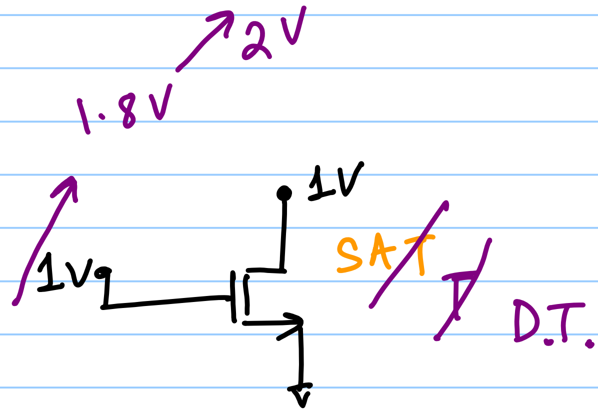
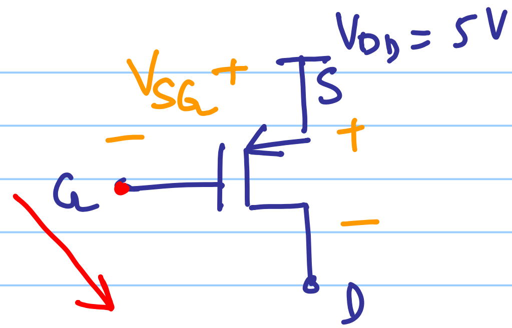
ECE 511- Lecture 2

Note Title 1/23/2014



$V_{THN} = 0.8V$

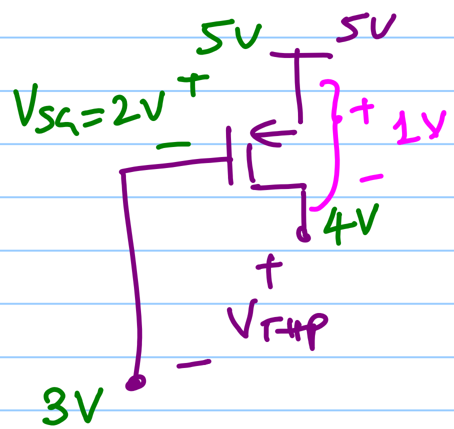
The NMOS can have the gate at max V_{THN} higher than the drain before the NMOS triodes.



for SAT,

$V_{SD} > V_{SD,sat}$

$\boxed{V_{THP} = 0.9V}$



$V_{SD,sat} = V_{SG} - V_{THP}$

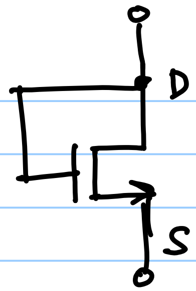
$= 1.1V$

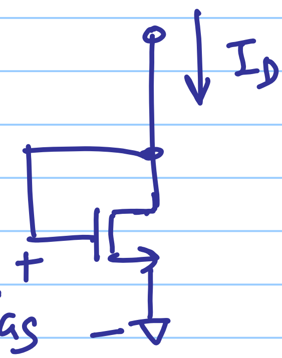
The gate at min, $|V_{THP}|$ lower than the drain, before PM triodes

