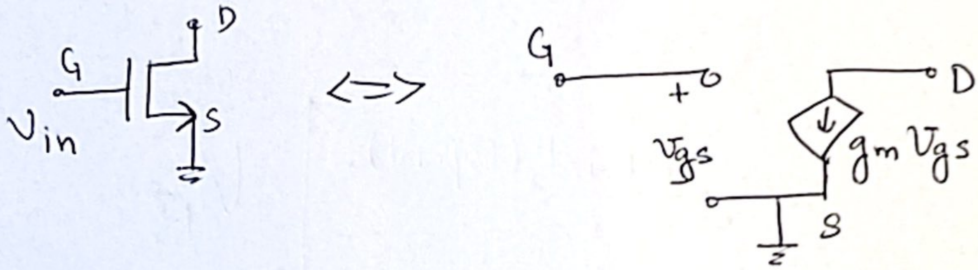
Lec17

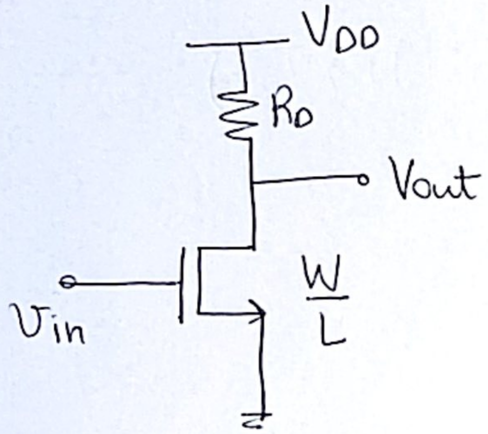
MOS Amplifiers [Low freq, models]

> We want to amplify from V_{in} to V_{out}.



> To convert from current to voltage we place a load.

