Lecture 22:

http://www.ee.iitm.ac.in/~nagendra/cadinfo.html

- 0.18μm CMOS process models

Exercise:

$\left\{ \frac{1.8\mu m}{0.18\mu m}, \frac{3.6\mu m}{0.36\mu m}, \frac{7.2\mu m}{0.72\mu m}, \frac{14.4\mu m}{1.44\mu m} \right\}$

* Plot I_D vs. V_{GS} of nMOS & pMOS transistors (in saturation region)

* Plot I_D vs. V_{DS} of nMOS & pMOS transistors (for a range of V_{GS} values – V_{GS}: parameter)

Channel length is very short:

$$I_D = \frac{\mu C_{ox}}{2} \frac{W}{L} (V_{GS} - V_T)^2$$

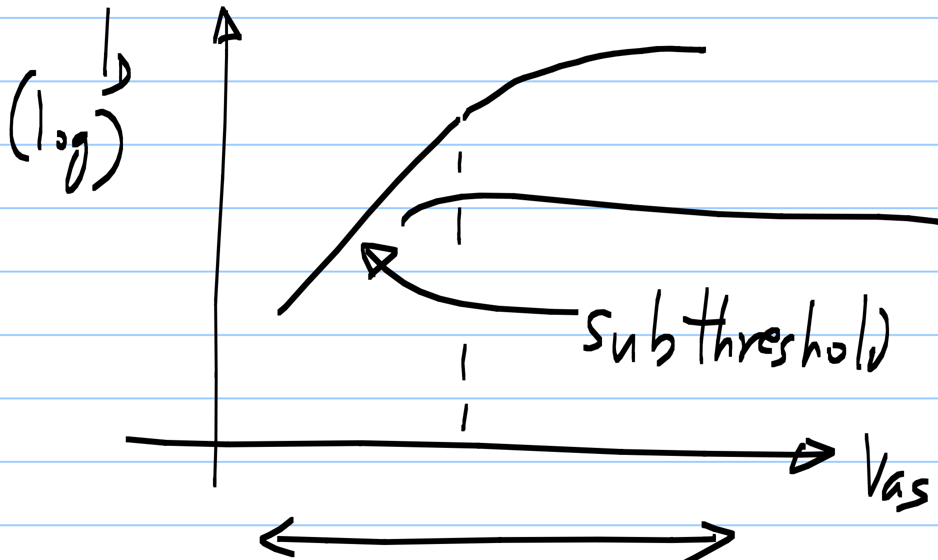
$$\frac{\mu (V_{GS} - V_T)}{L} = v$$

$$= W C_{ox} (V_{GS} - V_T)\, v_{SAT}$$

← saturation velocity

Current in subthreshold region.

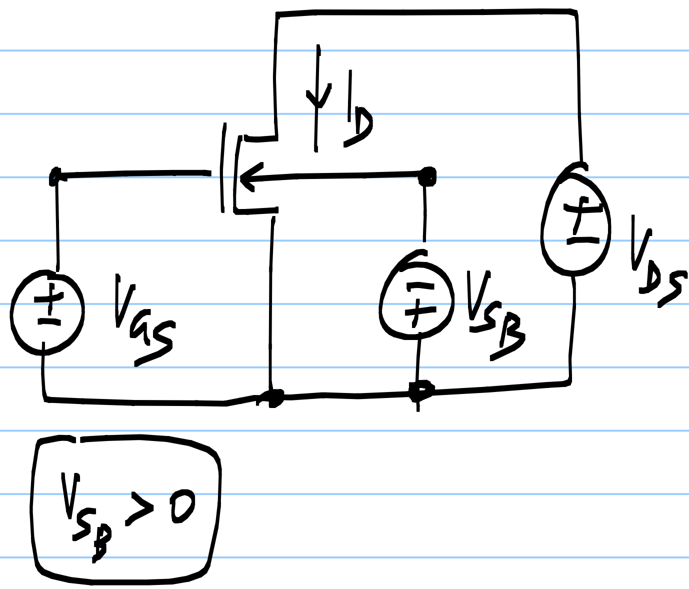
* Plot I_D vs. V_{GS} (on a log scale).