for saturation : $V_G > V_D - |V_{THP}|$

Diode connected MOSFET

→ gate – Drain are shorted





$V_{DS} = V_{GS}$

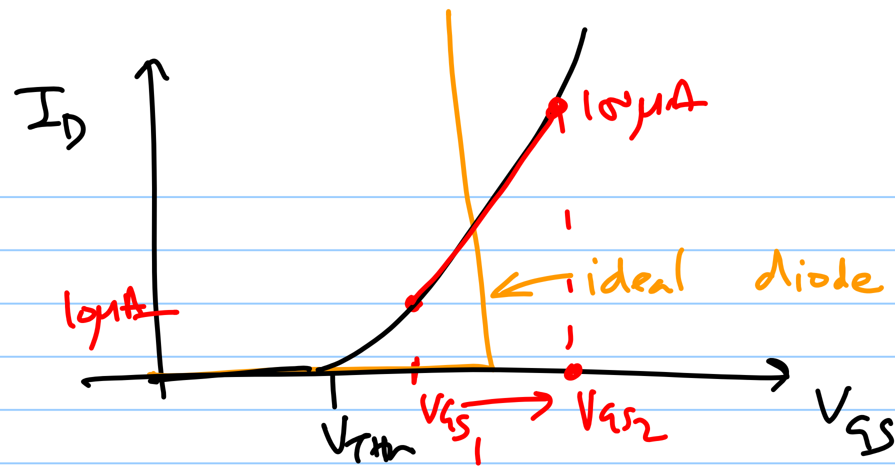
$I_D = f(V_{GS}, V_{DS})$

$\Rightarrow I_D = f(V_{GS})$

for $V_{GS} > V_{THN} \Rightarrow I_D > 0$

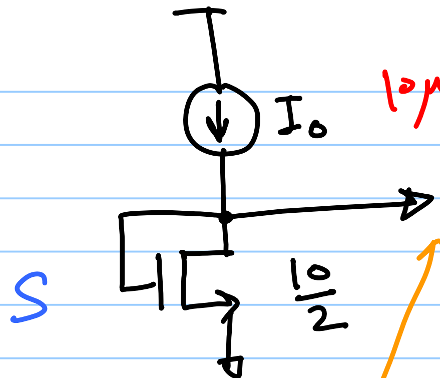
For saturation $\Rightarrow$ $V_{DS} \geq \underbrace{V_{GS}}_{V_{DS}} - V_{THN}$

$\Rightarrow$ Always in saturation!



removed 1 independent variable $\Rightarrow$ V_{DS}

$\lambda = 0$



$V_x = ?$

$10\mu A \rightarrow 100\mu A$

$\Lambda = V_{GS}$

$K'_n = 120 \frac{\mu A}{V^2}$

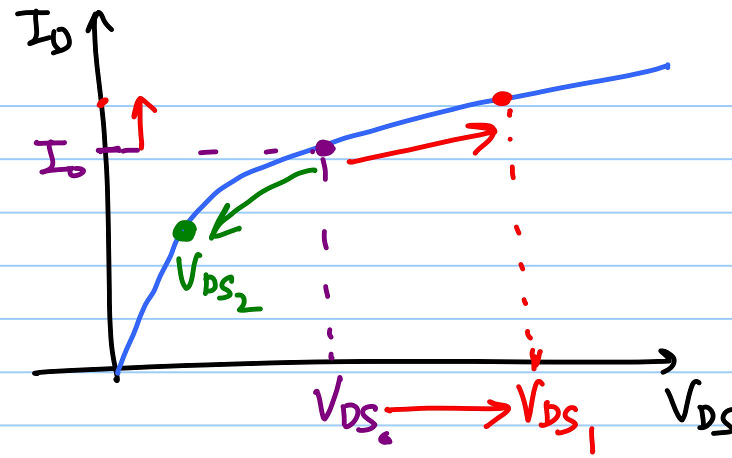
$V_{THN} = 0.8$

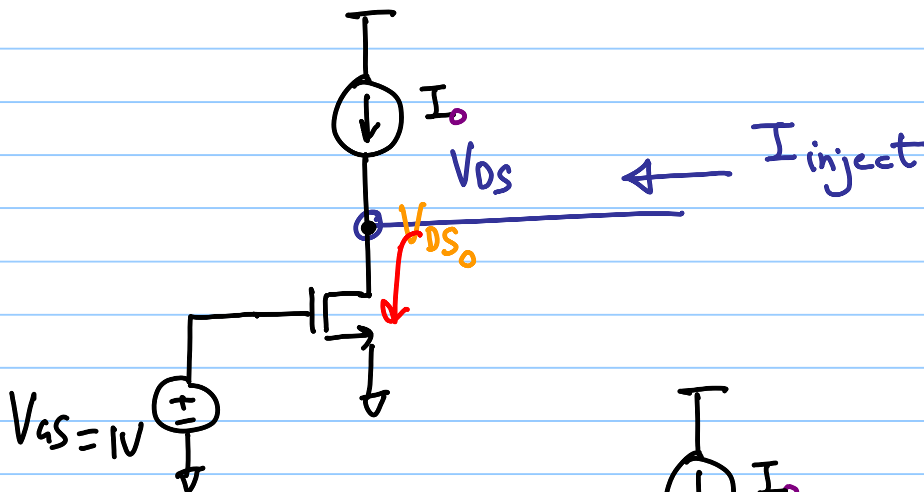
$I_o = 10 \mu A$

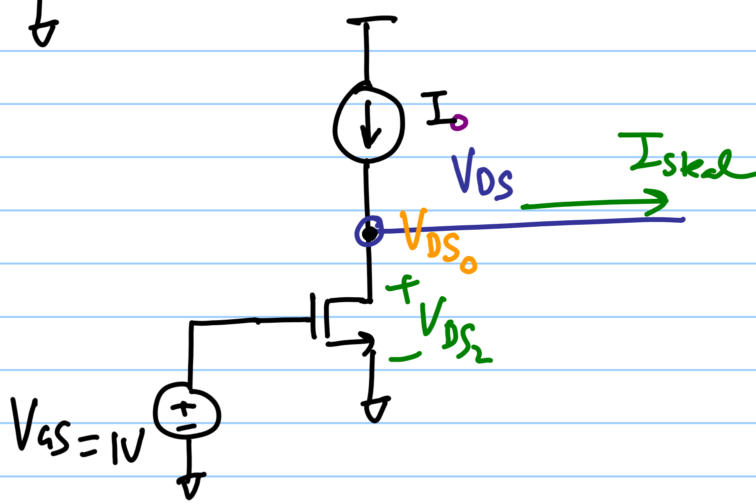
$$I_D = \underbrace{\frac{K'_n}{2} \frac{W}{L}}_{\beta} (V_{GS} - V_{THN})^2 \cancel{(1 + \lambda (V_{DS}))}$$

