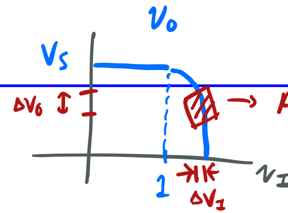
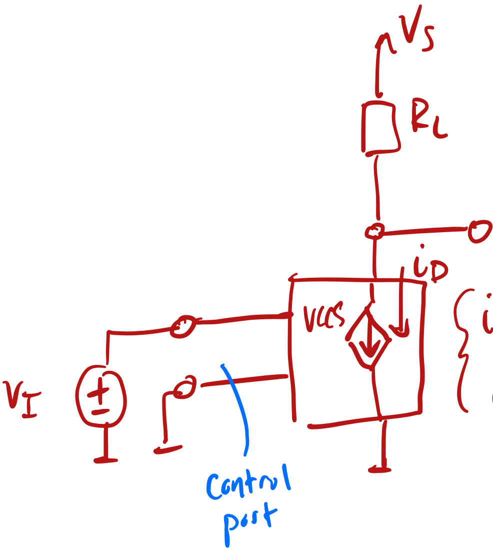
Notes) Amp Review



AMP. since $\frac{\Delta v_O}{\Delta v_I} > 1$



$$v_O = V_S - i_D R_L = V_S - \frac{R_L \cdot K}{2}(v_I - 1)^2$$

$$\begin{cases} i_D = \frac{K}{2}(v_I - 1)^2 & \text{for } v_I \geq 1V \\ i_D = 0 & \text{else} \end{cases}$$

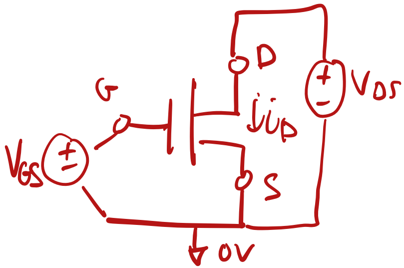
NB: $K = \frac{W}{L}\mu C_{ox}$

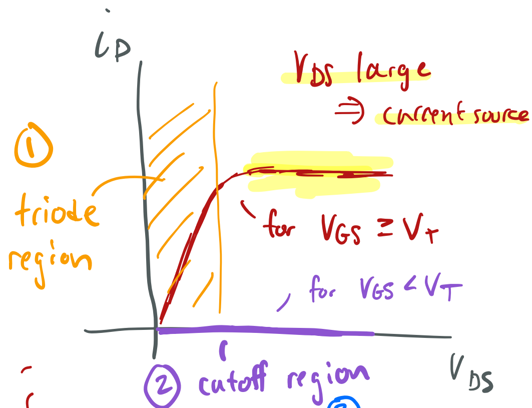
$\Rightarrow i_{D,SAT} = \frac{W}{L}\frac{\mu C_{ox}}{2}(V_{GS} - V_T)^2$

See §7.3-7.7

Notes) MOSFET SCS Model: Introducing Saturation

SCS = "Switch, Current Source"

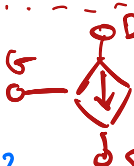




$V_{GS} < V_T$

("S")

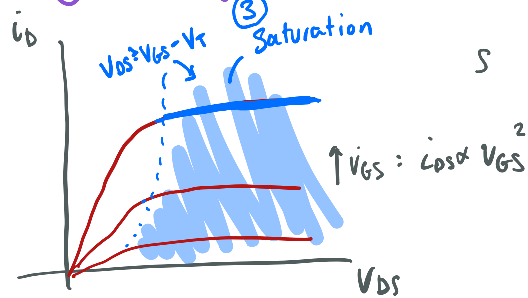
$V_{GS} \geq V_T$



$\boxed{i_{DS} = f(V_{GS})}$

("CS")

$i_{DS} = \frac{K}{2}(V_{GS} - V_T)^2$



Notes)