Common Source



Saturation

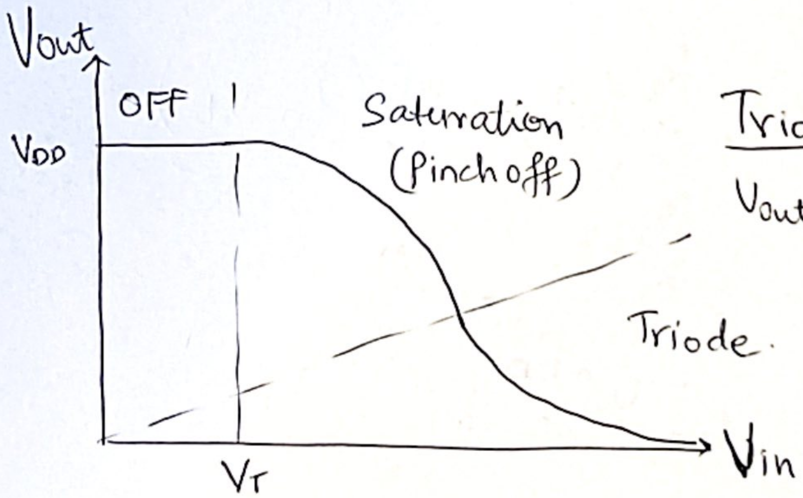
$$V_{out} = V_{DD} - I_D R_D$$

$$= V_{DD} - R_D \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_T)^2$$

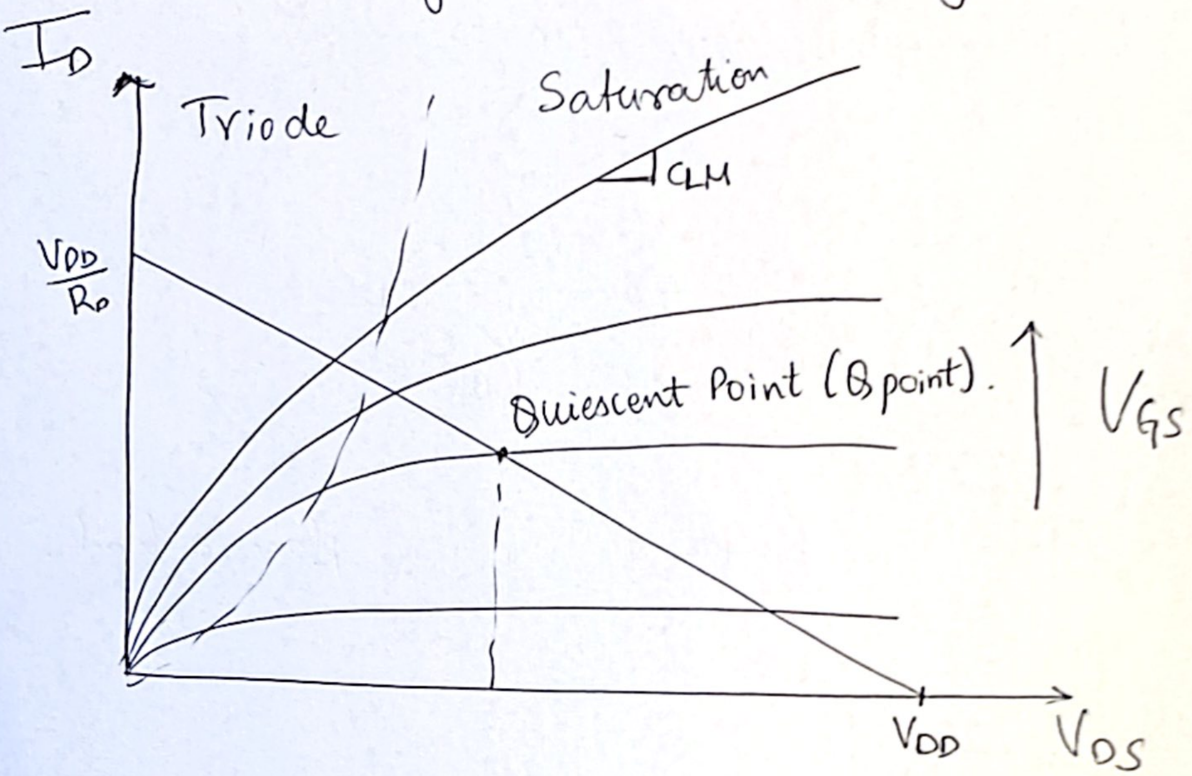
$$V_{out} = V_{DD} - R_D \left[\frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in} - V_T)^2 \right]$$

Triode

$$V_{out} = V_{DD} - R_D \mu_n C_{ox} \frac{W}{L} \left[(V_{in} - V_T) V_{out} - V_{out}^2 \right]$$



Load line analysis (Understanding Bias Points)



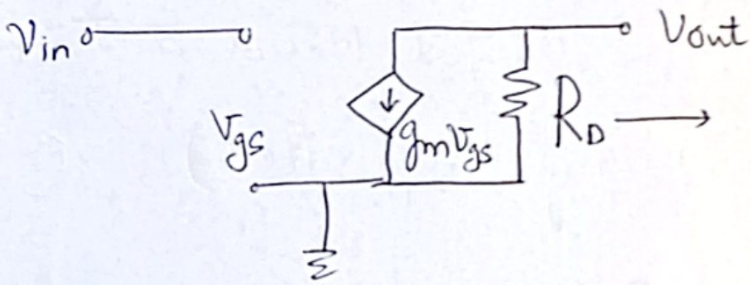
$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS})$$

$$V_{DS} = V_{DD} - I_D R_D$$

Small-Signal Gain

$$A_v = \frac{\partial V_{out}}{\partial V_{in}} = \frac{v_{out}}{v_{in}} = -R_D \underbrace{\mu_n C_{ox} \frac{W}{L} (V_{in} - V_t)}_{g_m}$$

$$\boxed{A_v = -g_m R_D}$$



Note: V_{DD} becomes a Small signal ground.