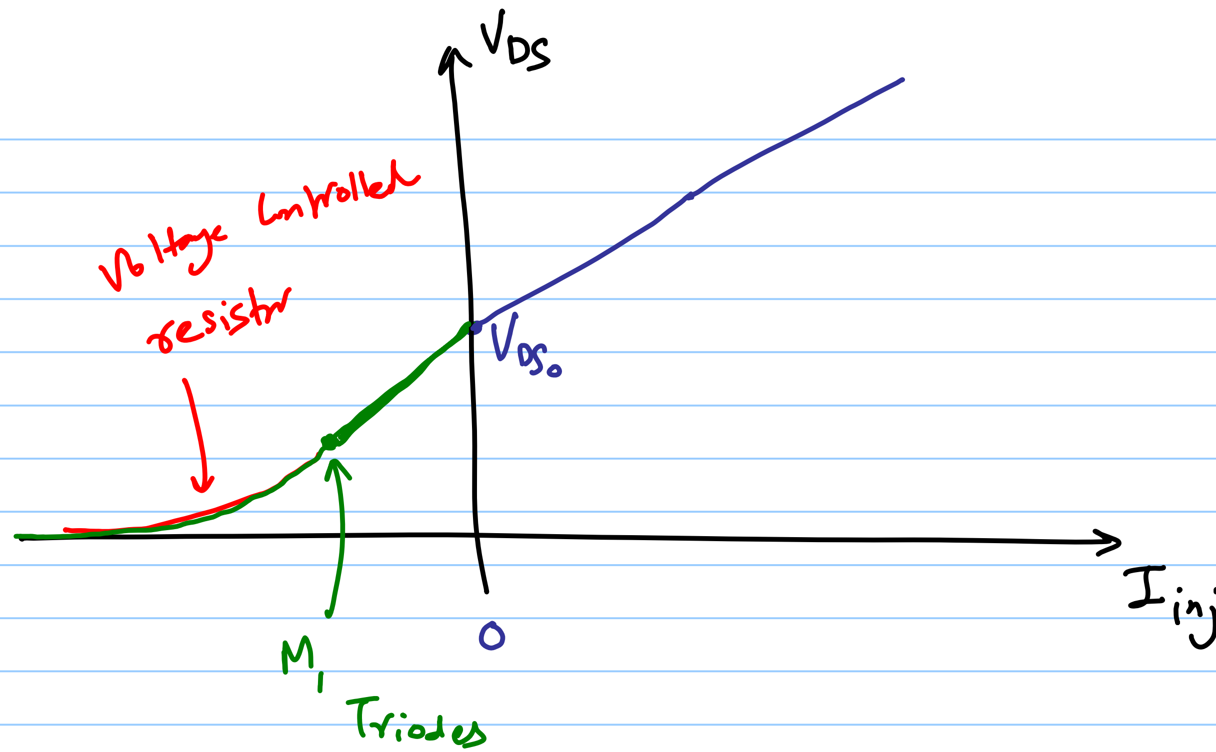
$$\boxed{V_{GS} = \sqrt{\frac{2 I_D}{\beta}} + V_{THN}}$$

