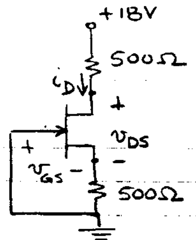
Assignment 8 Solutions from Instructor's Manual for Fundamentals of Elec. Engr., 2nd ed.

8.6



$I_{DSS} = 16\,mA \qquad V_p = -4\,V$

Assume active region.

$\therefore i_D = I_{DSS}\left(1 - \frac{v_{GS}}{V_p}\right)^2$

(a)
$$i_D = -\frac{v_{GS}}{500} = 16m\left(1 + \frac{v_{GS}}{4}\right)^2$$
$$-2m\, v_{GS} = 16m\left(1 + \frac{v_{GS}}{4}\right)^2$$
$$-2v_{GS} = 16 + 8v_{GS} + v_{GS}^2$$
$$v_{GS}^2 + 10v_{GS} + 16 = 0$$
$$(v_{GS}+2)(v_{GS}+8) = 0 \Rightarrow v_{GS} = -2\,V,\ -8\,V$$

Since $0 \ge v_{GS} \ge -4\,V$, then $v_{GS} = -2\,V$

(b) $i_D = -\frac{v_{GS}}{500} = \frac{2}{\frac{1}{2}k} = 4\,mA$

(c) $v_{DS} = -500 i_D + 18 - 500 i_D = 18 - 1k\, i_D = 18 - 1k(4m)$
$= 18 - 4 = 14\,V$

(d) Since $v_{DS} = 14\,V > v_{GS} - V_p = -2 + 4 = 2\,V$
then active-region operation is confirmed.

8.8 For ohmic region:

$$i_D = I_{DSS}\left[2\left(1 - \frac{v_{GS}}{V_p}\right)\frac{v_{DS}}{-V_p} - \left(\frac{v_{DS}}{V_p}\right)^2\right] \qquad (8.2)$$

On the border between the active and the ohmic regions,

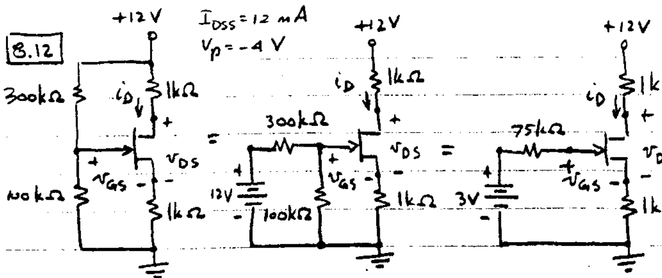
$$v_{DS} = v_{GS} - V_p$$

so

$$i_D = I_{DSS}\left[2\left(1 - \frac{v_{GS}}{V_p}\right)\frac{v_{GS}-V_p}{-V_p} - \left(\frac{v_{GS}-V_p}{V_p}\right)^2\right]$$
$$i_D = I_{DSS}\left[2\left(\frac{V_p - v_{GS}}{V_p}\right)\frac{V_p - v_{GS}}{V_p} - \left(\frac{V_p - v_{GS}}{V_p}\right)^2\right]$$
$$i_D = I_{DSS}\left[2\left(\frac{V_p - v_{GS}}{V_p}\right)^2 - \left(\frac{V_p - v_{GS}}{V_p}\right)^2\right]$$
$$i_D = I_{DSS}\left(\frac{V_p - v_{GS}}{V_p}\right)^2$$
$$i_D = I_{DSS}\left(1 - \frac{v_{GS}}{V_p}\right)^2 \qquad (8.3)$$

8.12

$I_{DSS} = 12\,mA$
$V_p = -4\,V$



(a) Assume active-region operation: Then $i_G = 0\,A$ and
$$i_D = I_{DSS}\left(1 - \frac{v_{GS}}{V_p}\right)^2 = 12m\left(1 + \frac{v_{GS}}{4}\right)^2 = 12m\left(1 + \frac{v_{GS}}{2} + \frac{v_{GS}^2}{16}\right)$$
Also, $i_D = \frac{-v_{GS}+3}{1k} = 12m\left(1 + \frac{v_{GS}}{2} + \frac{v_{GS}^2}{16}\right)$
$$-v_{GS} + 3 = 12 + 6v_{GS} + \frac{3}{4}v_{GS}^2$$
$$\frac{3}{4}v_{GS}^2 + 7v_{GS} + 9 = 0$$
$$3v_{GS}^2 + 28v_{GS} + 36 = 0 \Rightarrow v_{GS} = \frac{-28 \pm \sqrt{28^2 - 4(3)(36)}}{2(3)} = -7.8,\ -1.54\,V$$