$$\Rightarrow V_{out} = -g_m V_{gs} R_D$$

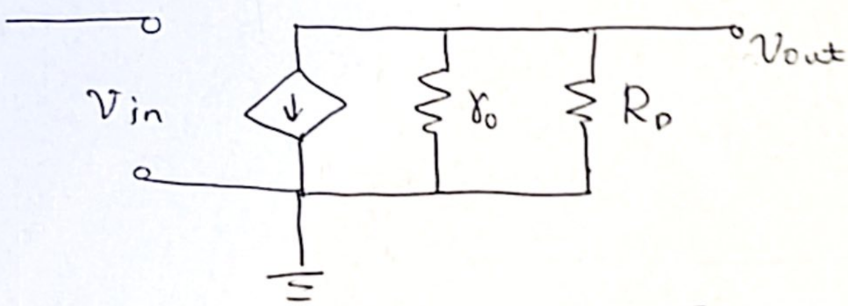
$$\Rightarrow \boxed{A_v = -g_m R_D}$$

What about CLM?

$$V_{out} = V_{DD} - R_D \left[\frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in}-V_T)^2 (1+\lambda V_{out}) \right]$$

$$A_v = \frac{\partial V_{out}}{\partial V_{in}} = -\frac{\partial}{\partial V_{in}} \left(R_D \mu_n C_{ox} \frac{W}{L} (V_{in}-V_T)^2 (1+\lambda V_{out}) \right] \ldots$$

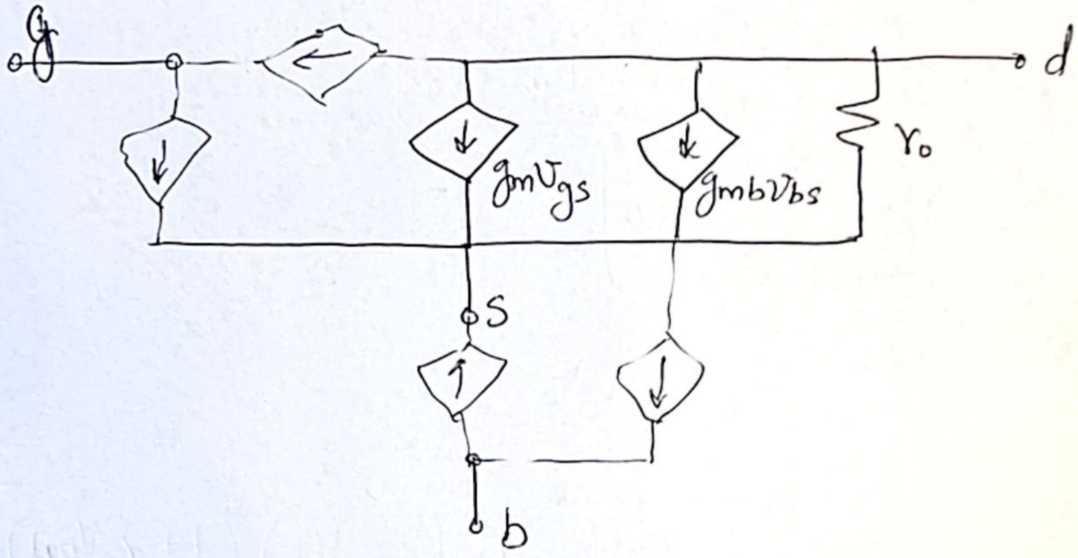
too complex!