for hand-calcs assume $\lambda = 0$


I_D
I_o
V_{DS_2}
V_{DS_o}
V_{DS_1}
V_{DS}


I_o
V_{DS}
I_{inject}
V_{DS_o}
$V_{GS} = 1V$

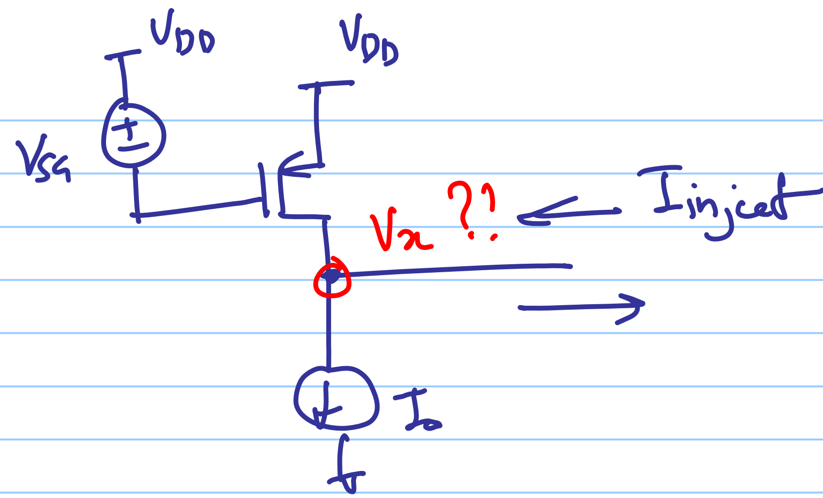

I_o
V_{DS}
I_{steal}
V_{DS_o}
$+$
V_{DS_2}
$-$
$V_{GS} = 1V$



V_{DS}
Voltage controlled resistor
V_{DS_0}
I_{inj}
0
M_1 Triodes

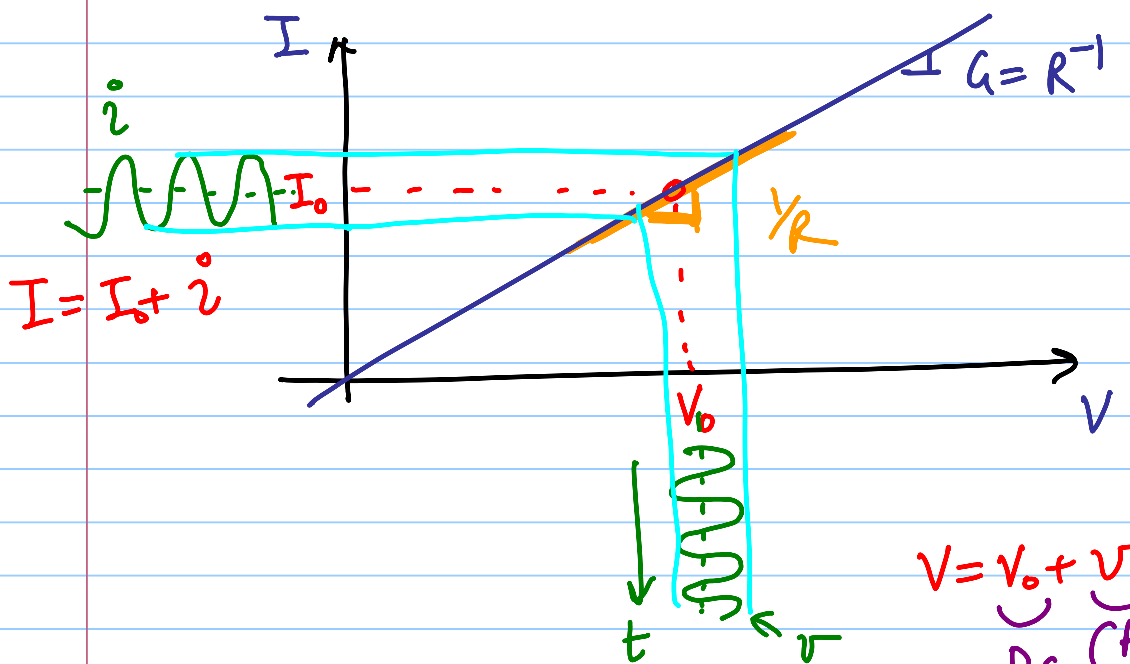
HW

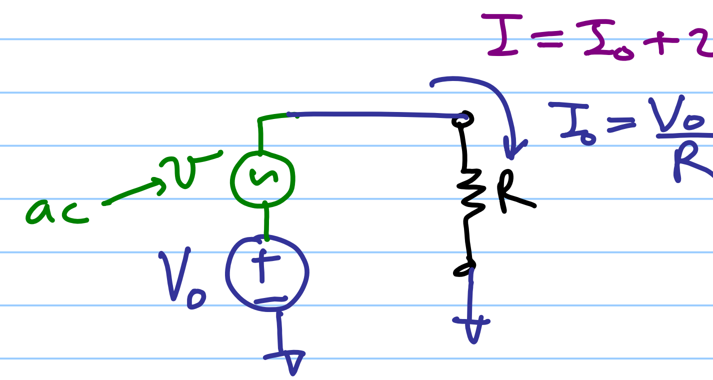
PMOS



"Small - Signal Analysis"

