12-03-2018

BILKENT UNIVERSITY

Department of Electrical and Electronics Engineering

EEE313 Electronic Circuit Design

Midterm Exam I

SOLUTION

Surname: ____________________

Name: ____________________

ID-Number: ____________________

Signature: ____________________

Duration is 120 minutes. Solve all 6 questions. Show all your work.
No books or notes.

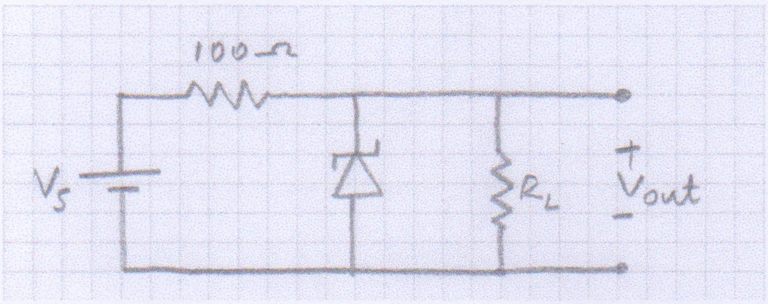
Q1 (20 points)	
Q2 (20 points)	
Q3 (20 points)	
Q4 (20 points)	
Q5 (20 points)	
Q6 (20 points)	
Total (120 points)	

The total collected points will be normalized to 100.

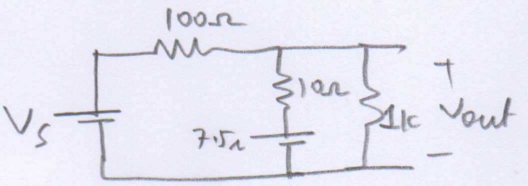
Q1. For the circuit below the Zener diode has a Zener voltage of 7.5 V and an incremental resistance of 10 Ω. The Zener current needs to be less than 100 mA and more than 5 mA for proper Zener operation.

a) For R_L = 1 KΩ, find the range of supply voltage V_S such that the current limitations of the Zener diode are not violated. Also for this range of supply voltage find the range of output voltage V_{out}.

b) For V_S = 12 V, find the range of load resistance R_L such that the current limitations of the Zener diode are not violated. Also for this range of supply voltage find the range of output voltage V_{out}.



a) $R_L = 1K$. $\quad I_Z = V_S \dfrac{10//1000}{10//1000+100} \times \dfrac{1}{10} - 7.5 \dfrac{1}{10+100//1000}$



$$\approx V_S \frac{1}{10+100} - 7.5 \frac{1}{10+90} = V_S \frac{1}{110} - \frac{7.5}{100}$$

$$\frac{V_S}{110} - \frac{7.5}{100} < 0.1 \qquad V_S < 110\left(0.1 + \frac{7.5}{100}\right)$$
$$= 110 \times 0.175$$
$$= 19.25\,V.$$

$$\frac{V_S}{110} - \frac{7.5}{100} > 0.005$$

$$V_S > 110\left(0.005 + \frac{7.5}{100}\right) = 8.8\,V.$$

$$V_{out} \cong V_S \frac{10}{110} + 7.5 \frac{100//1000}{100//1000+10} \approx V_S \frac{10}{110} + 7.5 \frac{90}{100}$$

$V_S = 19.25\,V \Rightarrow V_{out} = 7.5 + 10 \times 0.1 = 8.5\,V.$ $\quad \boxed{8.8 < V_S < 19.5\,V.}$

$V_S = 8.8\,V \Rightarrow V_{out} = 7.5 + 0.005 \times 10 = 7.55\,V.$ $\quad \boxed{7.55 < V_{out} < 8.5}$

b) $I_Z = 12 \times \dfrac{10//R}{10//R+100} \times \dfrac{1}{10} - 7.5 \dfrac{1}{10+100//R}$

$$= 12 \frac{10R}{10R+100(10+R)} \times \frac{1}{10} - 7.5 \frac{100+R}{100R+10(100+R)} = \frac{12R - 750 - 7.5R}{1000 + 110R}$$