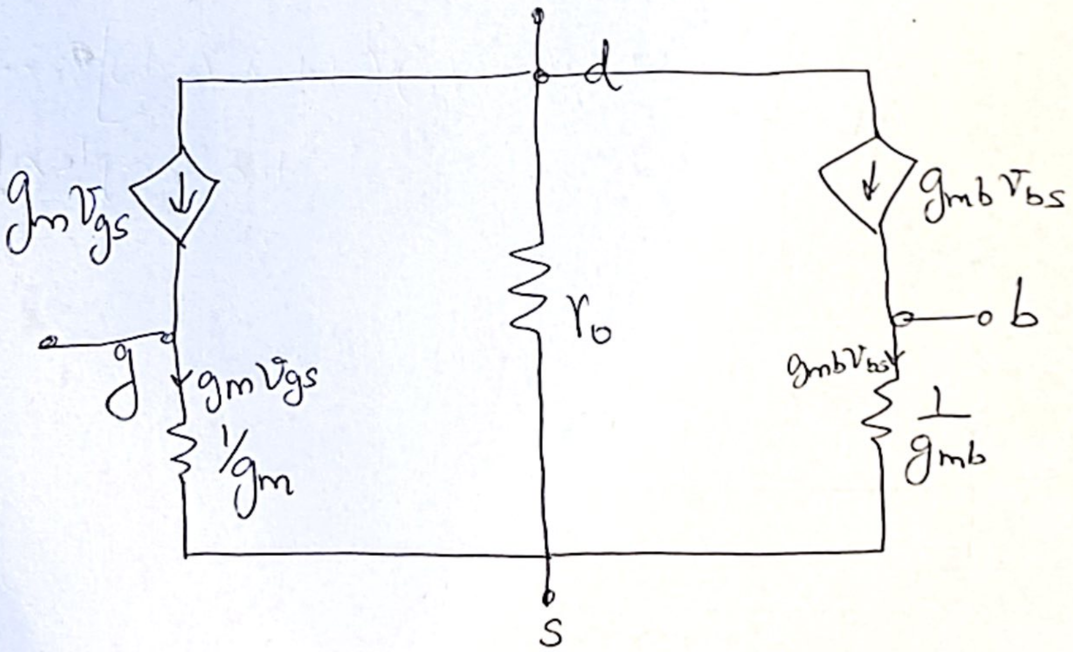


$$\Rightarrow \boxed{A_v = -g_m (R_D \| r_o)}$$

> Small Signal T-model (with body effect)

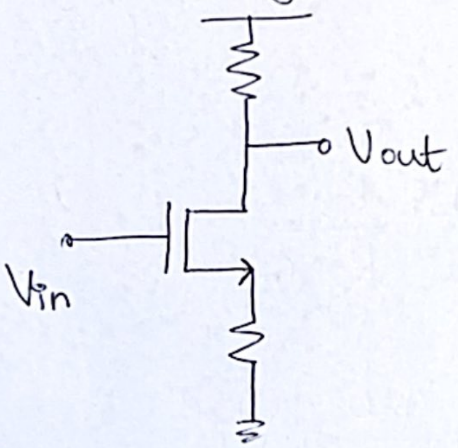
> Sometimes it is more useful to use a T-model, (especially when considering body effect)

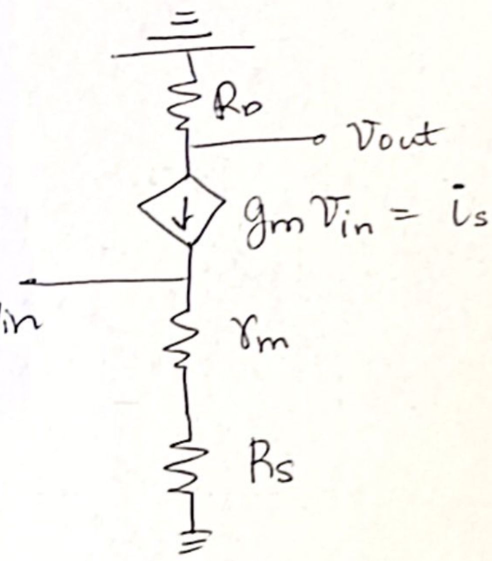




> This shows explicitly the two back to back "transistors".

