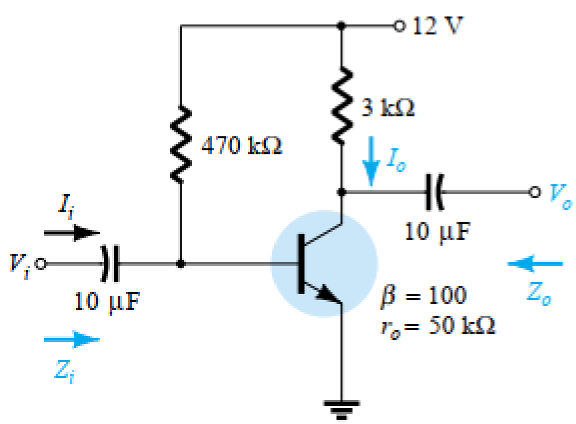
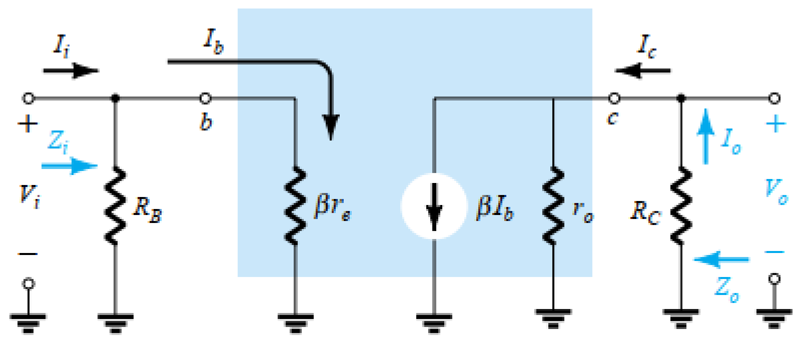
COMMON-EMITTER FIXED-BIAS CONFIGURATION (Phân cực Bazo)

EXAMPLE 8.1:





Solution

(a) DC analysis:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega} = 24.04\ \mu\text{A}$$

$$I_E = (\beta + 1)I_B = (101)(24.04\ \mu\text{A}) = 2.428\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{2.428\text{ mA}} = \mathbf{10.71\ \Omega}$$

(b) $\beta r_e = (100)(10.71\ \Omega) = 1.071\text{ k}\Omega$

$$Z_i = R_B \| \beta r_e = 470\text{ k}\Omega \| 1.071\text{ k}\Omega = \mathbf{1.069\text{ k}\Omega}$$

(c) $Z_o = R_C = \mathbf{3\text{ k}\Omega}$

(d) $$A_v = -\frac{R_C}{r_e} = -\frac{3\text{ k}\Omega}{10.71\ \Omega} = \mathbf{-280.11}$$

(e) Since $R_B \geq 10\beta r_e (470\text{ k}\Omega > 10.71\text{ k}\Omega)$

$$A_i \cong \beta = \mathbf{100}$$

(f) $Z_o = r_o \| R_C = 50\text{ k}\Omega \| 3\text{ k}\Omega = \mathbf{2.83\text{ k}\Omega}$ vs. 3 kΩ

$$A_v = -\frac{r_o \| R_C}{r_e} = \frac{2.83\text{ k}\Omega}{10.71\ \Omega} = \mathbf{-264.24}\text{ vs. } -280.11$$

$$A_i = \frac{\beta R_B r_o}{(r_o + R_C)(R_B + \beta r_e)} = \frac{(100)(470\text{ k}\Omega)(50\text{ k}\Omega)}{(50\text{ k}\Omega + 3\text{ k}\Omega)(470\text{ k}\Omega + 1.071\text{ k}\Omega)}$$

$$= \mathbf{94.13}\text{ vs. } 100$$

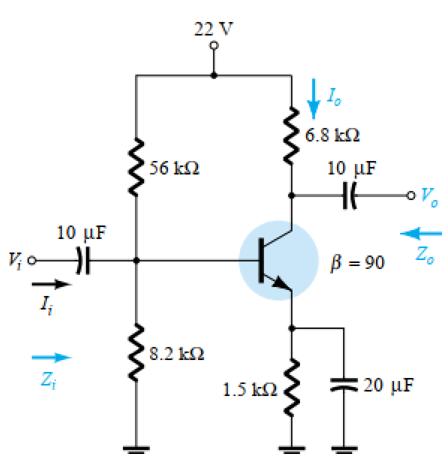
As a check:

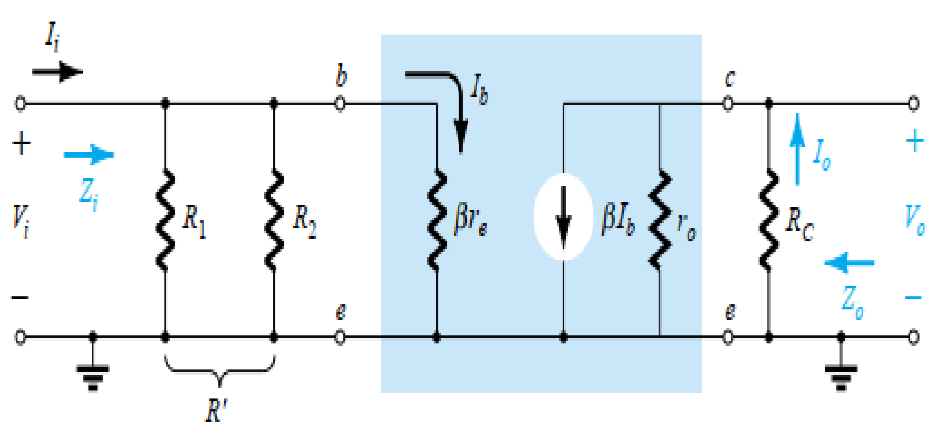
$$A_i = -A_v\frac{Z_i}{R_C} = \frac{-(-264.24)(1.069\text{ k}\Omega)}{3\text{ k}\Omega} = \mathbf{94.16}$$

which differs slightly only due to the accuracy carried through the calculations.