SR Model: for digital circuits (e.g. $R_{DS,on}$)

or $V_{DS} < V_{GS} - V_T$

SCS Model: for analog design

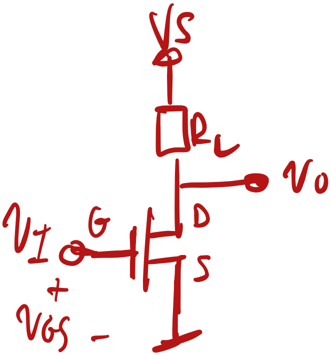
or $V_{DS} \geq V_{GS} - V_T$

SU Model see §7.8 (not 6.002)

1/39

Notes) MOSFET Amp.

c/



Saturation Discipline:

① $v_{GS} = v_I \geq V_T$ & ② $v_{DS} \geq v_{GS} - V_T$

↳ "large enough input"

↳ "must keep v_D high enough → low values of R_L, high values of V_S"

$$v_O = v_{DS} = V_S - \Delta V_{R_L}$$

$$= \overset{\uparrow\uparrow}{V_S} - \overset{\downarrow\downarrow}{i_{DS}} \cdot \overset{\downarrow\downarrow}{R_L}$$

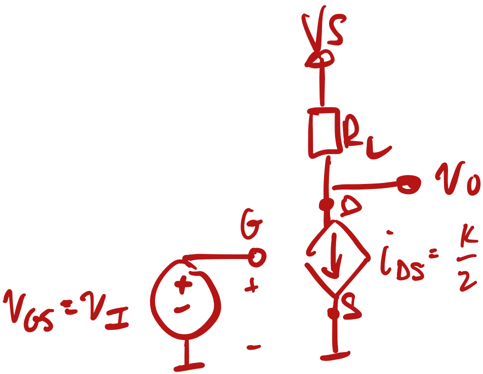
$$\Rightarrow v_O = v_{DS} = V_S - \alpha R_L (\underset{v_I}{v_{GS}} - V_T)^2$$

↳ v_{DS} large by small $v_{GS} = v_I$

$(\downarrow v_{GS} : \downarrow i_{DS} : \downarrow \Delta V_{R_L} : \uparrow v_{DS})$

Notes) MOSFET Amp. Cont'd

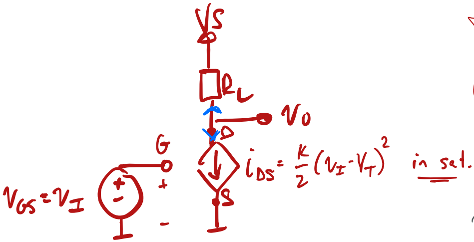
Replace w/ CS Model (for saturation)



$i_{DS} = \frac{K}{2}(v_I - V_T)^2$ <u>in sat.</u>

$$\begin{cases} \overset{v_I}{\cancel{v_{GS}}} \geq V_T \\ \underset{v_O}{\cancel{v_{DS}}} \geq \underset{v_I}{\cancel{v_{GS}}} - V_T \end{cases}$$

Notes) MOSFET Amp Analysis - Analytical Method



① Analytical Method

Use Node Method @ v_O

$$\frac{v_O - V_S}{R_L} + i_{DS} = 0 \qquad i_{DS}: f(v_I, V_T)$$

$$v_O = V_S - i_{DS} R_L$$

$$\boxed{v_O = V_S - \frac{K}{2}(v_I - V_T)^2 \cdot R_L}$$

for $v_I \geq V_T$ & $v_O \geq v_I - V_T$ (on & SAT)

$$\boxed{v_O = V_S}$$

for $v_I < V_T$ (OFF)

