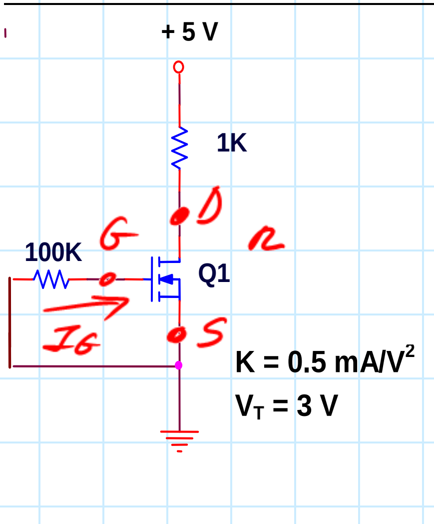
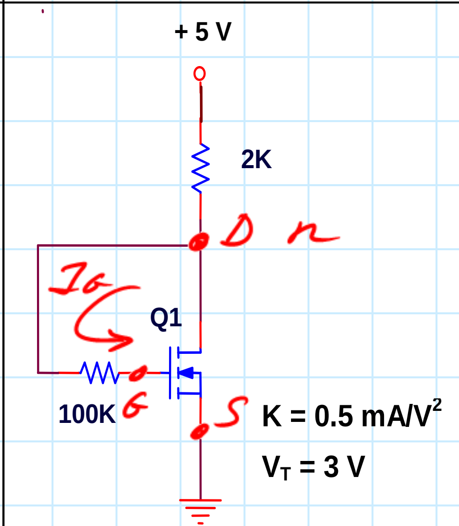
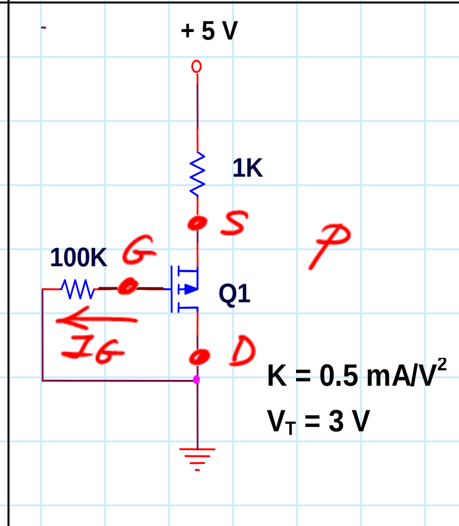
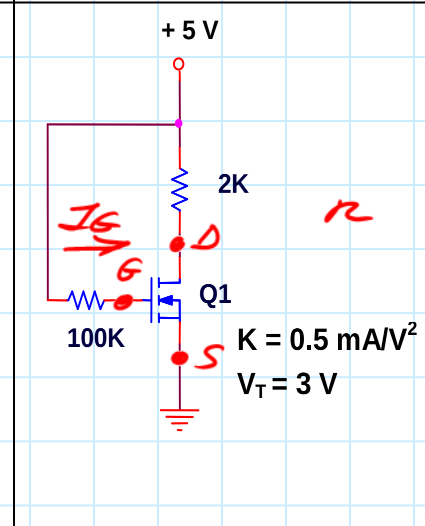
UNIT 2. MOSFETS: OPERATING REGIONS

2.1 Indicate the operating region of the MOSFET transistors of the following circuits:

A	B	C	D
			

$I_G = 0$ in all cases

A) $V_G = 0V$; $V_{GS} = 0V < V_T \Rightarrow$ Q1 OFF (cut-off region)

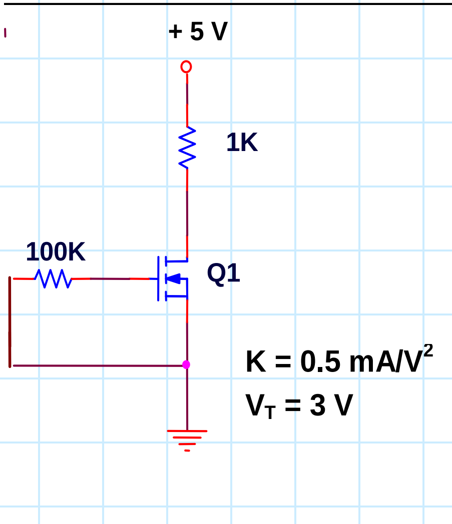
B) $I_G = 0 \Rightarrow V_D = V_G \Rightarrow V_{DS} = V_{GS} \Rightarrow V_{DS} > V_{GS} - V_T = V_{DS} - V_T \Rightarrow$
Q1 saturated

