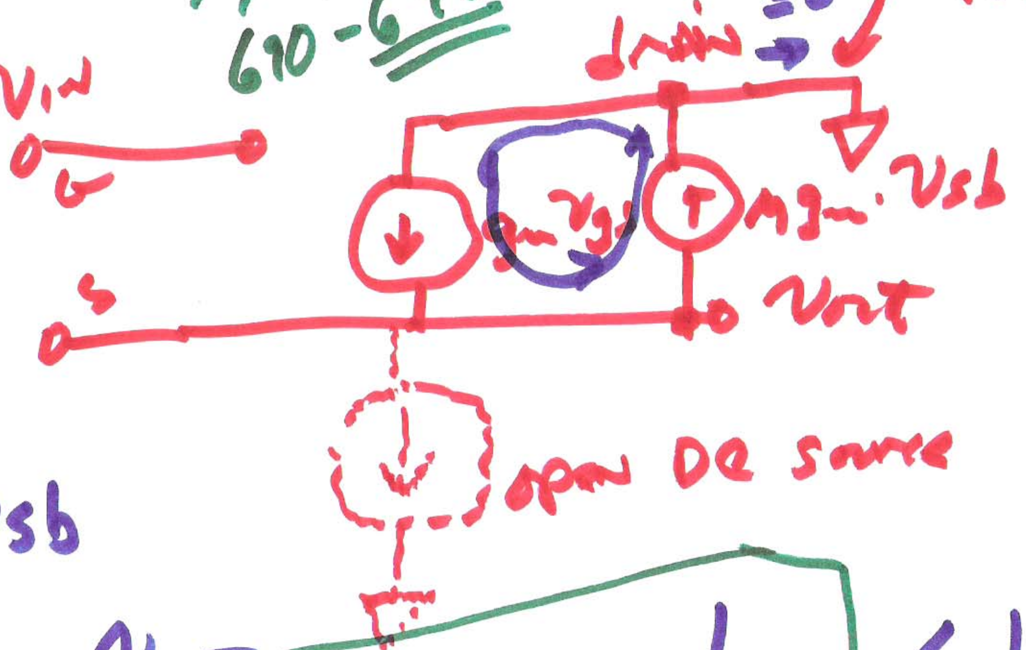



$v_{gs} = v_g - v_s$

$\left|\frac{v_{out}}{v_{in}}\right| = 1$ ideal, no body effect




$v_{sb} = v_{out}$

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

$g_m v_{gs} = n \cancel{g_m} v_{sb}$

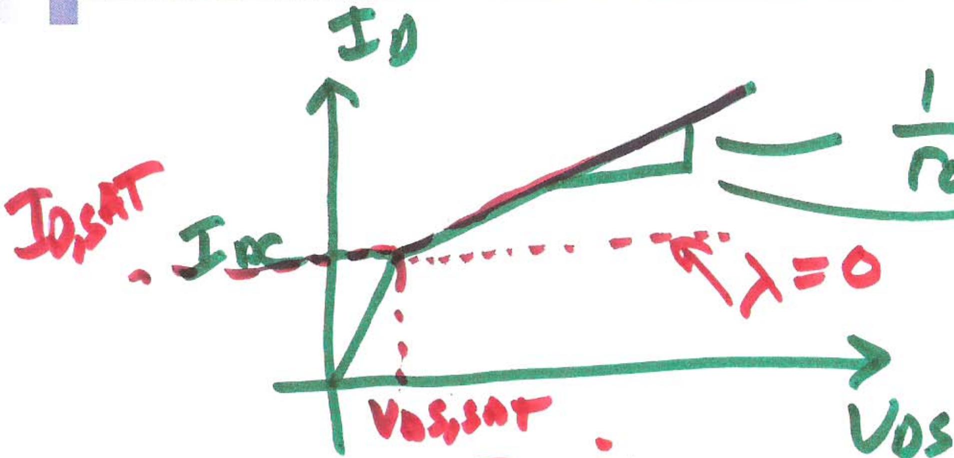
$v_{in} - v_{out} = n \cdot v_{out}$

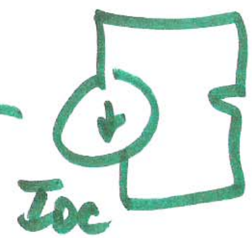
$\boxed{\frac{v_{out}}{v_{in}} = \frac{1}{1+n}} < 1$