② Graphical Method

$v_I = v_{GS}$

A $\quad i_{DS} = \frac{K}{2}(v_I - V_T)^2$

(element) $\quad (v_I \geq V_T$ & $v_O \geq v_I - V_T)$, v_{DS}, v_{GS}

sub $v_{GS} = v_{DS} + V_T$

$\Rightarrow \boxed{i_{DS} \leq \frac{K}{2}(v_{DS})^2}$

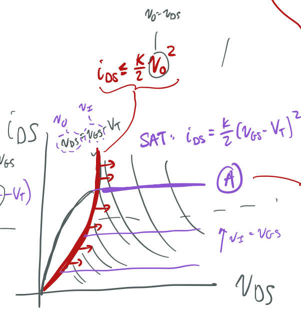
$v_{DS} = v_O$

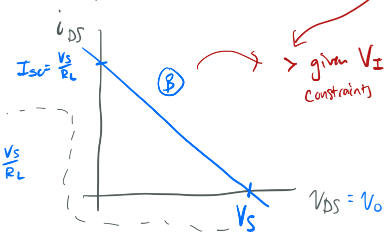
B $\quad v_O = V_S - i_{DS} R_L$ $\qquad i_{DS} = \frac{1}{R_L}(V_S - v_O)$

(circuit)

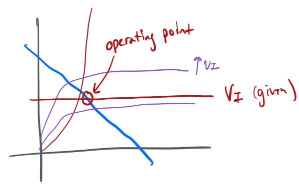
w/ $i_{DS} = 0$ (open circ.) $\Rightarrow v_O = V_S$

w/ $v_{DS} = v_O = 0$ (short) $\Rightarrow i_{DS} = \frac{V_S}{R_L}$





> given $V_I = v_{GS}$, meet constraints A & B



Notes)

Notes) Large Signal Analysis

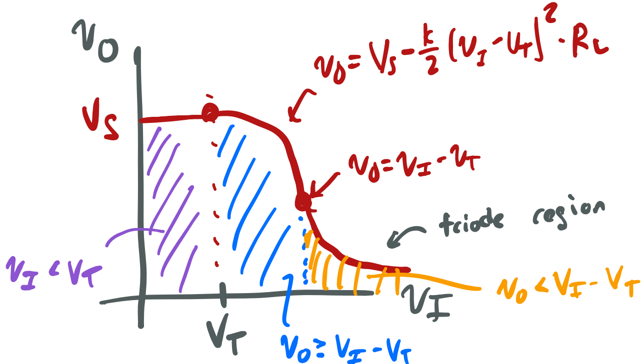
• Amplifier under "saturation discipline"

Steps

① v_O vs. v_I

$$v_O = V_S - \frac{k}{2}(v_I - V_T)^2 \cdot R_L \quad \text{if } v_I \geq V_T$$

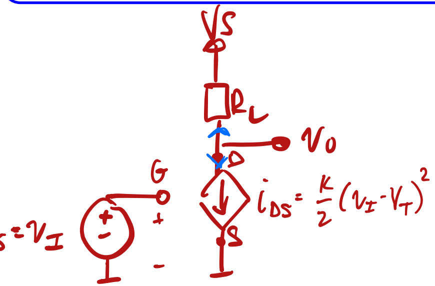
$$v_O = V_S \quad \text{if } v_I < V_T$$

