EEC 210 Solutions to HW #1

① From (1.1) $\psi_0 = V_T \ln \frac{N_A N_D}{n_i^2} = (26mV)\ln \frac{8\times10^{15}\times10^{17}}{2.25\times10^{20}} = 751 mV$

From (1.20) $C_{jo} = A\left[\frac{q\varepsilon N_A N_D}{2(N_A+N_D)}\right]^{1/2}\frac{1}{\sqrt{\psi_0}}$

$= 2\times10^{-5}\left[\frac{1.6\times10^{-19}\times1.04\times10^{-12}\times8\times10^{15}\times10^{17}}{2(8\times10^{15}+10^{17})}\right]^{1/2}\frac{1}{\sqrt{0.75}} = 0.57pF$

With $V_D = -5V$, $C_j = \frac{C_{jo}}{\sqrt{1+\frac{5}{0.75}}} = \frac{C_{jo}}{\sqrt{7.7}} = \boxed{0.2pF}$

with $V_D = 0.3V$, $C_j = \frac{C_{jo}}{\sqrt{1-\frac{0.3}{0.75}}} = \frac{C_{jo}}{\sqrt{0.6}} = \boxed{0.74pF}$

② ⓐ $\frac{k'}{2}\frac{W}{L} = 97\times\frac{10}{1} = 970\,\mu A/V^2$

So in triode region, $I_D = 970\left[2(V_{GS}-0.6)V_{DS} - V_{DS}^2\right]\,\mu A$

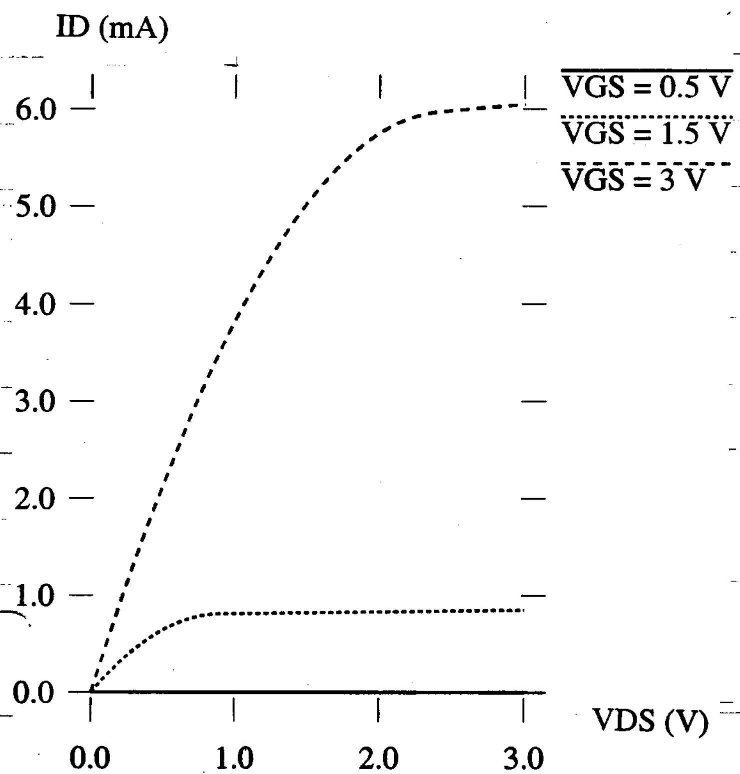
In active region (saturation) $I_D = 970(V_{GS}-0.6)^2(1+0.024V_{DS})\,\mu A$

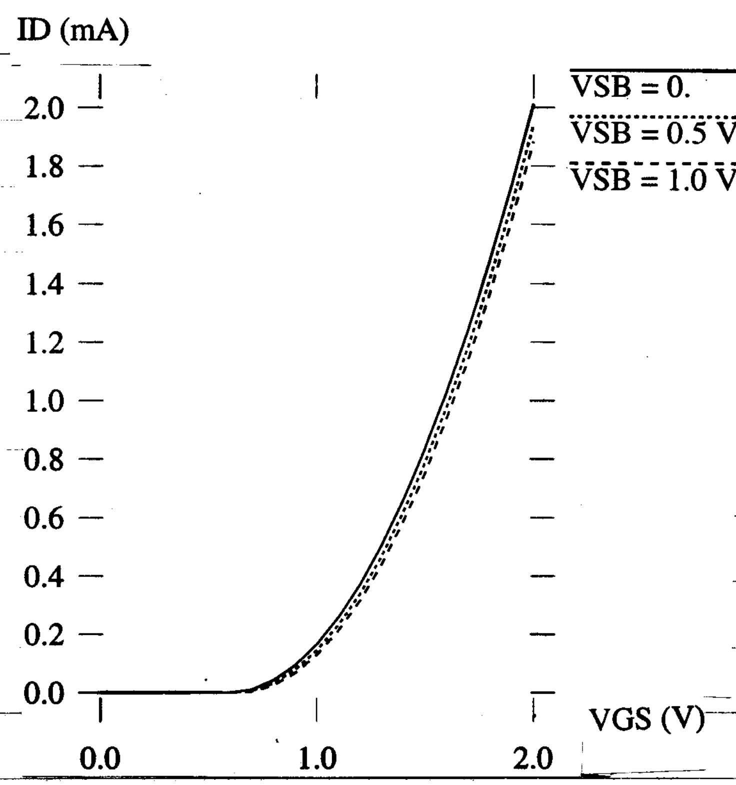
ⓑ From (1.140) $V_t = V_{to} + \gamma\left(\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F}\right)$

