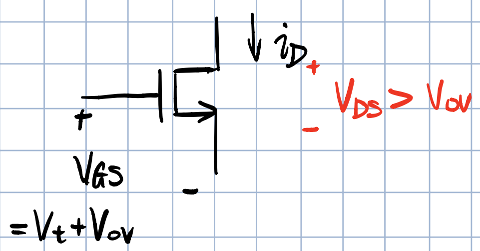
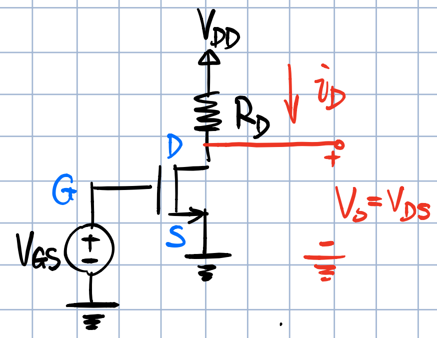
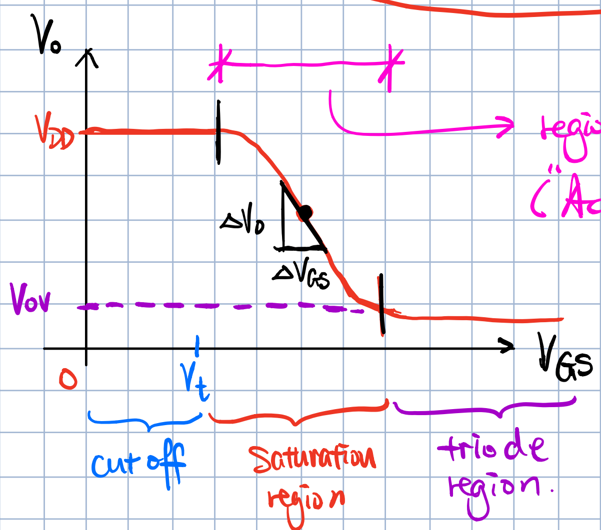
Transistor Amplifiers (MOS, BJT)

NMOS (in Saturation mode)



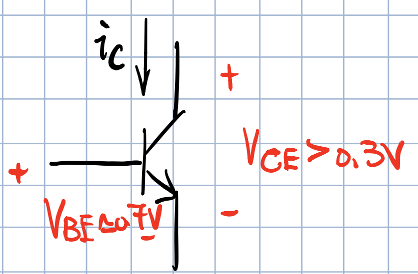


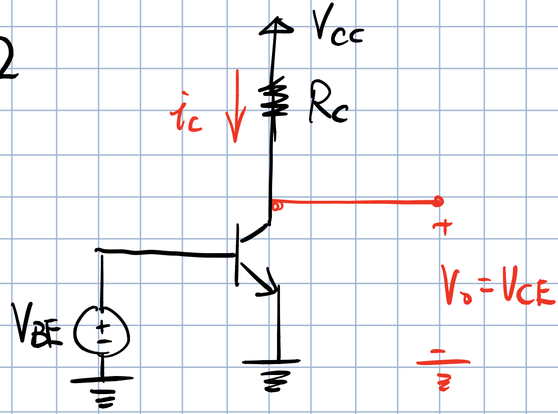
$$i_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) V_{ov}^2 \qquad V_o = V_{DD} - i_D R_D$$



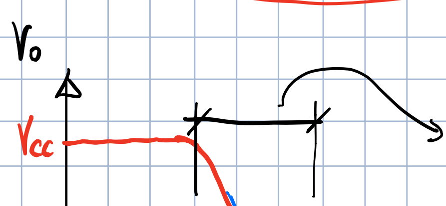
region use for amplifiers.
("Active Region")

npn BJT (in Active mode)