VOLTAGE-DIVIDER BIAS (Phân cực bằng phân áp)

EXAMPLE 8.2:





Solution

(a) DC: Testing $\beta R_E > 10R_2$

$$(90)(1.5\text{ k}\Omega) > 10(8.2\text{ k}\Omega)$$

$$135\text{ k}\Omega > 82\text{ k}\Omega \ (\textit{satisfied})$$

Using the approximate approach,

$$V_B = \frac{R_2}{R_1+R_2}V_{CC} = \frac{(8.2\text{ k}\Omega)(22\text{ V})}{56\text{ k}\Omega + 8.2\text{ k}\Omega} = 2.81\text{ V}$$

$$V_E = V_B - V_{BE} = 2.81\text{ V} - 0.7\text{ V} = 2.11\text{ V}$$

$$I_E = \frac{V_E}{R_E} = \frac{2.11\text{ V}}{1.5\text{ k}\Omega} = 1.41\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.41\text{ mA}} = \mathbf{18.44\ \Omega}$$

(b) $R' = R_1 \| R_2 = (56\text{ k}\Omega)\|(8.2\text{ k}\Omega) = 7.15\text{ k}\Omega$

$$Z_i = R' \| \beta r_e = 7.15\text{ k}\Omega \| (90)(18.44\ \Omega) = 7.15\text{ k}\Omega \| 1.66\text{ k}\Omega$$
$$= \mathbf{1.35\text{ k}\Omega}$$

(c) $Z_o = R_C = \mathbf{6.8\text{ k}\Omega}$

(d) $A_v = -\frac{R_C}{r_e} = -\frac{6.8\text{ k}\Omega}{18.44\ \Omega} = \mathbf{-368.76}$

(e) The condition $R' \ge 10\beta r_e$ ($7.15\text{ k}\Omega \ge 10(1.66\text{ k}\Omega) = 16.6\text{ k}\Omega$ is *not* satisfied. Therefore,

$$A_i \cong \frac{\beta R'}{R' + \beta r_e} = \frac{(90)(7.15\text{ k}\Omega)}{7.15\text{ k}\Omega + 1.66\text{ k}\Omega} = \mathbf{73.04}$$

(f) $Z_i = \mathbf{1.35\text{ k}\Omega}$

$Z_o = R_C \| r_o = 6.8\text{ k}\Omega \| 50\text{ k}\Omega = \mathbf{5.98\text{ k}\Omega}$ vs. $6.8\text{ k}\Omega$

$A_v = -\frac{R_C \| r_o}{r_e} = -\frac{5.98\text{ k}\Omega}{18.44\ \Omega} = \mathbf{-324.3}$ vs. -368.76

The condition

$$r_o \ge 10R_C \ (50\text{ k}\Omega \ge 10(6.8\text{ k}\Omega) = 68\text{ k}\Omega)$$

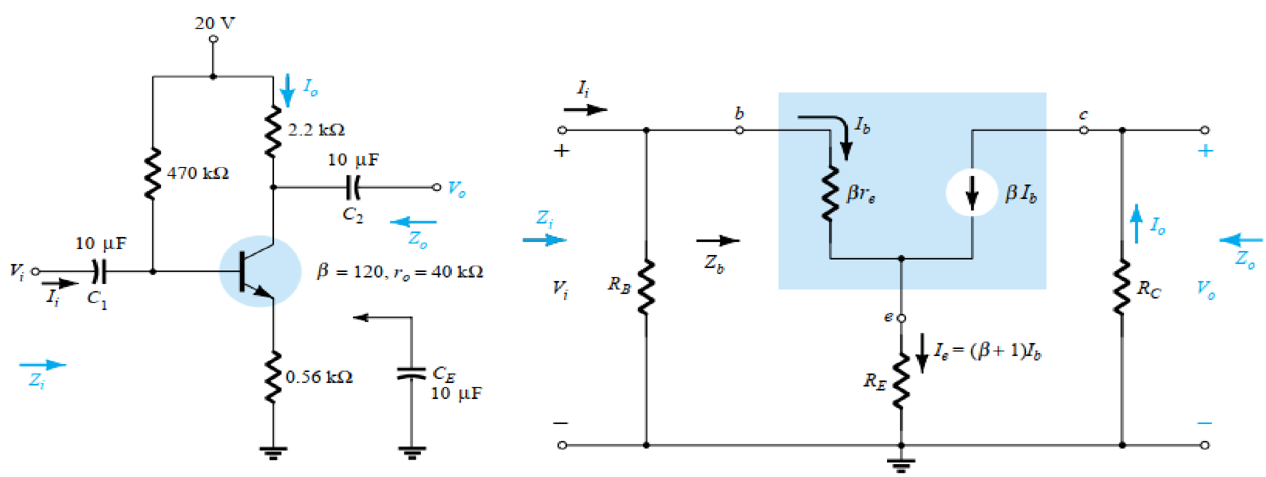
is *not* satisfied. Therefore,

$$A_i = \frac{\beta R' r_o}{(r_o + R_C)(R' + \beta r_e)} = \frac{(90)(7.15\text{ k}\Omega)(50\text{ k}\Omega)}{(50\text{ k}\Omega + 6.8\text{ k}\Omega)(7.15\text{ k}\Omega + 1.66\text{ k}\Omega)}$$
$$= \mathbf{64.3} \text{ vs. } 73.04$$

There was a measurable difference in the results for Z_o, A_v, and A_i because the condition $r_o \ge 10R_C$ was *not* satisfied.

