Digital Integrated Circuit
EC4202-01
HW#3

20194044
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Homework assignment #3

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Ex 2-1

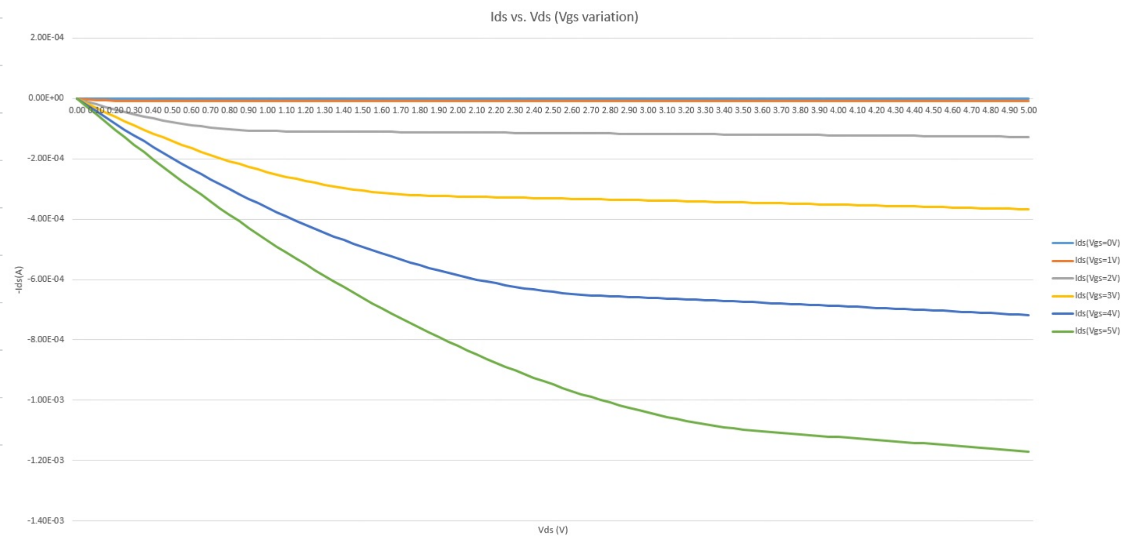
$$\begin{cases} k = \mu C_{ox} \frac{W}{L} = \left(350 \frac{cm^2}{V\cdot s}\right)\left[\frac{(3.9)(8.854\times 10^{-14})(F/cm)}{100\cdot 10^{-10}\ (cm)}\right] \\ \quad = (120.86\mu)(4/2) = 241.72\ \mu A/V^2 \\ V_{th} = 0.7V \end{cases}$$

$$I_{DS} = \begin{cases} 0, & V_{GS} < V_{th} \\ k\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right)V_{DS}, & V_{GS} > V_{th}\ \&\ V_{DS} < V_{dsat} = V_{GS} - V_{th} \\ \frac{1}{2}k(V_{GS}-V_{th})^2, & V_{GS} > V_{th}\ \&\ V_{DS} > V_{dsat} = V_{GS} - V_{th} \end{cases}$$

```
* ex2.1 for SPICE3F5

.MODEL NMOS NMOS LEVEL=2 LD=0.6U TOX=100.0E-10
+ NSUB=5.36726E+15 VTO=0.7 KP=1.208571E-04 GAMMA=0.543
+ PHI=0.6 U0=350 UEXP=0.157282 UCRIT=31443.8
+ DELTA=2.39824 VMAX=55260.9 XJ=0.25U LAMBDA=0.0367072
+ NFS=1E+12 NEFF=1.001 NSS=1E+11 TPG=1.0 RSH=70.00
+ CGDO=4.3E-10 CGSO=4.3E-10 CJ=0.0003 MJ=0.6585
+ CJSW=8.0E-10 MJSW=0.2402 PB=0.58

Vgs g 0 0
Vds d 0 0
M1 d g 0 0 NMOS W=2.4 L=1.2

.dc Vds 0 5.0 0.05 Vgs 0 5.0 1.0
.print dc V(g) I(Vds)
.end
~
```

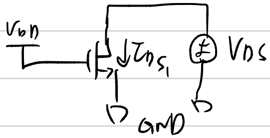
(1) I_{ds} for $V_{GS}=1V$ is around μA unit. Although it is turned on, cannot be easily distinguished from $V_{gs}=0V$ one.