C) $I_G = 0 \Rightarrow V_D = V_G \Rightarrow V_{DS} = V_{GS} \Rightarrow V_{DS} < V_{GS} + V_T = V_{DS} + V_T \Rightarrow$
Q1 saturated

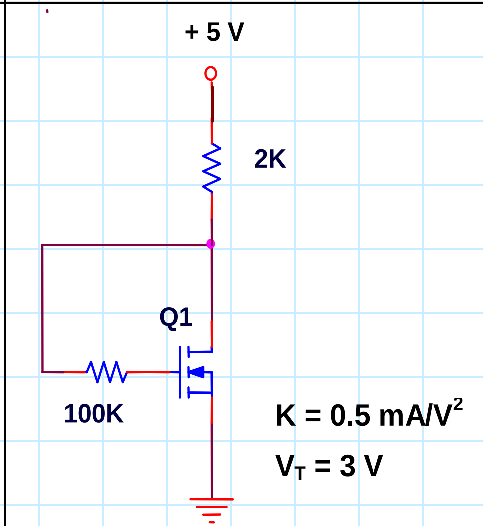
UNIT 2. MOSFETS: OPERATING REGIONS

2.1 Indicate the operating region of the MOSFET transistors of the following circuits (cont.):

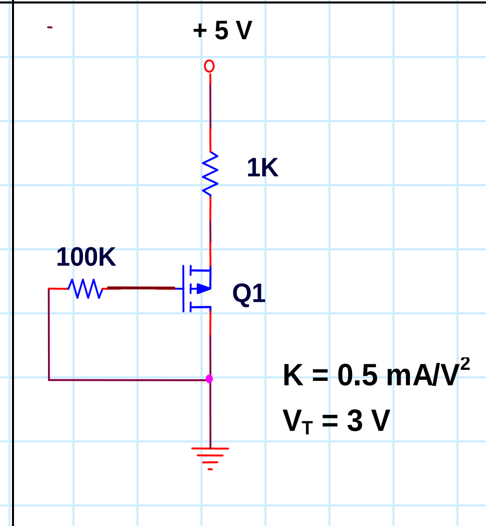
A



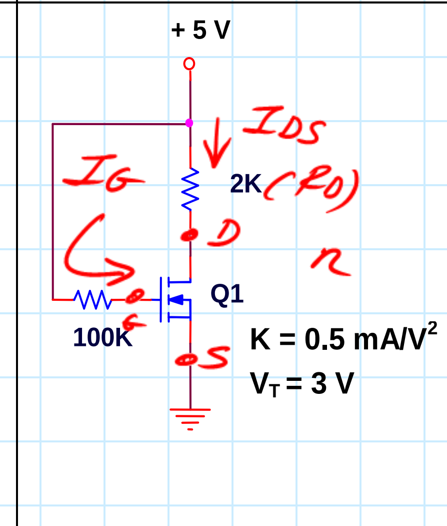
B



C



D



(D) $I_G=0 \Rightarrow V_{GS}=V_G=5V > V_T \Rightarrow Q_1$ ON, assume saturated