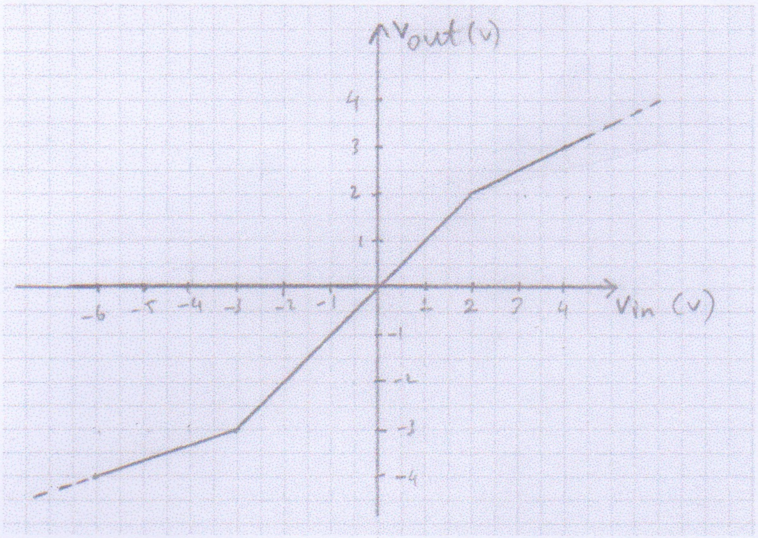
$\dfrac{4.5R - 750}{1000+110R} < 0.1 \quad 4.5R - 750 < 100 + 11R \quad -850 < 6.5R$ no solution

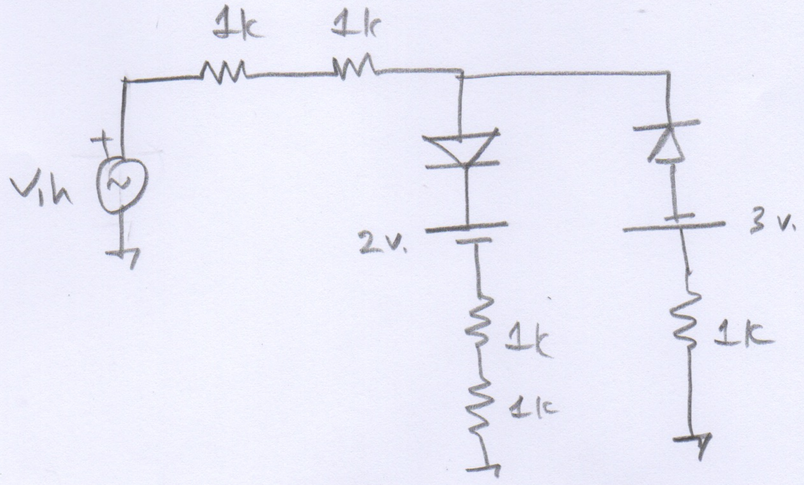
$\dfrac{4.5R - 750}{1000+110R} > 0.005 \quad 4.5R - 750 > 5 + 0.55R \quad 3.95R > 755 \quad \boxed{R > 191\,Ω}$

If $R = \infty$, then $I_Z = \dfrac{12-7.5}{110} = \dfrac{4.5}{110} = 41\,mA \Rightarrow V_{out} = \dfrac{4.5}{110} \times 10 + 7.5 = 7.91\,v.$

$R = 191K \Rightarrow I_Z = 0.005\,mA \Rightarrow V_{out} = 7.55\,v.$ $\quad \boxed{7.55 < V_{out} < 7.91}$

Q2. Design and draw a circuit that exhibits the input/output characteristic shown below. Use only 1 KΩ resistors, ideal diodes, and DC sources.

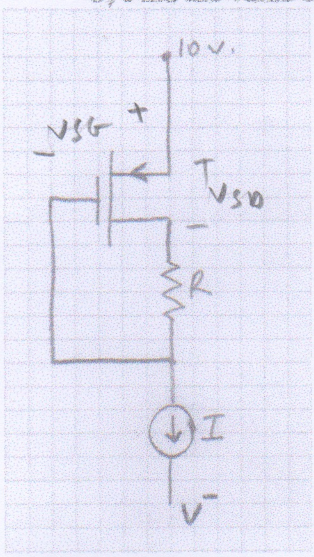




Q3. In the circuit below, the current source I is equal to 100 μA, and the pMOS transistor has the parameters $V_{TP} = -1$ V, $k_p' = 8\ \mu A/V^2$, W/L = 25, and $\lambda = 0$.

a) Find the range of R for which the transistor is in SAT condition.

b) Find the value of R for which $V_{SD} = V_{SG}/10$.