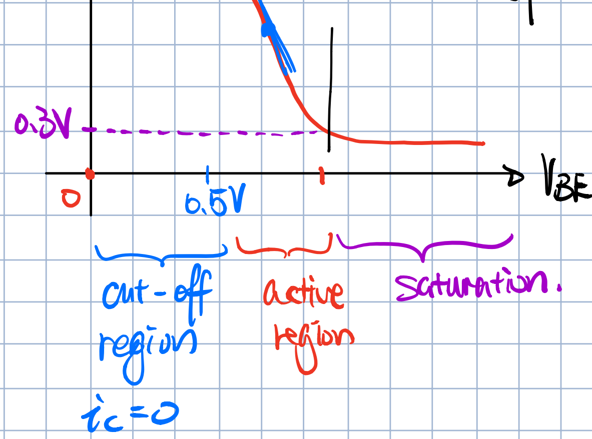




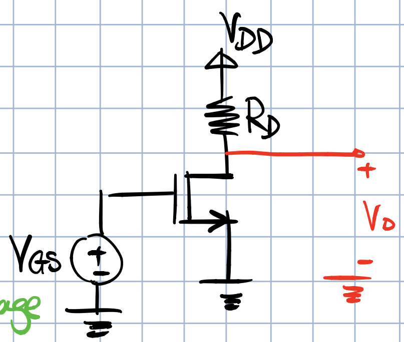
$$i_C = I_S e^{V_{BE}/V_T} \qquad V_o = V_{CC} - R_C i_C$$

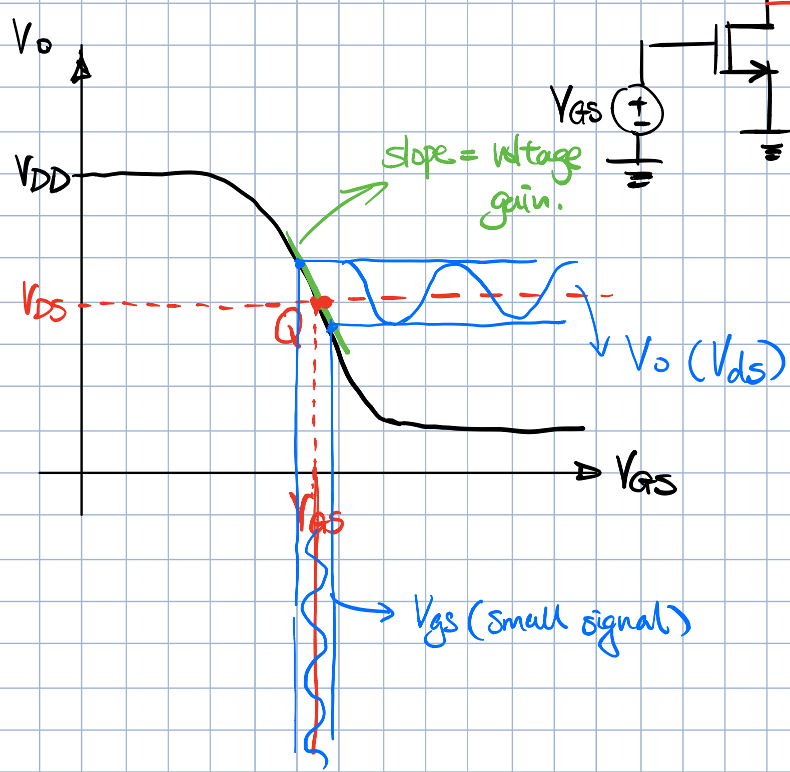


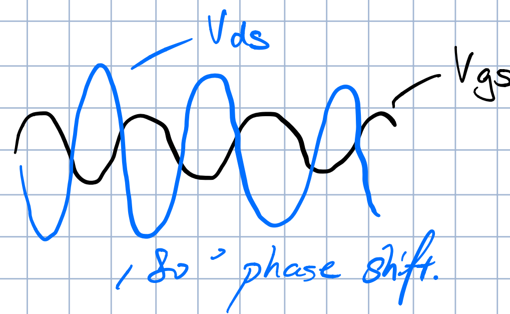
active region
(for amplifiers)



NMOS Amplifier.







