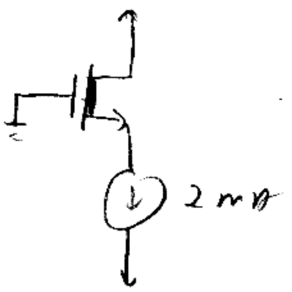
EE 321

Fall 2002

Homework #12

Solutions

5.31



$k_n' \frac{W}{L} = 4\, mA/V^2 = K_n$

$V_t = -2$

$V_{DS} = 1 - V_S$ $\quad$ $V_{GS} = 0 - V_S = -V_S$ $\quad$ $V_{GS} - V_t = -V_S - (-2) = 2 - V_S$

$V_{DS} < V_{GS} - V_t$, so MOSFET will be in triode mode

$I_D = K_n[(V_{GS} - V_t)V_{DS} - \frac{1}{2}V_{DS}^2)$

$2 = 4[(2 - V_S)(1 - V_S) - \frac{1}{2}(1 - V_S)^2)$

$2 = 6 - 8V_S + 2V_S^2$

$V_S^2 - 4V_S + 2 = 0$

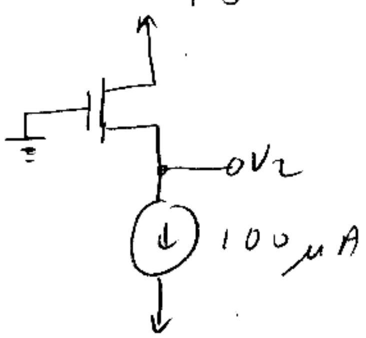
$V_S = 3.414\ V$ or $0.586V$

↑ Impossible, must be $< 1V$

$\therefore V_S = 0.586V$

5.41

(b)



$k_n' \frac{W}{L} = 0.5\, mA/V^2 = k_n$

$V_t = 2\,V$

$V_D = 5V \qquad V_G = 0V$

$V_{DS} = V_{GS} + 5V > V_{GS} - V_t$, so Q in saturation

$I_D = \frac{1}{2} k_n (V_{GS} - V_t)^2$

$0.1\, mA = \frac{1}{2}(0.5\, mA/V^2)(V_{GS} - 2)^2$

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

$0.623\, V = V_{GS} - 2$

$V_{GS} = 2.623\, V$

$V_2 = V_S = V_G - V_{GS} = 0 - 2.623V = -2.623\, V$

(d)

$V_{DS} = V_{GS} > V_{GS} - V_t$, so Q in saturation

$I_D = \frac{1}{2} k_n (V_{GS} - V_t)^2$

$0.01\, mA = \frac{1}{2}(0.5\, mA/V^2)(V_{GS} - 2)^2$

$0.04\, V^2 = (V_{GS} - 2)^2$

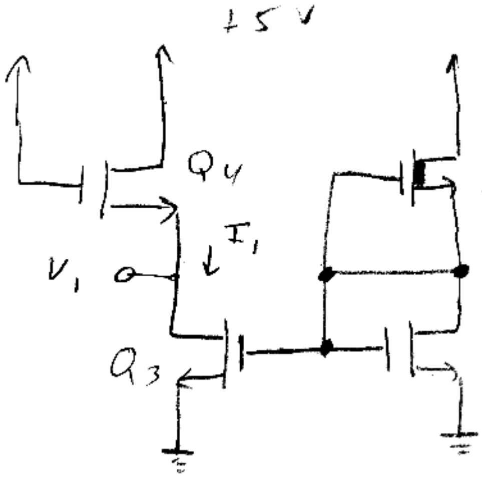
$0.2\, V = V_{GS} - 2$

$V_{GS} = 2.2V$

$V_4 = V_G = V_{GS} - V_S = 2.2V - 0V$

$V_4 = 2.2V$

5.45(a)



$k_n' \frac{W}{L} = \mu_n C_{ox} \frac{W}{L}$

$= (20 \mu A/V^2)\left(\frac{20 \mu m}{1 \mu m}\right)$

$= 0.4 \, mA/V^2$

$= K_n$

For Q_1, Q_3 and Q_4, $V_t = 1V$

For Q_3, $V_{t_3} = -1V$

For Q_1, $V_{DS} = V_{GS}$ $\therefore V_{DS} > V_{GS} - V_t$, so saturation

Also $I_{D_1} = I_{D_2}$

Assume Q_2 saturated

$I_{D_1} = I_{D_2}$

$\frac{1}{2} K_n (V_{GS_1} - V_{t_1}) = \frac{1}{2} K_n (V_{GS_2} - V_{t2})$

$\frac{1}{2} K_n (V_{GS_1} - 1) = \frac{1}{2} K_n (V_{GS_2} + 1)$

$V_{GS_1} = V_{GS_2} + 2$

$V_{GS_2} = 0$, so $V_{GS_1} = 2V$ => $V_{G_1} = 2V$ and $V_{S_2} = 2V$

$V_{DS_2} = V_{D_2} - V_{S_2} = 5 - 2 = 3V$

$V_{GS_2} - V_{t_2}$ $= 0 - (-1) = 1V$

$V_{DS_2} > V_{GS_2} - V_{t2}$, so assumption Q_2 in saturation is correct

$V_{G3} = V_{G1} = 2\,V$ $\qquad$ $V_{GS3} = V_{G3} - V_{S3} = 2\,V$

$V_{D4} = V_{G4} \Rightarrow V_{DS4} = V_{GS4} \Rightarrow V_{DS4} > V_{GS4} - V_{t4}$