$$K_p = \frac{8}{2} \times 25 = 100\ \mu A/V^2 = 0.1\ mA/V^2$$

a) Assume SAT

$$I_D = I = 0.1 = 0.1(V_{SG} - 1)^2$$

$$\Rightarrow V_{SG} = 1 \pm 1 \begin{cases} 2v. > 1 & ✓ \\ 0v. > 1 & X \end{cases}$$

$$\Rightarrow V_{SG} = 2v.$$

To be in SAT we need $V_{SD} > V_{SG} - 1$

$$V_{SG} = V_{SD} + I_D R$$

$$V_{SD} = V_{SG} - I_D R > V_{SG} - 1$$

$$-I_D R > -1$$

$$I_D R < 1$$

$$R < \frac{1}{I_D} = \frac{1}{0.1} = 10k. \qquad \boxed{R < 10k\Omega}$$

b) I = 0.1 mA Assume SAT: $V_{SD} = \frac{V_{SG}}{10} = \frac{2}{10} = 0.2v.$

$$0.2 \overset{?}{>} 2 - 1 \quad X$$

Take NON-SAT:

$$0.1 = 0.1\left[2(V_{SG} - 1)V_{SD} - V_{SD}^2\right]$$

$$1 = 2(V_{SG} - 1)\frac{V_{SG}}{10} - 0.01 V_{SG}^2$$

$$1 = 0.2 V_{SG}^2 - 0.2 V_{SG} - 0.01 V_{SG}^2$$

$$0.19 V_{SG}^2 - 0.2 V_{SG} - 1 = 0$$

$$V_{SG} \begin{cases} 2.88v & ✓ \\ -1.83v & X \end{cases}$$

$$V_{SG} = V_{SD} + IR = \frac{V_{SG}}{10} + IR$$

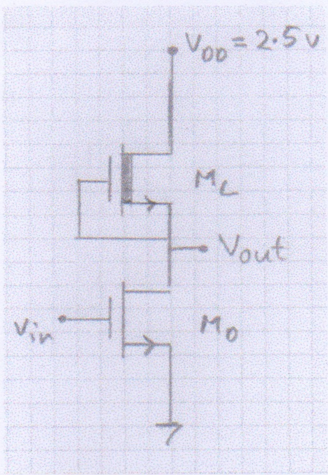
$$R = V_{SG}\left(1 - \frac{1}{10}\right)/I = \frac{1}{0.1} \times 2.88 \times \frac{9}{10} = 25.92\ k\Omega$$

$$\boxed{R = 25.92k\Omega}$$

Q4. In the circuit below, both the driver and load transistors have $k'_n = 1\ mA/V^2$ and $\lambda = 0$.
[illegible]
the depletion mode nMOS transistors respectively. Find the output voltage V_{out} for

a) $V_{in} = 0.2$ V,
b) $V_{in} = 1$ V,
c) $V_{in} = 2.5$ V.

Always check the state of the transistors.



a) $V_{in} = 0.2 < 0.5 \Rightarrow M_D$ is OFF

Assume M_L NONSAT

$$0 = 2(V_{GSL} - (-1))V_{DSL} - V_{DSL}^2$$

$$V_{GSL} = 0 \Rightarrow 0 = 2V_{DSL} - V_{DSL}^2 = 0$$

$$(2 - V_{DSL})V_{DSL} = 0 \Rightarrow V_{DSL} \begin{cases} 2v < 1 & \times \\ 0 < 1 & \checkmark \end{cases}$$

$$\Rightarrow V_{DSL} = 0 \Rightarrow \boxed{V_{out} = 2.5\text{ v.}}$$

b) $V_{in} = 1$ v. Assume M_D is SAT and M_L = NONSAT.

$$1(V_{in} - 0.5)^2 = 1\left[2(0+1)V_{DSL} - V_{DSL}^2\right]$$

$$0.25 = 2V_{DSL} - V_{DSL}^2$$

$$V_{DSL}^2 - 2V_{DSL} + 0.25 = 0 \Rightarrow V_{DSL} \begin{cases} 1.866 < 1 & \times \\ 0.1340 < 1 & \checkmark \end{cases}$$

$$\Rightarrow V_{out} = 2.5 - 0.134 = 2.36\text{ v.} \qquad V_{out} > 1 - 0.5 \ \checkmark$$

$$\boxed{V_{out} = 2.36\text{ v.}}$$

c) $V_{in} = 2.5$ v.