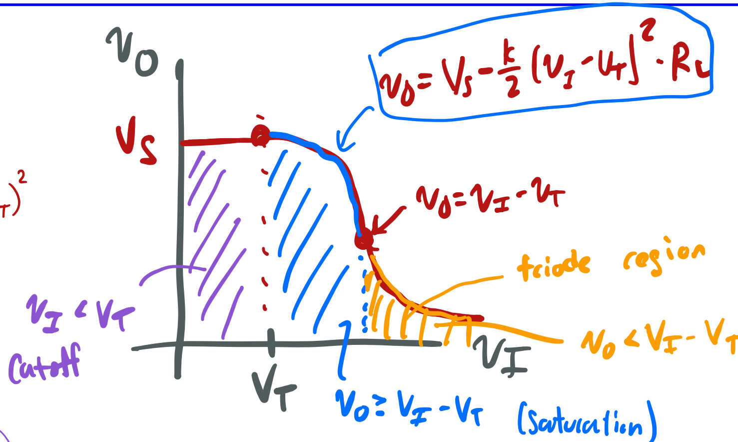


② Valid input operating range and output valid range to stay in saturation

S913

Notes) Large Signal Analysis ① v_O vs. v_I



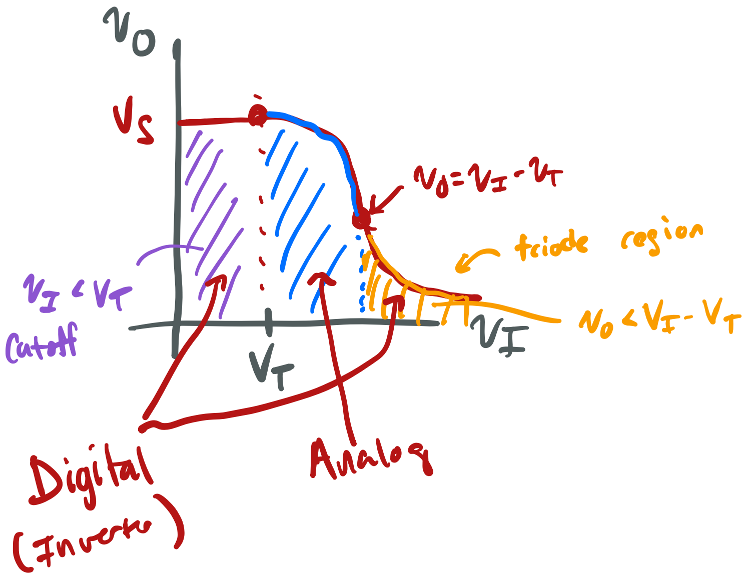


$i_{DS} \leq \frac{k}{2} v_{GS}^2$ makes intuitive sense because as v_{GS} increases, i_{GS} increases $\propto (v_{GS} - V_T)^2$ and as i_{GS} increases it pulls the output lower (more ΔV_{R_L}), so there is a limit to how much current we can draw

→ ↑ v_I

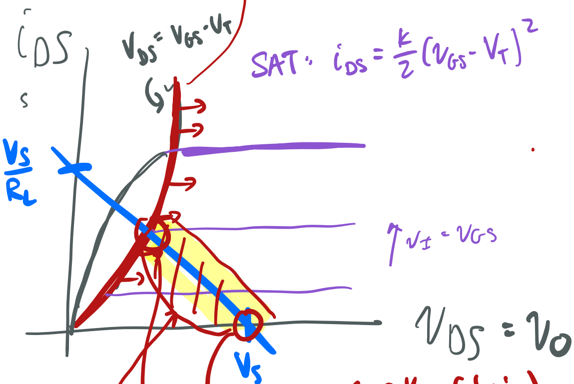
as $v_I = v_{GS}$ increases, more i_{DS} is driven over R_L, forcing $v_O = v_{DS}$ lower and when $v_O < v_I - V_T$ the device enters triode region

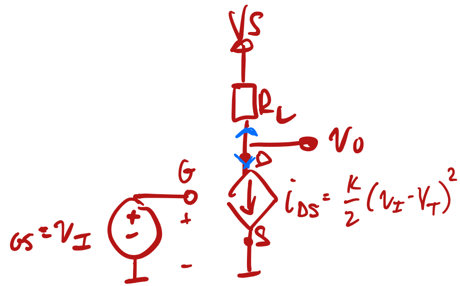
Notes) Large Signal Analysis ① v_O vs. v_I



Notes) Large Signal Analysis ② Valid Operating Ranges

$i_{DS} \leq \frac{K}{2} v_O^2$





Cutoff: $v_I = V_T$ (device)

$v_O = V_S$ (circ.)

valid op. region

2 Eqns:

1) Load Line: $i_{DS} = \frac{V_S}{R_L} - \frac{v_O}{R_L}$

2) Sat. Edge: $i_{DS} = \frac{K}{2} v_O^2$

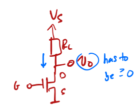
$\frac{V_S}{R_L} - \frac{v_O}{R_L} = \frac{K}{2} v_O^2$