CE EMITTER-BIAS CONFIGURATION (Phân cực Emitter)

<u>EXAMPLE 8.3:</u>



Solution

(a) DC: $I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \frac{20\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega + (121)0.56\text{ k}\Omega} = 35.89\ \mu\text{A}$

$$I_E = (\beta + 1)I_B = (121)(46.5\ \mu\text{A}) = 4.34\text{ mA}$$

and $\quad r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{4.34\text{ mA}} = 5.99\ \Omega$

(b) Testing the condition $r_o \ge 10(R_C + R_E)$,

$$40\text{ k}\Omega \ge 10(2.2\text{ k}\Omega + 0.56\text{ k}\Omega)$$
$$40\text{ k}\Omega \ge 10(2.76\text{ k}\Omega) = 27.6\text{ k}\Omega\ (\textit{satisfied})$$

Therefore,

$$Z_b \cong \beta(r_e + R_E) = 120(5.99\ \Omega + 560\ \Omega)$$
$$= 67.92\text{ k}\Omega$$

and $\quad Z_i = R_B \| Z_b = 470\text{ k}\Omega \| 67.92\text{ k}\Omega$
$$= \mathbf{59.34\text{ k}\Omega}$$

(c) $Z_o = R_C = \mathbf{2.2\text{ k}\Omega}$

(d) $r_o \ge 10R_C$ is satisfied. Therefore,

$$A_v = \frac{V_o}{V_i} \cong -\frac{\beta R_C}{Z_b} = -\frac{(120)(2.2\text{ k}\Omega)}{67.92\text{ k}\Omega}$$
$$= \mathbf{-3.89}$$

compared to -3.93 using Eq. (8.27): $A_v \cong -R_C/R_E$.

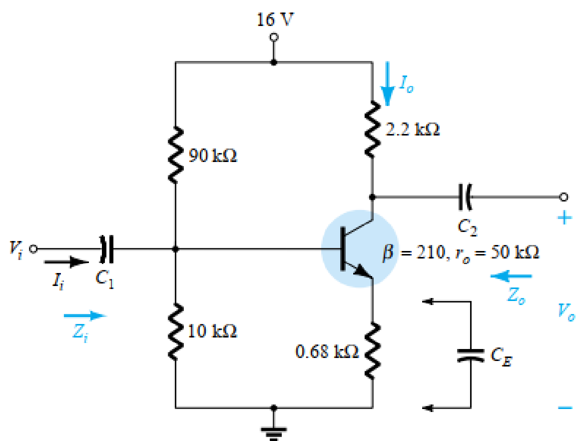
(e) $A_i = -A_v\frac{Z_i}{R_C} = -(-3.89)\left(\frac{59.34\text{ k}\Omega}{2.2\text{ k}\Omega}\right)$
$$= \mathbf{104.92}$$

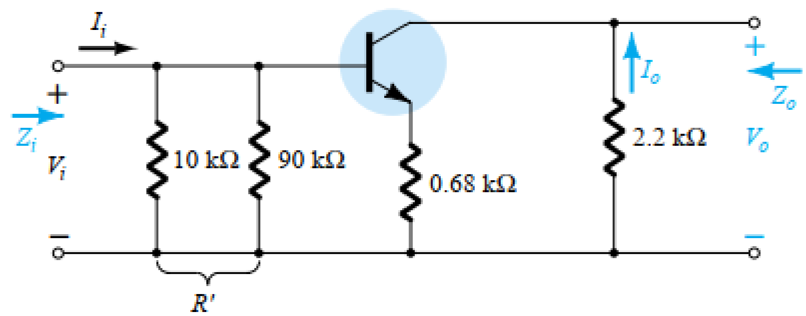
compared to 104.85 using Eq. (8.28): $A_i \cong \beta R_B/(R_B + Z_b)$.

Mở rộng bài này: Nối thêm Ce vào mạch trên

Solution (a) The dc analysis is the same, and $r_e = 5.99\ \Omega$. (b) R_E is "shorted out" by C_E for the ac analysis. Therefore, $Z_i = R_B \| Z_b = R_B \| \beta r_e = 470\ \text{k}\Omega \| (120)(5.99\ \Omega)$ $= 470\ \text{k}\Omega \| 718.8\ \Omega \cong \mathbf{717.70\ \Omega}$ (c) $Z_o = R_C = \mathbf{2.2\ k\Omega}$	(d) $A_v = -\frac{R_C}{r_e}$ $= -\frac{2.2\ \text{k}\Omega}{5.99\ \Omega} = \mathbf{-367.28}$ (a significant increase) (e) $A_i = \frac{\beta R_B}{R_B + Z_b} = \frac{(120)(470\ \text{k}\Omega)}{470\ \text{k}\Omega + 718.8\ \Omega}$ $= \mathbf{119.82}$

