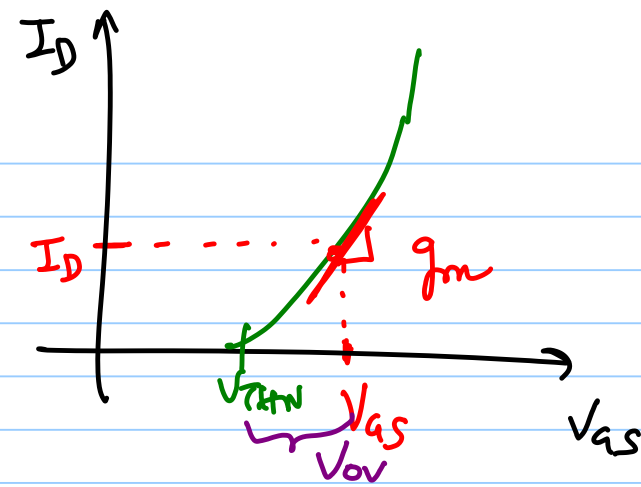
ECE 511 – Lecture 3

Note Title 1/28/2014

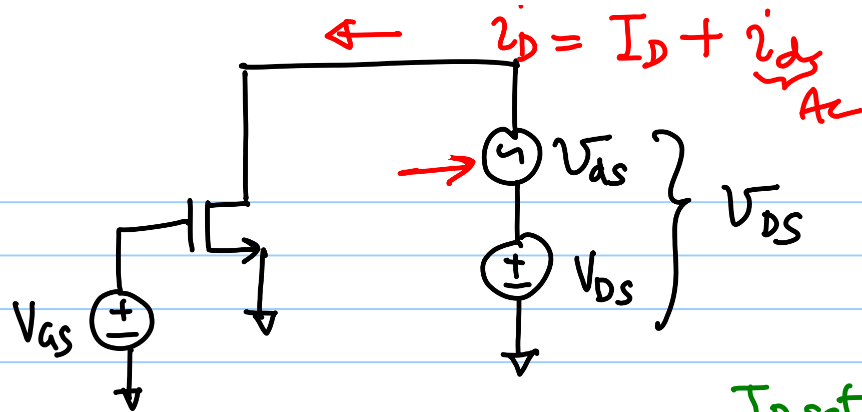
"Try OpenNX client"

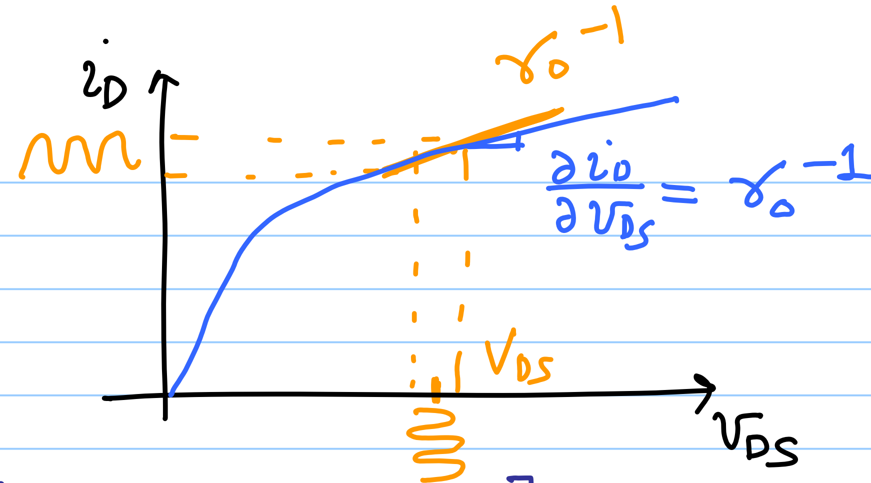
$$g_m = \left.\frac{\partial i_D}{\partial V_{GS}}\right|_{V_{GS}}$$