Since $-4 \le v_{GS} \le 0\,V$, then $v_{GS} = -1.54\,V$

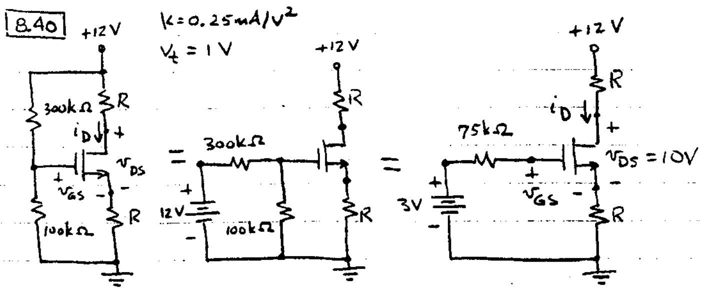
(b) $i_D = \frac{-v_{GS}+3}{1k} = \frac{1.54+3}{1k} = 4.54\,mA$

(c) $v_{DS} = -1k\, i_D + 12 - 1k\, i_D = -2k\, i_D + 12 = -2k(4.54m) + 12 = 2.92\,V$

(d) Since $v_{DS} = 2.92 > v_{GS} - V_p = -1.54 + 4 = 2.46\,V$, then active-region operation is confirmed.

8.40

$K = 0.25\,mA/V^2$
$V_t = 1\,V$



(a) By KVL, $12 = Ri_D + v_{DS} + Ri_D$
$12 = 2Ri_D + 10$
$2 = 2Ri_D$
$Ri_D = 1$

By KVL, $3 = 75k\, i_G + v_{GS} + Ri_D$
$3 = 0 + v_{GS} + 1$
$\therefore v_{GS} = 2\,V$

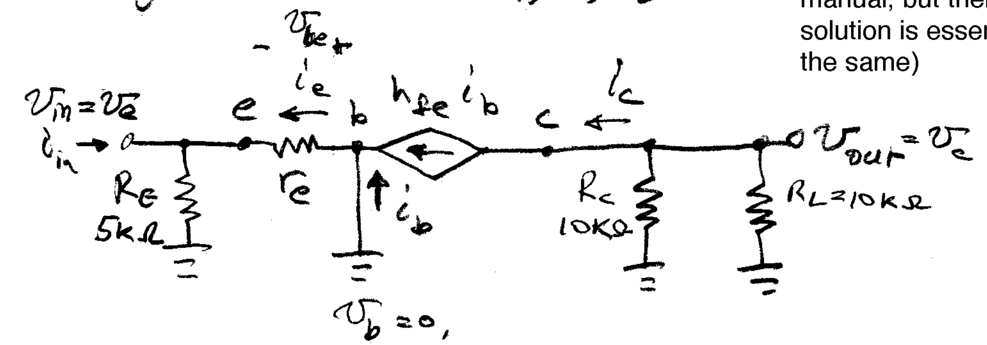
(b) Since $v_{DS} = 10 > v_{GS} - V_t = 2 - 1 = 1\,V$, then the MOSFET is in the active region.

Thus, $i_D = K(v_{GS} - V_t)^2 = 0.25m(2-1)^2 = 0.25\,mA$

(c) $Ri_D = 1 \Rightarrow R = \frac{1}{i_D} = \frac{1}{0.25m} = 4\,k\Omega$

9.21 Small signal AC model ($C_1, C_2, C_B \to \infty$)

(Not from instructor's manual, but their solution is essentially the same)



(a)
$$A_v = \frac{v_c}{v_e}, \quad v_c = -i_c R_c \| R_L$$
$$v_e = -v_{be} = -i_e r_e$$
$$A_v = +\frac{i_c}{i_e}\,\frac{R_c \| R_L}{r_e} = \frac{h_{fe} i_b}{h_{fe} i_b + i_b}\,\frac{R_c \| R_L}{r_e}$$
$$= \frac{h_{fe}}{h_{fe}+1}\,\frac{R_c R_L}{(R_c+R_L)\, r_e}$$

$$r_e = \frac{kT/q}{I_{E_Q}} = \frac{26\,mV}{I_{E_Q}} = \frac{26\,mV}{\frac{h_{FE}+1}{h_{FE}} I_{C_Q}} = \frac{26\,mV}{\frac{101}{100} \times .93\,mA} \quad @\,300k$$
$$= \underline{28\,\Omega}.$$

$$A_v = \frac{100}{101} \times \frac{5k\Omega}{28\,\Omega} = \underline{177}.$$

(b) $R_{in} = R_E \| r_e$ [Note that the resistance looking into the emitter is $\frac{v_e}{-i_e} = r_e$]
$$= 5k\Omega \| 28\,\Omega \simeq \underline{28\,\Omega}$$

(c) R_o is the resistance looking into the amplifier output (neglecting the load resistance, R_L).

Set $v_{in} = 0$ and find Thevenin equiv. resistance of circuit. If $v_{in} = 0$, $i_e = 0 \Rightarrow i_b = 0$ and $h_{fe} i_b = i_c = 0$. Thus the output node sees R_c connected to ground.

$$R_o = R_c = \underline{10k\Omega}.$$

Note: This is a voltage amplifier suitable for a signal with a low source impedance. With the 1kΩ source imped. shown in Fig. P9.21, $v_{out}/v_s = 4.8$, much less than A_v.

