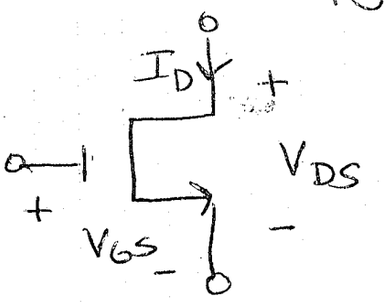
# Problem Set #~~XX~~ Solutions






① $V_{DS} = 0.1V$ $\quad k'_n = 25\mu A/V^2$

$V_t = 1.5V$ $\quad W/L = 10$

$V_{GS} = 0V$, $V_{GS} < V_t$ $\quad I_D = 0$

$V_{GS} = 1V$, $V_{GS} < V_t$ $\quad I_D = 0$

$V_{GS} = 2V$, $V_{GS} - V_t = 2 - 1.5 = 0.5$

$V_{DS} < V_{GS} - V_t$ } triode

$0.1 < 0.5$

$$I_D = k'_n \frac{W}{L} \left[ (V_{GS} - V_t) V_{DS} - \frac{1}{2} V_{DS}^2 \right]$$

$$= 25 \underset{(10)}{\left[ (0.5)(.1) - \frac{1}{2}(.1)^2 \right]}$$

$$= 1.1.25 \mu A$$

$V_{GS} = 3V$, $V_{GS} - V_t = 3 - 1.5 = 1.5V$

$.1V < 1.5V$ $\Rightarrow$ triode

$$I_D = k'_n \frac{W}{L} \left[ (V_{GS} - V_t) V_{DS} - \frac{1}{2} V_{DS}^2 \right]$$

