① $V_{DS} = .1V$

$V_t = 1.5V$

$k'_n = 25\mu A/V^2$

$\frac{W}{L} = 10$

$V_{GS} = 0V$

$V_{GS} < V_t \qquad I_D = 0 \longrightarrow$ cut off

$V_{GS} = 1V$

$V_{GS} < V_t \qquad I_D = 0 \longrightarrow$ cut off

$V_{GS} = 2V$

$V_{DS} < V_{GS} - V_t \longrightarrow$ triode region

$.1 < 2 - 1.5$

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

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

$$\boxed{I_D = 11.25\mu A}$$

$V_{GS} = 3V$

$0.1 < 3 - 1.5$

triode

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

$$= 36.25\ \mu A$$

(See my additional clarification note in the Module 4 lecture)

(2) $V_{DS} = 3.3V$ $\quad k'_n = 37.5\ \mu A/V^2$

$V_t = 1V$ $\quad W/L = 10$

$V_{GS} = 0V$ cutoff $\quad I_D = 0$

$V_{GS} = 1V$ cutoff $\quad I_D = 0$

$V_{GS} = 2V$ Saturation

$V_{DS} > V_{GS} - V_t$

$3.3 > 2 - 1$

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

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

$$\boxed{I_D = 187.5\ \mu A}$$

$V_{GS} = 3V$ saturation

$V_{DS} > V_{GS} - V_t$

$3.3 > 3 - 1$

$\boxed{I_D = 750\,\mu A}$

(3) $k'_n = 25 \frac{\mu A}{V^2}$ $V_t = 1V$ $\frac{W}{L} = 10$

a) $V_{GS} = 5V$ $V_{DS} = 6V$

$V_{DS} > V_{GS} - V_t \Rightarrow$ saturation

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

$= \frac{1}{2}(25)(10)(4)^2$

$\boxed{I_D = 2\,mA}$ or $2000\,\mu A$ ☺

b) $V_{GS} = 0$ $V_{DS} = 6V$

cutoff $I_D = 0$

c) $V_{GS} = 2V$ $V_{DS} < 0$

$V_{DS} = -0.5V$

cutoff

$I_D = 0$

④ $V_t = 0.8V$ $\quad \frac{W}{L} = 2$

$k'_n = 0.05 \frac{mA}{V^2}$ $\quad V_{GS} = 2.5V$

a) $\lambda = 0$

$V_{DS} = 2V$ $\quad V_{DS} = 10V$

$V_{DS} > V_{GS} - V_t$ $\quad V_{DS} > V_{GS} - V_t$

$2 > 1.7$ $\quad 10 > 1.7$

saturation $\quad$ saturation

$I_D = \frac{1}{2} k'_n \frac{W}{L} (V_{GS} - V_t)^2$ $\quad I_D = 0.14mA$

$I_D = 0.14mA$

b) $\lambda = 0.02\ V^{-1}$

$V_{DS} = 2V$ $\quad V_{DS} = 10V$

saturation $\quad$ saturation

$r_o = \frac{1}{\lambda I_D}$ $\quad r_o = \frac{1}{\lambda I_D}$

$r_o = \frac{1}{(.02)(.14mA)}$ $\quad r_o = 375.14\ k\Omega$

$r_o = 375.14\ k\Omega$

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

$I_D = 0.15\,mA$ $\qquad$ $I_D = 0.17\,mA$

---

c) $V_A = 35\,V$

$V_{DS} = 2\,V$ $\qquad$ still saturation $\qquad$ $V_{DS} = 10\,V$

$r_o = \frac{V_A}{I_D}$

$r_o = 250\,k\Omega$ $\qquad$ $r_o = 250\,k\Omega$

$I_D = 0.153\,mA$ $\qquad$ $I_D = 0.19\,mA$

(5) $k'_p = \frac{1\,mA}{V^2}$ $\qquad$ $\frac{W}{L} = 2$ $\qquad$ $V_t = -2\,V$

$V_{SG} = 3\,V$

a) $V_{SD} = 0.5\,V$ $\qquad$ triode

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

$0.5\,V < 1\,V$

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

$= 0.75\,\mu A$

b) $V_{SD} = 2V$

$V_{SD} > V_{SG} - |V_t|$

saturation

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

$I_D = 0.1mA$

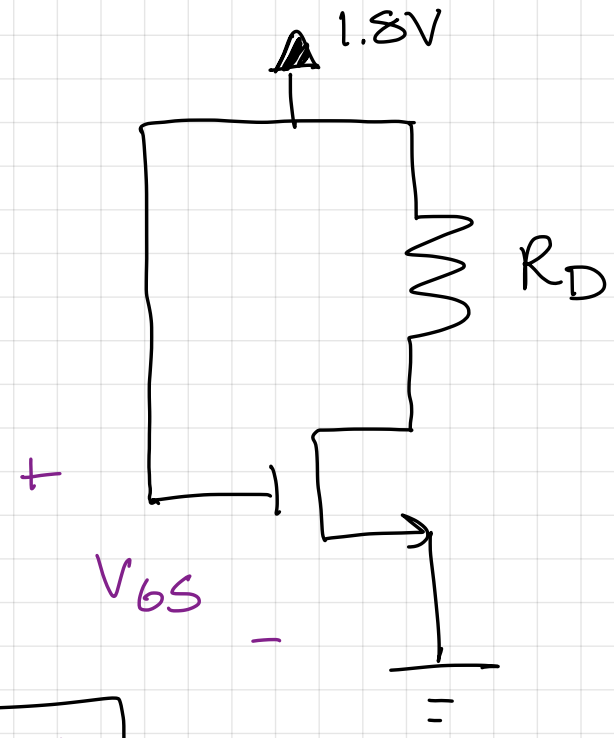
c) $V_{SD} = 5V$

$V_{SD} > V_{SG} - |V_t|$

saturation

$I_D = 0.1mA$

(6)