$0.1 < n \leq 0.4$

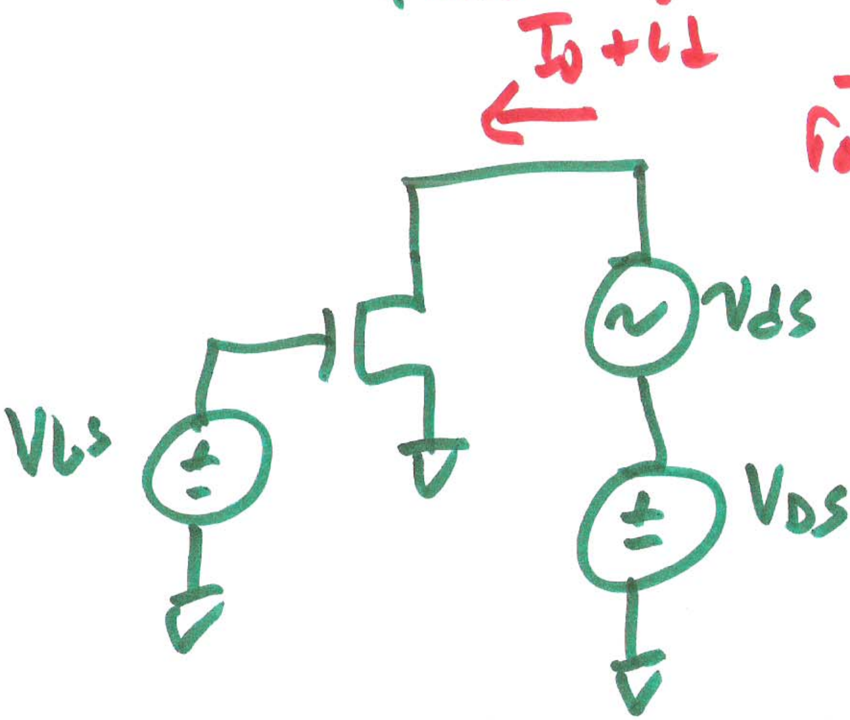
# OUTPUT Resistance






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




$$r_o^{-1} = \left.\frac{\delta i_D}{\delta V_{DS}}\right|_{\substack{I_D = \text{CONST.} \\ V_{DS} = \text{CONST.}}} = \frac{\delta}{\delta V_{DS}}\left(\frac{\beta}{2}\left(V_{GS}-V_{THN}\right)^2 \cdot \left(1+\lambda\left(V_{DS}-V_{DS,SAT}\right)\right)\right)$$

$$r_o^{-1} = \underbrace{\frac{\beta}{2}\left(V_{GS}-V_{THN}\right)^2}_{I_{D,SAT}} \cdot \lambda \cdot \cancelto{1}{\frac{\delta V_{DS}}{\delta V_{DS}}}$$

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

$$I_D = \frac{\beta}{2}\left(\underbrace{V_{GS} - V_{THN}}_{\text{overdrive } V_{OVN}}\right)^2\left(1 + \lambda\left(V_{DS} - V_{DS,SAT}\right)\right)$$