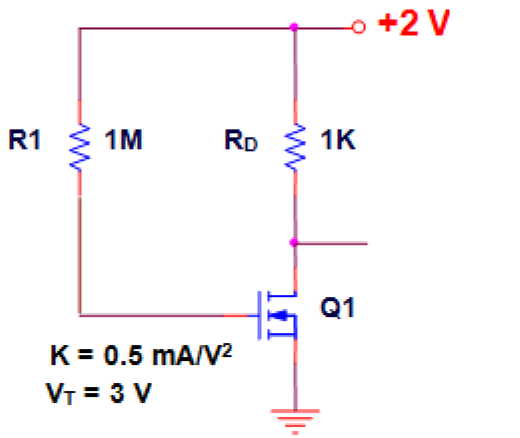
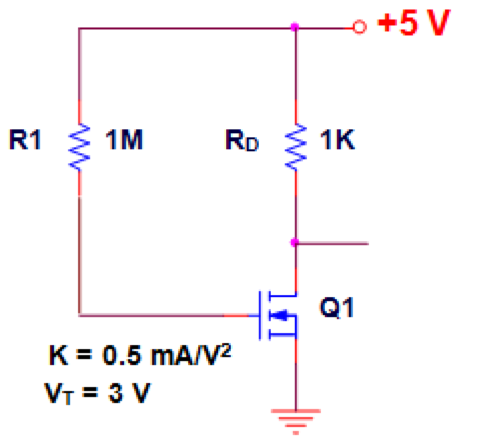
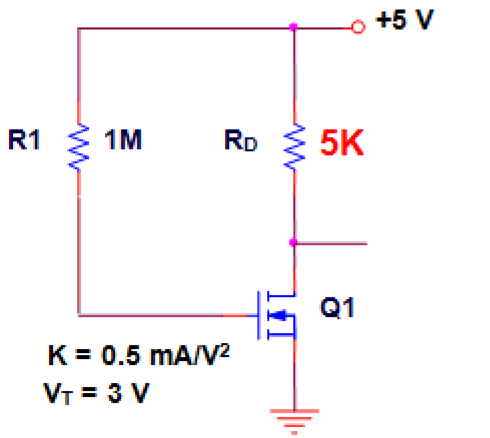
$\Rightarrow I_{DS}=K(V_{GS}-V_T)^2 = 0.5(5-3)^2=2mA \Rightarrow$

output loop: $5+I_{DS}R_D+V_{DS}=0 \Rightarrow V_{DS}=5-R_DI_{DS}=1V$

as $V_{DS} \not> V_{GS}-V_T=5-3=2V \Rightarrow Q_1$ is in OHMIC REGION

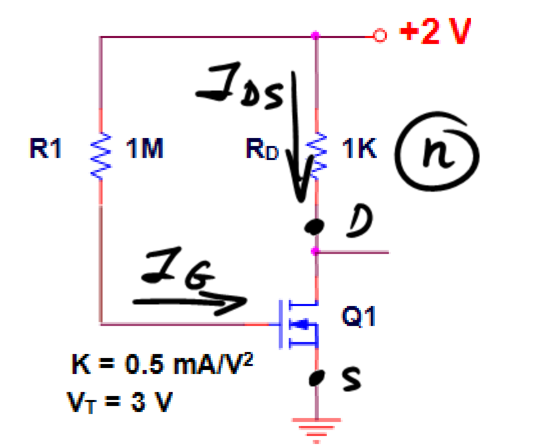
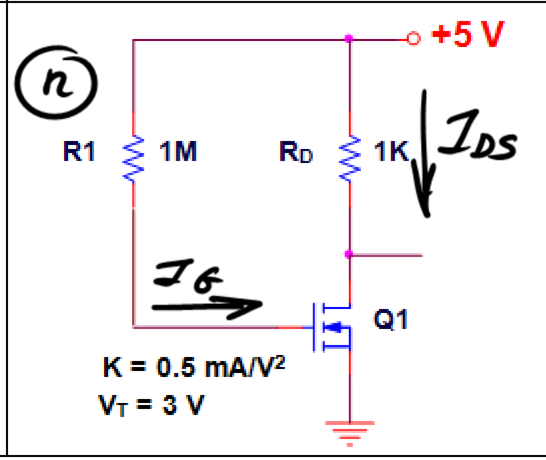
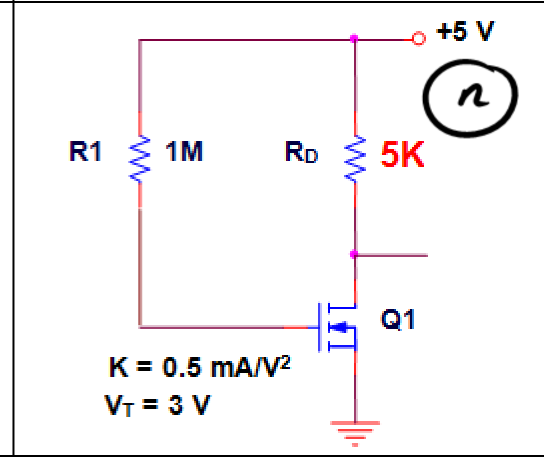
UNIT 2. MOSFETS: OPERATING REGIONS