Source Degeneration

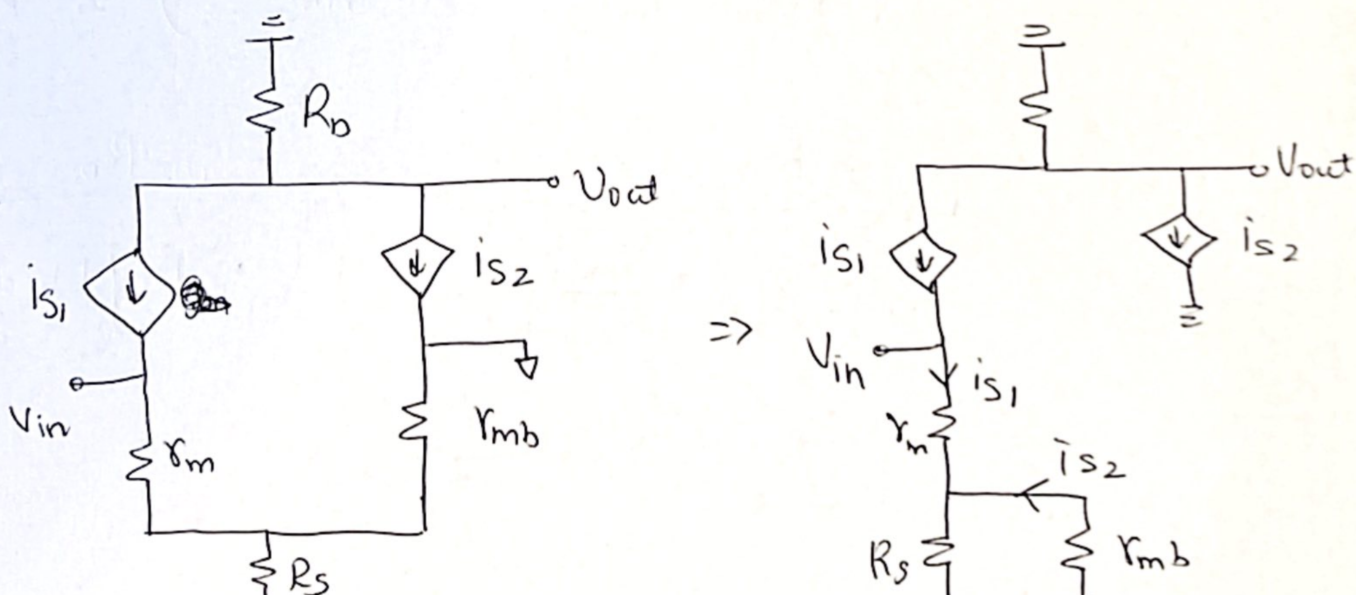




$$i_s = \frac{V_{in}}{R_S + r_m} \qquad V_{out} = -\, i_s R_D$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = -\frac{R_D}{R_S + r_m} = -\frac{g_m R_D}{1 + g_m R_S}$$

What about body effect?



$$V_{out} = -\underbrace{(i_{s1} + i_{s2})}_{i_s} R_D$$

$$-i_{s2} = +i_{s1} \frac{R_s}{R_s + r_{mb}} \Rightarrow i_s = i_{s1} - i_{s1} \frac{R_s}{R_s + r_{mb}}$$

$$= i_{s1} \left(\frac{r_{mb}}{R_s + r_{mb}} \right)$$

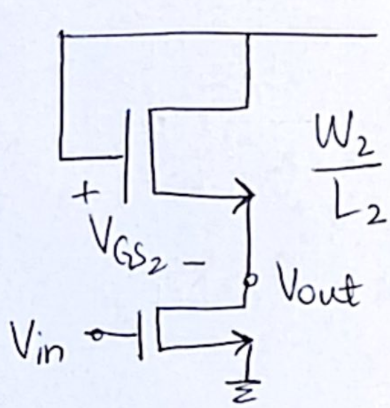
Also, $i_{s1} = \dfrac{V_{in}}{r_m + (R_s \| r_{mb})} = V_{in} \dfrac{R_s + r_{mb}}{R_s r_m + R_s r_{mb} + r_m r_{mb}}$

$$\Rightarrow V_{out} = -i_s R_D = -i_{s1} \left(\frac{r_{mb}}{R_s + r_{mb}} \right) R_D$$

$$\Rightarrow A_v = -\left(\frac{\cancel{R_s + r_{mb}}}{R_s r_m + R_s r_{mb} + r_m r_{mb}} \cdot \frac{r_{mb}}{\cancel{R_s + r_{mb}}} \cdot R_D \right)$$

$$\boxed{A_v = -\frac{R_D}{r_m + R_s\left(1 + \frac{r_m}{r_{mb}}\right)} = \frac{-g_m R_D}{1 + g_m R_s\left(1 + \frac{g_{mb}}{g_m}\right)}}$$