$g_m \propto V_{OV}$

$V_{GS} - V_{THN}$





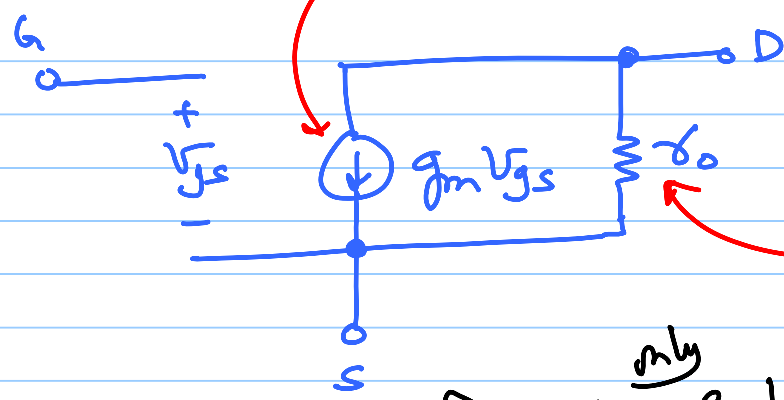
$$i_D = \underbrace{\frac{k'_n}{2}\frac{W}{L}(V_{GS} - V_{THN})^2}_{I_{D,sat}}\left[1 + \lambda(v_{DS} - V_{DS,sat})\right]$$

$$g_o = g_{ds} = r_o^{-1} = \frac{\partial i_D}{\partial v_{DS}} = I_{D,sat} \cdot \lambda$$

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

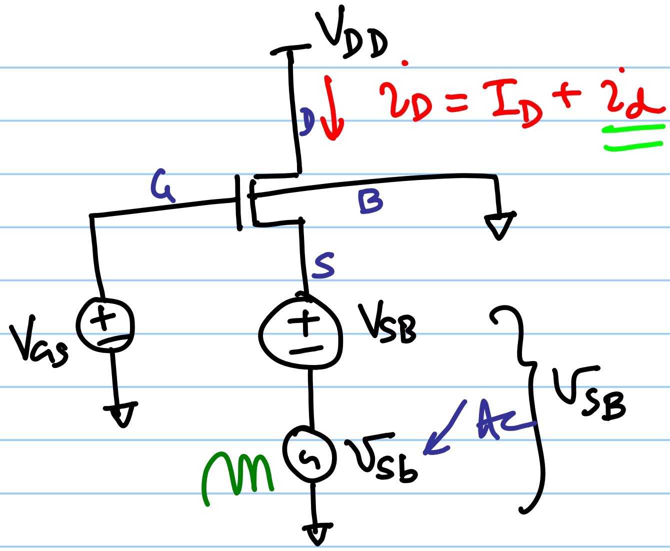
Small-signal Model "so-far"

