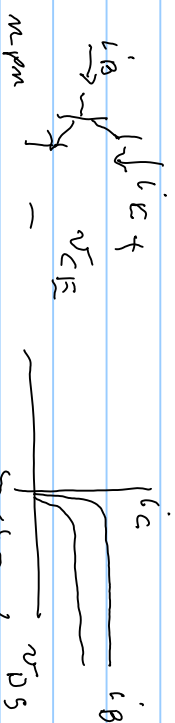


EE303

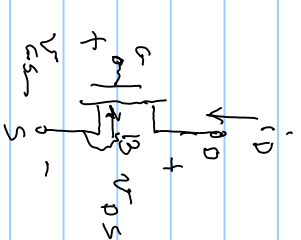
09/12/17

9/12/2017

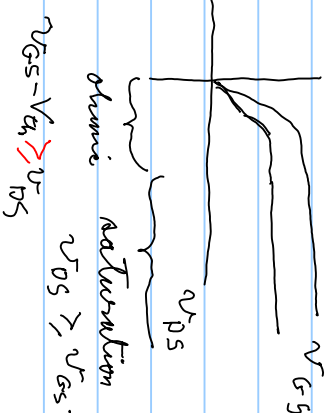


saturation
forward active

CCCS = current controlled current source



NMOS



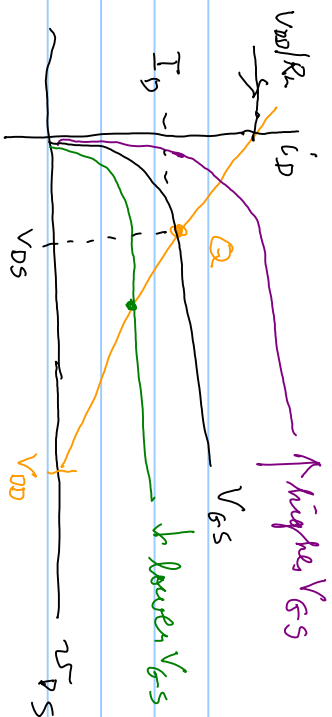
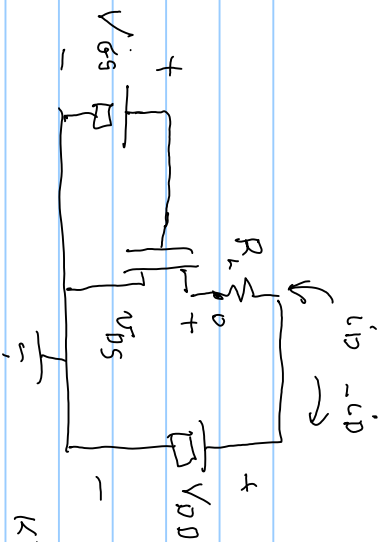
saturation
forward active
 $V_{GS} - V_{th} > V_{DS}$

V_GS = voltage controlled current source

$$i_{D, \text{sat}} = \frac{K_P}{2} \cdot \frac{W}{L} (V_{GS} - V_{th})^2 (1 + \lambda V_{DS})$$



$V_{th} = V_{DD}$ when $B = S$

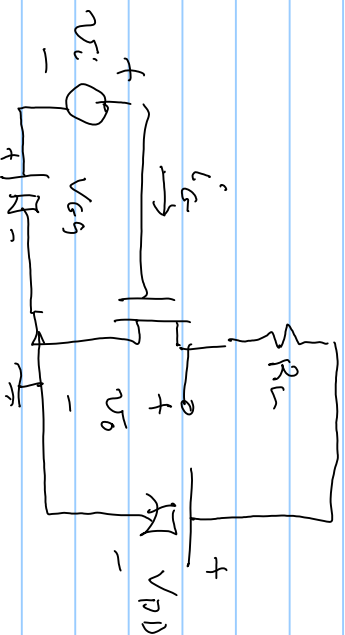


Load

$$\text{KVL: } v_{DS} = V_{DD} - R_L i_D \Rightarrow i_D = \frac{V_{DD} - v_{DS}}{R_L}$$

$$\frac{\partial i_D}{\partial v_{DS}} = -\frac{1}{R_L} = -G_L$$

$$i_D = f(v_{DS}, v_{GS})$$



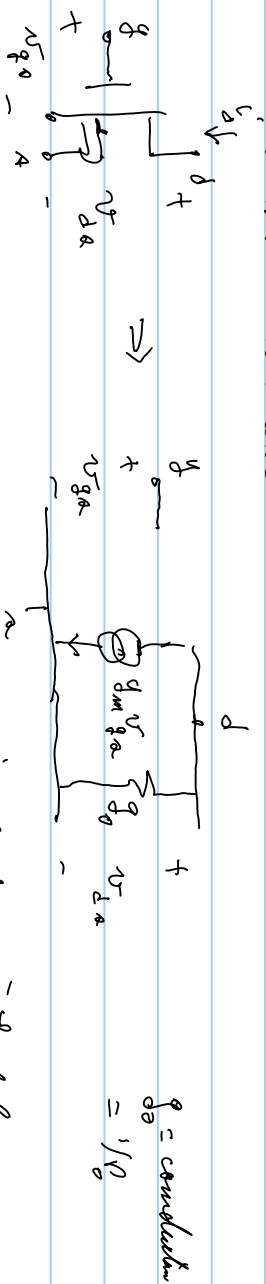
$$i_D \approx I_D + \frac{\partial i_D}{\partial v_{gs}} (v_{gs} - V_{gs}) + \frac{\partial i_D}{\partial v_{ds}} (v_{ds} - V_{ds}) + \text{higher orders}$$