Total voltage $V_o = V_{DD} - i_D R_D$

$$= V_{DD} - \left(\frac{1}{2} k_n' \left(\frac{W}{L}\right)(V_{GS} - V_t)^2\right) R_D$$

voltage gain @ the operating point (Q)

$$A_v = \left.\frac{dV_o}{dV_{GS}}\right|_Q$$

$$= -k_n'\left(\frac{W}{L}\right)(V_{GS} - V_t) R_D$$

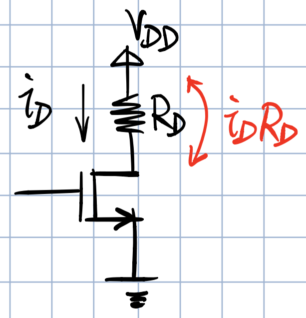
$$= -k_n'\left(\frac{W}{L}\right)(V_{OV}) R_D$$

voltage gain $\propto V_{OV}$, $\propto R_D$

$$A_v = -\frac{k_n'\left(\frac{W}{L}\right) V_{OV}^2 \; R_D}{2\, V_{OV}} = -\frac{i_D R_D}{V_{OV}/}$$

$2\ V_{ov}/2$ $\quad /2$

$= I_D$



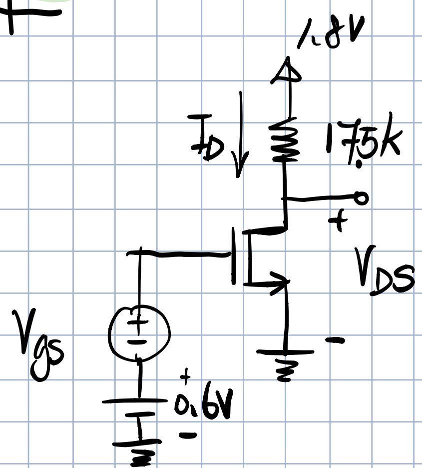
maximum value for $I_D R_D$ is V_{DD}

maximum voltage gain.

$$|A_v| = \frac{V_{DD}}{V_{ov}/2}$$

example.

ignore channel length modulation.



$V_t = 0.4V \quad k_n' = 0.4 mA/V^2, \ \frac{W}{L} = 10, \ \lambda = 0$

a) (DC operation) for $V_{gs} = 0$, find V_{OV}, I_D, V_{DS} and A_V

b) (Signal swing) what is the max allowable V_{gs}?

a) $V_{OV} = V_{GS} - V_t = 0.2V$

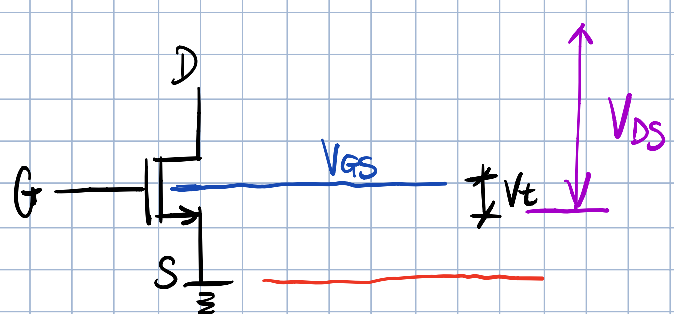
$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) V_{ov}^2 = 0.08mA$

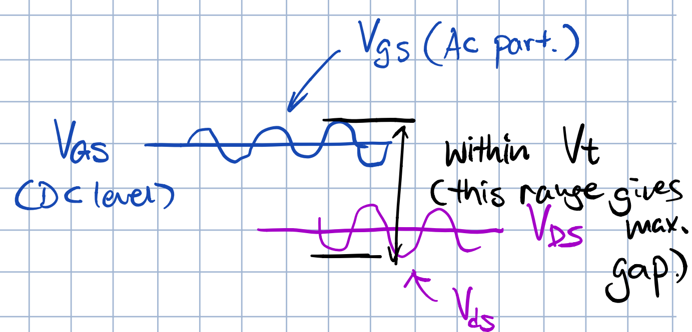
Eqn for mosfet saturation mode.