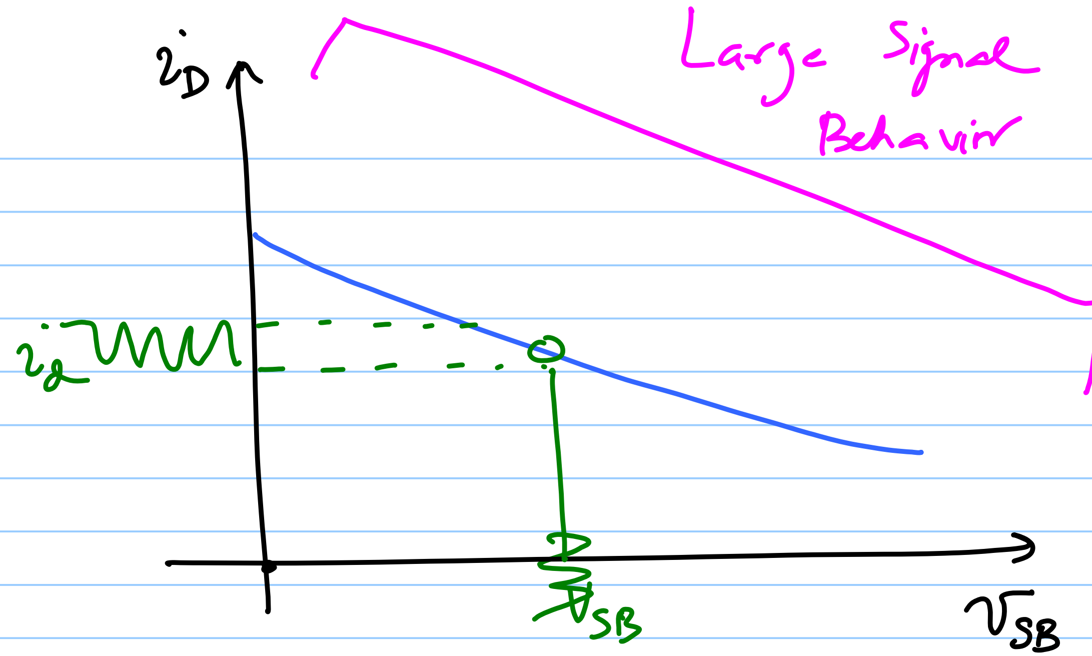
$i_d = g_m v_{gs}$



accounts for $\lambda > 0$ channel length modulation

Note only 3 terminals





Body transconductance

$$g_{mb} = \left.\frac{\partial i_D}{\partial v_{SB}}\right|_{V_{SB}}$$

$$i_D = \frac{Kp_n}{2}\frac{W}{L}\left(V_{GS} - \underbrace{V_{THN}}_{f(v_{SB})}\right)^2$$

$$g_{mb} = \left.\frac{\partial i_D}{\partial v_{SB}}\right|_{V_{SB}} = \left.\underbrace{Kp_n \cdot \frac{W}{L}\left(V_{GS} - V_{THN}\right)}_{g_m} \times \left(-\frac{\partial V_{THN}}{\partial v_{SB}}\right)\right|_{V_{SB}}$$

$$= g_m \cdot \left.\left(-\frac{\partial V_{THN}}{\partial v_{SB}}\right)\right|_{V_{SB}} \quad ?$$

$$V_{THN} = V_{THN0} + \gamma\left(\sqrt{V_{SB} + |2V_{fp}|} - \sqrt{2V_{fp}}\right)$$

$$= g_m \cdot \underbrace{\left(-\frac{\gamma}{2}\left(|2V_{fp}| + V_{SB}\right)^{-1/2}\right)}_{\eta}$$