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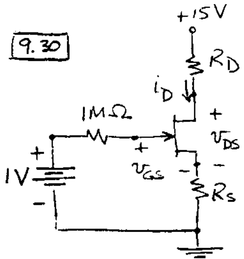
9.30



$I_{DSS} = 16mA$ $V_p = -4V$

$I_{DQ} = 1mA$ $V_{DSQ} = 7V$

For active region: $i_D = I_{DSS}(1-\frac{v_{GS}}{V_p})^2$

Thus,

$$\sqrt{\frac{i_D}{I_{DSS}}} = 1-\frac{v_{GS}}{V_p} \Rightarrow \frac{v_{GS}}{V_p} = 1-\sqrt{\frac{i_D}{I_{DSS}}}$$

$$\therefore v_{GS} = V_p\left(1-\sqrt{\frac{i_D}{I_{DSS}}}\right) = -4\left(1-\sqrt{\frac{1m}{16m}}\right) = -4\left(\frac{3}{4}\right)$$

$$v_{GS} = \underline{\underline{-3V}} = V_{GSQ}$$

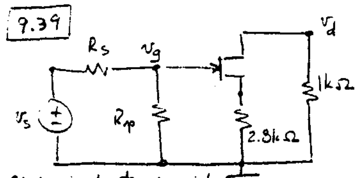
Since $i_G = 0A$,

$$R_S = \frac{-v_{GS}+1}{i_D} = \frac{-(-3)+1}{1m} = \underline{4k\Omega}$$

Also, $R_D = \frac{15-v_D}{i_D} = \frac{15-(v_{DS}-v_{GS}+1)}{i_D} = \frac{15-(7+3+1)}{1m} = \underline{\underline{4k\Omega}}$

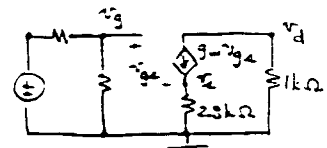
Since $v_{DS} = 7 > v_{GS} - V_p = -3+4 = 1V$, then active-region operation is confirmed.

9.39



ac-equivalent circuit

$R_p = 500k // 250k = 167k\Omega$



ac-equivalent circuit with small-signal model

$I_{DSS} = 10mA$ $V_p = -4V$ $V_{GSQ} = -2V$ $I_{DQ} = 2.5mA$

$$g_m = -\frac{2}{V_p}\sqrt{i_D I_{DSS}} = -\frac{2}{-4}\sqrt{(2.5m)(10m)} = \frac{1}{2}(5m) = 2.5m\mho$$

(a) By KCL at node v_s,

$$g_m v_{gs} = \frac{v_s}{2.8k}$$

$$2.5m(v_g - v_s) = \frac{v_s}{2.8k}$$

$$7v_g - 7v_s = v_s$$

$$7v_g = 8v_s$$

$$\therefore v_s = \frac{7}{8}v_g$$

$$\therefore \frac{v_s}{v_g} = \frac{7}{8} = \underline{\underline{0.875}}$$

(b) $v_d = -1k\, g_m v_{gs}$

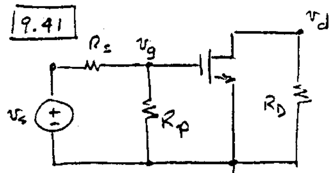
$$v_d = -1k(2.5m)(v_g - v_s)$$

$$v_d = -2.5\left(v_g - \frac{7}{8}v_g\right)$$

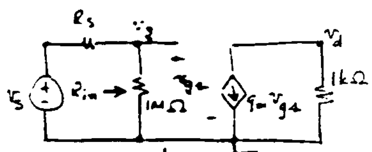
$$v_d = -\frac{2.5}{8}v_g$$

$$\therefore \frac{v_d}{v_g} = -\frac{2.5}{8} = \underline{\underline{-0.313}}$$

9.41



ac-equivalent circuit $R_p = 2M // 2M = 1M\Omega$



ac-equivalent circuit with small-signal model

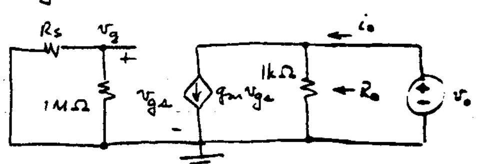
$V_{GSQ} = 6V$, $I_{DQ} = 4mA$, $V_{DSQ} = 12V$, $K = 0.25mA/V^2$, $V_t = 2V$

$$g_m = 2\sqrt{Ki_D} = 2\sqrt{(0.25m)(4m)} = 2m\mho$$

(a) $v_d = -1k\, g_m v_{gs} = -1k(2m)v_g = -2v_g$

$\therefore \frac{v_d}{v_g} = \underline{\underline{-2}}$ (b) $R_{in} = \underline{\underline{1M\Omega}}$

(c)



$R_o = \frac{v_o}{i_o}$

By KCL at node v_g, $\frac{v_g}{R_s} + \frac{v_g}{1M} = 0 \Rightarrow v_g = 0V \Rightarrow v_{gs} = v_g = 0V$

By KCL,

$$i_o = g_m v_{gs} + \frac{v_o}{1k} = 2m\, v_g + \frac{v_o}{1k} = \frac{v_o}{1k}$$

$$\therefore R_o = \frac{v_o}{i_o} = \underline{\underline{1k\Omega}}$$