Assume M_D NONSAT, M_L SAT.

$$2(\underset{2.5}{\underset{\shortparallel}{V_{in}}} - 0.5)V_o - V_o^2 = (0+1)^2 = 1$$

$$4V_o - V_o^2 - 1 = 0$$

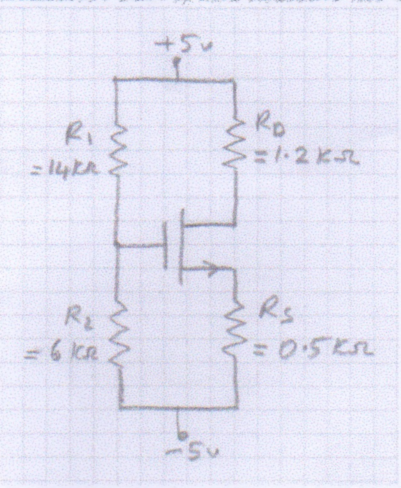
$$V_o^2 - 4V_o + 1 = 0$$

$$V_o \begin{cases} 3.732 < 2.5 - 0.5 & \times \\ 0.268 < 2.5 - 0.5 & \end{cases}$$

$$V_{DS_L} = 2.5 - 0.268 > 1 \ \checkmark$$

$$\Rightarrow \boxed{V_o = 0.268\text{ V}}$$

Q5. For the transistor in the circuit below, the parameters are $V_{TN} = 0.4\,V$, $k_n' = 120\,\mu A/V^2$, and $W/L = 25$. Determine V_{GS}, I_D, and V_{DS}. Sketch the load line and also the corresponding transistor curve, and indicate the Q-point. Check the state of the transistor.



$$V_G = 5 \times \frac{6}{6+14} - 5\,\frac{14}{6+14} = 5\,\frac{-8}{20} = -2v.$$

Assume SAT:

$$i_D = \frac{120}{2} \times 25\,(V_{GS}-0.4)^2 = 1.5\,mA/V^2\,(V_{GS}-0.4)^2$$

$$5 = 1.2\,I_D + V_{DS} + 0.5\,I_D - 5$$

$$\boxed{10 = 1.7\,I_D + V_{DS}}$$

$$V_G = 0.5\,I_D + (-5) + V_{GS}$$

$$-2 = 0.5\,I_D - 5 + V_{GS}$$

$$\boxed{3 - 0.5\,I_D = V_{GS}}$$

$$i_D = \frac{3 - V_{GS}}{0.5}$$

$$i_D = 6 - 2V_{GS}$$

$$6 - 2V_{GS} = 1.5\,(V_{GS} - 0.4)^2$$

$$6 = 2V_{GS} + 1.5\,(V_{GS}^2 - 0.8V_{GS} + 0.16)$$

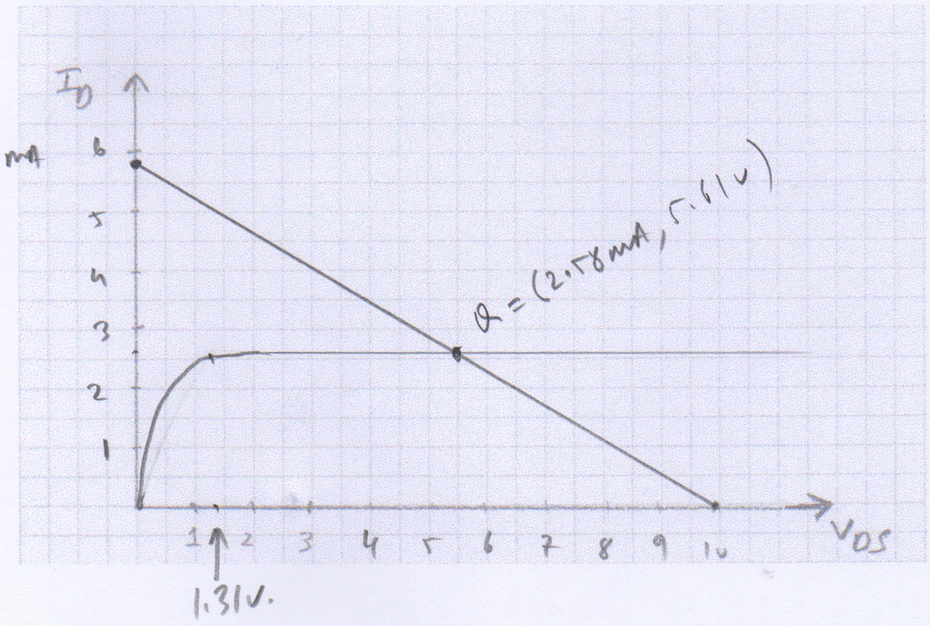
$$V_{GS} = \begin{cases} 1.71v. > 0.4 \checkmark \\ -2.24v. > 0.4 \times \end{cases}$$