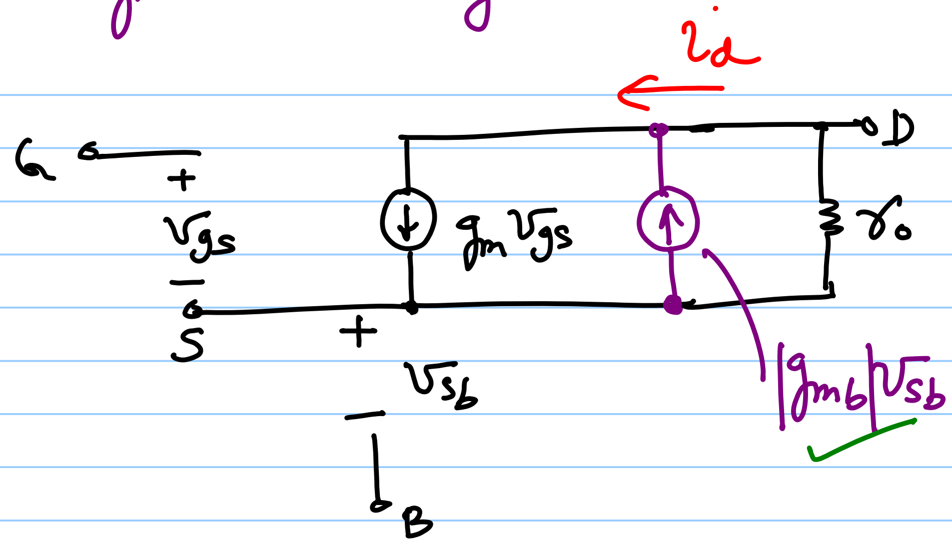
$g_{mb} = g_m \cdot \eta$

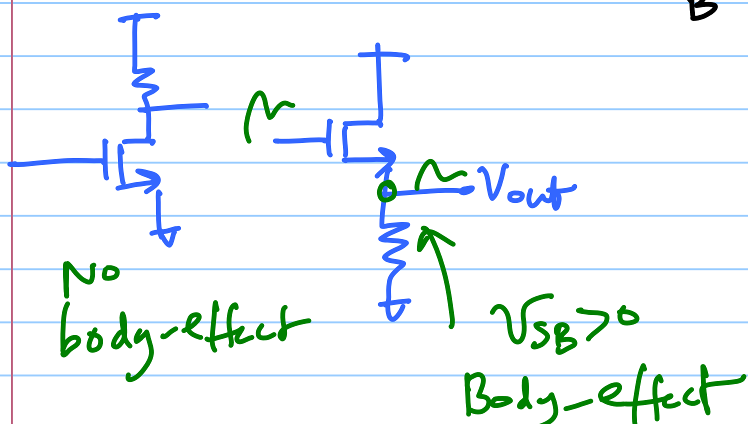
describes the dependence of i_d on V_{SB}

$$\eta = \frac{-\gamma}{2\sqrt{|2V_{fp}| + V_{SB}}}$$

Since $\eta < 0 \Rightarrow$ effect of g_{mb} opposes g_m

* Small signal model of 4-terminal NMOS

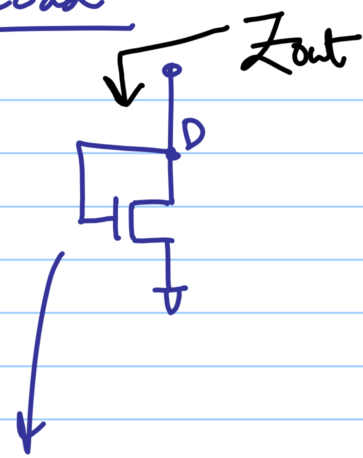




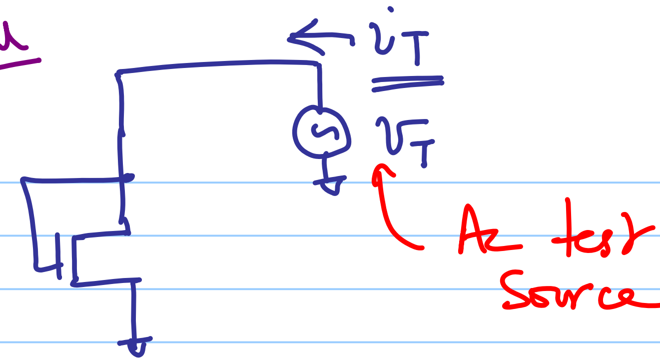
If source is "wiggling"

$\Rightarrow$ g_{mb} comes into picture.