ignores if small signal

$$\Rightarrow i_D - I_D = i_d = \frac{\partial i_D}{\partial v_{gs}} v_{gs} + \frac{\partial i_D}{\partial v_{ds}} v_{ds}$$

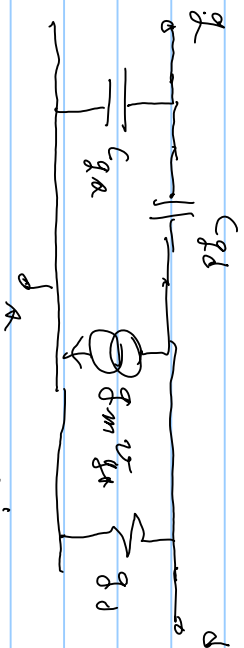
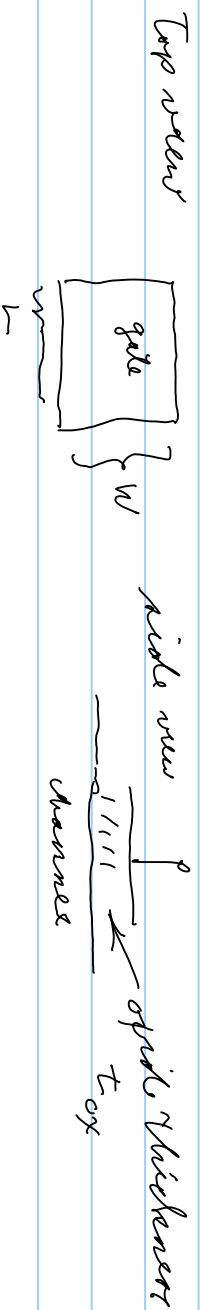
$$= g_m v_{gs} + g_o v_{ds}$$

↑↑ mutual output conductance



small signal equivalent circuit at low frequencies

as frequency goes up the gate capacitors become important

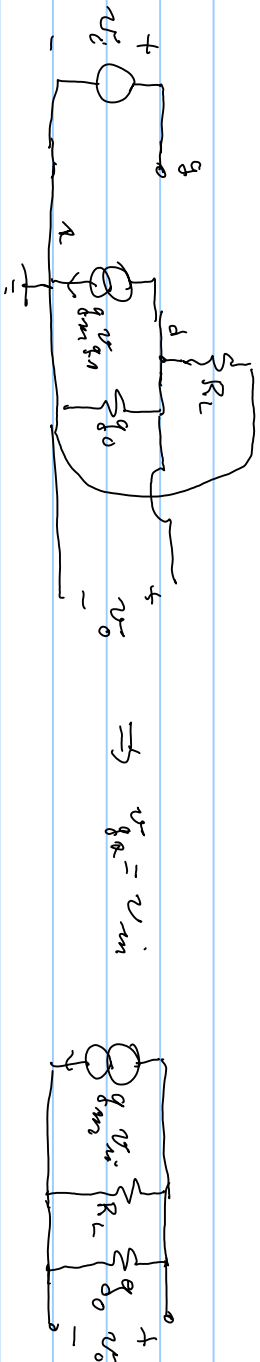


$$g_m = \frac{\partial i_D}{\partial v_{gs}} \Big|_Q, \quad g_d = \frac{\partial i_D}{\partial v_{ds}} \Big|_Q$$

in saturation: $i_D = \beta (v_{gs} - V_{th})^2 (1 + \lambda v_{ds})$, $\beta = \frac{k_p}{2} \cdot \frac{W}{L}$

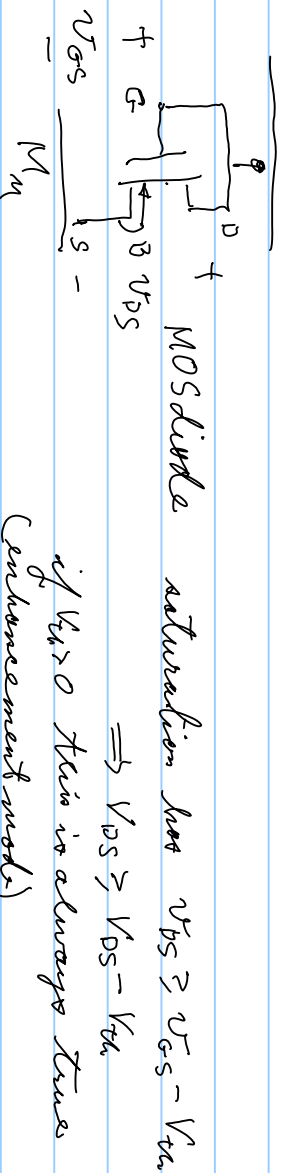
$$\frac{\partial i_D}{\partial v_{gs}} = 2\beta (v_{gs} - V_{th}) (1 + \lambda v_{ds}) \Big|_Q = 2 \frac{I_D}{(V_{gs} - V_{th})} = g_m$$