$$I_D = 6 - 2 \times V_{GS}$$
$$= 6 - 2 \times 1.71 = 2.58\,mA$$

$$V_{DS} = 10 - 1.7\,I_D = 10 - 1.7 \times 2.58$$
$$= 5.61v.$$

$$\boxed{I_D = 2.58\,mA}$$

$$\boxed{V_{DS} = 5.61\,v.}$$



Load line

$$I_D = \frac{10 - V_{DS}}{1.7}$$

$$= 5.88 - \frac{V_{DS}}{1.7}$$

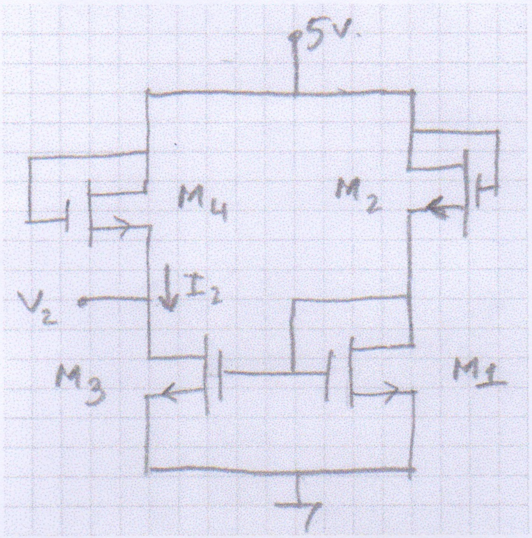
$$V_{GS} = 1.71$$

$$\Rightarrow I_D = (1.71 - 0.4)^2 \times 1.5$$
$$= 2.58\,mA$$

Critical pt

$$V_{DS} = V_{GS} - 0.4$$
$$= 1.31v.$$

Q6. For the transistors in the circuit below $V_{TN} = 1V$, $K_n = 250\ \mu A/V^2$, and $\lambda = 0$.
a) Find V_2 and I_2 (Always check the states of the transistors)
b) Find V_2 and I_2 if $K_{n3} = K_{n4} = 2.5mA/V^2$ (Always check the states of the transistors)



a) For M_1 and M_2 $\quad V_{DS} = V_{GS} > V_{GS} - V_{Tn}$

$\Rightarrow$ OFF or SAT.

Assume SAT:

$V_{GS_1} + V_{GS_2} = 5V.$

$K_{n_1}(V_{GS_1} - V_{Tn})^2 = K_{n_2}(V_{GS_2} - V_{TN})^2$

$\Rightarrow V_{GS_1} = V_{GS_2}$

$\Rightarrow V_{GS_1} = V_{GS_2} = 2.5V.$

$I_{D_1} = I_{D_2} = 250\,(2.5-1)^2 = 250 \times 2.25$

$\boxed{I_2 = 562.5\,\mu A.}$

Since $K_{N_3} = K_{N_1}$ and $V_{GS_1} = V_{GS_3}$

$\Rightarrow I_2 = 562.5\,\mu A$

check if SAT:

$V_{GS_4} + V_{DS_3} = 5$ Also $V_{GS_4} = V_{GS_3} = 2.5V.$

$\Rightarrow V_{DS_3} = 5 - 2.5 = 2.5V > 2.5 - 1$ ✓ $\Rightarrow \boxed{V_2 = 2.5V.}$

b) If $K_{n_3} = K_{n_4} = 2.5\,mA/V^2$

V_{GS_1} and I_{D_1} are the same as in part a).

$\Rightarrow I_{D_1} = 562.5\,\mu A$

$\Rightarrow I_2 = 562.5\,\mu A \times 10 = 5.625\,mA.$ $\boxed{I_2 = 5.625\,mA}$

check SAT: $V_{GS_4} = V_{GS_3} = V_{GS_1} = 2.5V.$ ✓ SAT.

$\boxed{V_2 = 2.5V.}$