"Bias"





$$V = \underbrace{V_0}_{DC} + \underbrace{v}_{\begin{cases}\text{AC} \\ \text{Small-signal} \\ \text{incremental}\end{cases}}$$

$$I = \frac{V}{R}$$

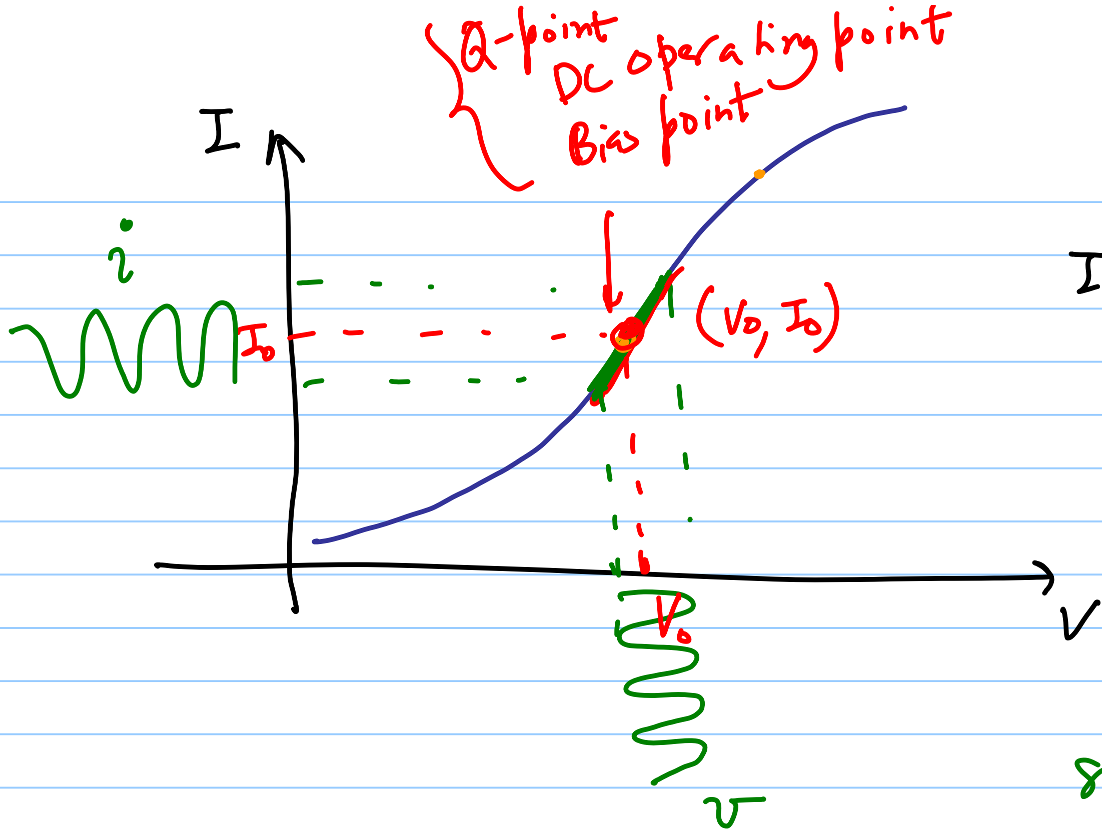
$$(I_o + i) = \frac{(V_o + v)}{R}$$

$$\cancel{I_o} + i = \cancel{\frac{V_o}{R}} + \frac{v}{R}$$

$\frac{V_o}{R}$ (bias point)

$$\boxed{i = \frac{v}{R}}$$

small signal behavior



$i \overset{??}{\longleftrightarrow} v$

$I = f(V)$

$= \tanh\left(\frac{V}{V_A}\right)$

$\text{slope} = \frac{\partial I}{\partial V} = \frac{i}{v}$

small signal

$\text{Resistance} = \frac{1}{\text{slope}} = \frac{v}{i}$

$$I = f(V)$$

DC operating point

$$\boxed{I_o = f(V_o)}$$

Taylor Series Expansion

$$V = V_o$$

$$(V = V_o + \underbrace{v}_{\text{AC signal}})$$

$$I = \underbrace{f(V_o)}_{I_o} + f'(V_o)\cdot\overbrace{(V-V_o)}^{v} + \frac{f''(V_o)}{\lfloor 2}\overbrace{(V-V_o)^2}^{v^2} + \frac{f'''(V_o)}{\lfloor 3}\overbrace{(V-V_o)^3}^{v^3} + \cdots$$

higher order terms

$$\overbrace{I - I_o}^{i} = f'(V_o)\cdot v + \frac{f''(V_o)}{2}v^2 + \frac{f'''(V_o)}{6}v^3 + \cdots\cdots$$

$$i = a_1 v + a_2 v^2 + a_3 v^3 + \cdots\cdots$$

$$a_1 = f'(V_o)$$

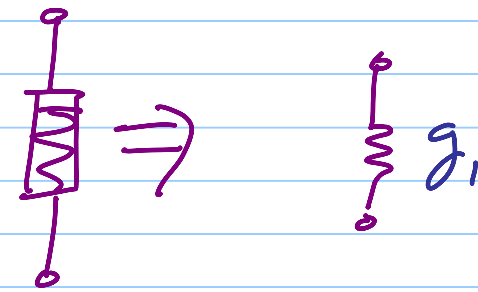
If v is sufficiently small, we can neglect higher-order terms

$$\boxed{i = g_1 v}$$

small-signal parameter

small-signal conductance

$$g_1 = \left.\frac{\partial f}{\partial v}\right|_{V=V_B}$$



$\Rightarrow$ We can linearize a non-linear circuit about the DC Bias point, by taking the first term in the Taylor Series expansion.