2.2 Indicate the operating region of the MOSFET transistors of the following circuits:

A	B	C
		

UNIT 2. MOSFETS: OPERATING REGIONS

2.2 Indicate the operating region of the MOSFET transistors of the following circuits:

A	B	C
		

A) $I_G = 0 \Rightarrow V_{GS} = 2V < V_T \Rightarrow$ Q_1 OFF $\Rightarrow$

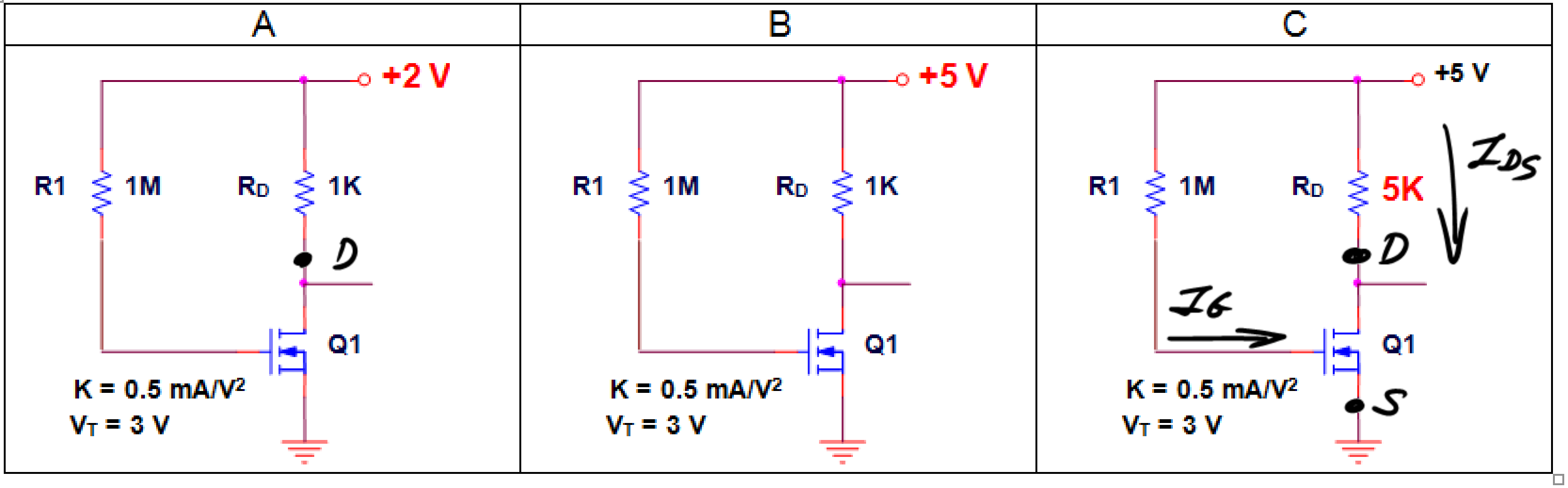
B) $I_G = 0 \Rightarrow V_{GS} = 5V > V_T \Rightarrow Q_1$ ON; Assume SAT $\Rightarrow$

$I_{DS} = K(V_{GS} - V_T)^2 = 0.5(5-3)^2 = 2mA$

$V_{DS} = 5 - I_{DS} R_D = 5 - 2 \cdot 1 = 3V > V_{GS} - V_T = 2V \Rightarrow \boxed{\text{SATURATED}}$