$$\frac{\partial I_D}{\partial v_{DS}} = \lambda \cdot \beta (v_{GS} - V_{th})^2 \cdot (1 + \lambda v_{DS}) \Big|_Q = \frac{\lambda I_D}{1 + \lambda v_{DS}} \approx \lambda I_D \text{ if } \lambda \text{ is small}$$



$$v_o = -g_m v_i \cdot R_L', \quad R_L' = R_L \parallel R_o$$

$$\frac{v_o}{v_i} = -g_m R_L' = \frac{v_o R_L}{V_o + R_L}, \quad \mu = 1/g_o$$



M_n could be off $\rightarrow$ when $v_{DS} = v_{GS} < V_{TO} = V_{th}$



$$v_p = v_{gs} = v_{ps}$$

$$i_D = \beta (V_{GS} - V_{th})^2 (1 + \lambda V_{DS})$$

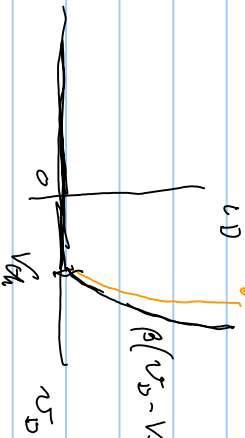
$$= \beta (\sigma_D - \sqrt{t_h})^2 (1 + \lambda \sigma_D)^2 \approx \beta (\sigma_D - \sqrt{t_h})^2$$

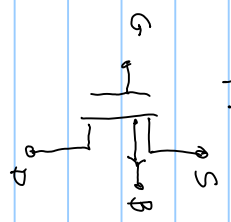
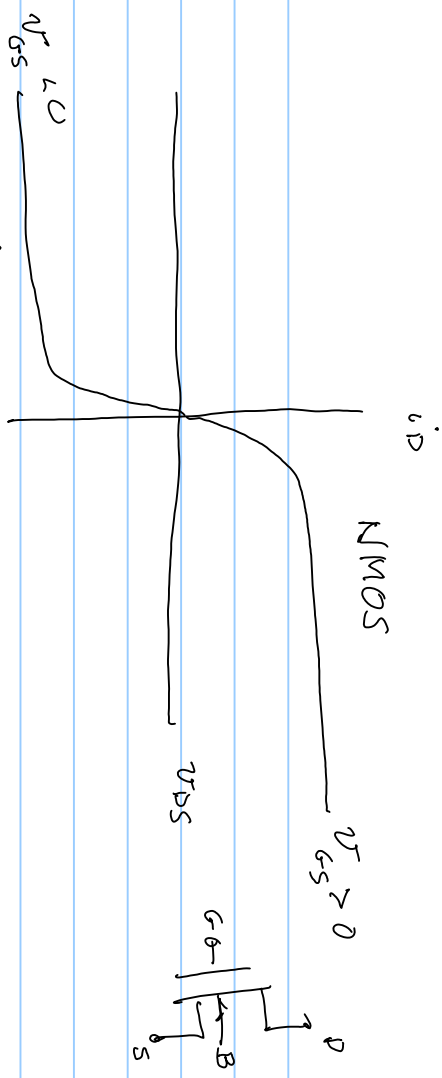
270

if $v_D > v_{a_1} \rightarrow$

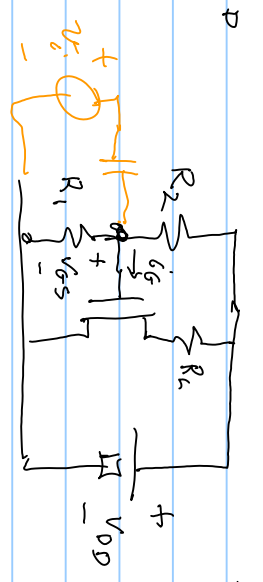
$$\|u\|_p \leq \|u\|_q \Rightarrow v_D = 0$$

$$\beta(v_D - v_{th})^2$$





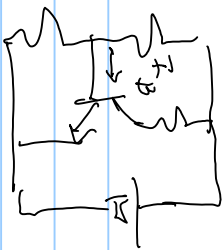
Biasing of MOS:



$$I_G \approx 0$$

$$V_G = \frac{R_2}{R_1 + R_2} V_{DD}$$

for BJT



$I_B \neq 0$