prob) 2.1

· using shockley model

$$\cdot I_d = \begin{cases} 0 & V_{GS} < V_{TH} \\ \mu_n C_{ox} \cdot \frac{W}{L} \cdot \left((V_{GS} - V_{TH}) V_{DS} - \frac{1}{2} V_{DS}^2 \right) & V_{DS} < V_{GS} - V_{TH} \\ \frac{1}{2} \mu_n C_{ox} \cdot \frac{W}{L} (V_{GS} - V_{TH})^2 & V_{DS} > V_{GS} - V_{TH} \end{cases}$$

$\mu_n = 350\ cm^2/V \cdot s$

$k_{ox} \cdot \varepsilon_0 = (3.9) \cdot (8.85) \cdot 10^{-14}\ F/cm$

$t_{ox} = 100 \cdot 10^{-8}\ cm$

let $\mu_n C_{ox} \cdot \frac{W}{L} = \beta = 350 \cdot (cm^2/V \cdot s) \cdot \frac{3.9 \cdot 8.85 \cdot 10^{-14}\ (F/cm)}{100 \cdot 10^{-8}\ cm}$

$= 1.208 \cdot 10^{-4}\ (A/V^2)$

· graph plotted in another file.

DIC HW 3

prob) 2.2

- the shockley model, let's assume $\mu_n C_{ox} \frac{W}{L} = \beta$, $V_{gs} - V_{TH} = V_{over}$

$$\cdot I_d = \begin{cases} 0 & \\ \beta\left((V_{over}) V_{DS} - \frac{1}{2} V_{DS}^2 \right) & V_{DS} < V_{over} \\ \frac{1}{2}\beta (V_{over})^2 & V_{DS} > V_{over} \end{cases}$$

- for this problem, we assume the linear region

where $V_{gs} > V_{TH}$, $V_{DS} \ll V_{over}$,

- hence, for a

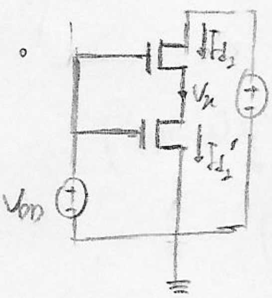
$V_{gs} - V_{TH} = V_{DD} - V_{TH} = V_{over}$

$I_d = \beta \cdot \frac{1}{2} \cdot \left(V_{over} \cdot V_{DS} - \frac{1}{2} V_{DS}^2 \right)$

$I_d \simeq \beta \cdot \frac{1}{2} \left(V_{over} \cdot V_{DS} \right)$

$(\because V_{DS} \ll V_{gs} - V_{TH})$

- for b)



- by KCL $\quad -I_{d_2} + I_{d_2}' = 0$

$I_{d_2} = \beta \cdot \left(V_{over} \cdot (V_{DS} - V_x) - \frac{1}{2} (V_{DS} - V_x)^2 \right)$

$I_{d_2}' = \beta \cdot \left(V_{over} \cdot (V_x) - \frac{1}{2} (V_x)^2 \right)$

hence, $\beta\left(V_{over} (V_{DS} - V_x) - \frac{1}{2} (V_{DS} - V_x)^2 \right) = \beta \left(V_{over} V_x - \frac{1}{2} V_x^2 \right)$

$V_{over} (V_{DS} - 2V_x) = \frac{1}{2} \cdot (V_{DS} - V_x - V_x)(V_{DS})$

$= \frac{1}{2} (V_{DS} - 2V_x) V_{DS}$

hence, $\left(V_{over} - \frac{1}{2} V_{DS} \right) \cdot (V_{DS} - 2V_x) = 0$

$\therefore \boxed{V_x = \frac{1}{2} V_{DS}}$

$I_{d_2} = \beta \left(V_{over} \cdot \frac{1}{2} V_{DS} - \frac{1}{2} \cdot \left(\frac{1}{4} V_{DS} \right) \right)$

$I_{d_2} \simeq \beta \left(V_{over} \frac{1}{2} V_{DS} \right) \quad (\because V_{GS} - V_{TH} \gg V_{DS})$

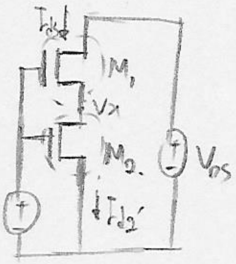
$I_{d_2} \simeq \frac{1}{2} \beta (V_{over}) \cdot V_{DS}$

finally, $I_{d_1} \simeq I_{d_2}$

prob 2.37

by the body effect

$\cdot V_T = V_{T0} + \gamma(\sqrt{\phi_s + V_{sb}} - \sqrt{\phi_s})$



considering previous prob. 2.24

· the threshold voltage of M1 will be increased $(V_{th1} = V_{tn} + \delta)$

· but still, the circuit obey KCL

hence, $-I_{d2} + I_{d2}' = 0$.

