Prob. 6.1

Find V_O, V_P, and V_T. Find $V_{D,sat}$ for V_G =-3V.

$$V_O = \frac{kT}{q} \cdot \ln \frac{N_a \cdot N_d}{n_i^2} = 0.0259\text{eV} \cdot \ln \frac{10^{18}\,\frac{1}{\text{cm}^3} \cdot 10^{16}\,\frac{1}{\text{cm}^3}}{\left(1.5 \cdot 10^{10}\,\frac{1}{\text{cm}^3}\right)^2} = 0.814\text{V}$$

$$V_P = \frac{q \cdot a^2 \cdot N_d}{2 \cdot \epsilon} = \frac{1.6 \cdot 10^{-19}\text{C} \cdot (10^{-4}\text{cm})^2 \cdot 10^{16}\,\frac{1}{\text{cm}^3}}{2 \cdot 11.8 \cdot 8.85 \cdot 10^{16}\,\frac{\text{F}}{\text{cm}}} = 7.66\text{V}$$

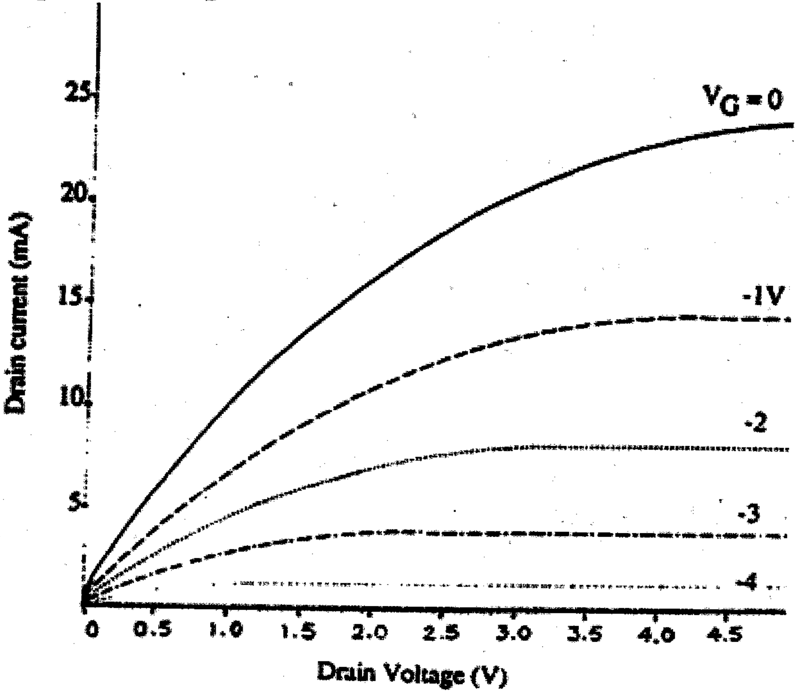
$$V_T = V_P - V_O = 6.85\text{V}$$

$$V_{D,sat} = V_T + V_G = 6.85\text{V} - 3.00\text{V} = 3.85\text{V}$$

V_D

Prob. 6.4

Graph the $I_D - V_D$ curve.



Prob. 6.6

For current I_D varying linearly with V_D at low values of V_D for a JFET,
(a) use the binomial expansion to rewrite Equation 6-9

Equation 6-9 may be rewritten as

$$I_D \approx G_O \cdot V_P \cdot \left[\frac{V_D}{V_P} + \frac{2}{3} \cdot \left(\frac{-V_G}{V_P} \right)^{\frac{3}{2}} - \frac{2}{3} \cdot \left(\frac{V_D - V_G}{V_P} \right)^{\frac{3}{2}} \right]$$

$$I_D = G_O \cdot \left[V_D + \frac{2}{3} \cdot \frac{(-V_G)^{\frac{3}{2}}}{V_P^{\frac{1}{2}}} - \frac{2}{3} \cdot \frac{(-V_G)^{\frac{3}{2}}}{V_P^{\frac{1}{2}}} \cdot \left(\frac{V_D}{-V_G} + 1 \right)^{\frac{3}{2}} \right]$$

use the binomial approximation $(1+x)^{\frac{3}{2}} \approx 1 + \frac{3}{2} \cdot x$

$$I_D = G_O \cdot \left[V_D + \frac{2}{3} \cdot \frac{(-V_G)^{\frac{3}{2}}}{V_P^{\frac{1}{2}}} - \frac{2}{3} \cdot \frac{(-V_G)^{\frac{3}{2}}}{V_P^{\frac{1}{2}}} \cdot \left(1 + \frac{3}{2} \cdot \left(-\frac{V_D}{V_G} \right) \right) \right]$$

$$I_D = G_O \cdot V_D \cdot \left[1 - \left(\frac{-V_G}{V_P} \right)^{\frac{1}{2}} \right]$$

(b) show that I_D/V_D in the linear range is the same as g_m (sat),

$$\frac{I_D}{V_D} = G_O \cdot \left[1 - \left(\frac{-V_G}{V_P} \right)^{\frac{1}{2}} \right] = g_m(\text{sat})$$

(c) and find the value of V_G for device turn off.