UNIT 2. MOSFETS: OPERATING REGIONS

2.2 Indicate the operating region of the MOSFET transistors of the following circuits:



c) $V_{GS} = 5V > V_T \Rightarrow Q_1$ ON ; assume SAT

$I_{DS} = K(V_{GS} - V_T)^2 = 0.5(5-3)^2 = 2mA$

$V_{DS} = 5 - I_{DS} \cdot R_D = 5 - 10 = -5V \Rightarrow$ $\boxed{\text{OHMIC REGION}}$

Then $I_{DS} = K[2(V_{GS} - V_T)V_{DS} - V_{DS}^2] = 0.5[4V_{DS} - V_{DS}^2]$

and from output loop:

$I_{DS} = \frac{5 - V_{DS}}{5K}$, Combining both equations:

$0.5(4V_{DS} - V_{DS}^2) = \frac{5 - V_{DS}}{5K}$

$0.5(4V_{DS}-V^2_{DS})=\frac{5-V_{DS}}{5K}$; $2.5(4V_{DS}-V^2_{DS})=5-V_{DS}$

$10V_{DS}-2.5V^2_{DS}=5-V_{DS}$; $2.5V^2_{DS}-11V_{DS}+5=0$

$V_{DS}=\frac{11\pm\sqrt{121-50}}{5}=\frac{11\pm 8.426}{5}=$ $V_{DS}=3.89$ ✗, $\underline{\underline{V_{DS}=0.51}}$ ✓, as

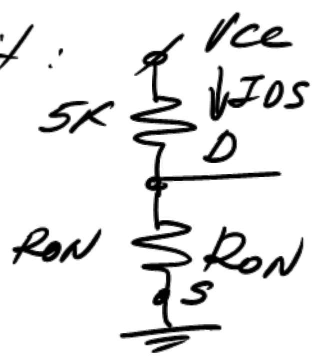
$V_{DS}<V_{GS}-V_T=2V$

$I_{DS}=\frac{5-V_{DS}}{5K}=\underline{\underline{0.898mA}} \Rightarrow \boxed{Q=(V_{GS}=5V,\ V_{DS}=0.51V,\ I_{DS}=0.898mA)}$

Approximate solution.

$R_{ON}=\frac{1}{2K(V_{GS}-V_T)}=\frac{1}{2\cdot 0.5(5-3)}=0.5K$

$\Rightarrow$ Eq. circuit:



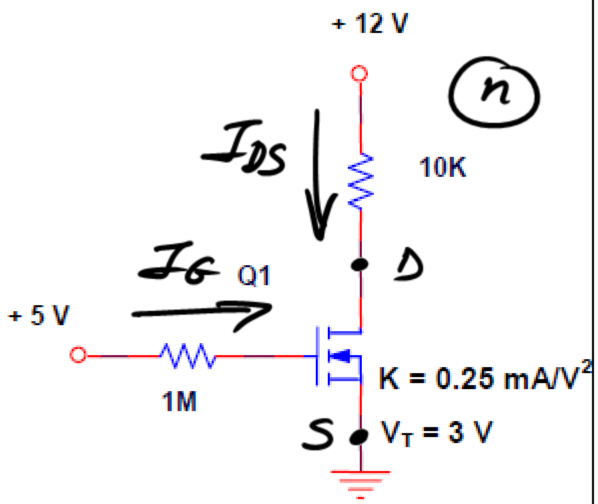
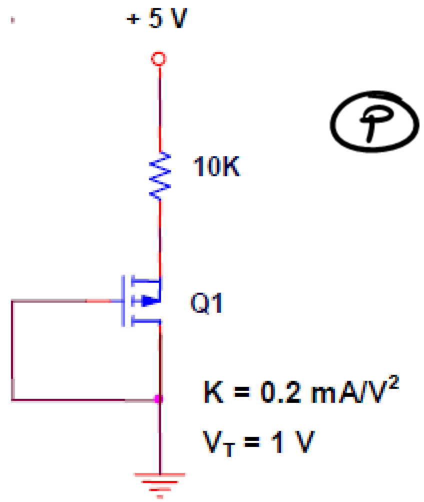
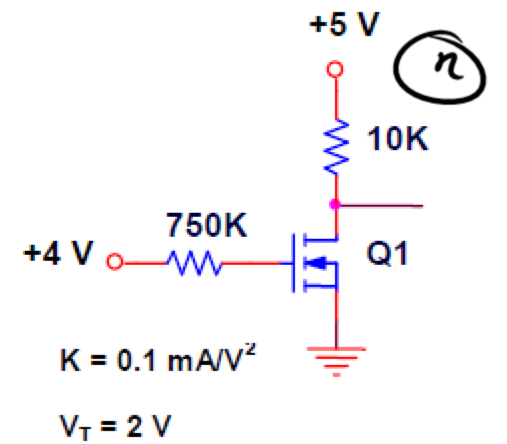
$V_D=V_{DS}=V_{cc}\frac{R_{ON}}{5+R_{ON}}=5\frac{0.5}{5.5}=\underline{\underline{0.45V}}$