EXAMPLE 8.5





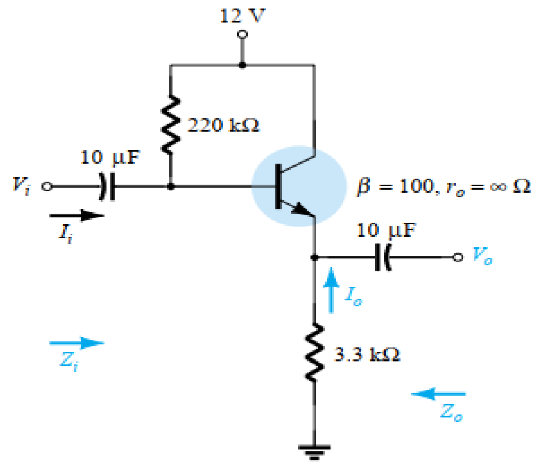
Solution (a) Testing $\beta R_E > 10R_2$ $(210)(0.68\ \text{k}\Omega) > 10(10\ \text{k}\Omega)$ $142.8\ \text{k}\Omega > 100\ \text{k}\Omega$ (*satisfied*) $V_B = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{10\ \text{k}\Omega}{90\ \text{k}\Omega + 10\ \text{k}\Omega}(16\ \text{V}) = 1.6\ \text{V}$ $V_E = V_B - V_{BE} = 1.6\ \text{V} - 0.7\ \text{V} = 0.9\ \text{V}$ $I_E = \frac{V_E}{R_E} = \frac{0.9\ \text{V}}{0.68\ \text{k}\Omega} = 1.324\ \text{mA}$ $r_e = \frac{26\ \text{mV}}{I_E} = \frac{26\ \text{mV}}{1.324\ \text{mA}} = \mathbf{19.64\ \Omega}$	$R_B = R' = R_1 \| R_2 = 9\ \text{k}\Omega$ The testing conditions of $r_o \geq 10(R_C + R_E)$ and $r_o \geq 10R_C$ are both satisfied. Using the appropriate approximations yields $Z_b \cong \beta R_E = 142.8\ \text{k}\Omega$ $Z_i = R_B \| Z_b = 9\ \text{k}\Omega \| 142.8\ \text{k}\Omega$ $= \mathbf{8.47\ k\Omega}$ (c) $Z_o = R_C = \mathbf{2.2\ k\Omega}$ (d) $A_v = -\frac{R_C}{R_E} = -\frac{2.2\ \text{k}\Omega}{0.68\ \text{k}\Omega} = \mathbf{-3.24}$ (e) $A_i = -A_v \frac{Z_i}{R_C} = -(-3.24)\left(\frac{8.47\ \text{k}\Omega}{2.2\ \text{k}\Omega}\right)$ $= \mathbf{12.47}$

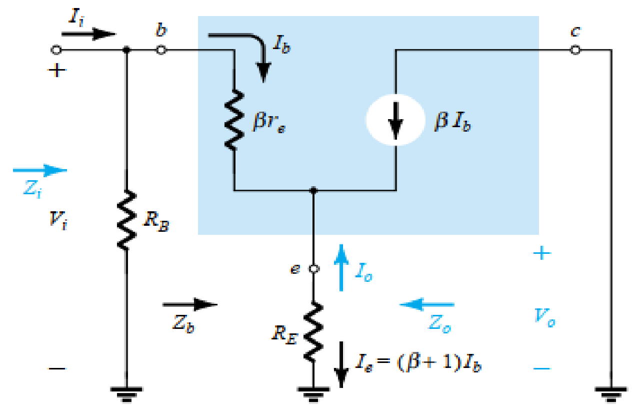
Mở rộng bài này: Nối thêm Ce vào mạch trên

Solution (a) The dc analysis is the same, and $r_e = \mathbf{19.64\ \Omega}$. (b) $Z_b = \beta r_e = (210)(19.64\ \Omega) \cong 4.12\ \text{k}\Omega$ $Z_i = R_B \| Z_b = 9\ \text{k}\Omega \| 4.12\ \text{k}\Omega$ $= \mathbf{2.83\ k\Omega}$ (c) $Z_o = R_C = \mathbf{2.2\ k\Omega}$	(d) $A_v = -\frac{R_C}{r_e} = -\frac{2.2\ \text{k}\Omega}{19.64\ \text{k}\Omega} = \mathbf{-112.02}$ (a significant increase) (e) $A_i = -A_v \frac{Z_i}{R_L} = -(-112.02)\left(\frac{2.83\ \text{k}\Omega}{2.2\ \text{k}\Omega}\right)$ $= \mathbf{144.1}$

EMITTER-FOLLOWER CONFIGURATION (Đầu ra ở chân E)

EXAMPLE 8.7:





Solution

(a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E}$

$= \dfrac{12\text{ V} - 0.7\text{ V}}{220\text{ k}\Omega + (101)3.3\text{ k}\Omega} = 20.42\ \mu\text{A}$

$I_E = (\beta + 1)I_B$

$= (101)(20.42\ \mu\text{A}) = 2.062\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.062\text{ mA}} = \mathbf{12.61\ \Omega}$

(b) $Z_b = \beta r_e + (\beta + 1)R_E$

$= (100)(12.61\ \Omega) + (101)(3.3\text{ k}\Omega)$

$= 1.261\text{ k}\Omega + 333.3\text{ k}\Omega$

$= 334.56\text{ k}\Omega \cong \beta R_E$

$Z_i = R_B \| Z_b = 220\text{ k}\Omega \| 334.56\text{ k}\Omega$

$= \mathbf{132.72\ k\Omega}$

(c) $Z_o = R_E \| r_e = 3.3\text{ k}\Omega \| 12.61\ \Omega$

$= \mathbf{12.56\ \Omega} \cong r_e$

(d) $A_v = \dfrac{V_o}{V_i} = \dfrac{R_E}{R_E + r_e} = \dfrac{3.3\text{ k}\Omega}{3.3\text{ k}\Omega + 12.61\ \Omega}$

$= \mathbf{0.996} \cong 1$

(e) $A_i \cong -\dfrac{\beta R_B}{R_B + Z_b} = -\dfrac{(100)(220\text{ k}\Omega)}{220\text{ k}\Omega + 334.56\text{ k}\Omega} = \mathbf{-39.67}$

versus

$A_i = -A_v \dfrac{Z_i}{R_E} = -(0.996)\left(\dfrac{132.72\text{ k}\Omega}{3.3\text{ k}\Omega}\right) = \mathbf{-40.06}$