$$i = g_1 v + \underbrace{g_2 v^2 + g_3 v^3}_{} + \cdots$$

distortion

$$\cos 2\theta = 1 - 2\sin^2\theta$$

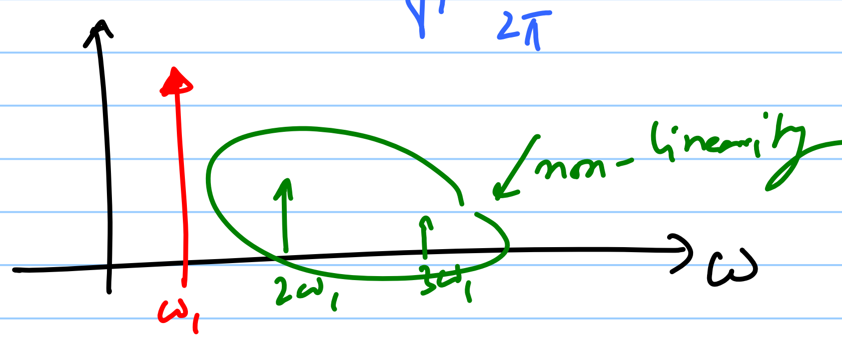
$$\sin^2\theta = \frac{1 - \cos 2\theta}{2}$$

$$v = A\sin(\omega_1 t)$$

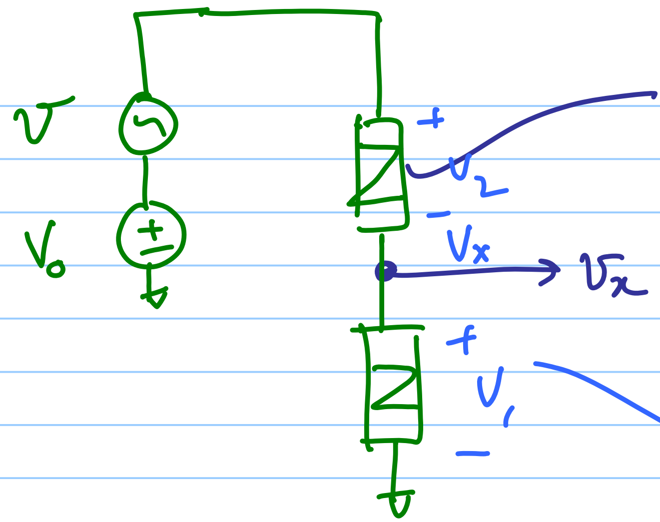
$$\boxed{i = g_1(A\sin\omega_1 t)} + g_2(A^2\sin^2\omega_1 t) + g_3(A^3\sin^3\omega_1 t)$$

$\underbrace{A^2\sin^2\omega_1 t}_{\omega_1 \,\&\, 2\omega_1}$ $\qquad$ $\underbrace{A^3\sin^3\omega_1 t}_{\omega_1,\ 3\omega_1}$

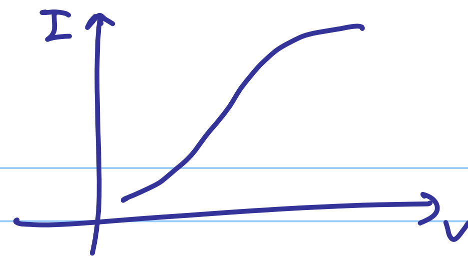
$$f_1 = \frac{\omega_1}{2\pi}$$



(RFIC)