From (1.141) $\gamma = \frac{\sqrt{2q\varepsilon N_A}}{C_{ox}} = \frac{\sqrt{2\times1.6\times10^{-19}\times1.04\times10^{-12}\times5\times10^{15}}}{4.3\times10^{-7}} = 0.094\sqrt{V}$

From (1.142) $C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.9\times8.854\times10^{-14}}{80\times10^{-8}}\times10^{8} = 4.3\frac{fF}{\mu m^2} = 4.3\times10^{-7}\frac{F}{cm^2}$

When $V_{SB}=0$, $V_t = 0.6V$ when $V_{SB} = 0.5V$, $V_t = 0.63V$ when $V_{SB} = 1V$, $V_t = 0.65V$



(3) $V_t = 0.6 + 0.094\left(\sqrt{1.6} - \sqrt{0.6}\right) \simeq 0.646\text{V}$

$I_D = \frac{k'}{2}\frac{W}{L}(V_{GS}-V_t)^2(1+\lambda V_{DS}) = \frac{194}{2}\frac{10}{1}(1-0.646)^2\left[1+0.024(2)\right] = 127\,\mu\text{A}$

From (1.180) $g_m = \sqrt{2k'\frac{W}{L}I_D} = \sqrt{2(194)\,10(127)} = 702\,\mu\text{A/V}$

From (1.199) $g_{mb} = \gamma\sqrt{\frac{k'\frac{W}{L}I_D}{2(2\phi_F+V_{SB})}} = 0.094\sqrt{\frac{194(10)(127)}{2(0.6+1)}} = 26\,\mu\text{A/V}$

From (1.194) $r_o = \frac{1}{\lambda I_D} = \frac{1}{0.024(127\mu)} \simeq 328\,\text{K}\Omega$

From (1.201) $C_{sb} = \frac{C_{sbo}}{\sqrt{1+\frac{V_{SB}}{\Psi_o}}} = \frac{20\text{fF}}{\sqrt{1+\frac{1}{0.7}}} = 13\text{fF}$

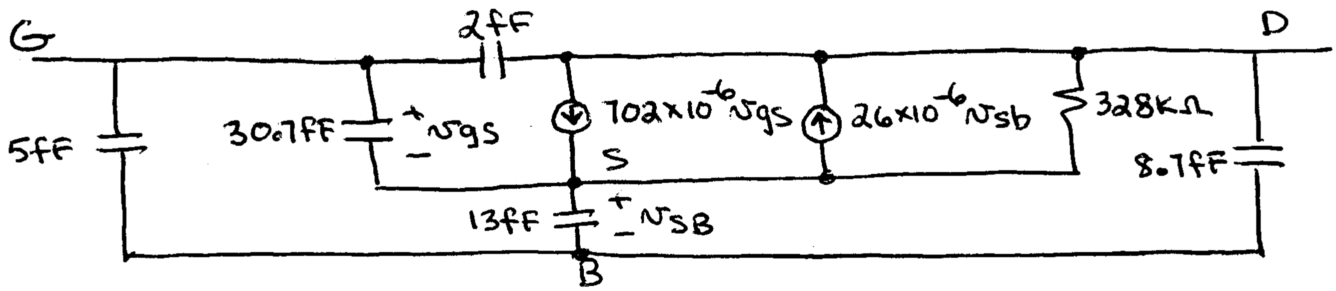
$V_{DB} = V_{DS} + V_{SB} = 2+1 = 3\text{V}$

From (1.202) $C_{db} = \frac{C_{dbo}}{\sqrt{1+\frac{V_{DB}}{\Psi_o}}} = \frac{20\text{fF}}{\sqrt{1+\frac{3}{0.7}}} = 8.7\text{fF}$

$C_{gd} = 2\text{fF}$

From (1.191) $C_{gsi} = \frac{2}{3}WLC_{ox} = \frac{2}{3}(10)(1)(4.3f) = 28.7\text{fF}$