(f) Checking the condition $r_o \geq 10R_E$, we have

$25\text{ k}\Omega \geq 10(3.3\text{ k}\Omega) = 33\text{ k}\Omega$

which is *not* satisfied. Therefore,

$$Z_b = \beta r_e + \frac{(\beta + 1)R_E}{1 + \dfrac{R_E}{r_o}} = (100)(12.61\ \Omega) + \frac{(100 + 1)3.3\text{ k}\Omega}{1 + \dfrac{3.3\text{ k}\Omega}{25\text{ k}\Omega}}$$

$= 1.261\text{ k}\Omega + 294.43\text{ k}\Omega$

$= 295.7\text{ k}\Omega$

with $Z_i = R_B \| Z_b = 220\text{ k}\Omega \| 295.7\text{ k}\Omega$

$= \mathbf{126.15\ k\Omega}$ vs. $132.72\text{ k}\Omega$ obtained earlier

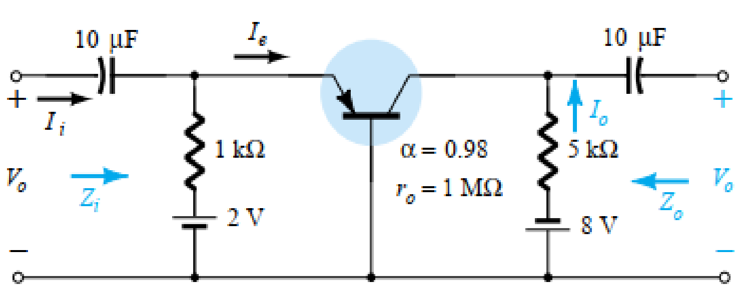
$Z_o = R_E \| r_e = \mathbf{12.56\ \Omega}$ as obtained earlier

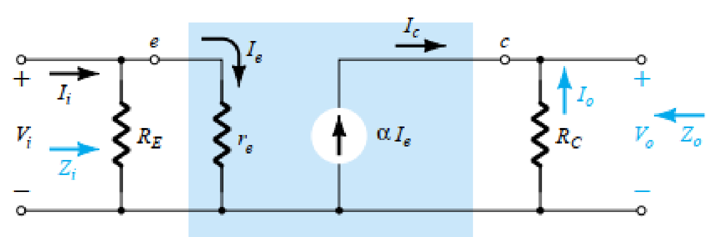
$$A_v = \frac{(\beta + 1)R_E/Z_b}{\left[1 + \dfrac{R_E}{r_o}\right]} = \frac{(100 + 1)(3.3\text{ k}\Omega)/295.7\text{ k}\Omega}{\left[1 + \dfrac{3.3\text{ k}\Omega}{25\text{ k}\Omega}\right]}$$

$= \mathbf{0.996} \cong 1$

COMMON-BASE CONFIGURATION (B chung)

EXAMPLE 8.8:





Solution

(a) $I_E = \dfrac{V_{EE} - V_{BE}}{R_E} = \dfrac{2\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = \dfrac{1.3\text{ V}}{1\text{ k}\Omega} = 1.3\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{1.3\text{ mA}} = \mathbf{20\ \Omega}$

(b) $Z_i = R_E \| r_e = 1\text{ k}\Omega \| 20\ \Omega$

$= \mathbf{19.61\ \Omega} \cong r_e$

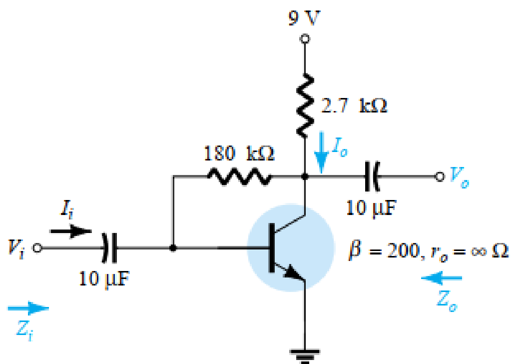
(c) $Z_o = R_C = \mathbf{5\text{ k}\Omega}$

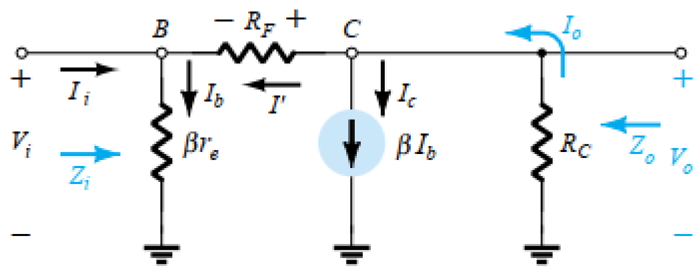
(d) $A_v \cong \dfrac{R_C}{r_e} = \dfrac{5\text{ k}\Omega}{20\ \Omega} = \mathbf{250}$

(e) $A_i = \mathbf{-0.98} \cong -1$

COLLECTOR FEEDBACK CONFIGURATION (Hồi tiếp Collector)

EXAMPLE 8.9:





Solution

(a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_F + \beta R_C} = \dfrac{9\text{ V} - 0.7\text{ V}}{180\text{ k}\Omega + (200)2.7\text{ k}\Omega}$

$= 11.53\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (201)(11.53\ \mu\text{A}) = 2.32\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.32\text{ mA}} = \mathbf{11.21\ \Omega}$

(b) $Z_i = \dfrac{r_e}{\dfrac{1}{\beta} + \dfrac{R_C}{R_F}} = \dfrac{11.21\ \Omega}{\dfrac{1}{200} + \dfrac{2.7\text{ k}\Omega}{180\text{ k}\Omega}} = \dfrac{11.21\ \Omega}{0.005 + 0.01}$

