EECS 311 PS5 Solution

P5.1

(a) For $V_{GS} = 0V$

$\Rightarrow$ cutoff region, $\boxed{I_D = 0}$ #

(b) For $V_{GS} = 1V$

$\Rightarrow$ cutoff region, $\boxed{I_D = 0}$ #

(c) For $V_{GS} = 2V$, $V_{DS} = 0.1V$

$\Rightarrow V_{GS} - V_t > V_{DS} \Rightarrow$ triode region

$$I_D = k_n' \frac{W}{L}\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right) V_{DS}$$

$$= \left(250 \frac{\mu A}{V^2}\right)\left(\frac{10}{1}\right)\left(2 - 1 - \frac{0.1}{2}\right)(0.1) = \boxed{237.5 \mu A}$$ #

(d) For $V_{GS} = 3V$, $V_{DS} = 0.1V$

$\Rightarrow V_{GS} - V_t = 2V > V_{DS} \Rightarrow$ triode region

$$I_D = k_n' \frac{W}{L}\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right) V_{DS}$$

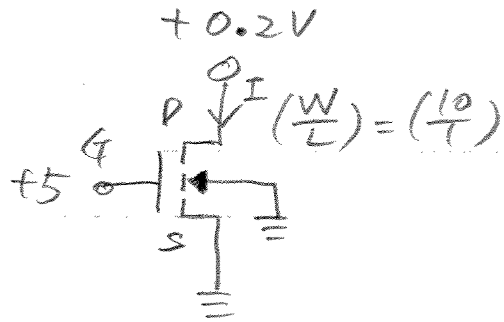
$$= \left(250 \frac{\mu A}{V^2}\right)\left(\frac{10}{1}\right)\left(3 - 1 - \frac{0.1}{2}\right)(0.1)$$

$$= \boxed{487.5 \mu A}$$ #

(e) $$k_n = k_n' \frac{W}{L} = 250 \frac{\mu A}{V^2} \times 10 = \boxed{2.5 \frac{mA}{V^2}}$$ #

P5.2

(a)



$V_{GS} = V_G - V_S = 5V$

$V_{DS} = V_D - V_S = 0.2V$

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

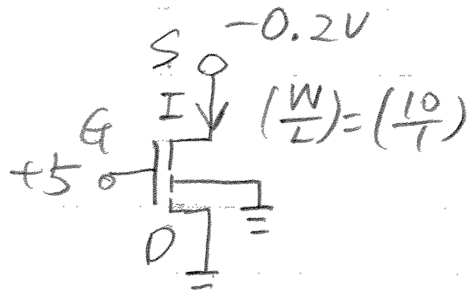
$\Rightarrow$ Triode region

$$I = K_n' \frac{W}{L}\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right) V_{DS}$$

$$= \left(100 \frac{\mu A}{V^2}\right)\left(\frac{10}{1}\right)\left(5 - 0.7 - \frac{0.2}{2}\right) 0.2$$

$$= \boxed{840 \mu A}$$ #

(b)



$V_{GS} = V_G - V_S = 5.2V$

$V_{DS} = V_D - V_S = 0.2V$

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

$$I = -K_n' \frac{W}{L}\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right) V_{DS}$$

$$= -\left(100 \frac{\mu A}{V^2}\right)\left(\frac{10}{1}\right)\left(5.2 - 0.7 - \frac{0.2}{2}\right) 0.2$$

$$= \boxed{-880 \mu A}$$ #

P5.3

(a)

$$R_{on} = \frac{1}{k_n' \frac{W}{L}(V_{GS} - V_{tn})}$$

$$= \frac{1}{100\times10^{-6} \times (\frac{100}{1}) \times (5-0.65)}$$

$$\approx \boxed{23\,\Omega}$$ #

(b)

$$R_{on} = \frac{1}{k_n' \frac{W}{L}(V_{GS} - V_{th})}$$

$$= \frac{1}{100\times10^{-6} \times (\frac{100}{1}) \times (3.3-0.5)}$$

$$\approx \boxed{35.7\,\Omega}$$ #

P5.4 NMOS, $K_n = 250\,\mu A/V^2$, $V_{tN} = 1\,V$

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

$V_{DS} > V_{GS} - V_t \Rightarrow$ $\boxed{\text{Saturation region}}$ #

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

$V_{GS} < V_t \Rightarrow$ $\boxed{\text{cutoff region}}$ #

(c) $V_{GS} = 2\,V$, $V_{DS} = 2\,V$

$V_{GS} - V_t = 1 < V_{DS} = 2\,V \Rightarrow$ $\boxed{\text{Saturation region}}$ #