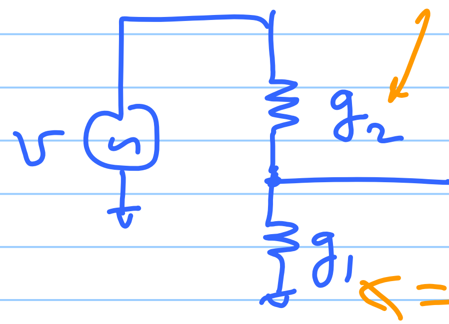
$v_x = ??$



Ac

$r_1 = \frac{1}{g_1}$

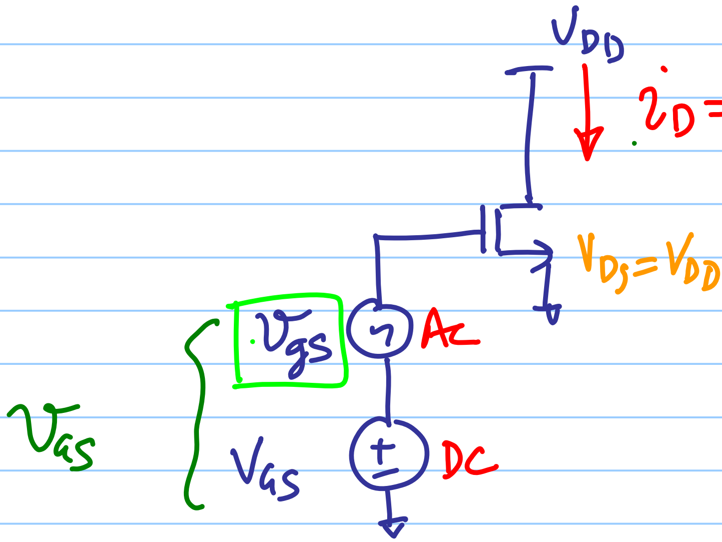
$g_2 = f'(v_2)$



$v_x = \frac{r_1}{r_1 + r_2} v$

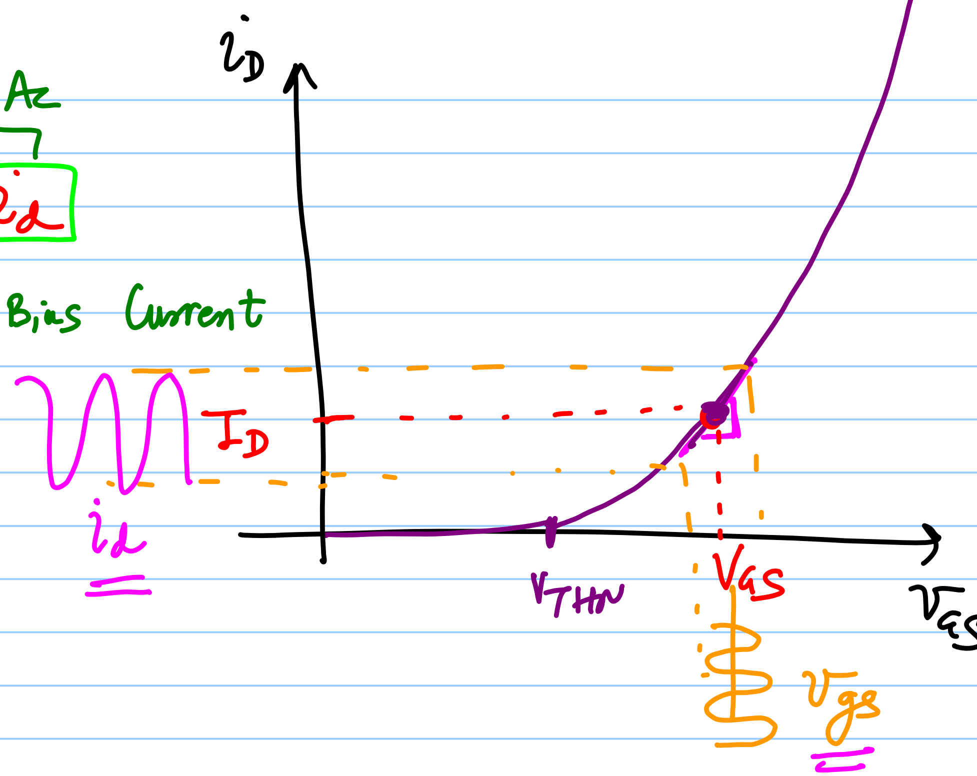
$g_1 = f'(v_1)$

NMOS in Saturation



$$i_D = \overbrace{I_D}^{DC} + \overbrace{i_d}^{AC}$$

DC Bias Current



$$i_D = \frac{K'_n}{2}\frac{W}{L}\left(v_{GS} - V_{THN}\right)^2$$

$I_D + i_d$

$V_{GS} + v_{gs}$

$$i_d = (\quad) v_{gs}$$

$$g_m = \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{GS}=V_{GS}} = \left.\frac{K'_n}{\cancel{2}}\frac{W}{L}\left(v_{GS} - V_{THN}\right)\right|_{v_{GS}=V_{GS}}$$

$$= \underbrace{K'_n \cdot \frac{W}{L}}_{\beta}\underbrace{\left(V_{GS} - V_{THN}\right)}_{V_{ov}}$$