(2) Although I_{ds} for NMOS is positive, spice3f5 returns it as negative quantity.



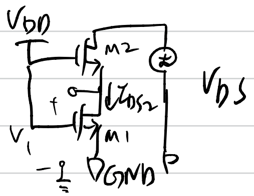
Ex 2.2

(a)



$$I_{DS_1} = \frac{1}{2}k\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right)V_{DS}$$
$$= \frac{1}{2}k\left(V_{DD} - V_{th} - \frac{V_{DS}}{2}\right)V_{DS}$$

(b)



$$\begin{cases} V_{GS,M2} = V_{DD} - V_1 \\ V_{DS,M2} = V_{DS} - V_1 \end{cases} \qquad \begin{cases} V_{GS,M1} = V_{DD} \\ V_{DS,M1} = V_1 \end{cases}$$

$$I_{DS_2} = I_{DS,M1} = k\left(V_{GS\,M1} - V_{th} - \frac{1}{2}V_{DS\,M1}\right)V_{DS\,M1}$$
$$= k\left(V_{DD} - V_{th} - \frac{V_1}{2}\right)V_1$$
$$= I_{DS,M2} = k\left(V_{GS\,M2} - V_{th} - \frac{1}{2}V_{DS\,M2}\right)V_{DS\,M2}$$
$$= k\left(V_{DD} - V_1 - V_{th} - \frac{V_{DS} - V_1}{2}\right)(V_{DS} - V_1)$$

$$\left(V_{DD} - V_{th} - \frac{V_1}{2}\right)V_1 = \left(V_{DD} - V_{th} - \frac{V_1}{2} - \frac{V_{DS}}{2}\right)(V_{DS} - V_1)$$
$$-\frac{V_1^2}{2} + (V_{DD} - V_{th})V_1 = \frac{V_1^2}{2} - V_1\left(V_{DD} - V_{th} - \frac{V_{DS}}{2} + \frac{V_{DS}}{2}\right) + \left(V_{DD}V_{DS} - V_{DS}V_{th} - \frac{V_{DS}^2}{2}\right)$$
$$V_1^2 - 2V_1(V_{DD} - V_{th}) + V_{DS}\left(V_{DD} - V_{th} - \frac{V_{DS}}{2}\right) = 0$$

$$V_1 = \frac{2(V_{DD} - V_{th}) \pm \sqrt{4(V_{DD} - V_{th})^2 - 4\left(V_{DD} - V_{th} - \frac{V_{DS}}{2}\right)V_{DS}}}{2}$$

$$= V_{DD} - V_{th} - \sqrt{(V_{DD} - V_{th})^2 - \left(V_{DD} - V_{th} - \frac{V_{DS}}{2}\right)V_{DS}} \quad (\because \text{triode}: V_1 < V_{DD} - V_{th})$$

$$= A - B \quad \begin{cases} A = V_{DD} - V_{th} \\ B = \sqrt{(V_{DD} - V_{th})^2 - \left(V_{DD} - V_{th} - \frac{V_{DS}}{2}\right)V_{DS}} \end{cases}$$

(i) $I_{DS_1} = \frac{1}{2}k\left(V_{DD} - V_{th} - \frac{V_{DS}}{2}\right)V_{DS}$

