HW12 Solutions

1. (10 points)

(a)

In the saturation region, $V_{DS} \geq V_{GS} - V_{t0} = 2V$

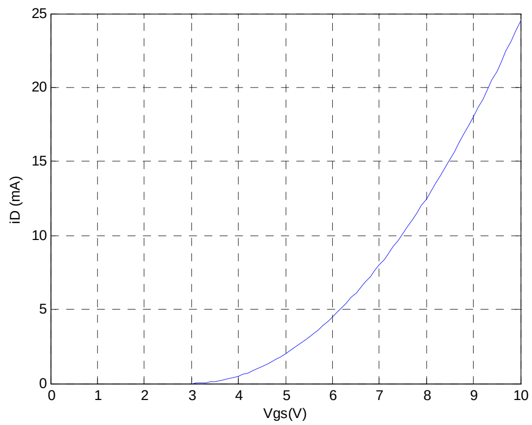
In the triode region, $V_{DS} \leq V_{GS} - V_{t0} = 2V$

Also check $V_{GS} \geq V_{t0}$ so it's not operated in the cutoff region

(b)

In the saturation region,

$i_D = K(V_{GS} - V_{t0})^2 = 0.5(V_{GS} - 2)^2$



2. (10 points)

When $V_{GS} = V_{DS} = 5V$, the transistor is operated in the saturation region.

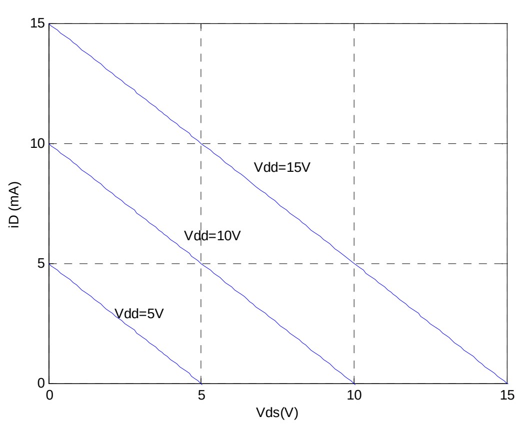
$$i_D = (\frac{W}{L})\frac{KP}{2}(V_{GS} - V_{t0})^2$$

Substitute all the values into the equation and we can solve W/L=1.25.

For L=2um, we need W=2.5um.

3. (10 points)

The load-line equation is $V_{DD} = R_D i_D + V_{DS}$, and the plots are:



4. (10 points)

(a) The 1.7Mohm and 300kohm resistors act as a voltage divider that gives a dc voltage $V_{GSQ} = 3V$. The capacitor is treated as a short for the ac signal, so we have,

$$V_{GS}(t) = 3 + \sin(2000\pi t)$$

(b) –(d)

Three operation regions:

Cutoff: $V_{GS} \le V_{t0}$

$$i_D = 0$$

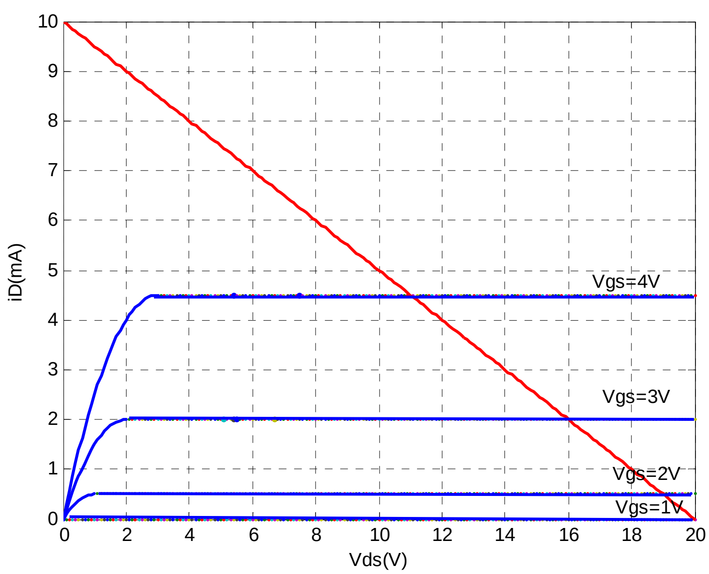
Triode: $V_{GS} \ge V_{t0}, V_{DS} \le V_{GS} - V_{t0}$