also, $\begin{cases} I_{d2} = \beta\left((V_{over} - \delta)(V_{DS} - V_x) - \frac{1}{2}(V_{DS} - V_x)^2\right) \\ I_{d2}' = \beta\left((V_{over})V_x - \frac{1}{2}V_x^2\right) \end{cases}$

($\because$ body effect affect the V_{th} of M_1 as $V_{tn} + \delta$)

but, M_2's source voltage is gnd as body.

so $I_{d2} = I_{d2}'$

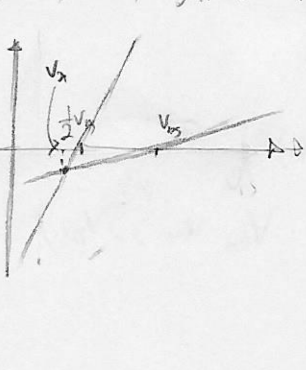
$\rightarrow$ $V_{over}(V_{DS} - V_x) - \delta(V_{DS} - V_x) - \frac{1}{2}(V_{DS} - V_x)^2 = V_{over}(V_x) - \frac{1}{2}V_x^2$

$V_{over}(V_{DS} - 2V_x) - \delta(V_{DS} - V_x) = \frac{1}{2}\cdot(V_{DS})\cdot(V_{DS} - 2V_x)$

$-\delta(V_{DS} - V_x) = \left(\frac{1}{2}V_{DS} - V_{over}\right)(V_{DS} - 2V_x)$

$-\delta(V_x - V_{DS}) = (2V_{over} - V_{DS})\left(V_x - \frac{1}{2}V_{DS}\right)$

· we assumed linear region hence, $V_{over} >> V_{DS}$, therefore, $2V_{over} - V_{DS} > 0$, $\delta > 0$



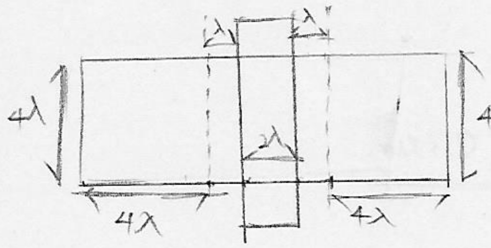
finally, we can know that new $V_x < \frac{1}{2}V_{DS}$

· it means that I_{d2}' is smaller than previous prob 2.2

· by KCL, we can know that the I_{DS2} will be smaller than I_{DS1}.

prob) 2.2.4

assume MOSFET,



. for 90nm process, $\lambda = 45$ nm.

and the capacitance of gate $C_g = k_{ox} \cdot \frac{\varepsilon_0}{t_{ox}} \cdot WL$.

hence, $C_{permicron} = k_{ox} \cdot \frac{\varepsilon_{ox}}{t_{ox}} \cdot L$

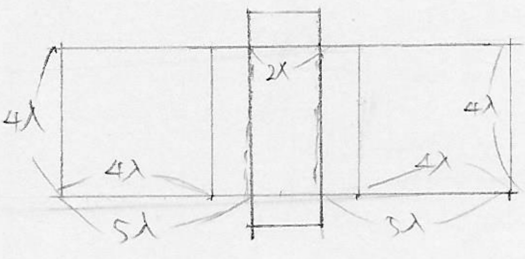
$$= 3.9 \cdot \frac{8.85 \cdot 10^{-12}\ F/m}{16 \cdot 10^{-10}\ m} \cdot 90 \cdot 10^{-9}\ m$$

$$= 3.9 \cdot (8.85) \cdot \frac{90 \cdot 10^{-9}}{16 \cdot 10^{-10}} \cdot 10^{-12} \cdot \left[\frac{10^{15}\ fF}{10^{6}\ um}\right].$$

$$= 3.9 \cdot (8.85) \cdot \frac{90 \cdot 10^{-9}}{16 \cdot 10^{-10}} \cdot 10^{-12} \cdot 10^{9}\ fF/um$$

$$= 1.941\ fF/um.$$

prob) 2.5.



