1) An NMOS transistor has parameters $W = 10\ \mu m$, $L = 0.25\ \mu m$, $k' = 200\ \mu A/V^2$, $\lambda = 0.01\ V^{-1}$, $V_{T0} = 0.5$ V, $\phi_f = 0.3$ V and $\gamma = 0.5\ V^{1/2}$.

a) Sketch the I_D-V_{DS} characteristics for V_{DS} from 0 to 2.5 V and $V_{GS} = 1.5$ V, 2.5 V. Assume $V_{BS} = 0$ V.

b) Sketch the I_D-V_{GS} characteristics for V_{GS} from 0 to 2.5 V and $V_{DS} = 1$V and 2.5 V. Assume $V_{BS} = -1$ V.

a) $V_T = V_{T0} + \gamma\left(\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right)$

$= V_{T0} = 0.5V$

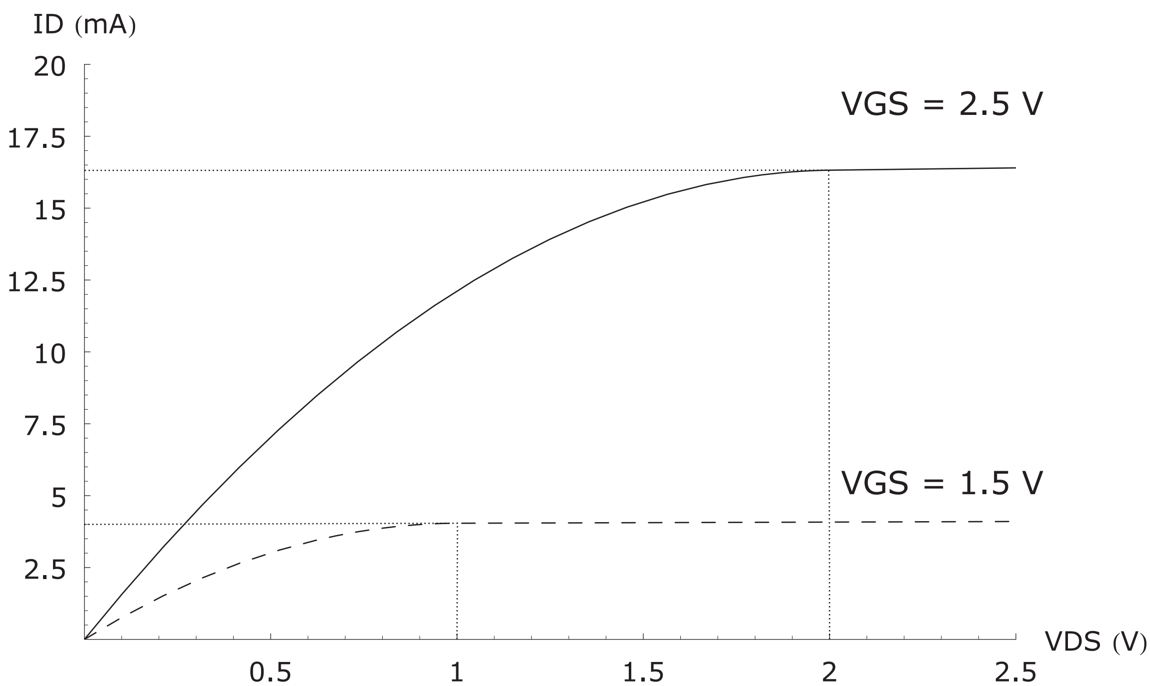
$\frac{k'}{2}\frac{W}{L} = 4\ mA/V^2$ $\qquad 1 + \lambda V_{DS} \leq 1 + 0.025 \approx 1$

$\Rightarrow I_{Dsat}\Big|_{V_{GS}=1.5V} = \frac{k'}{2}\frac{W}{L}(V_{GS} - V_T)^2 = 4mA$

$V_{Dsat}\Big|_{V_{GS}=1.5V} = V_{GS} - V_T = 1V$

$I_{Dsat}\Big|_{V_{GS}=2.5V} = \frac{k'}{2}\frac{W}{L}(V_{GS} - V_T)^2 = 16\ mA$

$V_{Dsat}\Big|_{V_{GS}=2.5V} = V_{GS} - V_T = 2V$



ID (mA)
20
17.5
15
12.5
10
7.5
5
2.5
VGS = 2.5 V
VGS = 1.5 V
VDS (V)
0.5
1
1.5
2
2.5

b) $V_T = V_{T0} + \gamma\left(\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right)$