Small $V_{OVN}$ devices slow

Large $V_{OVN}$ devices go into saturation earlier

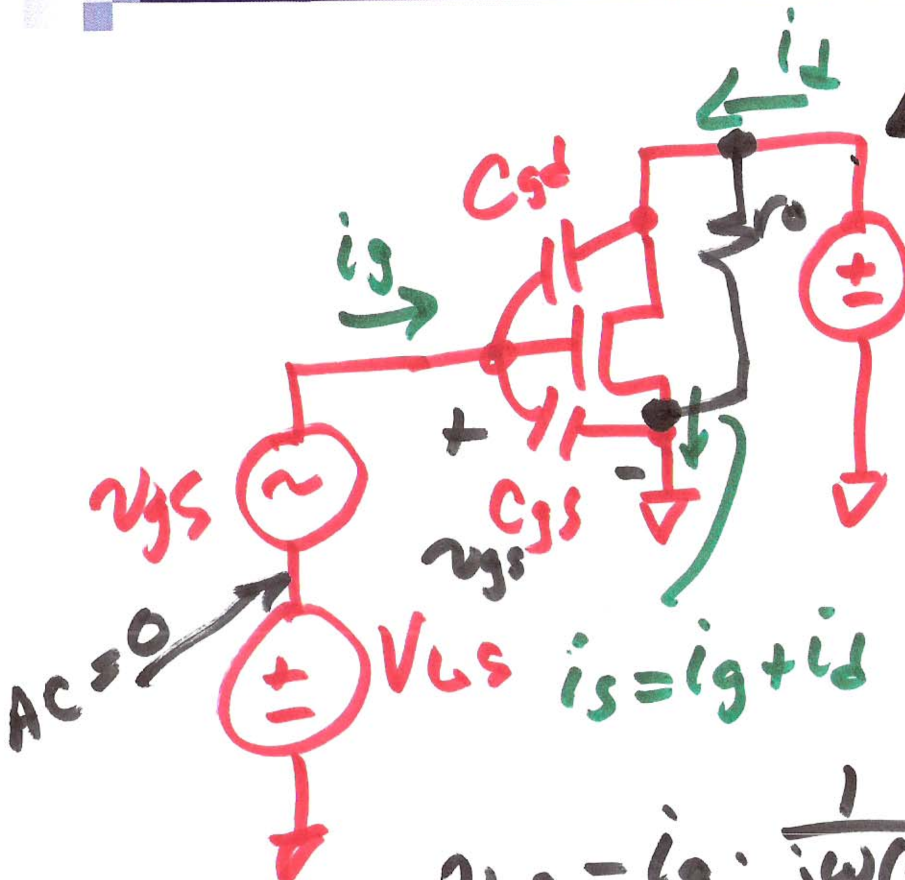
for saturation

$$V_{DS} > V_{GS} - V_{THN}$$

$$> V_{OVN}$$

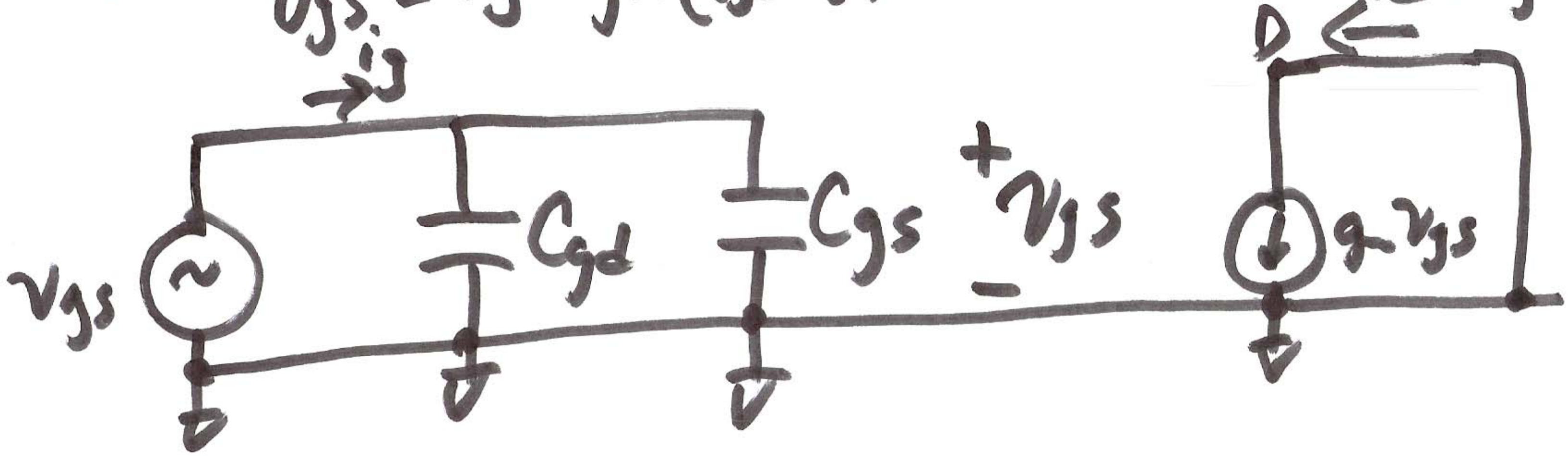
These comments based upon devices operating as "square-law"

# $f_T$ - transition frequency




$$i_s = i_g + i_d \qquad \left|\left|\frac{i_d}{i_g}\right|\right|_{f=f_T} = 1$$

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



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

$$\left|\frac{i_d}{i_g}\right| = \left|\frac{g_m + j0}{0 + j\omega(C_{gd} + C_{gs})}\right|$$