for 0.6 um process, $\underline{\lambda = 0.3\,um}$

· for diffusion capacitance

$$C_{db} = AS \cdot C_{jbs} + PS \cdot C_{jbssw} \quad (*)$$

$$\left\{ \begin{array}{l} \cdot\ C_{jbs} = C_J \cdot \left(1 + \frac{V_{db}}{\psi_0}\right)^{-M_J} \\ \cdot\ \psi_0 = V_T \ln \frac{N_A N_D}{n_i^2} \end{array} \right. \qquad \left\{ \begin{array}{l} \cdot\ C_{jbssw} = C_{JSW}\left(1 + \frac{V_{db}}{\psi_{SW}}\right)^{-M_{JSW}} \\ \cdot\ C_{jbsswg} = C_{JSW}\left(1 + \frac{V_{db}}{\psi_{SWG}}\right)^{-M_{JSWG}} \end{array} \right.$$

· $C_J = 0.42\,fF/um^2$, $M_J = 0.44$

· $C_{JSW} = 0.33\,fF/um$, $M_{JSW} = 0.12$.

· $\psi_0 = 0.98V$ at room temp.

· since, no constant are defined for C_{jbsswg},
we'll use $(*)$ equation, and define V_{db} as x (x will be 0 or 5V)

$$\text{hence, } C_{db} = 20\lambda^2 \cdot 0.42\,fF/um^2 \cdot \left(1 + \frac{x}{0.98}\right)^{-0.44} + 18\lambda \cdot 0.33\,fF/um \cdot \left(1 + \frac{x}{0.98}\right)^{-0.12}$$

$$= 20 \cdot (0.3\,um)^2 \cdot 0.42\,fF/um^2 \cdot \left(1 + \frac{x}{0.98}\right)^{-0.44} + 18 \cdot (0.3\,um) \cdot 0.33\,fF/um \cdot \left(1 + \frac{x}{0.98}\right)^{-0.12}$$

$=$

hence, $C_{db}(V_d = 0V) = 2.538\,fF$

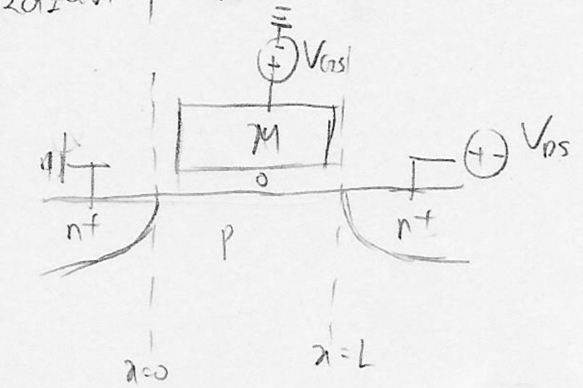
$C_{db}(V_d = 5V) = 1.755\,fF$

prob) 대응과제 2.

· $V_g = 1.8V$, $V_t = 0.4$ · $L = 180nm$ 의.

NMOS에 대하여,

Razavi의 microelectronics를 참고하여,



channel 위의 임의의 지점 x에 대하여 e^-의 밀도, $Q(x)$는 다음과 같다.

· $Q(x) = WC_{ox}\cdot(V_{GS} - V(x) - V_{TH})$

. 또한 drain current I_d는

$I_d = Q\cdot v$로 정의되며,

· 이때 속력 v는 $v = -\mu_n\cdot E$ 와 같으며,

voltage 형태로 표현하면 $v = +\mu_n\cdot\frac{dV}{dx}$ 이다.

$\therefore I_D = WC_{ox}\cdot(V_{GS} - V(x) - V_{TH})\cdot\mu_n\cdot\frac{dV(x)}{dx}$ 이나,

I_D는 전하량보존 법칙에 의해서 위치 x에 관계없이 일정하므로, 상수로 취급한다.

이때, $\frac{I_D}{\mu_n C_{ox}\cdot W} = k$ 의 상수로 두자.

그리하여, $\frac{I_D}{\mu_n C_{ox}\cdot W} = (V_{GS} - V_{TH} - V(x))\cdot\frac{dV(x)}{dx}$

then, $k = (1.4 - V)\cdot V'$

differential equation을 풀자.

$kx + C_0 = (1.4 - V)\cdot V + \int V\,dV$

$kx + C_0 = 1.4V - \frac{1}{2}V^2$

$V^2 - 2.8V + (2kx + 2C_0) = 0$

hence, $V = 1.4 \pm \sqrt{(1.4)^2 - 2kx - 2C_0}$

boundary condition $V(0) = 0V$ 을 이용하여

임의의 V_{ds}에 대하여,

$V = 1.4 - \sqrt{(1.4)^2 - 2kx}$ 의 꼴을 가진다!

(*)

(*)의 과정을 통해 유도된 식을 이용하여 0 부터 1.4V 까지의 V_{ds}에 대해서 graph를 그리자.

graph plotted in another file