$\frac{V_S}{R_L} - \frac{v_O}{R_L} = \frac{K}{2} v_O^2$

$0 = \frac{K}{2} v_O^2 + \frac{1}{R_L} v_O - \frac{V_S}{R_L}$

$0 = \frac{KR_L}{2} v_O^2 + v_O - V_S$

$$\boxed{v_{DS} = v_O = \frac{-1 + \sqrt{1 + 2KR_L V_S}}{KR_L}}$$



next: find v_I, V_S for boundary

Notes) Large Signal Analysis ② Valid Operating Ranges

(cont'd) find I_{DS}, V_I :

$i_{DS} = \frac{V_S}{R_L} - \frac{V_O}{R_L}$

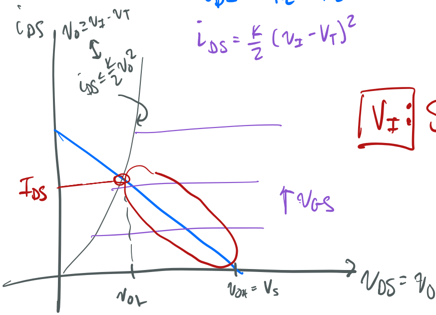
$i_{DS} = \frac{K}{2}(V_I - V_T)^2$

Constraints

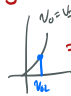
$V_I = V_{GS} \geq V_T$

$V_O = V_{DS} \geq V_I - V_T$

$i_{DS} \leq \frac{K}{2} V_O^2$



$\boxed{V_I:}$ Simply add V_T to V_{OL} since $V_O \doteq V_I - V_T$ is the saturation constraint



$\Rightarrow V_{I_L} = V_{OL} + V_T$

$$\boxed{I_{DS}} = \frac{V_S}{R_L} - \frac{V_O}{R_L}\Bigg|_{V_{OL}}$$

$V_{OL} = \frac{-1 + \sqrt{1 + 2KR_LV_S}}{KR_L} \leftrightarrow V_{I_L} = V_{OL} + V_T$

@ V_{OH}: $V_O = V_S$

$V_I = V_T$ and $i_{DS} = 0$ (cutoff)

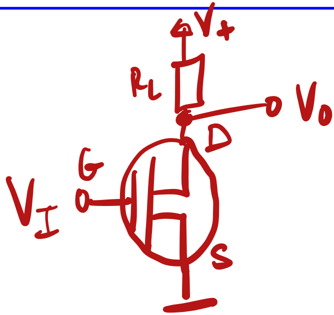
Conclusion:

V_O must be low enough not to pull output below ground (passive device cannot source power) $\rightarrow V_S$

V_O must be high enough to come out of triode & into Sat $\hookrightarrow\ > V_{OL}$

S9V16

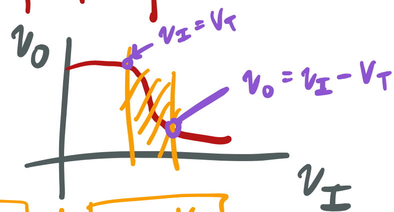
Notes) Summary : Large Signal



① V_O vs. V_I : $V_O = V_+ - \frac{K}{2}(V_I - V_T)^2 \times R_L$

② Valid op. range

input:



$v_O > v_I - V_T$

$\therefore \boxed{v_I < v_O + V_T}$ & $\boxed{v_I > V_T}$

output:

$$v_O > \overbrace{\frac{-1 + \sqrt{1 + 2KR_LV_+}}{KR_L}}^{V_{OL}}$$

$$v_O < V_+$$

Notes) V_{OL}, another way

Sat: $v_O = V_+ - \frac{k}{2}\underbrace{(v_I - V_T)}_{\text{Sub}}{}^2 \times R_L$ (1)

Sub (2) Solve v_O