$$= 25 (10) \left[ (1.5)(.1) - \frac{1}{2}(.1)^2 \right]$$

$$I_D = 36.25 \mu A$$

② $V_{DS} = 3.3V$ $k'_n = 37.5\mu A$ $V_t = 1V$ $W/L = 10$

$V_{GS} = 0$ , $V_{GS} < V_t$ , $I_D = 0$

$V_{GS} = 1$ , $V_{GS} = V_t$ , $I_D = 0$

$V_{GS} = 2$ , $V_{GS} - V_t = 1$ $3.3 > 1$ saturation

$$I_D = \frac{1}{2} k'_n \frac{W}{L} (V_{GS} - V_t)^2$$

$$= \frac{1}{2}(37.5)(10)(1)^2$$

$$= 187.5\mu A$$

$V_{GS} = 3$ , $V_{GS} - V_t = 2V$ $3.3 > 2$ saturation

$$I_D = \frac{1}{2}(37.5)(10)(2)^2$$

$$= 750\mu A$$

③ $k'_n = 25\mu A/V^2$ $W/L = 10$ $V_t = 1V$

a) $V_{GS} = 5V$ $V_{DS} = 6V$ $6 > 5-1$ saturation

$$I_D = \frac{1}{2}(25)(10)(5-1)^2$$

$$= 2mA$$

b) $V_{GS} = 0$ $V_{GS} < V_t \Rightarrow$ cut off $I_D = 0$

③ c) $V_{GS} = V_{DS} = 2 \Rightarrow$ saturation

$$I_D = \frac{1}{2}(25)(10)(1)^2$$

$$= 125\,\mu A$$

d) $V_{DS} < 0$ cutoff $I_D = 0$

④ $V_t = 0.8V$ $k'_n = 0.05\,mA/V^2$ $\frac{W}{L} = 2$

$V_{GS} = 2.5$ $V_{DS} = 2V$ & $10V$

a) $\lambda = 0$

$V_{DS} = 2V$

$V_{GS} - V_t = 1.7V$

$$I_D = \frac{1}{2} k'_n \frac{W}{L}(V_{GS} - V_t)^2$$

$$= 0.14\,mA$$

$V_{DS} = 10V$

$V_{GS} - V_t = 1.7V$

$$I_D = \frac{1}{2} k'_n \frac{W}{L}(V_{GS} - V_t)^2$$

$$= 0.14\,mA$$

b) $\lambda = 0.02$

$V_{DS} = 2V$

$V_{GS} - V_t = 1.7V$

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

$$= 0.15\,mA$$

$V_{DS} = 10V$

$V_{GS} - V_t = 1.7V$

$I_D = 0.17\,mA$

# Problem Set #6

④ c) $V_A = 35V$ $\lambda = 0.03\,V^{-1}$

$V_{DS} = 2V$
$I_D = 0.153\,mA$

$r_O = \frac{35}{.1445} = 242.21\,k\Omega$

$V_{DS} = 10V$
$I_D = 0.19\,mA$
$r_O = 242.21\,k\Omega$

⑤ $V_t = 0.8V$ $k'_n = 0.05\frac{mA}{V^2}$ $\frac{W}{L} = 2$

$V_{GS} = 2.5$
$V_{DS} = 4V$

$V_A = 40V$

a) $\lambda = \frac{1}{V_A} = 0.025\,V^{-1}$

b) $I_D = \frac{1}{2} k'_n \frac{W}{L} (V_{GS} - V_t)^2$

$= \frac{1}{2}(.05)(2)(1.7)^2$

$= 0.1445\,mA$

c) $I_D = \frac{1}{2} k'_n \frac{W}{L} (V_{GS} - V_t)^2 (1 + \lambda V_{DS})$

$I_D = 0.159\,mA$

d) $r_O = \frac{V_A}{I_{D_1}} = \frac{40}{.1445} = 276.82\,k\Omega$

no channel mod.

$r_O = \frac{\Delta V_{DS}}{\Delta I_D}$ $\Delta I_D = \frac{2}{r_O} = 7.22\,\mu A$

# PS #6 - Solutions

6. $k'_p = 0.1\ mA/V^2$ $\quad V_t = -2V$ $\quad V_{SG} - |V_{tp}| = 1V$

$W/L = 2$ $\quad V_{SG} = 3V$

triode: $I_D = k'_p \frac{W}{L}\left[(V_{SG} - |V_{tp}|)V_{SD} - \frac{1}{2}V_{SD}^2\right]$

$V_{SD} < V_{SG} - |V_{tp}|$

saturation: $I_D = \frac{1}{2} k'_p \frac{W}{L}(V_{SG} - |V_{tp}|)^2$

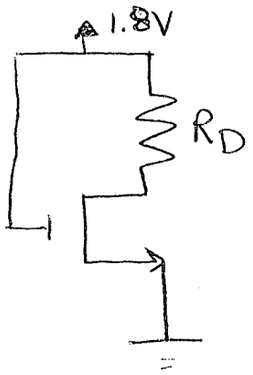
$V_{SD} \geq V_{SG} - |V_{tp}|$

a) $V_{SD} = 0.5V < 1V$ triode $I_D = 75\mu A$

b) $V_{SD} = 2V > 1$ saturation $I_D = 0.1\ mA$

c) $V_{SD} = 5V > 1$ saturation $I_D = 0.1mA$

7.




$V_t = 0.5V$

$k'_n = 0.4mA/V^2$

$W/L = 5$

$I_D = 1mA$

edge of saturation

$V_{GS} = 1.8 - 0$
$= 1.8V$

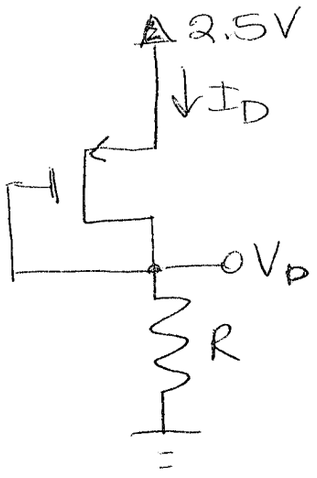
$V_{DS} = V_{GS} - V_t$
$= 1.8 - 0.5$
$= 1.3V$

$V_D = 1.3V$

$R_D = \frac{1.8 - 1.3}{1mA} = 0.5\ k\Omega$

# PS#6 Solutions

8.




$V_t = 0.6\,V$

$k'_p = 250\,\frac{\mu A}{V^2}$

$L = 0.25\,\mu m$

$I_D = 0.8\,mA = 800\,\mu A$

$V_D = 1.5V$

$V_{SG} = 2.5 - 1.5 = 1.0V$

device in saturation because gate & drain are tied together.