$$i_D = K[2(v_{GS} - V_{t0})v_{DS} - v_{DS}^2]$$

Saturation: $V_{GS} \ge V_{t0}, V_{DS} \ge V_{GS} - V_{t0}$

$$i_D = K(V_{GS} - V_{t0})^2$$

The load-line equation is $V_{DD} = 2k * i_D + V_{DS}$



From the load-line, we find $V_{DSQ} = 16V$, $V_{DS\max} = 19V$, and $V_{DS\min} = 11V$.

5. (10 points)

(a) Assume the FET is operated in the saturation region,

$$I_{DQ} = K(V_{GSQ} - V_{t0})^2 \quad (1)$$

$V_G = 20\dfrac{1M}{1M + 1M} = 10V$ from voltage divider.

Using KVL, we get $V_{GSQ} + I_{DQ} \times 1k\Omega = 10V$ (2)

Solving equations (1) & (2), $I_{DQ} = 4mA$, $V_{GSQ} = 6V$, and

$$V_{DSQ} = 20V - I_{DQ}(1k + 1k) = 12V$$

Verification: $V_{DSQ} \geq V_{GSQ} + V_{t0}$, so it's in the saturation region.

(b) Assume the FET is operated in the saturation region. Similar to part (a), we can solve
$I_{DQ} = 6.234mA$, $V_{GSQ} = 3.765V$, and $V_{DSQ} = 20V - I_{DQ}(1k + 1k) = 7.53V$

Verification: $V_{DSQ} \geq V_{GSQ} + V_{t0}$, so it's in the saturation region.

6. (10 points)
Write $V_{DD}=R_D I_{DQ}+V_{DSQ}+R_S I_{DQ}$. Substituting values and solving we obtain $R_S=3k\Omega$. Next We have $K=1/2\ KP(W/L)=0.2mA/V^2$. Assuming the NMOS operates in saturation, we have $I_{DQ} = K(V_{GSQ} - V_{to})^2$. Substituting values and solving we obtain $V_{GSQ}=-1.236V$ and $V_{GSQ}=3.236$ V. The correct root is $V_{GSQ}=3.236$ V. Then we have $V_G = V_{GSQ} + R_S i_D = 6.236V$. However we also have $V_G=V_{DD}R_2/(R_1+R_2)$. Substituting values and solving we obtain $R_2 = 1.082M\Omega$

7. (10 points)
We have $V_G=V_{GSQ}=10\ R_2/(R_1+R_2)=2.5V$. Then we have $I_{DQ} = K(V_{GSQ} - V_{to})^2=0.5625$ mA.
$V_{DSQ} = V_{DD}-R_D I_{DQ} = 4.375V$.

8. (10 points)
For constant drain current in the saturation region, we have $r_d = \infty$.

9. (10 points)

$$g_m = \left.\frac{\partial i_D}{\partial V_{GS}}\right|_{Q-point} = 9V_{GS}^{\ 2}\Big|_{Q-point} = 9mS$$

$$1/r_d = \left.\frac{\partial i_D}{\partial V_{DS}}\right|_{Q-point} = 0.1\Big|_{Q-point} = 0.1mS$$

$$r_d = 10k\Omega$$

10. (10 points)

From Figure P12.41 at an operating point defined by V_{GSQ}=2.5 V and V_{DSQ}=6 V, we have

$$g_m = \frac{\Delta i_D}{\Delta V_{GS}} = \frac{(6.4-1.5)mA}{1V} = 4.9mS$$

$$1/r_d = \frac{\Delta i_D}{\Delta V_{GS}} \cong \frac{(4.0-3.1)mA}{(8-4)V} = 0..225 \times 10^{-3}$$

Taking the reciprocal, we find $r_d = 4.44k\Omega$