Basic Electronic Devices and Circuits

FET Solution

1.

(a) $V_{GS_Q} = -V_{GG} = \mathbf{-2\ V}$

(b) $I_{D_Q} = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 10\text{ mA}\left(1 - \frac{-2\text{ V}}{-8\text{ V}}\right)^2$

$= 10\text{ mA}(1 - 0.25)^2 = 10\text{ mA}(0.75)^2 = 10\text{ mA}(0.5625)$

$= \mathbf{5.625\ mA}$

(c) $V_{DS} = V_{DD} - I_D R_D = 16\text{ V} - (5.625\text{ mA})(2\text{ k}\Omega)$

$= 16\text{ V} - 11.25\text{ V} = \mathbf{4.75\ V}$

2.

(a) & (b)

$I_{DQ} = I_{DSS}(1 - V_{GS}/V_P)^2 = 8(1 + V_{GS}/6)^2$ --- (i)

$V_{GS} = -I_{DQ} \times Rs = -I_{DQ}$ ------ (ii)

From Equations (i) & (ii)

I_{DQ} = 2.59 mA and V_{GS} = -2.59 V

© **V_{DS} = 20 - 2.59(3.3+1) = 8.86 V**

3. (a) $I_{DQ} = I_{DSS}(1 - V_{GS}/V_P)^2 = 8(1 + V_{GS}/4)^2$ --- (i)

$V_{GS} = 1.82 - I_{DQ} \times Rs = 1.82 - 1.5 I_{DQ}$ ------ (ii)

From Equations (i) & (ii)

I_{DQ} = 2.414 mA and V_{GS} = -1.8 V

(b) V_{DS} = 16 -2.4(2.4+1.5) = 6.64 V

© $V_{DG} = V_{DS} - V_{GS} = 8.44\text{ V}$

4.

The level of V_G is determined as follows:

$$V_G = \frac{47\ \text{k}\Omega(16\ \text{V})}{47\ \text{k}\Omega + 91\ \text{k}\Omega} = 5.44\ \text{V}$$

with
$$I_D = \frac{V_{DD} - V_D}{R_D}$$
$$= \frac{16\ \text{V} - 12\ \text{V}}{1.8\ \text{k}\Omega} = 2.22\ \text{mA}$$

The equation for V_{GS} is then written and the known values substituted:

$$V_{GS} = V_G - I_D R_S$$
$$-2\ \text{V} = 5.44\ \text{V} - (2.22\ \text{mA})R_S$$
$$-7.44\ \text{V} = -(2.22\ \text{mA})R_S$$

and
$$R_S = \frac{7.44\ \text{V}}{2.22\ \text{mA}} = \mathbf{3.35\ k\Omega}$$

The nearest standard commercial value is 3.3 kΩ.

5.

(a)

At $V_{GS} = -0.5$ V,

$$g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right] = 4\ \text{mS}\left[1 - \frac{-0.5\ \text{V}}{-4\ \text{V}}\right] = \mathbf{3.5\ mS}$$ (versus 3.5 mS graphically)

(b) & (C)

At $V_{GS} = -1.5$ V,

$$g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right] = 4\ \text{mS}\left[1 - \frac{-1.5\ \text{V}}{-4\ \text{V}}\right] = \mathbf{2.5\ mS}$$

At $V_{GS} = -2.5$ V,

$$g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right] = 4\ \text{mS}\left[1 - \frac{-2.5\ \text{V}}{-4\ \text{V}}\right] = \mathbf{1.5\ mS}$$

6.