$V_{DS} = 1.8 - 17.5k\, I_D = 0.4V$

$$A_V = -\frac{I_D R_D}{V_{ov}/2} = -14 V/V$$

b)





gate voltage − drain voltage < V_t

cond. for transistor in

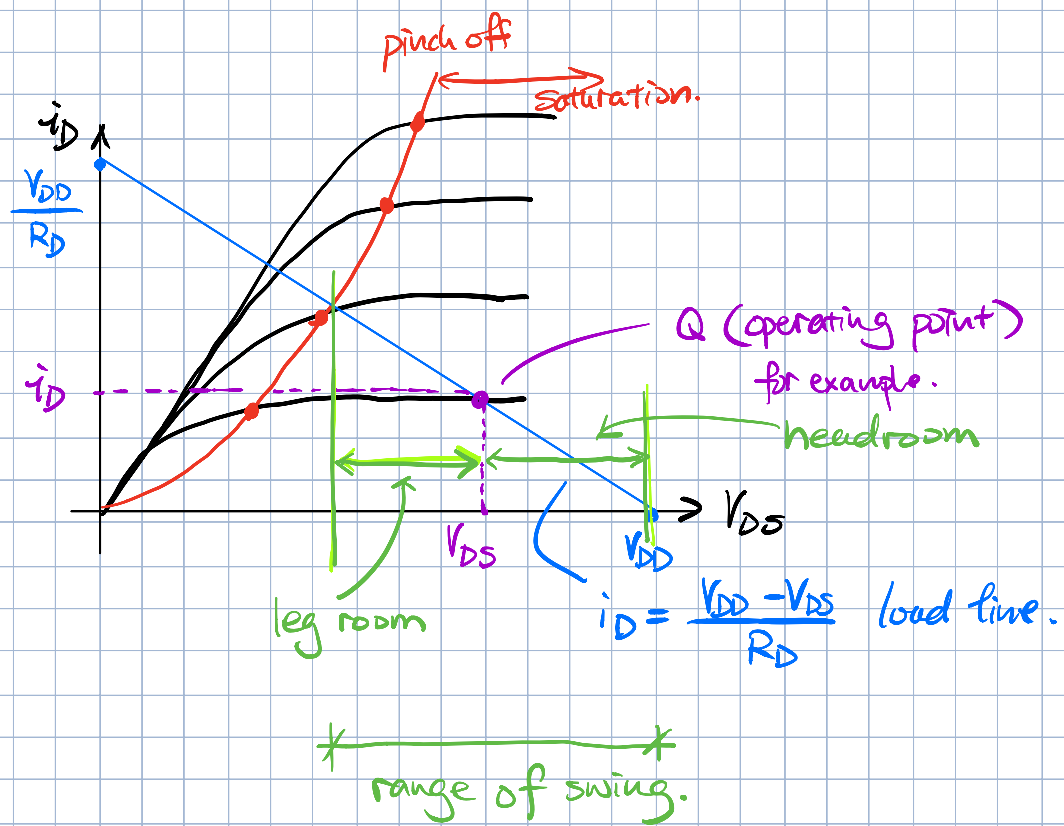
Saturation mode.

$$V_{GS} + \hat{v}_{gs} - (V_{DS} - \hat{v}_{ds}) = V_t$$

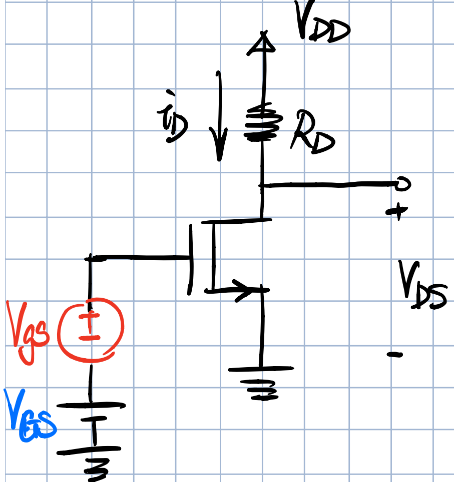
$$0.6 + \hat{v}_{gs} - (0.4 - \underbrace{14\, v_{gs}}) = 0.4$$