$$I_D \propto \exp\left(\frac{V_{GS}}{\eta V_t}\right)$$

range includes values $< V_T$

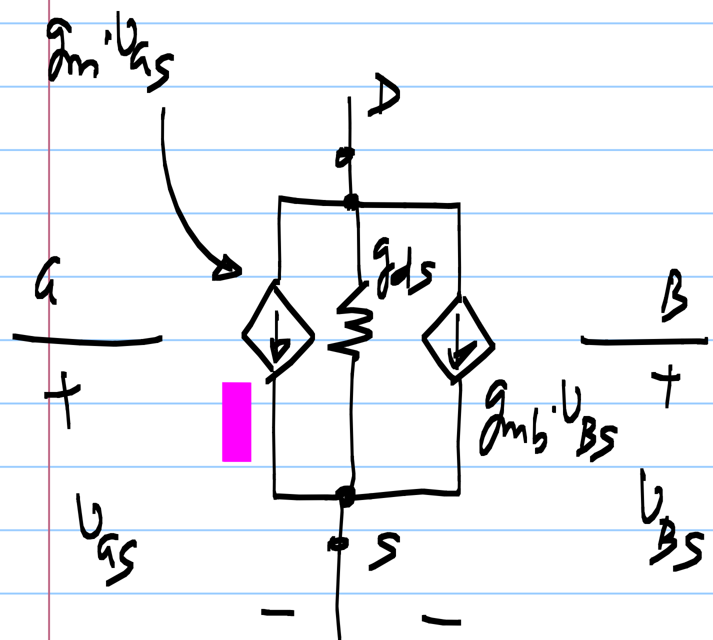
* Find the effect of V_{SB}



* Plot I_D vs. V_{SB}
  (V_{DS}, V_{GS} : strong inversion & saturation)

* Plot I_D vs. V_{DS} for different values of V_{SB}
  (V_{SB} : parameter)

dc Small signal model of the MOS transistor:



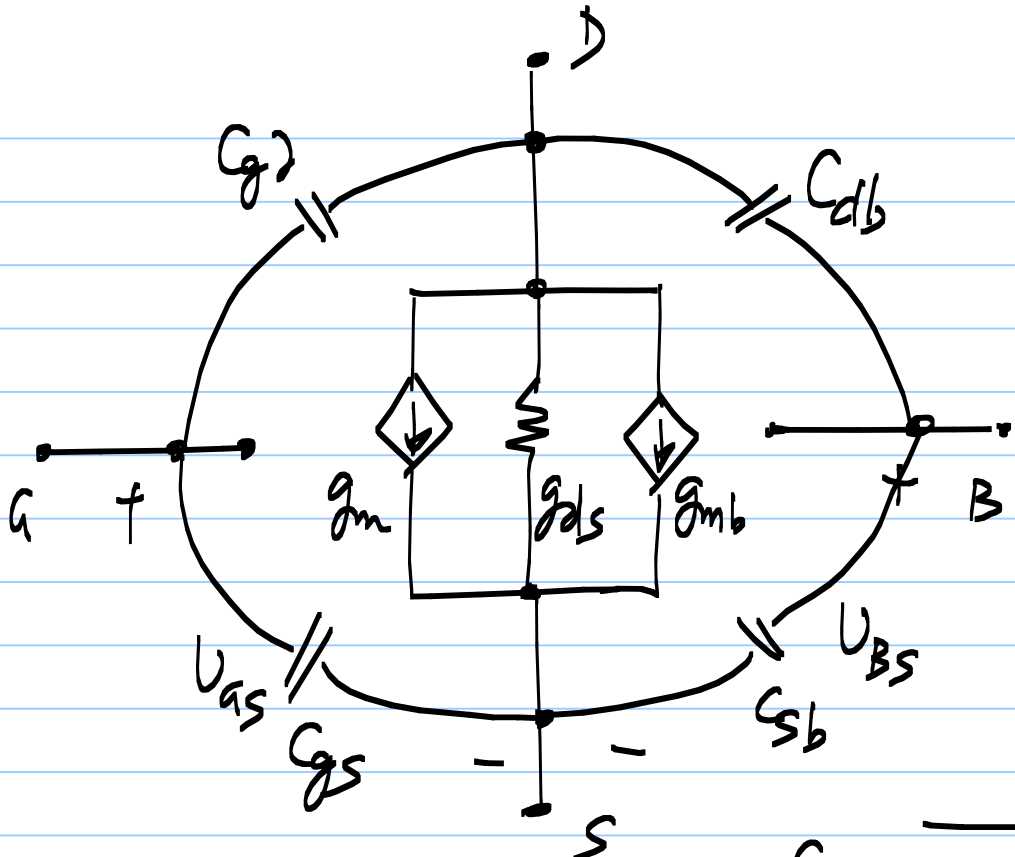
$$I_D = f(V_{GS}, V_{DS}, V_{BS})$$

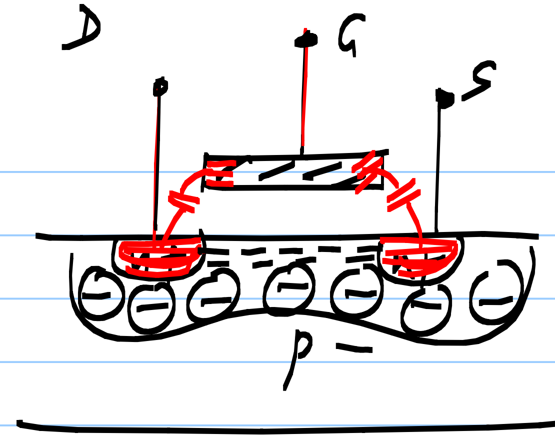
$$\Delta I_D \;(i_D) = \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{op} v_{GS} + \left.\frac{\partial I_D}{\partial V_{DS}}\right|_{op} v_{DS} + \left.\frac{\partial I_D}{\partial V_{BS}}\right|_{op} v_{BS}$$

$\left.\frac{\partial I_D}{\partial V_{GS}}\right|_{op} \rightarrow g_m$

$\left.\frac{\partial I_D}{\partial V_{DS}}\right|_{op} \rightarrow g_{ds}$

$\left.\frac{\partial I_D}{\partial V_{BS}}\right|_{op} \rightarrow g_{mb}$



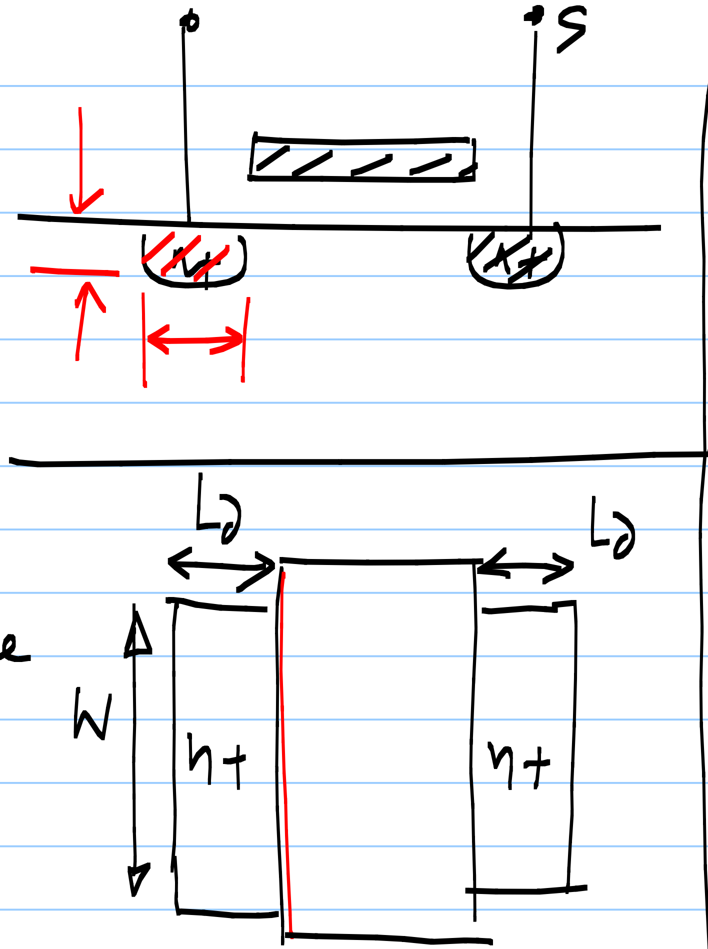


C_{gd}, C_{gs}: intrinsic capacitances

	Triode	Saturation
C_{gd} :	$\frac{1}{2} \cdot W \cdot L \cdot C_{ox}$	$0 + C'_{ov} W$
C_{gs} :	$\frac{1}{2} W L C_{ox}$	$\frac{2}{3} W L C_{ox} + C'_{ov} \cdot W$

C_{sb}, C_{db}:

Area capacitance
+
perimeter capacitance



$$L_d = 2 \cdot L_{min}$$

$$C_{sb} = W \cdot L_d \cdot C_{area} \quad (A_s)$$
$$+ \; 2(W + L_d) \cdot C_{perim} \quad (P_s)$$

$$C_{db} = A_d \cdot C_{area} + P_d \cdot C_{peri}$$

Small signal model:

dc:

$$g_m = \frac{2 I_D}{V_{GS} - V_T} \text{ (strong inv.)} \; ; \; \frac{I_D}{\eta V_t} \text{ (weak inv.)}$$

$$g_{ds} = \lambda \cdot I_D$$

$$g_{mb} = g_m \cdot \frac{\partial V_T}{\partial V_{SB}}$$

Capacitances:

$$C_{gd} = 0 + C_{ov}' \cdot W$$

$$C_{gs} = \frac{2}{3} C_{ox} W L + C_{ov}' \cdot W$$

$$C_{sb} = A_s \cdot C_{j,area} + P_s \cdot C_{j \cdot peri}$$

$$C_{db} = A_d \, C_{j \cdot area} + P_d \cdot C_{j \cdot peri}$$

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

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \mu_n C_{ox} \cdot \frac{W}{L} \left(V_{GS} - V_T\right) \left(1 + \lambda V_{DS}\right)$$

$$\simeq \mu_n C_{ox} \frac{W}{L} \left(V_{GS} - V_T\right)$$

$$= \frac{2 \cdot I_D}{V_{GS} - V_T}$$

$$= \sqrt{2 \cdot \mu_n C_{ox} \frac{W}{L} \cdot I_D}$$

$$g_m = \frac{2 I_D}{V_{GS} - V_T}$$

Square law model is valid.

$V_{GS} - V_T > 6 \cdot V_t$ (thermal voltage) $\simeq 150\,mV$

Subthreshold region

$$I_D = I_0 \cdot \exp\left(\frac{V_{GS}}{\eta \cdot V_t}\right)$$

$$\frac{\partial I_D}{\partial V_{GS}} = \frac{I_D}{\eta V_t}$$

$$g_{ds} = \frac{\partial I_D}{\partial V_{DS}} = \underbrace{\frac{\mu C_{ox}}{2} \frac{W}{L} \left(V_{GS} - V_T\right)^2} \cdot \lambda$$

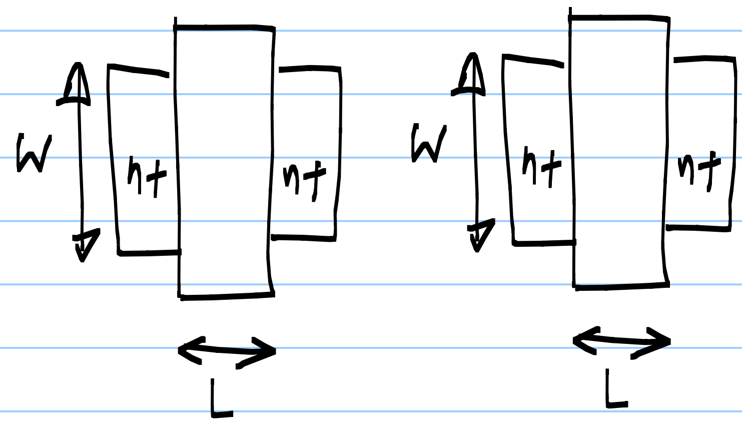
$$= \lambda I_D$$

$$g_{mb} = \frac{\partial I_D}{\partial V_{BS}} = \frac{\partial I_D}{\partial V_T} \cdot \frac{\partial V_T}{\partial V_{BS}} = + \mu C_{ox} \frac{W}{L} \left(V_{GS} - V_T\right)\left(1 + \lambda V_{DS}\right) \left(\frac{\partial V_T}{\partial V_{SB}}\right)$$

$$= g_m \cdot \left(\frac{\partial V_T}{\partial V_{SB}}\right)$$

$$\frac{\partial V_T}{\partial V_{SB}} = \frac{1}{2} \,..\, \frac{1}{4}$$

MOS transistor mismatch:



For a given V_{GS}, V_{DS}, V_{SB}

same current

$$I_D = \left\{\frac{\mu C_{ox}}{2}\frac{W}{L}\right\}(V_{GS} - V_T)^2$$

$$= \frac{\beta}{2}(V_{GS} - V_T)^2$$

V_T mismatch: $\sigma_{V_T} = \sigma(V_{T_1} - V_{T_2}) = \frac{A_{V_T}}{\sqrt{WL}}$

$\{mV\}$

β mismatch: $\sigma_\beta = \sigma\left(\frac{\beta_1 - \beta_2}{\beta_0}\right) = \frac{A_\beta}{\sqrt{WL}}$

$\{\%\}$