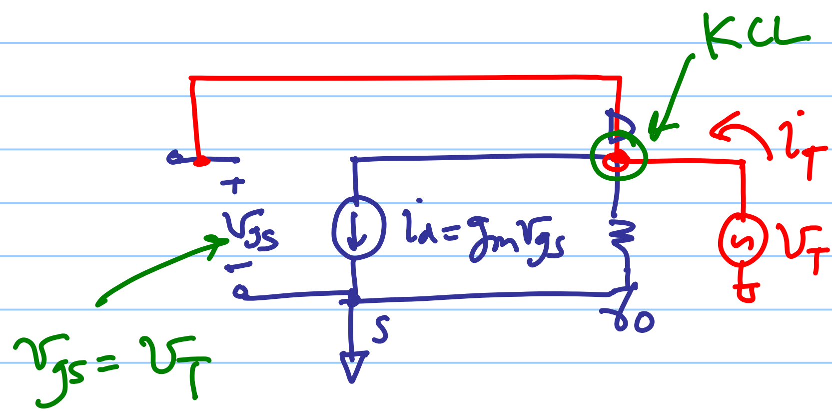
Diode Load



Small signal



$$Z_{out} = \frac{v_T}{i_T}$$



Find an expression for i_T

KCL:

$$i_T - \underbrace{g_m v_T}_{i_d} - \frac{v_T}{r_o} = 0$$

$$i_T = \left(g_m + 1/r_o\right) v_T$$

$$Z_{out} = \frac{v_T}{i_T} = \frac{1}{g_m + 1/r_o} = \frac{r_o}{1 + g_m r_o} = \frac{\frac{1}{g_m} \cdot r_o}{\frac{1}{g_m} + r_o}$$

$$= \frac{1}{g_m} \| r_o$$

$$\simeq \frac{1}{g_m}$$

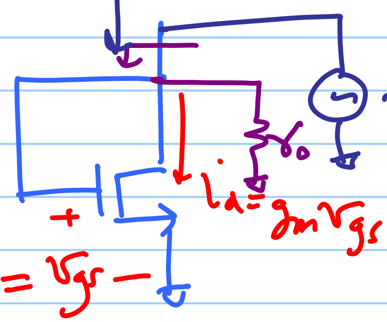
if $r_o >> \frac{1}{g_m}$

Long channel MOSFET

Again

$\underline{\underline{\lambda = 0}}$

$i_T = g_m v_T$

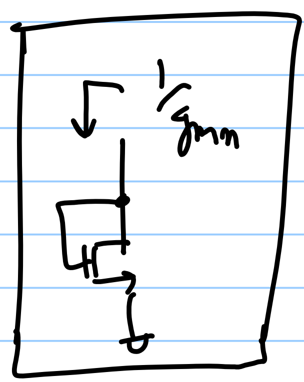


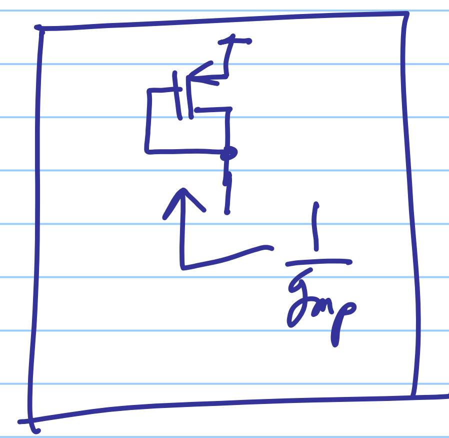
$v_T = v_{gs}$ −

$i_T = g_m v_T$

$\Rightarrow \boxed{Z_{out} = \frac{v_T}{i_T} = \frac{1}{g_m}}$

$\frac{1}{g_m} \| r_o$





$$Z_{out} \simeq \frac{1}{g_m} \simeq \boxed{\frac{1}{\beta V_{ov}}} \quad 5k\Omega$$

$$\text{Deep Triode} \Rightarrow R_{ch} \simeq \boxed{\frac{1}{\beta (V_{GS} - V_{THN})}} \quad \text{for} \quad V_{DS} \ll V_{DS,sat}$$