$\approx 0.75\,V$

$V_{DS} = 2.5\,V$

$0 \leq V_{GS} \leq V_T$: transistor in cut-off
$I_{DS} = 0\,A$

$V_T \leq V_{GS} \leq 2.5V$: transistor in saturation

$$I_{DS} = \frac{k'}{2}\frac{W}{L}\left(V_{GS}-V_T\right)^2\left(1+\lambda V_{DS}\right)$$

$$\approx \frac{k'}{2}\frac{W}{L}\left(V_{GS}-V_T\right)^2 = \frac{4\,mA}{V^2}\left(V_{GS}-0.75V\right)^2$$

→ quadratic in V_{GS}

$V_{Dsat} = V_{GS} - V_T \leq 2.5V - 0.75V < V_{DS}$

$\Rightarrow V_{Dsat} < V_{DS}$

$\Rightarrow$ transistor always in saturation

$V_{DS} = 1V$

$0 \leq V_{GS} \leq V_T$: transistor in cut-off

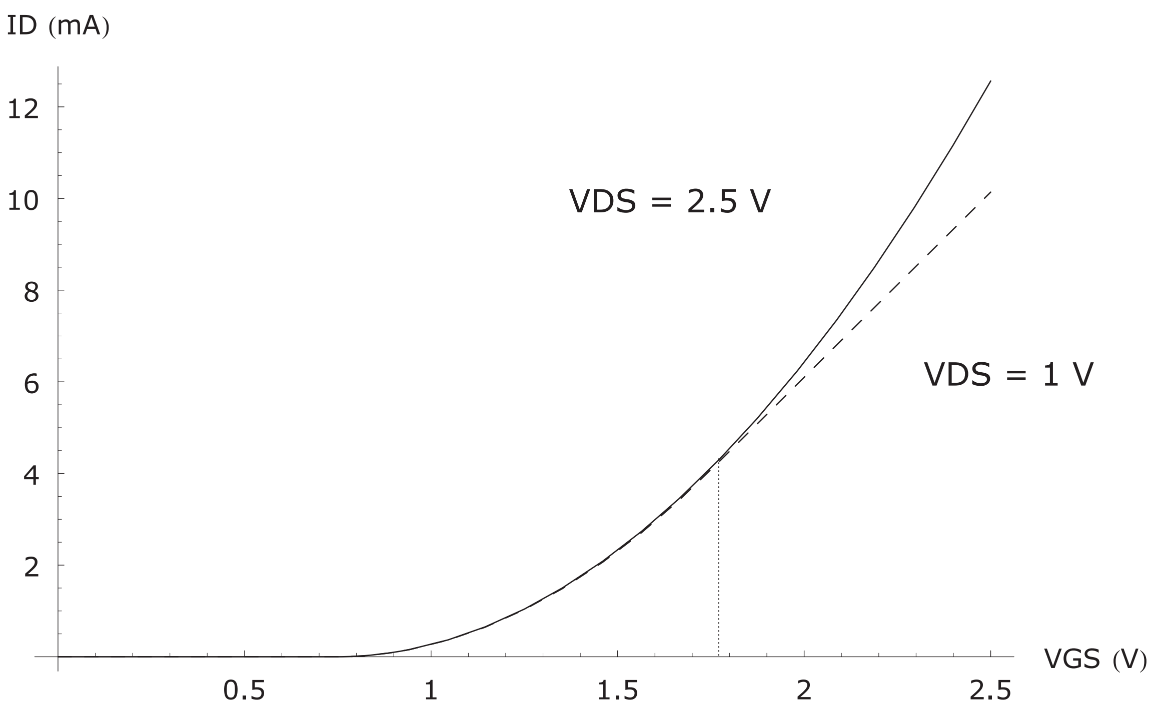
$V_T \leq V_{GS} \leq V_{DS} + V_T$: transistor in saturation

$V_{DS} + V_T \leq V_{GS}$: transistor in linear region,

since $V_{GS} - V_T = V_{Dsat} \geq V_{DS}$

$$\Rightarrow I_{DS} = k'\frac{W}{L}\left(V_{GS} - V_T - V_{DS}/2\right)V_{DS}$$

→ linear in V_{GS}



ID (mA)
12
10
8
6
4
2
VDS = 2.5 V
VDS = 1 V
VGS (V)
0.5
1
1.5
2
2.5

2) There are several different methods to obtain the parameters. Some methods are more accurate than others, and accumulated errors in the successive approximations can cause the values to deviate from the true parameters