(Quite good approx)

$I_{DS}=\frac{V_{cc}}{5+R_{ON}}=\frac{V_{cc}}{5.5}=\underline{\underline{0.91mA}}$

UNIT 2. MOSFETS: OPERATING REGIONS

(3.1) Analyze the operating point Q (V_{GS}, I_{DS}, V_{DS}) of the MOSFETs of the following circuits:

A	B	C
		

[A] $I_G=0 \Rightarrow V_G=5V=V_{GS}>V_T \Rightarrow T_{ON}$; assume SAT

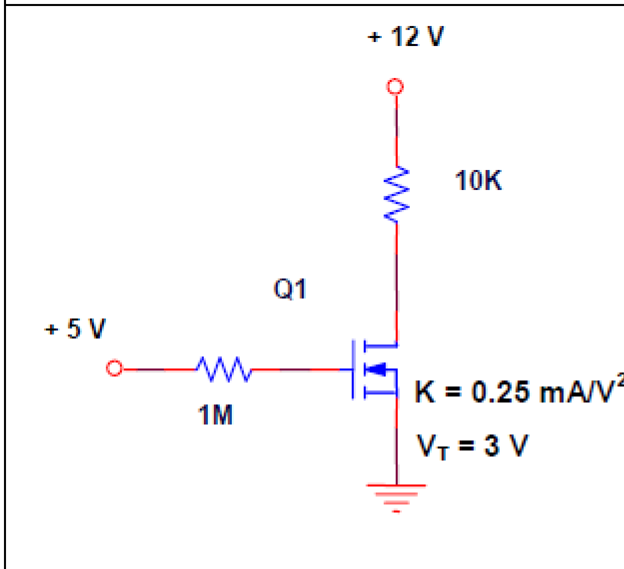
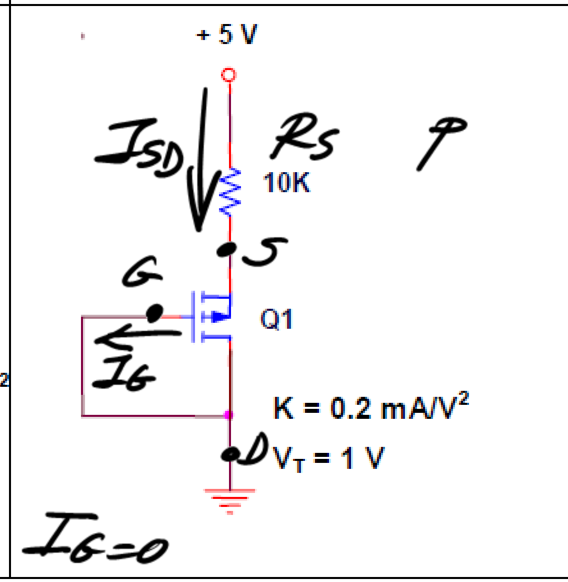
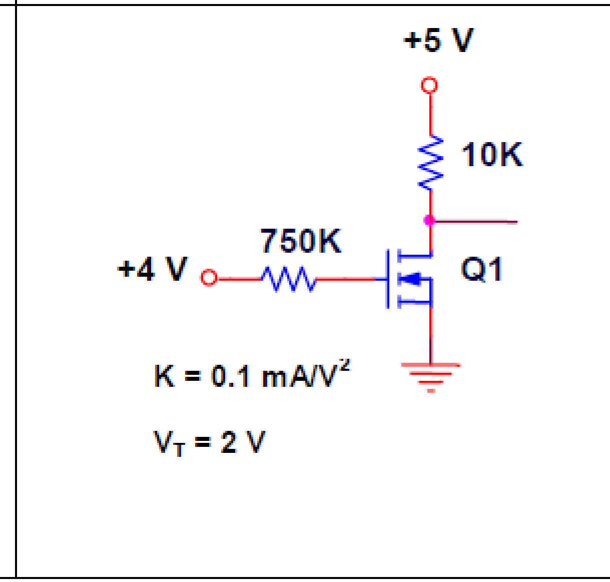
$I_{DS}=K(V_{GS}-V_T)^2=0.25(5-3)^2=1mA$