$\Rightarrow Q_4$ in saturation

Also $I_{D3} = I_{D4}$

Assume Q_3 in saturation

$I_{D3} = I_{D4}$

$\frac{1}{2} k_n (V_{GS3} - V_{t3})^2 = \frac{1}{2} k_n (V_{GS4} - V_{t4})^2$

$$V_{GS4} = V_{GS3} - V_{t3} + V_{t4}$$
$$= 2 - 1 + 1$$
$$= 2\,V$$

$V_{GS4} = V_{G4} - V_{S4} = V_{DD} - V_{S4} \Rightarrow$

$V_{S4} = V_{DD} - V_{GS4} = 5 - 2 = 3\,V$

$V_{D3} = V_{S4}$, so $V_{DS3} = V_{D3} - V_{S3} = 3 - 0 = 3\,V$

$V_{DS3} > V_{GS3} - V_{t3}$ so Q_3 in saturation as assumed

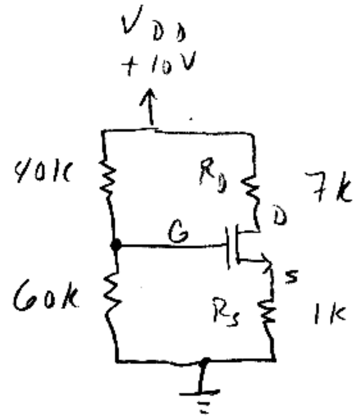
$\therefore V_1 = V_{D3} = 3\,V$

$I_1 = I_{D4} = \frac{1}{2} k_n (V_{GS4} - V_t)^2 = \frac{1}{2}(0.4)(2v - 1v) = 0.2\,mA$

$V_1 = 3\,V$

$I_1 = 0.2\,mA$

4.



$k_n' \frac{W}{L} = 0.25\ mA/V^2 = K_n$

$V_t = 2V$

$$V_G = \frac{60k}{40k + 60k} 10V = 6V$$

$V_D = V_{DD} - I_D R_D \qquad V_S = I_D R_S \qquad V_{GS} = 6V - I_D R_S$

$V_{DS} = V_{DD} - I_D (R_D + R_S)$

Assume saturation

$$I_D = \frac{1}{2} K_n (V_{GS} - V_t)^2 = \frac{1}{2}(0.25)\ (6V - I_D \overset{1k}{R_S} - 2V)^2$$

$8 I_D = (4 - I_D)^2 = 16 - 8 I_D + I_D^2$

$I_D^2 - 16 I_D + 16 = 0$

$I_D = 14.9\ mA$ or $1.1\ mA$

Try 9.9 mA: $V_D = 10 - I_D R_D = 10 - (14.9)(7) = -109V$ impossible

Try 1.1 $\quad V_{DS} = 10 - I_D (R_D + R_S) = 10 - 1.1(7+1) = 1.43V$

$V_{GS} = 6V - I_D R_S = 6 - (1.1)(1) = 4.93V$

$V_{GS} - V_t = 1.93V$

$V_{DS} < V_{GS}$ – cannot be (we assumed saturation, so should get $V_{DS} > V_{GS}$)

Assume triode

$$I_D = K_n\left[(V_{GS}-V_t)V_{DS} - \tfrac{1}{2}V_{DS}^2\right]$$

$$= 0.25\left[(6 - I_D R_S - 2)(10 - I_D R_D) - \tfrac{1}{2}(10 - I_D R_D)^2\right]$$

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

$$4I_D = -10 + 38I_D - 24I_D^2$$

$$24I_D^2 - 34I_D + 10 = 0$$

$I_D = 0.42$ mA or 1.0 mA

Try 0.42 mA:

$V_{DS} = 10 - I_D(R_D + R_S) = 10 - (0.42)(8) = 6.7\,V$

$V_{GS} = 6 - I_D R_S = 6 - (0.42)(1) = 5.6\,V$

$V_{GS} - V_t = 5.6\,V - 2\,V = 3.6\,V$

This makes $V_{DS} > V_{GS} - V_t \Rightarrow$ saturation, but we assumed triode, so this is wrong.

Try 1 mA

$V_{DS} = 10 - I_D(R_D + R_S) = 10 - (1)(8) = 2\,V$

$V_{GS} = 6 - I_D R_S = 6 - (1)(1) = 5\,V$

$V_{GS} - V_t = 5\,V - 2\,V = 3\,V$

Now $V_{DS} < V_{GS} - V_t$, so triode as we assumed

$V_D = V_{DD} - I_D R_D = 10 - (1)(7) = 3\,V$

$V_S = I_D R_S = (1)(1) = 1\,V$