Transconductance

$$i_d = g_m v_{gs}$$

$$g_m = \beta_n (V_{GS} - V_{THN}) = \beta_n V_{ov} \longrightarrow 1$$

$$V_{GS} - V_{THN} = \sqrt{\frac{2I_D}{\beta_n}}$$

$$g_m = \beta_n \cdot \sqrt{\frac{2I_D}{\beta_n}} = \sqrt{2\beta_n I_D} \longrightarrow 2$$

$$g_m = \beta_n (V_{GS} - V_{THN})$$

$$= \frac{2I_D}{(V_{GS} - V_{THN})^{\cancel{2}}} \times \cancel{(V_{GS} - V_{THN})} = \frac{2I_D}{V_{GS} - V_{THN}} = \frac{2I_D}{V_{ov}} \longrightarrow 3$$

$$g_m = \begin{cases} \beta_n V_{ov} \\ \sqrt{2\beta_n I_D} \\ \dfrac{2I_D}{V_{ov}} \end{cases}$$

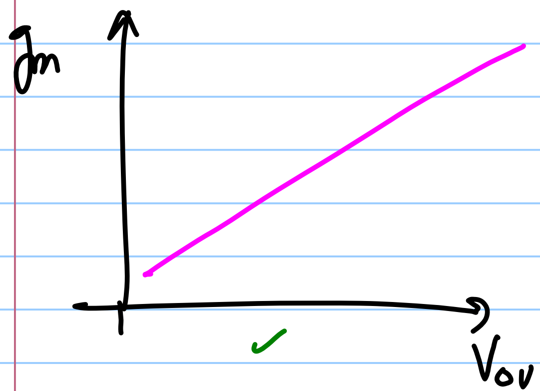
(W/L) sizing

$\beta_n,\ V_{ov},\ I_D$

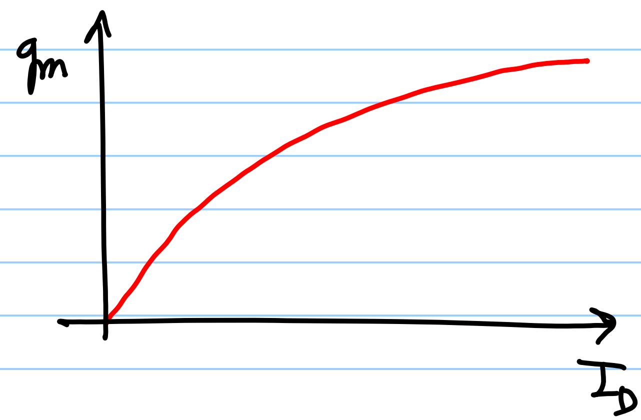
$g_m = \beta V_{ov}$

$g_m = \sqrt{2\beta_n I_D}$

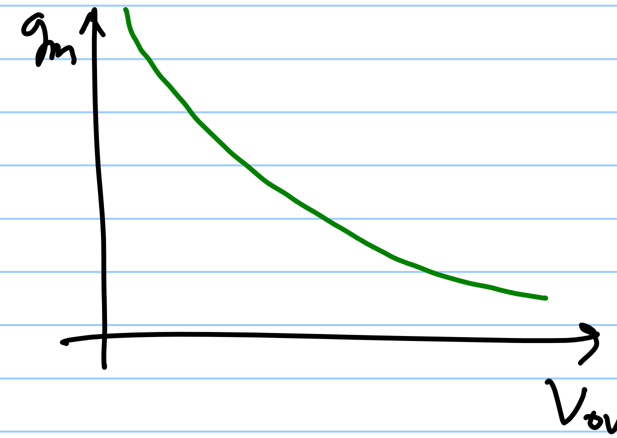
$g_m = \frac{2I_D}{V_{ov}}$



$\left(\frac{W}{L}\right) = \text{constant}$

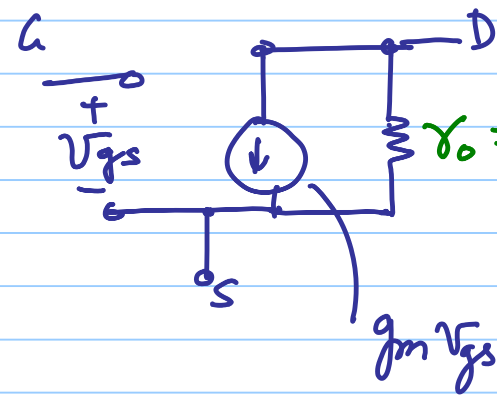


$\left(\frac{W}{L}\right) = \text{constant}$



$I_D = \text{constant}$

Small-signal model (so far)



$r_o = \dfrac{1}{\lambda I_{Dsat}}$