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

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

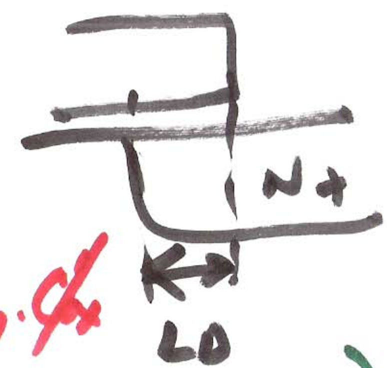
$$f_T = \frac{g_m}{2\pi\left(C_{gd}+C_{gs}\right)} \simeq \frac{g_m}{2\pi C_{gs}}$$

$C_{gs} = \frac{2}{3}WL\cdot C_{ox}$ $\quad C_{gs} >> C_{gd}$

$C_{gd} = LD\cdot C_{ox}$

Lateral diffussion

$$f_T \approx \frac{\beta\left(V_{GS}-V_{THN}\right)}{2\pi C_{gs}} = \frac{\beta\cdot V_{ovn}}{2\pi C_{gs}}$$




$V_{ovn}\nearrow$ $\quad f_T\nearrow$

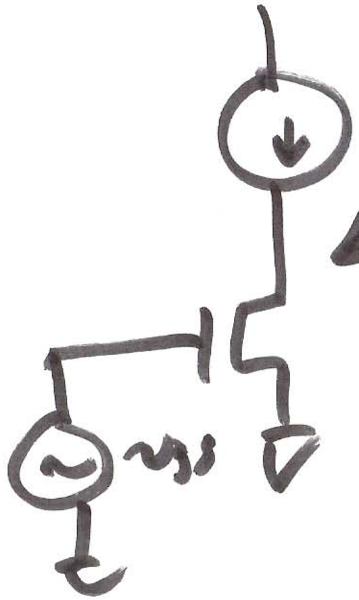
$$f_T \approx \frac{KP\cdot W\left(V_{GS}-V_{THN}\right)}{2\pi L\cdot C_{gs}} = \frac{\overset{\mu_n\cdot\cancel{C_{ox}}}{\cancel{KP}}\cdot\left(V_{GS}-V_{THN}\right)}{2\pi\cdot\frac{2}{3}L^2\,\cancel{C_{ox}}}$$

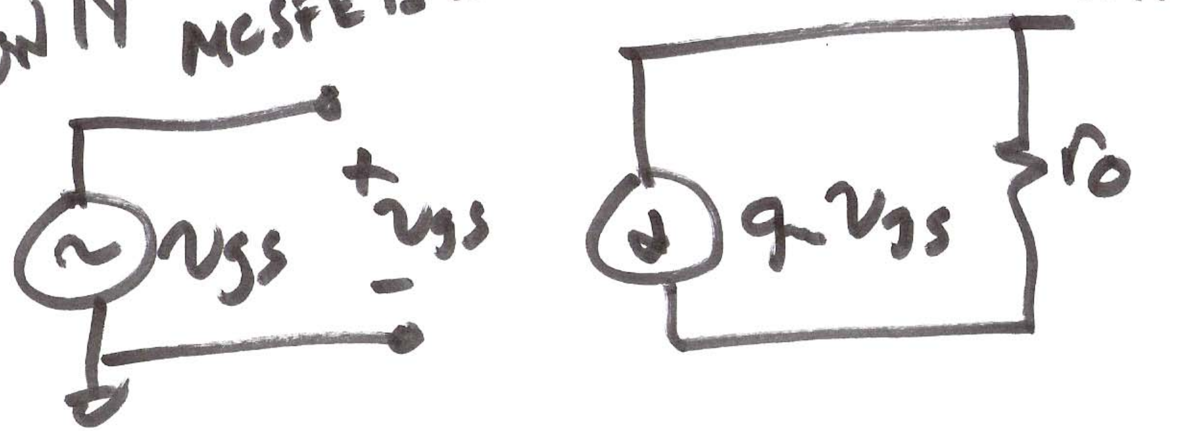
$f_T\uparrow$ $\quad L\downarrow$

$$\boxed{f_T \approx \frac{\mu_n\cdot\left(V_{GS}-V_{THN}\right)}{\frac{4\pi}{3}L^2}}$$

# OPEN-CKT gain

only load is the MOSFET's own resistance




$$v_{out} = -g_m v_{gs} r_o$$

$$\text{OPEN-CKT} = \left|\frac{v_{out}}{v_{in}}\right| = g_m r_o$$

$L \downarrow \quad r_o \downarrow \quad g_m \nearrow$

see pages 300 - 302

$$GFT = g_m r_o \cdot f_T$$

$$= \frac{3\mu_n}{2\pi L^2 \lambda} \propto \frac{\mu_n}{L}$$