(ii) $I_{DS_2} = k\left(V_{DD} - V_{th} - \frac{V_1}{2}\right)V_1$

$$= k\left(A - \frac{V_1}{2}\right)V_1$$
$$= k\left(A - \frac{A - B}{2}\right)(A - B)$$
$$= \frac{k}{2}(A + B)(A - B) = \frac{k}{2}(A^2 - B^2)$$
$$= \frac{k}{2}\left[(V_{DD} - V_{th})^2 - (V_{DD} - V_{th})^2 + \left(V_{DD} - V_{th} - \frac{V_{DS}}{2}\right)V_{DS}\right]$$
$$= \frac{k}{2}\left(V_{DD} - V_{th} - \frac{V_{DS}}{2}\right)V_{DS} = I_{DS_1}$$

$$\boxed{\therefore I_{DS_1} = I_{DS_2}}$$

Ex 2.3

When $V_{sb} > 0$, body effect is applied, thus, V_{th} increases.
Increased V_{th} will decrease drain current in top MOSFET
since drain current is proportional to "$V_{ocar} = V_{gs} - V_{th}$".

$\therefore I_{DS_1} > I_{DS_2}$

Ex 2.4

$$C_g = C_{ox}WL = C_{permicron} \cdot W$$

$$C_{permicron} = C_{ox} \cdot L = \frac{\varepsilon_{ox}}{t_{ox}} \cdot L \qquad \begin{cases} t_{ox} = 16\,\text{Å} = 16 \times 10^{-8}\ cm \\ L = 90\,nm = 9 \times 10^{-6}\ cm \end{cases}$$

$$= \frac{(3.9)(8.854 \times 10^{-14})}{16 \times 10^{-8}} \cdot (9 \times 10^{-6}) = 19.42\ pF/cm$$

$$= \frac{19.42\,pF}{cm} \cdot \frac{1\,cm}{10^4\,\mu m} = 1.942\ fF/\mu m$$

$$\boxed{\therefore C_{permicron} = 1.942\,fF/\mu m}$$

Ex 2.5

$$\begin{cases} CJ = 0.42\,fF/\mu m^2 \\ MJ = 0.44 \\ CJSW = 0.33\,fF/\mu m \\ MJSW = 0.12 \\ \psi_0 = 0.98 \end{cases} \qquad \begin{cases} S_{min,\,diff\ contact} = 4 \times 5\,\lambda \\ \qquad = 1.2 \times 1.5 = 1.8\,\mu m^2 \\ P_{min,\,diff\ contact} = 1.2 \times 2 + 1.5 \times 2 = 5.4\,\mu m \end{cases}$$

(i) $C_{db}(0V) = S_{min,\,diff\ contact} \cdot CJ + P_{min,\,diff\ contact} \cdot CJSW$

$= (1.8)(0.42) + (5.4)(0.33) = 2.538\,fF$

(ii) $C_{db}(5V) = S_{min,\,diff\ contact} \cdot CJ \cdot \left(1 + \frac{V_{sb}}{\psi_0}\right)^{-MJ}$

$+ P_{min,\,diff\ contact} \cdot CJSW \left(1 + \frac{V_{sb}}{\psi_0}\right)^{-MJSW}$

$= (1.8)(0.42)\left(1 + \frac{5}{0.98}\right)^{-0.44} + (5.4)(0.33)\left(1 + \frac{5}{0.98}\right)^{-0.12}$

$\simeq 1.775\,fF$

$$\boxed{\begin{cases} C_{db}(0V) = 2.538\,fF \\ C_{db}(5V) \cong 1.775\,fF \end{cases}}$$