$V_{DS}=12-10I_{DS}=2V=V_{GS}-V_T \Rightarrow$ limit OHMIC – SAT

$$\boxed{Q(V_{GS}=5V;\ I_{DS}=1mA;\ V_{DS}=2V)}$$

UNIT 2. MOSFETS: OPERATING REGIONS

(3.1) Analyze the operating point Q (V_{GS}, I_{DS}, V_{DS}) of the MOSFETs of the following circuits:

A	B	C
		

[B] $V_G = V_D \Rightarrow V_{GS} = V_{DS} \Rightarrow V_{DS} < V_{DS} + V_T = V_{GS} - V_T \Rightarrow Q_1$ SAT

a) $I_{SD} = K(V_{GS}+V_T)^2 = 0.2(V_{GS}+1)^2 = 0.2(V_{DS}+1)^2$ (1)

b) Output loop: $5 - I_{SD}R_S - V_{SD} = 0 \Rightarrow I_{SD} = \dfrac{5 - V_{SD}}{R_S}$

$I_{SD} = \dfrac{5+V_{DS}}{R_S}$ (2); Combining (1) and (2)

$$0.2(V_{DS}^2 + 2V_{DS} + 1) = \frac{5+V_{DS}}{10}$$

$$2(V_{DS}^2 + 2V_{DS} + 1) = 5 + V_{DS}$$

$$2V_{DS}^2 + 3V_{DS} - 3 = 0 \Rightarrow V_{DS} = \frac{-3 \pm \sqrt{9+24}}{4}$$

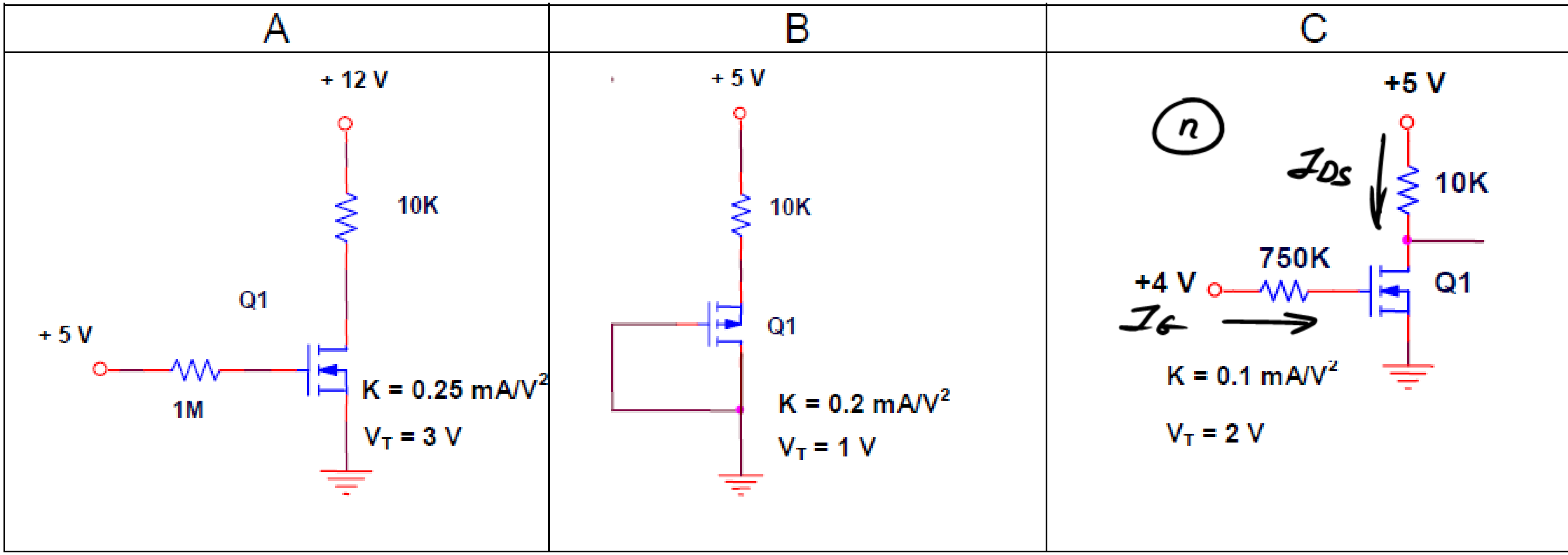
$$V_{DS} = \frac{-3 \pm}{4} \begin{cases} 0.69 \times \\ -2.19V < -V_T \Rightarrow \text{Correct} \end{cases}$$