V_{T0} : for $V_{DS} = 1.2V$, $V_{BS} = 0$
find I_{DS} for two different V_{GS} and take the ratio

$$\left.\frac{I_{DS}(V_{GS}=1V)}{I_{DS}(V_{GS}=0.8V)}\right|_{\substack{V_{BS}=0\\V_{DS}=1.2V}} = \frac{9.6\,mA}{4.9\,mA}$$

$$= \left(\frac{1-V_{T0}}{0.8-V_{T0}}\right)^2 = \left(1+\frac{0.2V}{0.8V-V_{T0}}\right)^2$$

$$\Rightarrow \boxed{V_{T0} \approx 0.3V}$$

γ : for $V_{DS} = 1.2V$, $V_{GS} = 1V$,
find I_{DS} for two different V_{BS} and take the ratio

$$\frac{I_{DS}(V_{BS}=0V)}{I_{DS}(V_{BS}=-0.5V)} = \frac{9.6\,mA}{8.2\,mA} = \left(\frac{1V-V_{T0}}{1V-V_T}\right)^2$$

$$\Rightarrow V_T - V_{T0} = 53\,mV = \gamma\left(\sqrt{0.6+0.5}-\sqrt{0.6}\right)$$

$$\Rightarrow \boxed{\gamma \approx 0.2\,V^{1/2}}$$

λ : for $V_{GS} = 1V$, $V_{BS} = 0V$
find I_{DS} for two different V_{DS}
and take the ratio;
to get the best approximation
we extrapolate the I_{DS} curve
to the point which would intersect
the axis when $V_{DS} = 0$ (see figure)

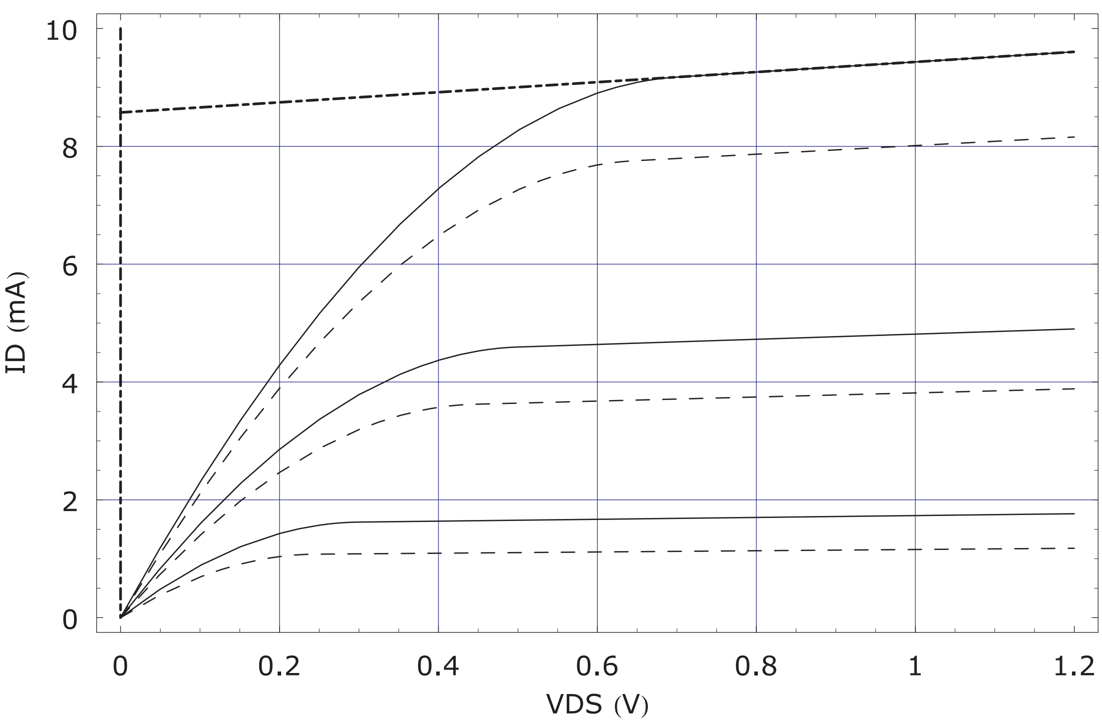
$$\frac{I_{DS}(V_{DS} = 1.2V)}{I_{DS}(V_{DS} = 0V)} = \frac{9.6\,mA}{8.6\,mA} = \frac{1 + \lambda \cdot 1.2V}{1 + \lambda\ 0V}$$

$$\Rightarrow \lambda \approx 0.1\ V^{-1}$$

k' : plug into the equation
for saturation current

$$9.6\,mA = \frac{k'}{2}\ 100\ (1 - 0.3)^2 (1 + 0.1 \cdot 1.2)$$

$$\Rightarrow k' \approx 350\ \mu A/V^2$$



10
8
6
4
2
0
ID (mA)
0
0.2
0.4
0.6
0.8
1
1.2
VDS (V)