(d) $V_{GS} = 1.5\,V$, $V_{DS} = 0.5\,V$

$V_{GS} - V_t = 0.5 = V_{DS}$

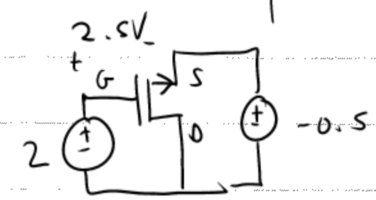
$\Rightarrow$ $\boxed{\text{Boundary between triode and saturation region}}$ #

(e) $V_{GS} = 2\,V$, $V_{DS} = -0.5\,V$

$\cancel{V_{GS} - V_t = 2 - 1 = 1 > V_{DS}}$

$\Rightarrow$ $\boxed{\text{triode region}}$ #

Drain & Source flip



$V_{GS} = 2.5V$

$V_{DS} = 0.5V$

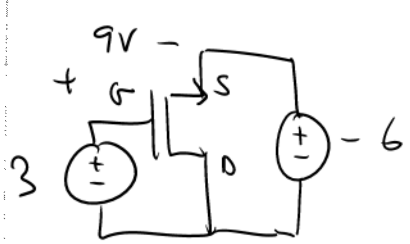
$\boxed{\text{Linear}}$

(f) $V_{GS} = 3\,V$, $V_{DS} = -6\,V$

$\cancel{V_{GS} - V_t = 2 > V_{DS} = -6\,V}$

$\Rightarrow$ $\boxed{\text{triode region}}$ #

$V_{DS} < 0$ D & S terminals flip

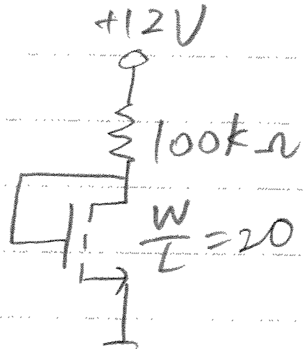


$V_{GS} = 9V > V_T$

$V_{DS} = 6V < V_{GS} - V_T$

$\boxed{\text{Linear}}$

P5.5



(a) $\lambda = 0$, $W/L = 20$.

The transistor is in saturation region since its gate and drain are connected together.

$$I_D = \frac{12 - V_{GS}}{100K} = \frac{1}{2} \times 100 \frac{\mu A}{V^2} \times 20 \times (V_{GS} - 0.75)$$

$\Rightarrow V_{GS} = 0.4V$ or $1.08V$

(V_{GS} should be greater than V_{th})

$$I_D = \frac{12 - 1.08}{100K} = \boxed{109.2 \mu A}$$ #

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

$$I_D = \frac{12 - V_{GS}}{100K} = \frac{1}{2} \times 100 \frac{\mu A}{V^2} \times 20 (V_{GS} - 0.75)^2 (1 + 0.02 V_{GS})$$

$\Rightarrow V_{GS} = 0.41V$ or $1.07V$

$$I_D = \frac{12 - 1.07}{100K} = \boxed{109.3 \mu A}$$ #

P5.6 NMOS, $W/L = 8$, $V_{T0} = 1V$, $2\Phi_F = 0.6V$,
$\gamma = 0.7\sqrt{V}$, $V_{SB} = 3V$, $V_{GS} = 2.5V$, $V_{DS} = 5V$

(a)

$V_{TN} = 1 + 0.7(\sqrt{3+0.6} - \sqrt{0.6}) = 1.79\ V$

$V_{GS} - V_{TN} = 2.5 - 1.79 = 0.71 < V_{DS} = 5V$

$\Rightarrow$ Saturation region

$I_D = 100\mu \times \frac{1}{2} \times 8 \times (0.71)^2$

$= \boxed{201.64\mu A}$ #

(b) $V_{DS} = 0.5V \Rightarrow$ Triode region.