$$I_D = \frac{1}{2} k'_p \frac{W}{L} (V_{SG} - |V_t|)^2$$

$$800 = \frac{1}{2}(250)\left(\frac{W}{.25}\right)(1-.6)^2$$

$$W = 10\,\mu m$$

$$R = \frac{V_D}{I_D} = 1.875\,k\Omega$$

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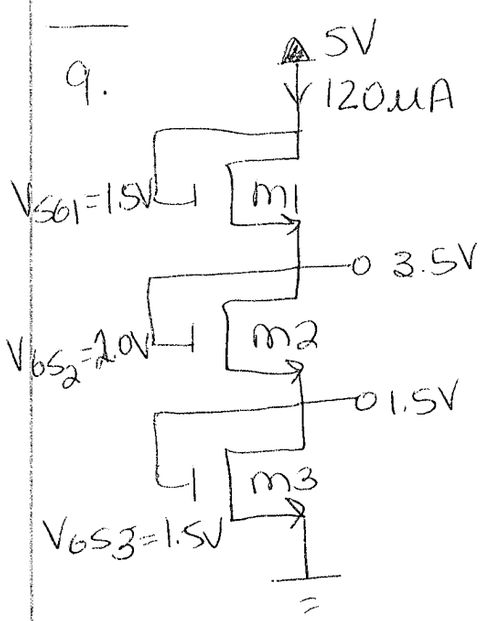
9.




$V_t = 1V$ $\quad I_D = 120\,\mu A$

$k'_n = 120\,\mu A/V^2$

$L = 1\,\mu m$

$120 = \frac{1}{2}(120)(W_3)(1.5-1)^2$

$W_3 = 8\,\mu m$

$120 = \frac{1}{2}(120)(W_2)(2-1)^2$

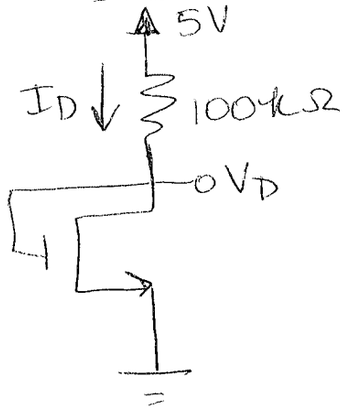
$W_2 = 2\,\mu m$

$120 = \frac{1}{2}(120)(W_1)(0.5)^2$

$W_1 = 8\,\mu m$

# PS #6 - Solutions

10. $V_t = 0.8V$ $\quad k'_n = 0.25 \frac{mA}{V^2}$ $\quad \frac{W}{L} = 2$




$V_D = V_G \Rightarrow$ saturation

$V_{GS} = V_{DS} = V_D$

Alt $I_D = I_D$

$$I_D = \frac{1}{2} k'_n \frac{W}{L} (V_{GS} - V_t)^2$$

$$I_D = \frac{1}{2}(.25)(2)(V_D - .8)^2$$

$$I_D = .25(V_D - .8)^2$$

also $I_D = \frac{5 - V_D}{100}$ (mA)

$$.25(V_D - .8)^2 = \frac{5 - V_D}{100}$$

$$25(V_D^2 - 1.6V_D + .64) = 5 - V_D$$

$$25V_D^2 - 40V_D + 16 = 5 - V_D$$

$$25V_D^2 - 39V_D + 11 = 0$$

$$V_D = \frac{39 \pm \sqrt{39^2 - 4(25)(11)}}{50}$$

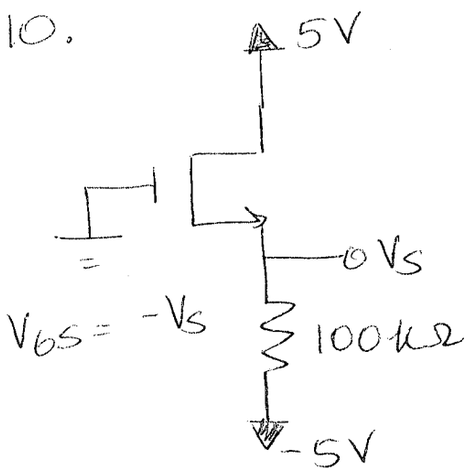
$$= \frac{39 \pm 20.52}{50}$$

$$= 1.19\,V \text{ or } 0.37\,V$$

$$\boxed{V_D = 1.19V}$$

# PS#6 - Solutions

10.