$= \dfrac{11.21\ \Omega}{0.02} = 50(11.21\ \Omega) = \mathbf{560.5\ \Omega}$

(c) $Z_o = R_C \| R_F = 2.7\text{ k}\Omega \| 180\text{ k}\Omega = \mathbf{2.66\text{ k}\Omega}$

(d) $A_v = -\dfrac{R_C}{r_e} = -\dfrac{27\text{ k}\Omega}{11.21\ \Omega} = \mathbf{-240.86}$

(e) $A_i = \dfrac{\beta R_F}{R_F + \beta R_C} = \dfrac{(200)(180\text{ k}\Omega)}{180\text{ k}\Omega + (200)(2.7\text{ k}\Omega)}$

$= \mathbf{50}$

(f) Z_i: The condition $r_o \geq 10R_C$ is *not* satisfied. Therefore,

$$Z_i = \frac{1 + \dfrac{R_C \| r_o}{R_F}}{\dfrac{1}{\beta r_e} + \dfrac{1}{R_F} + \dfrac{R_C \| r_o}{R_F r_e}} = \frac{1 + \dfrac{2.7\text{ k}\Omega \| 20\text{ k}\Omega}{180\text{ k}\Omega}}{\dfrac{1}{(200)(11.21)} + \dfrac{1}{180\text{ k}\Omega} + \dfrac{2.7\text{ k}\Omega \| 20\text{ k}\Omega}{(180\text{ k}\Omega)(11.21}}$$

$$= \frac{1 + \dfrac{2.38\text{ k}\Omega}{180\text{ k}\Omega}}{0.45 \times 10^{-3} + 0.006 \times 10^{-3} + 1.18 \times 10^{-3}} = \frac{1 + 0.013}{1.64 \times 10^{-3}}$$

$= \mathbf{617.7\ \Omega}$ vs. 560.5 Ω above

Z_o:

$Z_o = r_o \| R_C \| R_F = 20\text{ k}\Omega \| 2.7\text{ k}\Omega \| 180\text{ k}\Omega$

$= \mathbf{2.35\text{ k}\Omega}$ vs. 2.66 kΩ above

A_i:

$$A_i = -A_v \frac{Z_i}{R_C}$$

$$= -(-209.56)\frac{617.7\ \Omega}{2.7\text{ k}\Omega}$$

$= \mathbf{47.94}$ vs. 50 above

A_v:

$$A_v = \frac{-\left[\frac{1}{R_F}+\frac{1}{r_e}\right](r_o \| R_C)}{1+\frac{r_o \| R_C}{R_F}} = \frac{-\left[\frac{1}{180\text{ k}\Omega}+\frac{1}{11.21\Omega}\right](2.38\text{ k}\Omega)}{1+\frac{2.38\text{ k}\Omega}{180\text{ k}\Omega}}$$

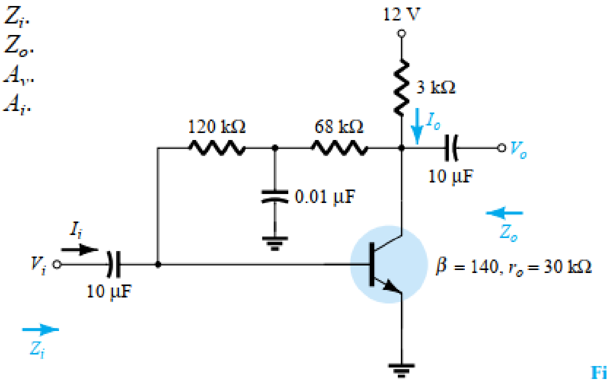
$$= \frac{-[5.56\times10^{-6} - 8.92\times10^{-2}](2.38\text{ k}\Omega)}{1+0.013}$$

$= \mathbf{-209.56}$ vs. -240.86 above

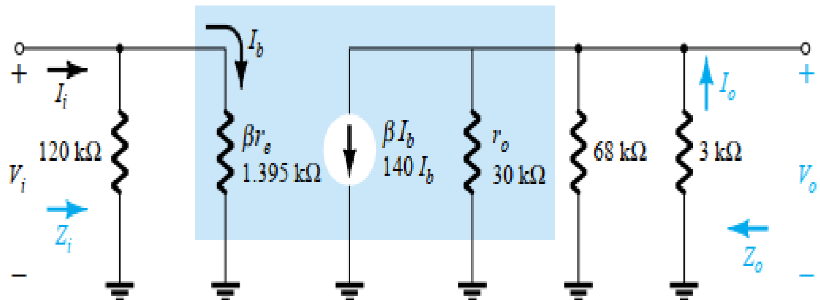
COLLECTOR DC FEEDBACK CONFIGURATION

EXAMPLE 8.10:

(a) r_e.
(b) Z_i.
(c) Z_o.
(d) A_v.
(e) A_i.



Fi



Solution

(a) DC: $I_B = \dfrac{V_{CC}-V_{BE}}{R_F+\beta R_C}$

$$= \frac{12\text{ V} - 0.7\text{ V}}{(120\text{ k}\Omega + 68\text{ k}\Omega) + (140)3\text{ k}\Omega}$$

$$= \frac{11.3\text{V}}{608\text{ k}\Omega} = 18.6\mu\text{A}$$

$$I_E = (\beta+1)I_B = (141)(18.6\mu A)$$

$$= 2.62\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{2.62\text{ mA}} = \mathbf{9.92\ \Omega}$$

(b) $\beta r_e = (140)(9.92\ \Omega) = 1.39\text{ k}\Omega$

The ac equivalent network appears in Fig. 8.34.