500Ω

r_o

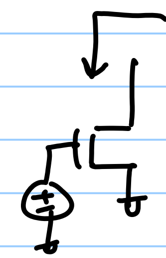
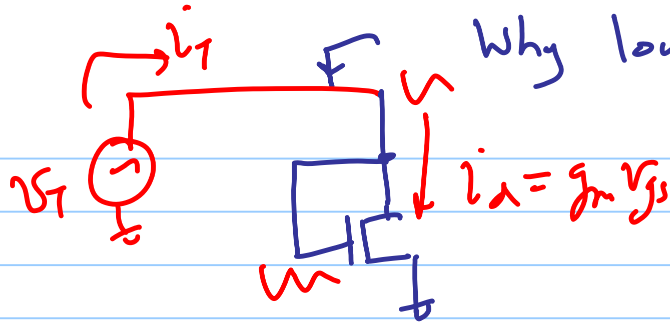
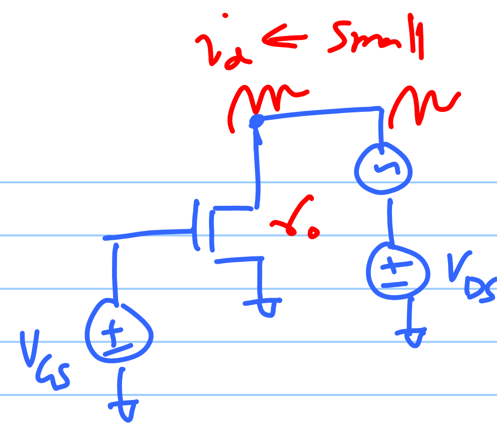


Table 9.1

	$1/g_m$	r_o
	$6.67k\Omega$	$5M\Omega$
	low-Impedance	High-Impedance

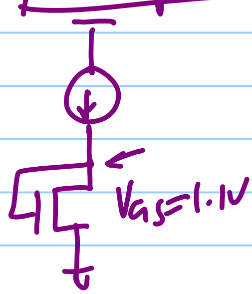
Why low-Z?

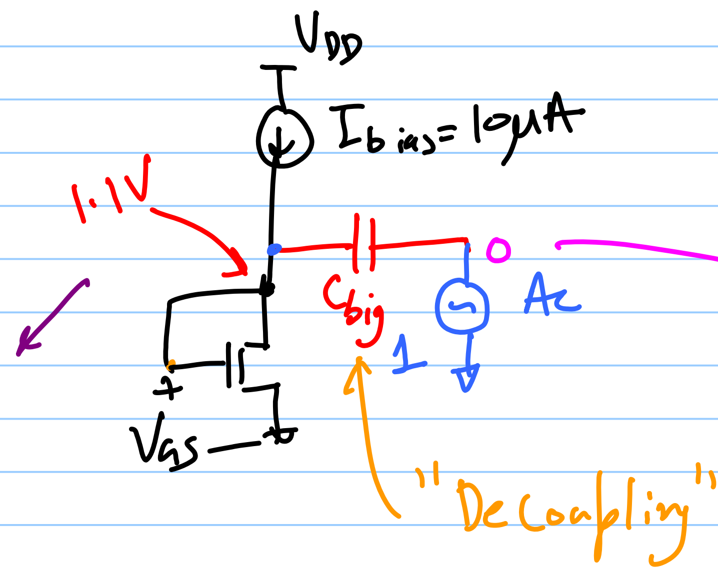




Simulation

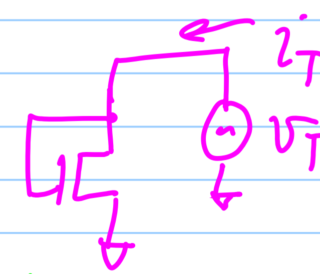
DC picture





"AC analysis"

AC picture



Small-Signal Analysis

"equivalent circuit"

1. Given a circuit, draw the DC picture
   - → short AC voltage sources
   - → open AC current sources

   Solve for DC operating point for all the devices.

2. Use DC operating points from step 1, find small-signal parameters (g_m, r_o, g_{mb}, ...)

   "Linearization Step"

③ Draw AC picture

↳ replace devices by small-signal models

↳ short all DC voltage sources

↳ open all DC current sources

Solve for AC values in the circuit

Final result ⇒ Superposition of ② & ③

Ex 9.5 of CMOS book