↳ $|A_v| \times \hat{v}_{gs} = \hat{v}_{ds}$

$\Rightarrow \hat{v}_{gs} = 13.3\,mV$ (max. allowed signal @ the gate)



Small signal operation.



$$i_D = \tfrac{1}{2} k_n' (W/L)(V_{GS} - V_t)^2$$

$$= \tfrac{1}{2} k_n' (\tfrac{W}{L})(V_{GS} + v_{gs} - V_t)^2$$

$$= \tfrac{1}{2} k_n' (\tfrac{W}{L})(V_{GS} - V_t + v_{gs})^2$$

$$= \tfrac{1}{2} k_n' (\tfrac{W}{L})(V_{GS} - V_t)^2$$ ← DC component

if $V_{gs} << 2V_{ov}$, we can drop this distortion term $\longrightarrow$

$+ k_n'(\frac{W}{L})(V_{GS}-V_t)V_{gs}$ ← AC component

$+ \frac{1}{2}k_n'(\frac{W}{L})V_{gs}^2$ ← non-linear distortion.

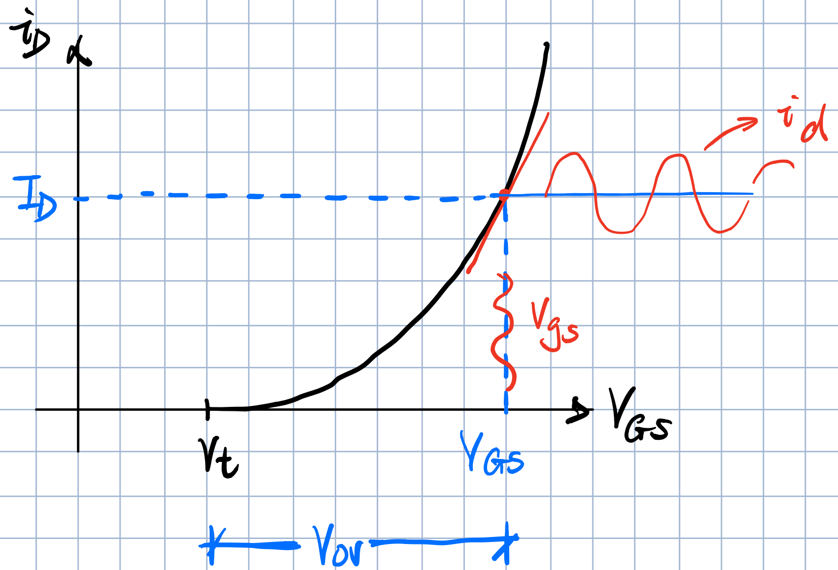
$i_D \simeq I_D + i_d$

$I_D = \frac{1}{2}k_n'(\frac{W}{L})(V_{GS}-V_t)^2$

$i_d = k_n'(\frac{W}{L})(V_{GS}-V_t)V_{gs}$

$[A] \qquad \underbrace{k_n'(\frac{W}{L})(V_{GS}-V_t)}_{\frac{1}{\text{resistance}}\left(\frac{1}{\Omega}\right)} \qquad [V]$

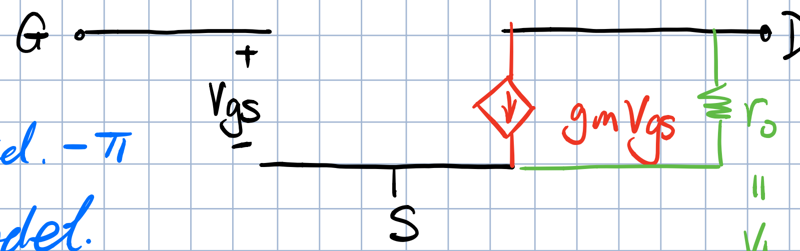
("gm" trans-conductance)



$i_d = g_m V_{gs}$

Small signal model.