$$Z_i = R_{F1} \| \beta r_e = 120\text{ k}\Omega \| 1.39\text{ k}\Omega$$

$$\cong \mathbf{1.37\ k\Omega}$$

(c) Testing the condition $r_o \geq 10R_C$, we find

$$30\text{ k}\Omega \geq 10(3\text{ k}\Omega) = 30\text{ k}\Omega$$

which is satisfied through the equals sign in the condition. Therefore,

$$Z_o \cong R_C \| R_{F_2} = 3\text{ k}\Omega \| 68\text{ k}\Omega$$

$$= \mathbf{2.87\ k\Omega}$$

(d) $r_o \geq 10R_C$, therefore,

$$A_v \cong -\frac{R_{F_2} \| R_C}{r_e} = -\frac{68\text{ k}\Omega \| 3\text{ k}\Omega}{9.92\ \Omega}$$

$$\cong -\frac{2.87\text{ k}\Omega}{9.92\ \Omega}$$

$$\cong \mathbf{-289.3}$$

(e) Since the condition $R_{F_1} \gg \beta r_e$ is satisfied,

$$A_i \cong \frac{\beta}{1+\frac{R_C}{r_o \| R_{F_2}}} = \frac{140}{1+\frac{3\text{ k}\Omega}{30\text{ k}\Omega \| 68\text{ k}\Omega}} = \frac{140}{1+0.14} = \frac{140}{1.14}$$

$$\cong \mathbf{122.8}$$

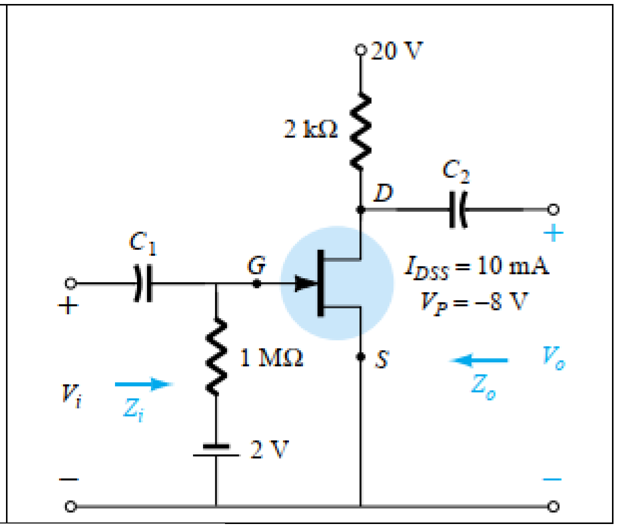
-----HẾT-----

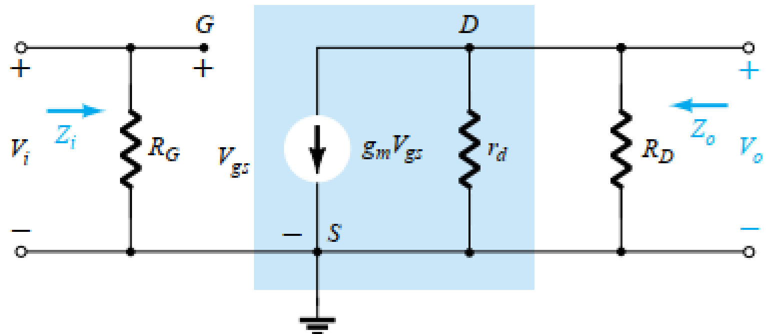
JFET FIXED-BIAS CONFIGURATION

EXAMPLE 9.7:

The fixed-bias configuration of Example 6.1 had an operating point defined by $V_{GS_Q} = -2$ V and $I_{D_Q} = 5.625$ mA, with $I_{DSS} = 10$ mA and $V_P = -8$ V. The network is redrawn as Fig. 9.14 with an applied signal V_i. The value of y_{os} is provided as 40 μS.

(a) Determine g_m.
(b) Find r_d.
(c) Determine Z_i.
(d) Calculate Z_o.
(e) Determine the voltage gain A_v.
(f) Determine A_v ignoring the effects of r_d.





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

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

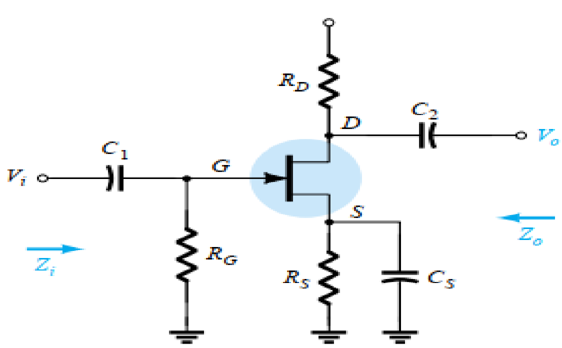
(d) $Z_o = R_D \| r_d = 2\text{ k}\Omega \| 25\text{ k}\Omega = \mathbf{1.85\ k\Omega}$

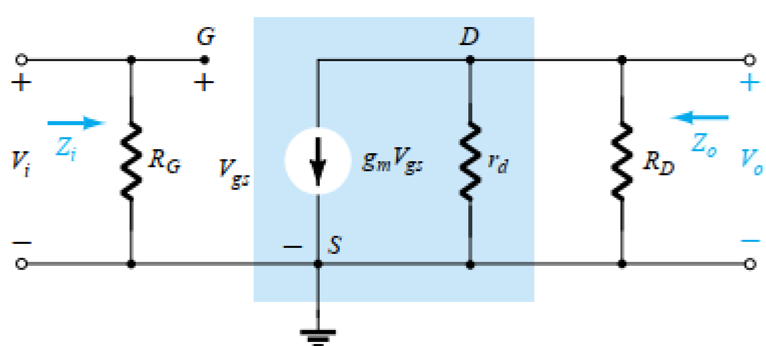
(e) $A_v = -g_m(R_D \| r_d) = -(1.88\text{ mS})(1.85\text{ k}\Omega)$
$= \mathbf{-3.48}$