$V_G = -V_P$

Prob. 6.20

$$V_T = V_{FB} + 2\phi_F - \frac{Q_d}{C_i}$$

$$V_{FB} = 2\phi_F - \frac{Q_i}{C_i}$$

$$C_i = \frac{\varepsilon_i}{d} = \frac{8.85\times10^{-14}\times3.9}{100\times10^{-8}} = \mathbf{3.452\times10^{-7}F/cm^2}$$

Note: Here we use dielectric constant of oxide.

According to Fig. (6-17) in the textbook, for $N_a = 10^{18}\text{cm}^{-3}$

$$\Rightarrow \quad \Phi_{ms} = -1.1\text{V}$$

$$V_{FB} = \Phi_{ms} - \frac{Q_i}{C_i} = -1.1 - \frac{5\times10^{10}\times1.6\times10^{-19}}{3.452\times10^{-7}} = -1.12\text{V}$$

$$\phi_F = \frac{kT}{q}\ln\frac{N_a}{n_i} = 0.0259\cdot\ln\left(\frac{10^{18}}{1.5\times10^{10}}\right) = 0.467\text{V}$$

$$W = \sqrt{\frac{2\varepsilon_s(2\phi_F)}{qN_a}} = \sqrt{\frac{2(11.8)(8.85\times10^{-14})(2\times0.347)}{1.6\times10^{-19}\times10^{18}}} = 3.49\times10^{-6}\text{cm}$$

Note: Here we used dielectric constant of Si.

$$Q_d = -qN_aW_m$$

$$V_T = V_{FB} + 2\phi_F - \frac{Q_d}{C_i} = -1.12 + 2(0.467) + \frac{1.6\times10^{-19}\times10^{18}\times3.49\times10^{-6}}{3.452\times10^{-7}} = 1.43\mathbf{V}$$

Prob. 6.21

For the MOSFET, calculate the drain current at $V_G = 5V$, $V_D = 0.1V$. Repeat for $V_G = 3V$, $V_D = 5V$.

For $V_G = 5\text{V}$, $V_D = 0.1\text{V}$, since $V_T = 1\text{V}$

$V_D < (V_G - V_T) \rightarrow$ linear region

$$I_D = \frac{Z}{L}\cdot\bar{\mu}_n\cdot C_i\cdot\left[(V_G-V_T)\cdot V_D - \frac{1}{2}\cdot V_D^2\right]$$

$$= \frac{50\mu\text{m}}{2\mu\text{m}}\cdot200\tfrac{\text{cm}^2}{\text{V}\cdot\text{s}}\cdot3.452\cdot10^{-7}\text{F}\cdot\left[(5\text{V}-1\text{V})\cdot0.1\text{V}-\frac{1}{2}(0.1\text{V})^2\right] = 6.82\cdot10^{-4}\text{A}$$

For $V_G = 3\text{V}$, $V_D = 5\text{V}$, $V_D(\text{sat}) = V_G - V_T = 3\text{V}-1\text{V} = 2\text{V}$

$$I_D = \frac{Z}{L}\cdot\bar{\mu}_n\cdot C_i\left[(V_G-V_T)\cdot V_D(\text{sat}) - \frac{1}{2}\cdot V_D^2(\text{sat})\right]$$

$$= \frac{50\mu\text{m}}{2\mu\text{m}}\cdot200\tfrac{\text{cm}^2}{\text{V}\cdot\text{s}}\cdot3.452\cdot10^{-7}\text{F}\cdot\left[(2\text{V})^2 - \frac{1}{2}(2\text{V})^2\right] = 3.45\cdot10^{-3}\text{A}$$

Prob. 6.22

For the given MOSFET, calculate the linear V_T and k_N, saturation V_T and k_N.

1. Choose $V_D \ll V_D(sat)$ to ensure that I_D-V_D curve is in the linear regime
   e.g., choose $V_D = 0.2$V

(1)	$V_G = 4$ V	$V_D = 0.2$ V	$I_D = 0.35$ mA
(2)	$V_G = 5$ V	$V_D = 0.2$ V	$I_D = 0.62$ mA

In linear regime

(3) $I_D = k_N[(V_G - V_T)V_D - V_D^2/2]$

From equation (3), inserting the values from (1) and (2)

$0.35 \cdot 10^{-3} = k_N\,[(4 - V_T)(0.2)]$
$0.62 \cdot 10^{-3} = k_N\,[(5 - V_T)(0.2)]$
$0.35/0.62 = (4 - V_T) / (5 - V_T)$
$1.75 - 0.35V_T = 2.48 - 0.62V_T$
$V_T = 2.71$V, therefore, $k_N = 1.36 \cdot 10^{-3}$ A/V^2

2. Choose $V_D \gg V_D(sat)$ to ensure that I_D-V_D curve is in the saturation regime
   e.g. choose $V_D = 3$V

(4)	$V_G = 4$ V	$V_D = 3$ V	$I_D = 0.74$ mA
(5)	$V_G = 5$ V	$V_D = 3$ V	$I_D = 1.59$ mA

In saturation regime

(6) $I_D = (1/2)\,k_N\,(V_G - V_T)^2$

$$0.74 \cdot 10^{-3} = \frac{k_N}{2}(4V - V_T)^2$$

$$1.59 \cdot 10^{-3} = \frac{k_N}{2} \cdot (5V - V_T)^2$$

$$\frac{0.74}{1.59} = \frac{(4V - V_T)^2}{(5V - V_T)^2}$$

$V_T = 1.85$V, $k_N = 3.20 \cdot 10^{-4}$A/V^2