Name *MASTER*

ECE 321 Electronics I
Test #2 Winter 2008

Time allowed: 1 hour 50 minutes (including the first 5 minutes for exam review.... no writing.)

Calculator permitted. There are five questions at 20 points each.

Closed book; one-side 8½x11in "crib-sheet" permitted; (turn in the crib sheet with the test paper.)

Answer questions on these pages. If you need more space, use the back of the page.

In all your answers, <u>state all approximations</u> clearly, and <u>explain each step</u> succinctly.

Assume $\gamma=0$, $K'=100\mu A/V^2$, and $V_T=1V$ for all devices, unless otherwise specified. All symbols, these and others, have their conventional meanings.

1 What is the W/L ratio required for the NMOS transistor specified above to have an on resistance $R_{ON}=500\Omega$ at $V_{GS}=5V$?.

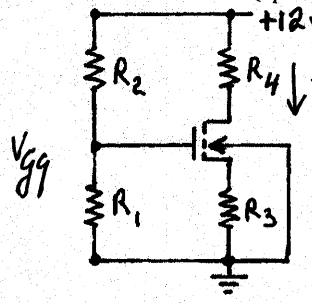
$$R_{on} = \frac{1}{K_n' \frac{W}{L}(V_{GS}-V_{TN})} \longrightarrow \frac{W}{L} = \frac{1}{K_n'(V_{GS}-V_{TN})R_{on}}$$

$$\frac{W}{L} = \frac{1}{100\times10^{-6}\times(5-1)500} = \frac{100}{5\times4} = 5$$

(Two Bonus points for derivation of R_{on} from the triode I_D formula i.e. find $\left(\frac{dI_D}{dV_{DS}}\right)^{-1}$)

W/L = 5

2. Find the Q-point for the transistor for R_1=100kΩ, R_2=220kΩ, R_3=24kΩ, R_4=12kΩ.if W/L=5.



Assume saturation region

$$V_{gg} = \frac{R_1}{R_1+R_2} V_{DD} = \frac{100}{320} 12 = 3.75\text{v}$$

$$3.75\text{v} = V_{gs} + I_D R_3 = V_{gs} + 24\times10^3 I_D$$

$$\& \; I_D = \frac{K_n'}{2}\frac{W}{L}(V_{gs}-V_T)^2 = \frac{10^{-4}}{2} 5 (V_{gs}-1)^2$$

i.e. $$3.75 = V_{gs} + 24\times10^3 \times 10^{-4} \times \frac{5}{2}(V_{gs}^2 - 2V_{gs} + 1)$$

$$6V_{gs}^2 - 11V_{gs} + 2.25 = 0 \rightarrow V_{gs} = \frac{11 \pm (11^2 - 4\times6\times2.25)^{1/2}}{12}$$

$$= (11 \pm \sqrt{67})/12$$

$$= 1.6 \text{ or } 0.233\text{ v}$$

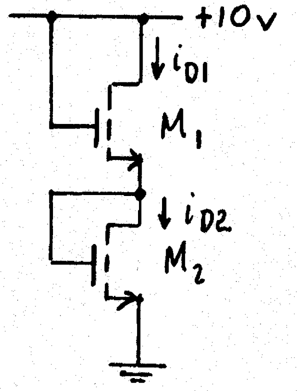
$0.233\text{v} < V_T$, $\therefore V_{gs} = 1.6\text{v}$ and $I_D = \frac{5}{2}10^{-4}(0.6)^2 = 90\mu A$

$\therefore V_{DS} = 12 - 9\times10^{-5}(24+12)10^3 = 12 - 3.24 = 8.76\text{ v}$

Check: $V_{DS} = 8.76\text{v} > V_{gs} - V_T = 0.6\text{ v}$ $\therefore$ Confirm saturation

i_D= 90 μA $\qquad$ V_{DS} = 8.76 V

3. Find the currents. i_D in the transistors shown, for $(W/L)_1=25$, $(W/L)_2=12.5$, and $\lambda=0$. for both transistors.