$V_t = 0.8V$

$k'_n = 0.25\,mA/V^2$

$W/L = 2$

$V_G = 0$, $V_D = 5$ } saturation

$$I_D = \frac{V_S + 5}{100}\ (mA)$$

$$I_D = \frac{1}{2}(25)(2)(-V_S - .8)^2$$

Set $I_D = I_D$

$$25(-V_S - .8)^2 = V_S + 5$$

$$25(V_S^2 + 1.6V_S + 0.64) = V_S + 5$$

$$25V_S^2 + 40V_S + 16 = V_S + 5$$

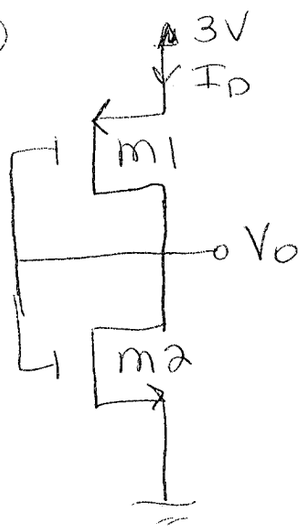
$$25V_S^2 + 39V_S + 11 = 0$$

$V_S = -0.36\ V$ or $= -1.19\ V$ } $V_{GS} = 0.36$ or $V_{GS} = 1.19V$

$\boxed{V_{GS} = 1.19V}$

$\boxed{V_S = -1.19V}$

11.




$V_{SG1} = 3 - V_o$, $V_{GS2} = V_o$ } both in saturation

$$I_{D1} = \frac{1}{2}(8)(3)(3 - V_o - 1)^2$$

$$I_{D2} = \frac{1}{2}(20)(3)(V_o - 1)^2$$

$I_{D1} = I_{D2}$

$$12(2 - V_o)^2 = 30(V_o - 1)^2$$

$$4 - 4V_o + V_o^2 = 2.5(V_o^2 - 2V_o + 1)$$

# PS #6 - Solutions

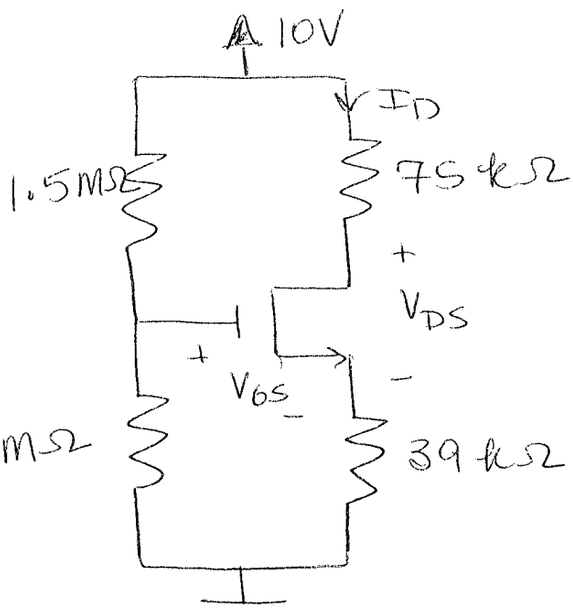
(11) cout

$1.5V_o^2 - V_o - 1.5 = 0$ $\quad V_o = 1.39\,V$

$V_o = -0.72\,V$

$\boxed{V_o = 1.39\,V}$ $\quad I_D = 4.56\,\mu A$

(12)




$k'_n = 0.02\,mA/V^2$

$V_t = 2V$

$\frac{W}{L} = 5$

by voltage division

$V_G = 10 \cdot \frac{1}{2.5}$

$= 4V$

Assume saturation

$I_D = \frac{1}{2}(.02)(5)(4 - V_S - 2)^2$ $\quad I_D = \frac{V_S}{39}\,(mA)$

$\frac{V_S}{39} = 0.05(2 - V_S)^2$

$V_S = 1.95(4 - 4V_S + V_S^2)$

$1.95V_S^2 - 8.8V_S + 7.8 = 0$ $\quad V_{GS} = 0.70V$

or

$\boxed{2.79V}$

$V_S = \frac{8.8 \pm \sqrt{(8.8)^2 - 4(1.95)(.78)}}{2(1.95)}$

$= \frac{8.8 \pm 4.07}{3.9}$

$V_S = 3.30V$ $\quad$ or $\quad \boxed{1.21V}$

(12) cont $V_S = 1.21V$

$V_{GS} = 2.79V$ $I_D = V_S/39$

$I_D = 0.031mA$

$V_D = 10 - I_D(75)$

$= 7.66V$

$V_{DS} = 6.44V$

$V_{DS} \geq V_{GS} - V_t$

assumption is correct.