Homework 5 Solution:

5.2 $C_{ox} = 9\ \text{fF}/\mu\text{m}^2,\ V_{OV} = 0.2\ \text{V}$

$L = 0.36\ \mu\text{m},\ V_{DS} = 0\ \text{V}$

$W = 3.6\ \mu\text{m}$

$Q = C_{ox}.W.L.V_{OV} = 2.33\ \text{fC}$

5.3 $k_n' = \mu_n C_{ox}$

$$= \frac{\text{m}^2}{\text{V}\cdot\text{s}}\ \frac{\text{F}}{\text{m}^2} = \frac{\text{F}}{\text{V}\cdot\text{s}} = \frac{\text{C/V}}{\text{V}\cdot\text{s}} = \frac{\text{C}}{\text{s}}\ \frac{1}{\text{V}^2}$$

$$= \frac{\text{A}}{\text{V}^2}$$

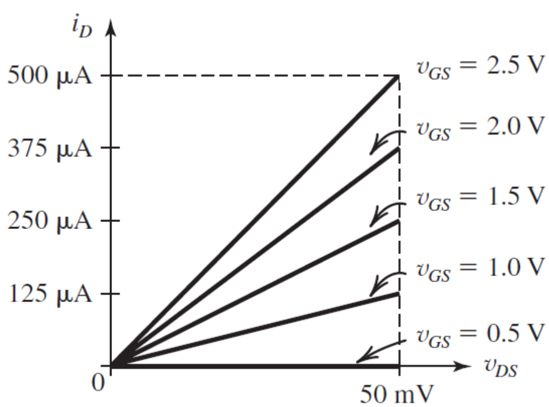
Since $k_n = k_n' W/L$ and W/L is dimensionless, k_n has the same dimensions as k_n'; that is, A/V^2.

5.6 $k_n = 5\ \text{mA/V}^2,\ V_{tn} = 0.5\ \text{V},$

small v_{DS}

$$i_D = k_n(v_{GS} - V_t)\,v_{DS} = k_n v_{OV} v_{DS}$$

$$g_{DS} = \frac{1}{r_{DS}} = k_n v_{OV}$$



V_{GS} (V)	V_{OV} (V)	g_{DS} (mA/V)	r_{DS} (Ω)
0.5	0	0	∞
1.0	0.5	2.5	400
1.5	1.0	5.0	200
2.0	1.5	7.5	133
2.5	2.0	10	100

5.8 $r_{ds} = 1/\left.\dfrac{\partial i_D}{\partial v_{DS}}\right|_{v_{DS} = V_{DS}}$

$$= \left[\frac{\partial}{\partial v_{DS}}\left(k_n\left(V_{OV} v_{DS} - \frac{1}{2}v_{DS}^2\right)\right)\right]^{-1}$$

$$= \left[k_n\left(\frac{\partial}{\partial v_{DS}}\right)(v_{OV} v_{DS}) - 1/2\frac{\partial}{\partial v_{DS}}\left(v_{DS}^2\right)\right]^{-1}$$

$$= \left[k_n\left(V_{OV} - \frac{1}{2}\cdot 2V_{DS}\right)\right]^{-1}$$

$$= \frac{1}{k_n\left(V_{OV} - V_{DS}\right)}$$

If $V_{DS} = 0 \Rightarrow r_{ds} = \dfrac{1}{k_n V_{OV}}$

If $V_{DS} = 0.2V_{OV} \Rightarrow r_{ds} = \dfrac{1.25}{V_{OV}}$

If $V_{DS} = 0.5V_{OV} \Rightarrow r_{ds} = \dfrac{1}{k_n\left(V_{OV} - 0.5V_{OV}\right)}$

$$= 1/k_n\left(0.5V_{OV}\right) = \frac{2}{k_n V_{OV}}$$

If $V_{DS} = 0.8V_{OV} \Rightarrow r_{ds} = \dfrac{1}{k_n\left(V_{OV} - 0.8V_{OV}\right)}$

$$= 1/k_n\left(0.2V_{OV}\right) = \frac{5}{k_n V_{OV}}$$

If $V_{DS} = V_{OV}$,

$$r_{ds} = \frac{1}{0} \Rightarrow \infty$$

5.11 $V_{tp} = -0.7$ V

(a) $|V_{SG}| = |V_{tp}| + |V_{OV}|$

$= 0.7 + 0.4 = 1.1$ V

$\Rightarrow V_G = -1.1$ V

(b) For the p-channel transistor to operate in saturation, the drain voltage must not exceed the gate voltage by more than $|V_{tp}|$. Thus

$v_{D\max} = -1.1 + 0.7 = -0.4$ V

Put differently, V_{SD} must be at least equal to $|V_{OV}|$, which in this case is 0.4 V. Thus $v_{D\max} = -0.4$ V.

(c) In (b), the transistor is operating in saturation, thus

$$I_D = \frac{1}{2}k_p|V_{OV}|^2$$

$$0.5 = \frac{1}{2} \times k_p \times 0.4^2$$

$\Rightarrow k_p = 6.25$ mA/V^2

For $V_D = -20$ mV, the transistor will be operating in the triode region. Thus

$$I_D = k_p\left[v_{SD}|V_{OV}| - \frac{1}{2}v_{SD}^2\right]$$

$$= 6.25\left[0.02 \times 0.4 - \frac{1}{2}(0.02)^2\right]$$

$= 0.05$ mA

For $V_D = -2$ V, the transistor will be operating in saturation, thus

$$I_D = \frac{1}{2}k_p|V_{OV}|^2 = \frac{1}{2} \times 6.25 \times 0.4^2 = 0.5 \text{ mA}$$

5.18 $V_{tn} = 0.5$ V, $\quad k_n = 1.6$ mA/V^2

$$I_D = 0.05 = \frac{1}{2} \times 1.6 \times V_{OV}^2$$

$\Rightarrow V_{OV} = 0.25$ V and $V_{DS} \geq 0.25$ V

$V_{GS} = 0.5 + 0.25 = 0.75$ V

$$I_D = 0.2 = \frac{1}{2} \times 1.6 \times V_{OV}^2$$

$\Rightarrow V_{OV} = 0.5$ V and $V_{DS} \geq 0.5$ V

$V_{GS} = 0.5 + 0.5 = 1$ V