Transistors saturated by D-G connection

$(V_{DS} = V_{GS}$ and $V_T > 0)$

$$i_{D1} = i_{D2}$$

$$\frac{K'}{2}\left(\frac{W}{L}\right)_1 (V_{GS1} - V_T)^2 = \frac{K'}{2}\left(\frac{W}{L}\right)_2 (V_{GS2} - V_T)^2$$

$$\left(\frac{W}{L}\right)_1 (V_{GS1} - V_T)^2 = \left(\frac{W}{L}\right)_2 (V_{GS2} - V_T)^2$$

and $V_{GS1} + V_{GS2} = V_{DD} = 10V \rightarrow V_{GS2} = 10 - V_{GS1}$

$$25(V_{GS1} - 1)^2 = 12.5(10 - V_{GS1} - 1)^2$$

$$(2V_{GS1}^2 - 4V_{GS1} + 2) = (81 - 18V_{GS1} + V_{GS1}^2)$$

$$V_{GS1}^2(2 - 1) + V_{GS1}(-4 + 18) + (-2 - 81)$$

$$V_{GS1}^2 + 14V_{GS1} - 79 = 0$$

$V_{GS1} = -7 \pm (49 + 79)^{1/2} = 4.314V$ (other solution negative)

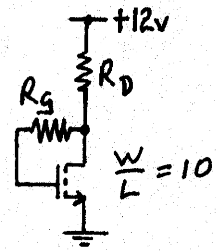
$\therefore V_{GS2} \approx 5.686V$

$i_{D1} = \frac{10^{-4}}{2} 25(3.314)^2 = 13.73\ mA$

$i_{D2} = \frac{10^{-4}}{2} 12.5(4.686)^2 = 13.72\ mA$

i_{D1} = 13.7mA = i_{D2} = 13.7mA

4. Design the circuit (i.e. find resistor values) to establish $V_{DS}=V_{DD}/2 = 6V$.
State your design criteria for R_G clearly



For $I_g = 0$ $V_{GS} = V_{DS}$ ∴ Saturation

For $V_{DS} = 6v$

$$I_D R_D = 6v$$

$$\therefore 6 = R_D \frac{K'}{2} \frac{W}{L}(6 - V_T)^2 = R_D \frac{10^{-4}}{2} 10 (6-1)^2$$

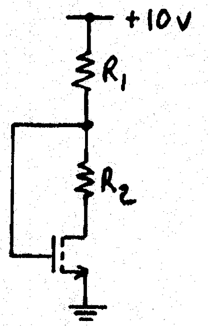
$$\therefore R_D = \frac{12 \times 10^3}{25} = 480\Omega$$

$R_g = 1M\Omega$ — fairly arbitrary choice

Need large to isolate gate from drain for ac signals to be amplified, but not too big or will create noise problems and possibly environmental variations (e.g. humidity)

$R_D =$ 480Ω $R_G =$ 1MΩ

5. Find the Q-point for the transistor if $R_1=R_2=20k\Omega$ for W/L = 2.



Assume saturation

$$I_D = \frac{K'}{2}\frac{W}{L}(V_{GS}-V_T)^2 \text{ where } V_{GS}=10-2\times10^4 I_D$$

$$= \frac{10^{-4}}{2} 2 (10-2\times10^4 I_D)^2$$

$$= 10^{-3}(1-2\times10^3 I_D)^2$$

$$= 10^{-3} - 4I_D + 4\times10^3 I_D^2$$

$$I_D^2 - 1.25\times10^{-3} I_D + 0.25\times10^{-6} = 0$$

$$(I_D - 10^{-3})(I_D - 0.25\times10^{-3}) = 0$$

$\therefore I_D =$ 1mA or 0.25mA

For 1mA $40K \times 1mA > 10V$ $\therefore$ not possible

For 0.25mA $V_{DS} = 10 - 40K \times .25mA = 0$

$\therefore V_{GS} = 0$ i.e. $V_{GS} < V_T$

$\therefore$ Not saturated.

Assume triode operation

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

$$= 2\times10^{-4}\left(10-2\times10^4 I_D - 1 - \frac{10-4\times10^4 I_D}{2}\right)(10-4\times10^4 I_D)$$

$$= 2\times10^{-4}(4)(10)(1-4\times10^3 I_D) = 8\times10^{-3}(1-4\times10^3 I_D)$$

$$= 8\times10^{-3}/33 = 242\,\mu A$$

$\therefore V_{GS} = 10 - 4.84 = 5.16V$ $\quad V_{DS} = 10 - 9.68 = 0.32V$

$\therefore V_{DS} < V_{GS} - V_T$ & triode assumption correct

$I_D =$ 242 μA $\quad V_{DS} =$ 0.32 V