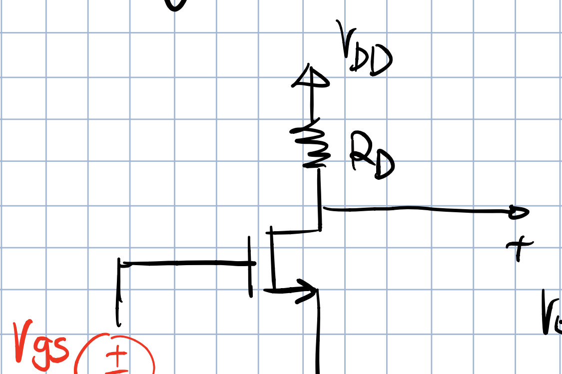
hybrid-π model.



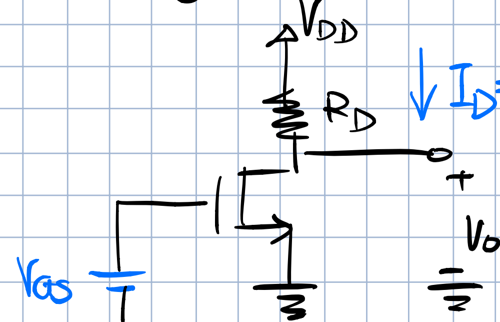
← w/ channel length modulation.

$r_o = \frac{V_A}{I_D} = \frac{1}{\lambda I_D}$

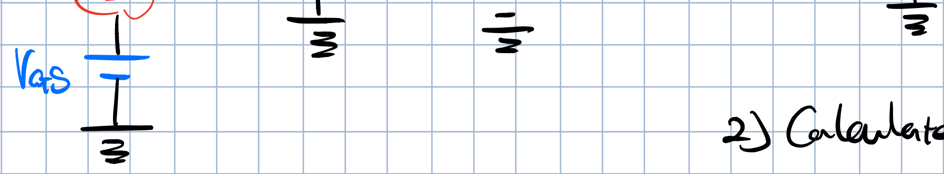
Summary:



1) DC Analysis.



$I_D = \frac{1}{2}k_n'(\frac{W}{L})(V_{GS}-V_t)^2$



2) Calculate parameter used in small signal model

$$g_m = k_n'\left(\frac{W}{L}\right)V_{ov}$$

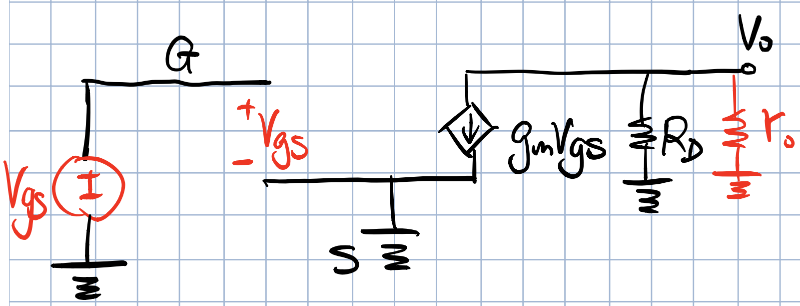
or

$$g_m = \sqrt{2k_n'\frac{W}{L}I_D}$$

or

$$g_m = \frac{2I_D}{V_{ov}}$$

3) Build small signal model.



$V_o = -g_m V_{gs}\,(R_D \,/\!/\, r_o)$, voltage gain $\frac{V_o}{V_{gs}} = -g_m\,(R_D \,/\!/\, r_o)$