EE140 HW#1 Solution

1.

(a) As $V_{SB} = 0V$, $V_T = V_{T0} = 0.6V$

1) When $V_{GS} = 0.5V \Rightarrow$ cut off $\Rightarrow I_{DS} = 0$

2) when $V_{GS} = 1.5V$, $V_{GS} - V_T = 1.5V - 0.6V = 0.9$

$$I_{DS}(V_{DS} = 0.9V) = \frac{1}{2} K' \frac{W}{L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS}$$

$$= \frac{1}{2} \times 194\mu A/V^2 \times 10 \times 0.9V^2 \times (1 + 0.024V^{-1} \times 0.9V)$$

$$= 803\mu A$$

$$I_{DS}(V_{DS} = 3V) = \frac{10}{2} \times 194\mu A/V^2 \times (0.9V)^2 \times (1 + 0.024V^{-1} \times 0.9V)$$

$$= 842\mu A$$

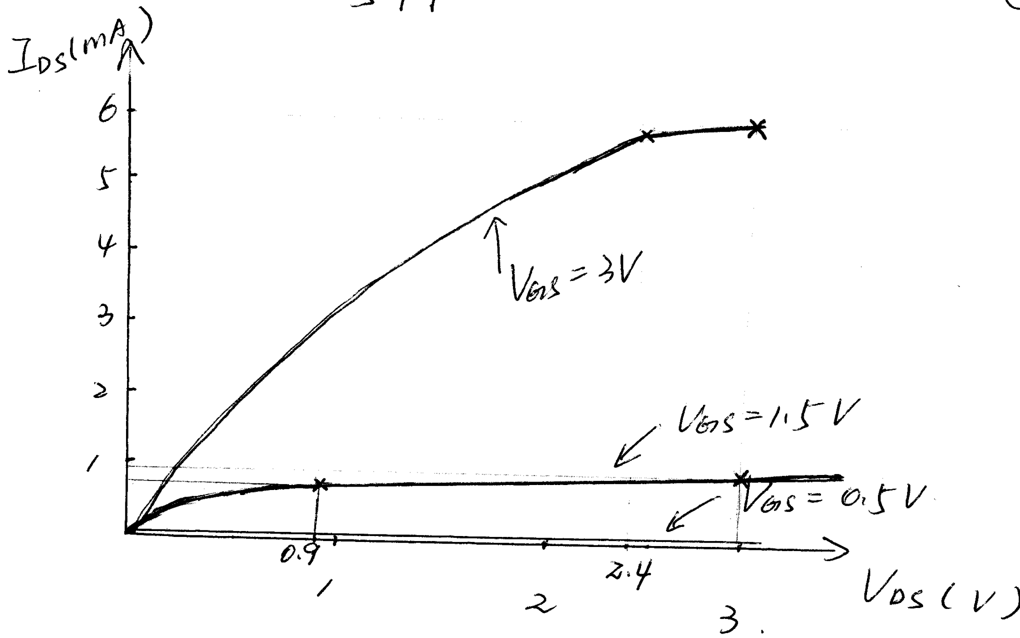
3) when $V_{GS} = 3V$, $V_{GS} - V_T = 3V - 0.6V = 2.4V$

$$I_{DS}(V_{DS} = 2.4V) = \frac{1}{2} \times 10 \times 194\mu A/V^2 \times (2.4V)^2 \times (1 + 0.024V^{-1} \times 2.4V$$

$$= 5.91 mA$$

$$I_{DS}(V_{DS} = 3V) = \frac{1}{2} \times 10 \times 194\mu A/V^2 \times (2.4V)^2 \times (1 + 0.024V^{-1} \times 3V$$

$= 5.99\,mA.$



(b) $V_T = V_{T0} + \frac{1}{C_{ox}}\sqrt{2q\varepsilon N_A}\left(\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right)$

$= 0.6 + \left(\frac{3.9 \times 8.854 \times 10^{-14}}{80 \times 10^{-8}}\right)^{-1} \cdot \sqrt{2 \times 1.6 \times 10^{-19} \times 11.7 \times 8.85 \times 10^{-14} \times 5 \times 10^{15}}$

$\cdot \left(\sqrt{0.6V + V_{SB}} - \sqrt{0.6V}\right)$

$\therefore V_T(V_{SB} = 0V) = 0.6V$

$V_T(V_{SB} = 0.5V) = 0.626V$

$V_T(V_{SB} = 1.0V) = 0.646V$

Since $V_{DS} = 2V > V_{GS} - V_T \Rightarrow$ always in saturation.

$$I_{DS} = \frac{K'}{2}\frac{W}{L}(V_{GS} - V_t)^2(1+\lambda V_{DS})$$

When $V_{GS} = 2V$, $V_{SB} = 0V$

$$I_{DS} = \frac{1}{2} \times 194\mu \times 10 \times (2-0.6)^2 \times (1+0.024 \times 2)$$

$$= 1.99mA$$

$V_{SB} = 0.5V$:

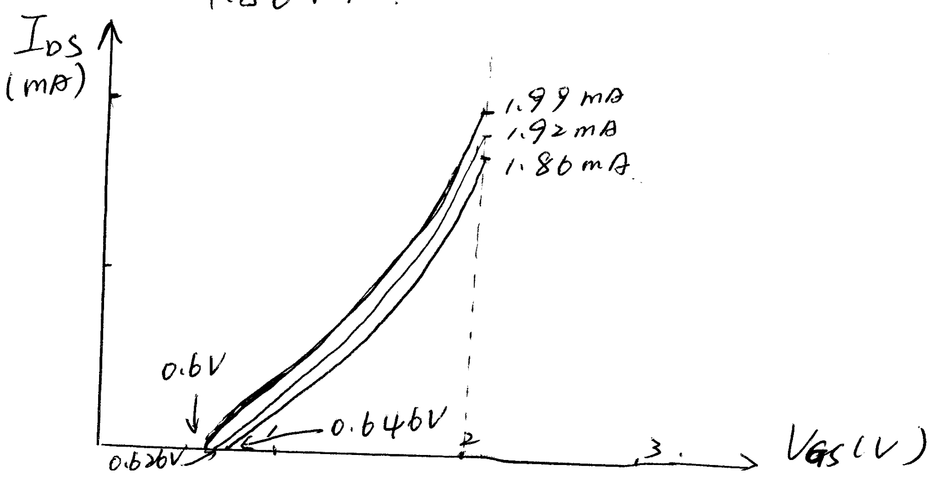
$$I_{DS} = \frac{1}{2} \times 194\mu \times 10 \times (2-0.626)^2 \times (1+0.024 \times 2)$$

$$= 1.92mA$$

$V_{SB} = 1V$:

$$I_{DS} = \frac{1}{2} \times 194\mu \times 10 \times (2-0.646)^2 (1+0.024 \times 2)$$

$$= 1.86mA.$$



(2)

V_{TO}: for $V_{DS} = 1.5V$, $V_{BS} = 0$, find I_{DS} for two different V_{GS} and take the ratio

$$\left.\frac{I_{DS}(V_{GS}=1.5V)}{I_{DS}(V_{GS}=1.2V)}\right|_{\substack{V_{SB}=0 \\ V_{DS}=1.5V}} = \frac{10.3\ mA}{5.5\ mA}$$

$$= \left(\frac{1.5 - V_{TO}}{1.2 - V_{TO}}\right)^2 \Rightarrow \boxed{V_{TO} \cong 0.4V}$$

γ: for $V_{DS} = 1.5V$, $V_{GS} = 1.2V$. Find I_{DS} for two different V_{BS} and take the ratio

$$\frac{I_{DS}(V_{SB}=0V)}{I_{DS}(V_{SB}=0.3V)} = \frac{5.5mA}{5mA} = \left(\frac{1.2V - V_{TO}}{1.2V - V_T}\right)^2$$

$$\Rightarrow V_T - V_{TO} = 37\ mV = \gamma\left(\sqrt{0.6V+0.3V} - \sqrt{0.6V}\right)$$

$$\therefore \boxed{\gamma \cong 0.21\ V^{\frac{1}{2}}}$$

λ: for $V_{GS} = 1.2V$, $V_{SB} = 0V$. find I_{DS} for two different V_{DS} and take the ratio.

$$\frac{I_{DS}(V_{DS} = 1.5V)}{I_{DS}(V_{DS} = 1V)} = \frac{5.5mA}{5.26mA} = \frac{1 + \lambda \cdot 1.5V}{1 + \lambda \cdot 1V}$$

$$\Rightarrow \boxed{\lambda \cong 0.1\ V^{-1}}$$

K': plug into the equation for saturation current.

$$10.3mA = \frac{K'}{2} \cdot 50 \cdot (1.5V - 0.4V)^2 (1 + 0.1 \cdot 1.5)$$

$$\Rightarrow \boxed{K' = 296\ \mu A/V^2}$$

point A: $I_{DS} = 10.5mA$. $V_{GS} = 1.5V$

$$\therefore\ g_m = \frac{2 I_{DS}}{V_{GS} - V_{to}} = \frac{2 \times 10.5mA}{1.5V - 0.4V} = \underline{\underline{19.1mS}}$$

$$r_o = \frac{1}{\lambda I_{DS}} = \frac{1}{0.1 \times 10.5} = \underline{\underline{952\ \Omega}}$$

$$g_{mb} = g_m \cdot \frac{\gamma}{2\sqrt{2\phi_f + V_{CB}}} = \underline{\underline{2.59\ mS}}.$$

(6)

point B: $g_m = \frac{2I_{DS}}{V_{GS} - V_{t0}} = \frac{2 \times 5.3mA}{1.2V - 0.4V}$

$= \underline{\underline{13.25\ mS}}$

$r_o = \frac{1}{\lambda I_D} = \frac{1}{0.1V^{-1} \times 5.3mA} = \underline{\underline{1.89K\Omega}}$

$g_{mbs} = g_m \cdot \frac{\gamma}{2\sqrt{2\phi_f + V_{SB}}} \cong \underline{\underline{1.80\ mS}}$

point C: $g_m = \frac{2I_{DS}}{V_{GS} - V_t} = \frac{2 \times 5mA}{1.2V - 0.44V}$

$= \underline{\underline{13.16\ mS}}$

$r_o = \frac{1}{\lambda I_D} = \frac{1}{0.1V^{-1} \times 5mA} = \underline{\underline{2K\Omega}}$

$g_{mbs} = g_m \cdot \frac{\gamma}{2\sqrt{2\phi_f + V_{SB}}} = \underline{\underline{1.46\ mS}}$