Solution

(a) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(10 \text{ mA})}{8 \text{ V}} = 2.5 \text{ mS}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 2.5 \text{ mS}\left(1 - \frac{(-2 \text{ V})}{(-8 \text{ V})}\right) = \mathbf{1.88 \text{ mS}}$$

(b) $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{40 \ \mu\text{S}} = \mathbf{25 \text{ k}\Omega}$

(c) $Z_i = R_G = \mathbf{1 \text{ M}\Omega}$

(d) $Z_o = R_D \| r_d = 2 \text{ k}\Omega \| 25 \text{ k}\Omega = \mathbf{1.85 \text{ k}\Omega}$

(e) $A_v = -g_m(R_D \| r_d) = -(1.88 \text{ mS})(1.85 \text{ k}\Omega)$

$= \mathbf{-3.48}$

(f) $A_v = -g_m R_D = -(1.88 \text{ mS})(2 \text{ k}\Omega) = \mathbf{-3.76}$

As demonstrated in part (f), a ratio of $25 \text{ k}\Omega : 2 \text{ k}\Omega = 12.5:1$ between r_d and R_D resulted in a difference of 8% in solution.

7.

(a) $g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(16 \text{ mA})}{4 \text{ V}} = 8 \text{ mS}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 8 \text{ mS}\left(1 - \frac{(-2.86 \text{ V})}{(-4 \text{ V})}\right) = \mathbf{2.28 \text{ mS}}$$

(b) $r_d = \frac{1}{y_{os}} = \frac{1}{25 \ \mu\text{S}} = \mathbf{40 \text{ k}\Omega}$

(c) $Z_i = R_G = \mathbf{1 \text{ M}\Omega}$

(d) With r_d:

$$\begin{aligned} Z_o = r_d \| R_S \| 1/g_m &= 40 \text{ k}\Omega \| 2.2 \text{ k}\Omega \| 1/2.28 \text{ mS} \\ &= 40 \text{ k}\Omega \| 2.2 \text{ k}\Omega \| 438.6 \ \Omega \\ &= \mathbf{362.52 \ \Omega} \end{aligned}$$

revealing that Z_o is often relatively small and determined primarily by $1/g_m$. Without r_d:

$$Z_o = R_S \| 1/g_m = 2.2 \text{ k}\Omega \| 438.6 \ \Omega = \mathbf{365.69 \ \Omega}$$

revealing that r_d typically has little impact on Z_o.

(e) With r_d:

$$A_v = \frac{g_m(r_d \| R_S)}{1 + g_m(r_d \| R_S)} = \frac{(2.28 \text{ mS})(40 \text{ k}\Omega \| 2.2 \text{ k}\Omega)}{1 + (2.28 \text{ mS})(40 \text{ k}\Omega \| 2.2 \text{ k}\Omega)}$$

$$\frac{(2.28 \text{ mS})(2.09 \text{ k}\Omega)}{1 + (2.28 \text{ mS})(2.09 \text{ k}\Omega)} = \frac{4.77}{1 + 4.77} = \mathbf{0.83}$$

which is less than 1 as predicted above.
Without r_d:

$$\begin{aligned} A_v &= \frac{g_m R_S}{1 + g_m R_S} = \frac{(2.28 \text{ mS})(2.2 \text{ k}\Omega)}{1 + (2.28 \text{ mS})(2.2 \text{ k}\Omega)} \\ &= \frac{5.02}{1 + 5.02} = \mathbf{0.83} \end{aligned}$$

revealing that r_d usually has little impact on the gain of the configuration.

8. After converting the voltage divider network R_1 and R_2 To Thevenin Equivalent Circuit

R_{TH} =(10x90)/(10+90)=9 MΩ

V_{TH} = (18X10)/(10+90)=1.8 V

Applying KVL in input loop with V_{TH} & R_{TH}

$1.8 = I_G R_{TH} + V_{GS} + I_D R_S$ -------- (i)
$I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = 8(1 + V_{GS}/4)^2$ -------- (ii)

From Equation (i) & (ii)
$V_{GS} = 0.1$ V and $I_D = 7.6$ mA

$g_{mo} = (2 I_{DSS} / |V_P) = 0.004$ A/V
$g_m = g_{mo} (I_{DQ} / I_{DSS})^{1/2} = 0.0039$ A/V

$Av = Vo/Vi = (-g_m R_D v_{gs})/v_{gs}$
$= -7.8$

$Zi = Vi/Ii = R_G = R_{TH} = 9$ MΩ
$Zo = Voc/Isc = (-g_m R_D v_{gs})/(-g_m v_{gs})$
$= R_D = 2$ KΩ