$I_D = 100\mu \times 8 \times (0.71 - \frac{0.5}{2}) \times 0.5$

$= \boxed{184\mu A}$ #

P.7

P5.7 $V_{BS} = 0V$, $W/L = 20$, PMOS, $V_{tp} = -0.75$

(a) $V_{GS} = -1.1V$, $V_{DS} = -0.2V$

$V_{SG} - |V_{tp}| = 1.1 - 0.75 = 0.35V$

$V_{SD} = 0.2V$

$V_{SD} < V_{SG} - |V_{tp}| \Rightarrow$ triode region

$I_D = 40\mu \times 20 \times (0.35 - \frac{0.2}{2})0.2$

$= \boxed{40\mu A}$ #

(b) $V_{GS} = -1.3V$, $V_{DS} = -0.2V$

$V_{SG} - |V_{tp}| = 1.3 - 0.75 = 0.55V$, $V_{SD} = 0.2V$

$V_{SD} < V_{SG} - |V_{tp}| \Rightarrow$ triode region

$I_D = 40\mu \times 20 \times (0.55 - \frac{0.2}{2})0.2 = \boxed{72\mu A}$ #

(c) $V_{BS} = 1V$, $V_{GS} = -1.1V$, $V_{DS} = -0.2V$

$V_{tp} = -0.75 - 0.5(\sqrt{1+0.6} - \sqrt{0.6})$

$= -0.995V$

$V_{SG} - |V_{tp}| = 1.1 - 0.995 = 0.105V$

$V_{SD} = 0.2V$, $V_{SD} > V_{SG} - |V_{tp}|$

$\Rightarrow$ saturation region

$I_D = \frac{1}{2} \times 40\mu \times 20 \times (0.105)^2$

$= \boxed{4.41\mu A}$ #

(d) $V_{BS} = 1V$,

$V_{SG} - |V_{tp}| = 1.3 - 0.995 = 0.3V$

$V_{SD} = 0.2V$

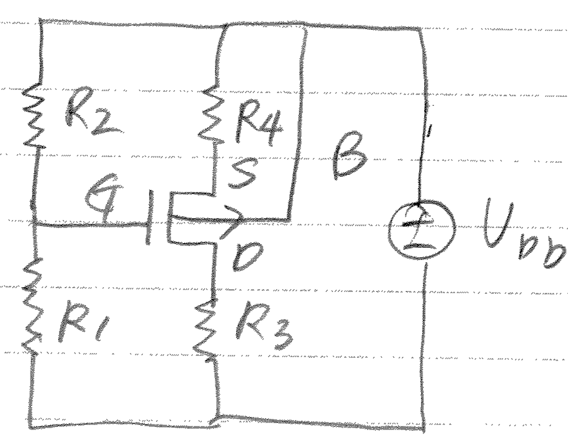
⇒ Triode region

$$I_D = 40\mu \times \left(0.3 - \frac{0.2}{2}\right) \times 0.2 \times 20$$

$$= \boxed{32\mu A}$$ #

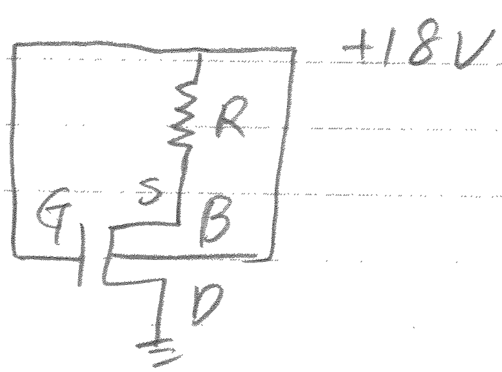
P5.8

(a)