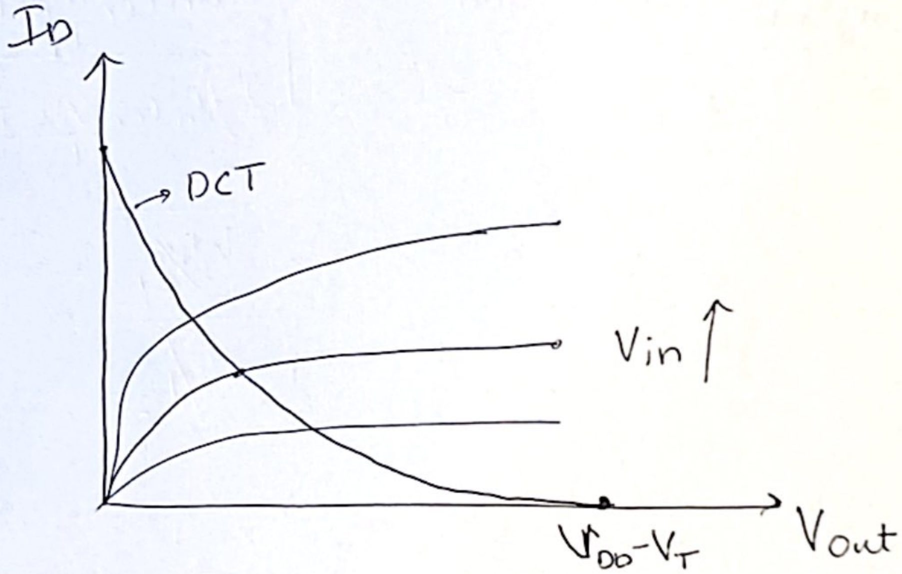
Diode Connected Loads



> To avoid resistors.

> Always in off or pinch-off.

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W_2}{L_2}\left(V_{DD}-V_{out}-V_{T_2}\right)^2 = \frac{1}{2}\mu_n C_{ox}\frac{W_1}{L_1}\left(V_{in}-V_{T_1}\right)^2$$

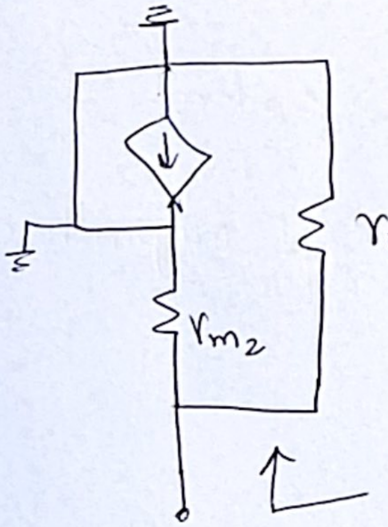


$$\underline{V_{out}} = V_{DD} - V_{T_2} - \sqrt{\frac{W_1/L_1}{W_2/L_2}}\left(V_{in}-V_{T_1}\right) \longrightarrow$$ Large signal Gain is now "Linear"

$$\Rightarrow \boxed{\frac{v_{out}}{v_{in}} = -\sqrt{\frac{W_1/L_1}{W_2/L_2}}}$$ (ignoring CLM)

$\longrightarrow$ Low distortion, well defined.

Small signal model



$r_{m_2} \| r_o \simeq r_{m_2}$

$$\Rightarrow A_v = -g_{m_1} r_{m_2} = -\frac{g_{m_1}}{g_{m_2}} = -\sqrt{\frac{2\mu_n C_{ox} \frac{W_1}{L_1} I_D}{2\mu_n C_{ox} \frac{W_2}{L_2} I_D}}$$

$$= -\sqrt{\frac{W_1/L_1}{W_2/L_2}}$$