$$I_{SD} = \frac{5+V_{DS}}{10} = 0.281mA$$

$$Q\,(V_{GS} = -2.19V,\ I_{SD} = 0.281\ mA,\ V_{DS} = -2.19V)$$

UNIT 2. MOSFETS: OPERATING REGIONS

3.1 Analyze the operating point Q (V_{GS}, I_{DS}, V_{DS}) of the MOSFETs of the following circuits:



[C] $V_{GS} = 4V > V_T \Rightarrow Q_1$ ON. ASSUME SAT.

$I_{DS} = K\,(V_{GS} - V_T)^2 = 0.1\,(4-2)^2 = 0.4\,mA$

$V_{DS} = 5 - 10\,I_{DS} = 1V \ngtr V_{GS} - V_T \Rightarrow$ OHMIC REGION

$I_{DS} = K\,[2(V_{GS} - V_T)\,V_{DS} - V_{DS}^2] = 0.1\,[2(4-2)V_{DS} - V_{DS}^2]$

$I_{DS} = 0.4\,V_{DS} - 0.1\,V_{DS}^2 \quad (1)$

From output loop:

$I_{DS} = \dfrac{5 - V_{DS}}{10} \quad (2)$

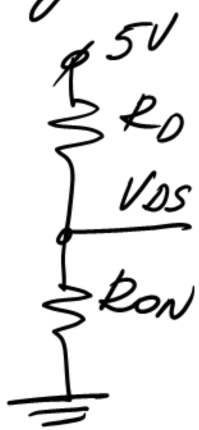
$0.4\,V_{DS} - 0.1\,V_{DS}^2 = \dfrac{5 - V_{DS}}{10}$

$$4V_{DS} - V_{DS}^2 = 5 - V_{DS}; \quad V_{DS}^2 - 5V_{DS} + 5 = 0$$

$$V_{DS} = \frac{5 \pm \sqrt{25-20}}{2} = \frac{5 \pm 2.24}{2} = \begin{cases} 3.62\,V \times \\ 1.38\,V \; (V_{DS} < \underset{4-2}{V_{GS}-V_T}) \end{cases}$$

$$\left.\begin{aligned} \text{Then } V_{DS} &= 1.38\,V \Rightarrow \\ I_{DS} &= \frac{5-1.38}{10} = 0.362\,mA \end{aligned}\right\} Q(V_{GS}=4V;\ I_{DS}=0.362\,mA;\ V_{DS}=1.38\,V)$$

Assuming linear region: $R_{ON} = \frac{1}{2K(V_{GS}-V_T)} = \frac{1}{2\cdot 0.1(4-2)} = 2K5$



$$V_{DS} = 5\frac{R_{ON}}{R_D+R_{ON}} = 5\frac{2.5}{10+2.5} = 1V$$

$$I_{DS} = \frac{5}{R_D+R_{ON}} = 0.4\,mA$$

(Note the error in approximation, because V_{DS} ↑↑ and we can't neglect V_{DS}^2).