* channel potential versus channel position

$$\begin{cases} V_g = 1.4V \\ V_{th} = 0.4V \\ \lambda_L = 180nm \end{cases}$$

$$\begin{cases} V(x) = V_G - V_{th} - \sqrt{(V_G - V_{th})^2 - \frac{2I_D}{\mu_n C_{ox} W} x} \\ I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)\left[(V_G - V_{th})V_{DS} - \frac{1}{2}V_{DS}^2\right] \quad (V_{DS} < V_G - V_{th}) \\ I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS} - V_{th})^2 \quad (V_{DS} \geq V_G - V_{th}) \end{cases}$$

$$\text{(i)}\quad V(x) = V_G - V_{th} - \sqrt{(V_G - V_{th})^2 - \frac{x}{L}\left[(V_{GS} - V_{th}) - \frac{1}{2}V_{DS}\right]V_{DS}}$$

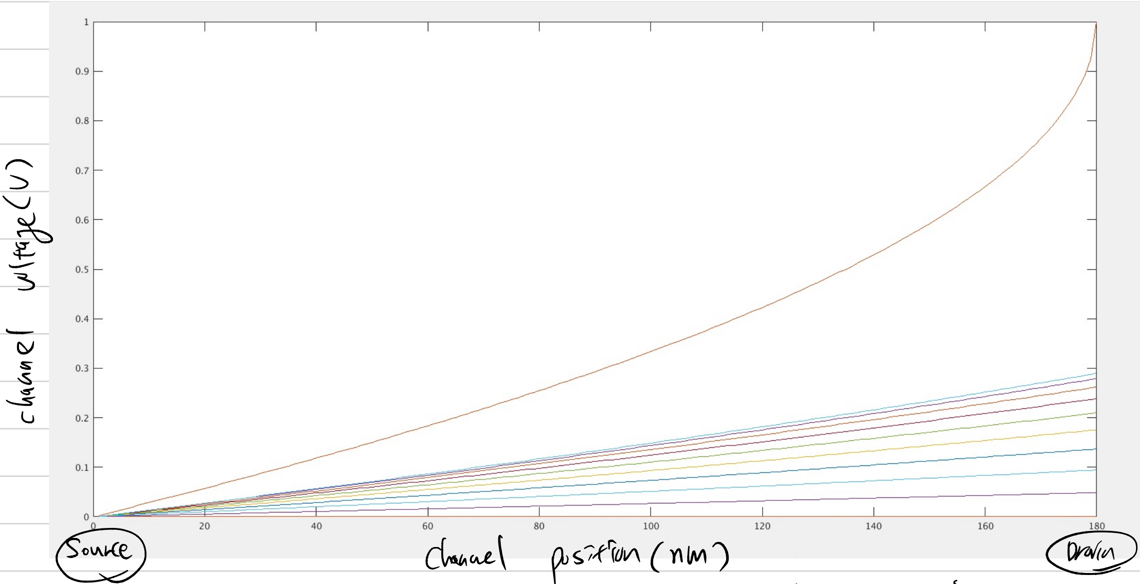
$$= 1 - \sqrt{1 - \frac{x}{180n}\left[1 - \frac{1}{2}V_{DS}\right]V_{DS}} \quad (V_{DS} < V_G - V_{th})$$

$$\text{(ii)}\quad V(x) = V_G - V_{th} - \sqrt{(V_G - V_{th})^2 - \frac{x}{L}(V_{GS} - V_{th})^2} = 1 - \sqrt{1 - \frac{x}{180n}}$$

$(V_{DS} > V_G - V_{th})$

```
clear all;
close all;

figure(1);

for Vds=0:0.1:1.4
    table(:,1)=1:1:180;

    for x=1:1:180
        if(Vds >= 1.0)
            table(x,2)=1-sqrt(1-x/180);
        else
            table(x,2)=1-sqrt(1-(x/180)*(1-Vds/2)*Vds);
        end
    end

    plot(table);

    hold on;


end
 ylim(1);
```

<matlab code for plotting graph>



< channel potential vs. channel position >

(1) As channel position value (x) increases to drain node, the channel voltage increases.

(2) As V_{DS} increases, channel potential increases for triode region.

(3) without channel length modulation affect, channel potential is all same for different V_{DS} value. The potential value itself is higher than the ones in triode regions