$V_t = 0.5V$

$k'_n = 0.4 \frac{mA}{V^2}$

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

at edge of saturation

$V_{DS} = V_{GS} - V_t$

$V_{DS} = 1.8 - 0.5$

$V_{DS} = 1.3V$

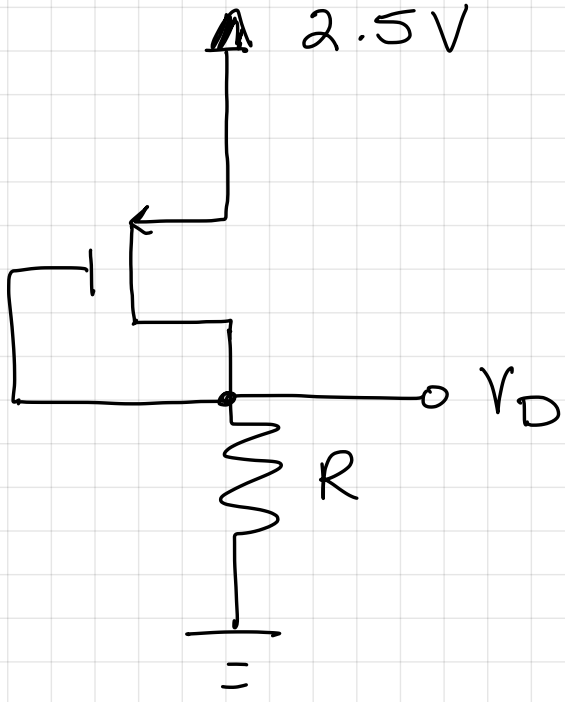
$I_D = 1mA$

$V_{GS} = 1.8V$

$V_D = 1.3V$

$$R_D = \frac{1.8 - V_D}{I_D} = \frac{1.8 - 1.3}{1 \times 10^{-3}} = 0.5\ k\Omega$$

(7)



$|V_t| = 0.6V$

$k'_p = 250\ \mu A/V^2$

$L = 0.25\ \mu m$

$I_D = 0.8\ mA$

$V_D = 1.5V$

gate & drain are tied together so device in saturation.

$V_D = V_G = 1.5V$

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

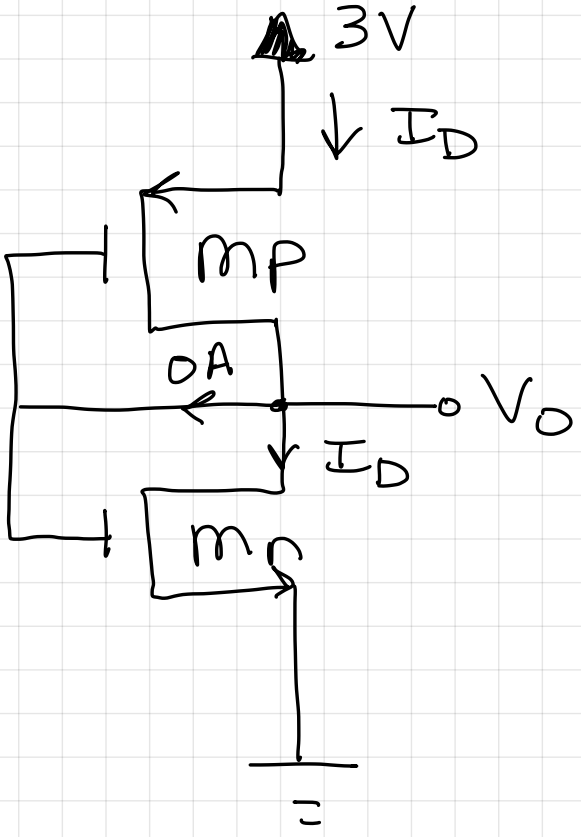
$$I_D = \frac{1}{2} k'_p \frac{W}{L} (V_{SG} - |V_t|)^2$$

$$0.8 \times 10^{-3} = \frac{1}{2} (250 \times 10^{-6}) \left(\frac{W}{0.25\mu m}\right) (1 - .6)^2$$

$$\boxed{W = 10\ \mu m}$$

$$R = \frac{V_D}{I_D} = \frac{1.5}{.8 \times 10^{-3}} = 1.875\ k\Omega$$

(8)



$V_{tn} = |V_{tp}| = 1V$

$k'_n = 20\ \mu A/V^2$

$k'_p = 8\ \mu A/V^2$

$\frac{W}{L} = 3$

step 1: what mode is each device in?

for both devices: the drain and gate are tied together

$\Downarrow$

Saturation

$V_{GSn} = V_O$ $\quad$ $V_{SGp} = 3 - V_O$

② Write current equations

$$I_{DP} = \frac{1}{2} k'_p \left(\frac{W}{L}\right)(V_{SG} - |V_{tp}|)^2$$

$$I_{Dn} = \frac{1}{2} k'_n \left(\frac{W}{L}\right)(V_{GS} - V_{tn})^2$$

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

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

$$I_{DP} = I_{Dn}$$

$$\frac{1}{2}(8)(3)(2 - V_o)^2 = \frac{1}{2}(20)(3)(V_o - 1)^2$$

$$1.5V_o^2 - V_o - 1.5 = 0$$

two solutions

$V_o = 1.39V$

$V_o = -0.72V$ ← results in cutoff

$I_D = 4.56\mu A$