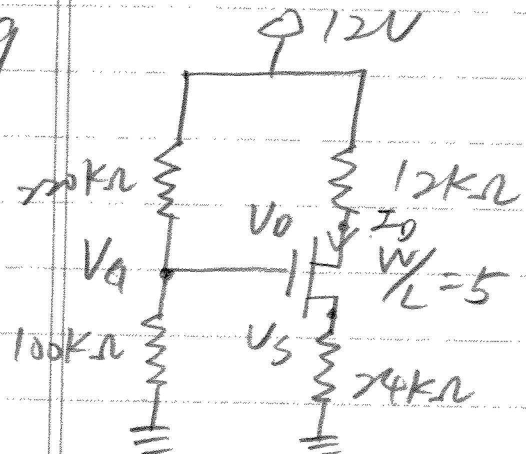


$V_{DD} = 10V$

(b)



P5.9



$V_{tn} = 1V$, $\lambda = 0$,
$\mu_n C_{ox} = k_n' = 100\ \mu A/V^2$

$$V_G = 12 \times \frac{100}{100+220} = 3.75V$$

$$V_D = 12 - I_D \times 12K$$

$$V_S = 24K \times I_D$$

$$I_D = \frac{1}{2} \times 100\mu \times 5 \times (3.75 - 24K \cdot I_D - 1)^2$$

$$\Rightarrow I_D = 90\ \mu A \text{ or } 146\ \mu A$$

① $I_D = 90\mu A$

$V_{GS} = 3.75 - 2.16 = 1.59V$

$V_{DS} = 10.92 - 2.16 = 8.76V$

$V_{DS} > V_{GS} - V_t \Rightarrow$ Saturation region.

② $I_D = 146\mu A$

$V_{GS} = 3.75 - 3.5 = 0.25V$

$V_{GS} < V_t \Rightarrow$ cutoff region

$$\Rightarrow \boxed{I_D = 90\mu A}$$

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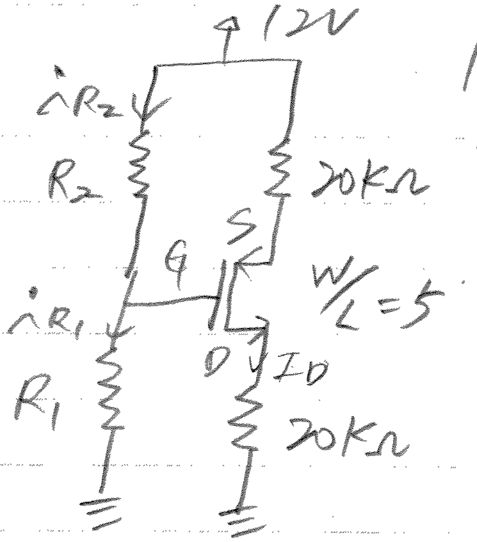
P5.10



PMOS, $I_D = 100\mu A$

$i_{R1} = i_{R2} = 10\mu A$

$V_{TP} = -1V$, $\lambda = 0$, $\mu_n C_{ox} = 40\mu A/V^2$

$$100\mu = \frac{1}{2} \times 40\mu \times 5 \times \{[(12 - 20k \cdot 100\mu) - V_G] - 1\}^2$$

$$V_G = i_{R1} \times R_1 = 10\mu \cdot R_1$$

$\Rightarrow V_G = 8\,V$ or $10\,V$

① $V_G = 8V$

$V_S = 12 - 20k \times 100\mu = 10V$

$V_{SG} = 2V > |V_{tp}|$

$V_{SG} - |V_{tp}| = 1 < V_{SD} = 8\,V$

Saturation region

② $V_G = 10V$

$V_S = 10V \Rightarrow V_{SG} = 0\,V < |V_{tp}|$

Cutoff region

$\therefore \boxed{V_G = 8V}$

$$\Rightarrow \frac{R_1}{R_1 + R_2} \times 12 = 8, \qquad \frac{12}{R_1 + R_2} = 10\mu$$

$$\Rightarrow \boxed{\begin{cases} R_1 = 0.8\,M\Omega \\ R_2 = 0.4\,M\Omega \end{cases}}$$

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