$C_{gs} = C_{gsi} + C_{gsOL} = 28.7 + 2 = 30.7\text{fF}$




(4) From (1.208) $f_T = \frac{1}{2\pi}\frac{g_m}{C_{gs}+C_{gd}+C_{gb}} = \frac{1}{2\pi}\frac{g_m}{37.1\times10^{-15}}$

From (1.179) $g_m = k'\frac{W}{L}(V_{GS}-V_t)(1+\lambda V_{DS}) = 194\,\frac{10}{1}(V_{GS}-0.6)(1+\lambda V_{DS})$

Here $1+\lambda V_{DS} = 1+0.024(3) = 1.072$. This term is usually ignored but is included here to demonstrate its use. Ignoring the term would cause a 7.2% error here

| $V_{GS}$ (V) | $V_{GS}-V_t$ (V) | $g_m$ (mA/V) | $f_T$ (GHz) |
|---|---|---|---|
| 1.0 | 0.4 | 0.83 | 3.5 |
| 1.5 | 0.9 | 1.87 | 7.9 |
| 2.0 | 1.4 | 2.91 | 12.3 |

(5) From (1.157) $I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_t)^2$

$$100\,\mu A = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (1.5 - V_t)^2 \quad (1)$$

$$10\,\mu A = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (0.8 - V_t)^2 \quad (2)$$

Divide (1) by (2) and Solve for $V_t$ → Result: $\boxed{V_t = 0.48V}$

Substitute $V_t$ into (1) to get $\boxed{\mu_n C_{ox} \frac{W}{L} = 191 \frac{\mu A}{V}}$

(6) The metallurgical channel length is $L = L_{drawn} - 2L_d = 7\mu m - 2(0.3) = 6.4\mu m$

The effective chan. length is L minus the width of the depletion region at the drain.

In the active region, the voltage at the drain end of the chan $= V_{GS} - V_t = V_{OV}$

To calculate $V_{OV}$, assume at first that $L_{eff} \simeq L$. Then from (1.166)

$$V_{OV} = \sqrt{\frac{2I_D}{k' \frac{W}{L}}} = \sqrt{\frac{2(10\,\mu A)}{700 \frac{cm^2}{Vs} \cdot 0.86 \frac{fF}{\mu^2} \left(\frac{100}{6.4}\right)}} = 0.15V$$

Thus the voltage across the drain depletion region $= 5 - 0.15 = 4.85V$

To estimate the depletion-region width, assume it is a one-sided step junction that mainly exists in the lightly doped side. Since the channel and the drain are both n-type regions, the built in potential of the junction is near zero.

Using (1.14) and assuming $N_D >> N_A$

substrate doping + Extra implant for threshold adjust

$$x_d = \sqrt{\frac{2\epsilon (V_{DS} - V_{OV})}{q N_A}} = \sqrt{\frac{2(1.04 \times 10^{-12})(5 - 0.15)}{1.6 \times 10^{-19} (2 \times 10^{16} + 10^{15})}} = 0.55\,\mu m$$

So $L_{eff} = 7\mu m - 2(0.3\mu m) - 0.55\mu m = 5.85\mu m$

Therefore since $r_o = \frac{1}{\lambda I_D} = \frac{L_{eff}}{I_D} \Big/ \frac{dx_d}{dV_{DS}} = 5M\Omega = \frac{5.85\mu m}{10\,\mu A} \Big/ \frac{dx_d}{dV_{DS}}$

So $\frac{dx_d}{dV_{DS}} = 0.12 \frac{\mu m}{V}$. Since the other device uses the same technology, $\frac{dx_d}{dV_{DS}}$ is unchanged. But should calculate $V_{OV}$ for $2^{nd}$ transistor.

$$V_{OV} = \sqrt{\frac{2I}{k' \frac{W}{L}}} = \sqrt{\frac{2(30)}{(60.2)\frac{50}{12 - 2(0.3)}}} = 0.48V$$

$$\text{So } x_d = \sqrt{\frac{2(1.04 \times 10^{-12})(5 - 0.48)}{1.6 \times 10^{-19} (2.1 \times 10^{+16})}} = 0.53\mu m$$

$L_{eff2} = 12 - 2(0.3) - 0.53 = 10.87\,\mu m$

$$r_o = \frac{L_{eff}}{I_D} \Big/ \frac{dx_d}{dV_{DS}} = \frac{10.87\,\mu m}{30\,\mu A} \Big/ 0.12 = \boxed{3.02\,M\Omega}$$

Note that using the same $V_{OV}$ as for the $1^{st}$ transistor (0.15V) gives an answer of $3.1\,M\Omega$. (The change in $V_{OV}$ hardly matters.)