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

JFET SELF-BIAS CONFIGURATION

+ Bypassed *Rs*



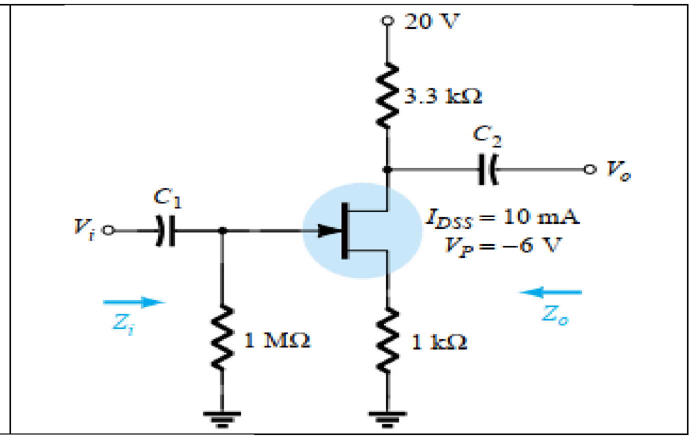


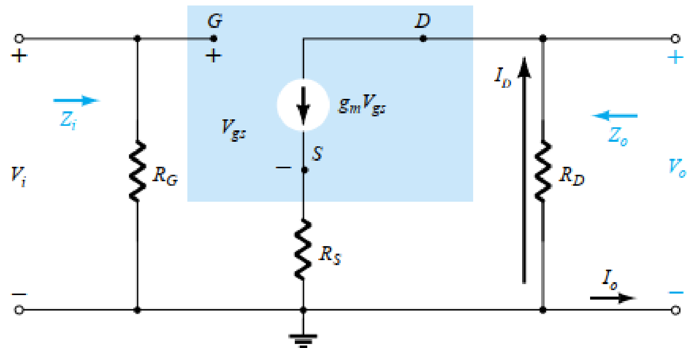
+ Unbypassed *Rs*

EXAMPLE 9.8:

The self-bias configuration of Example 6.2 has an operating point defined by $V_{GS_Q} = -2.6$ V and $I_{D_Q} = 2.6$ mA, with $I_{DSS} = 8$ mA and $V_P = -6$ V. The network is redrawn as Fig. 9.20 with an applied signal V_i. The value of y_{os} is given as 20 μS.

(a) Determine g_m.
(b) Find r_d.
(c) Find Z_i.
(d) Calculate Z_o with and without the effects of r_d. Compare the results.
(e) Calculate A_v with and without the effects of r_d. Compare the results.





Solution

(a) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(8\text{ mA})}{6\text{ V}} = 2.67\text{ mS}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 2.67\text{ mS}\left(1 - \frac{(-2.6\text{ V})}{(-6\text{ V})}\right) = \mathbf{1.51\text{ mS}}$$

(b) $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{20\ \mu\text{S}} = \mathbf{50\text{ k}\Omega}$

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

(d) With r_d:

$$r_d = 50\text{ k}\Omega > 10\,R_D = 33\text{ k}\Omega$$

Therefore,

$$Z_o = R_D = \mathbf{3.3\text{ k}\Omega}$$

If $r_d = \infty\ \Omega$

$$Z_o = R_D = \mathbf{3.3\text{ k}\Omega}$$

(e) With r_d:

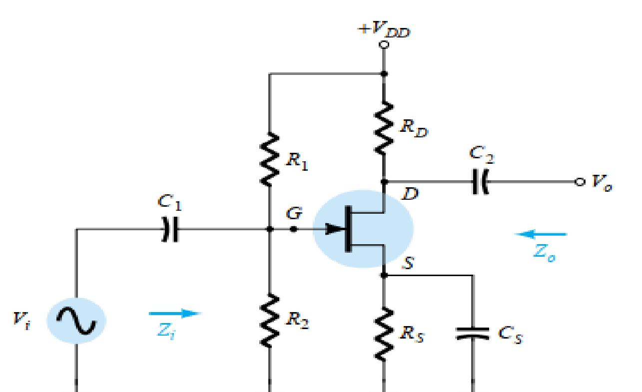
$$A_v = \frac{-g_mR_D}{1 + g_mR_S + \dfrac{R_D + R_S}{r_d}} = \frac{-(1.51\text{ mS})(3.3\text{ k}\Omega)}{1 + (1.51\text{ mS})(1\text{ k}\Omega) + \dfrac{3.3\text{ k}\Omega + 1\text{ k}\Omega}{50\text{ k}\Omega}}$$

$$= \mathbf{-1.92}$$

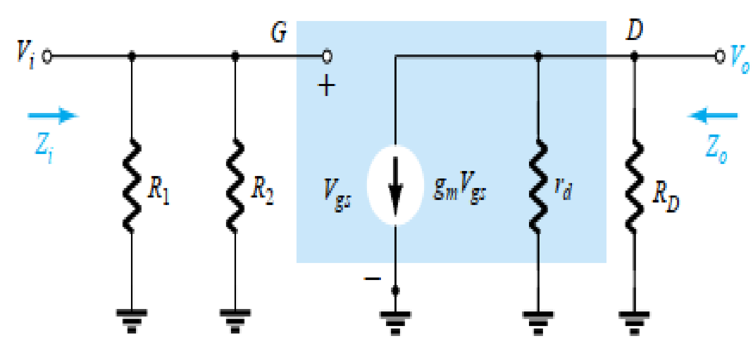
Without r_d:

$$A_v = \frac{-g_m R_D}{1 + g_mR_S} = \frac{-(1.51\text{ mS})(3.3\text{ k}\Omega)}{1 + (1.51\text{ mS})(1\text{ k}\Omega)} = \mathbf{-1.98}$$

JFET VOLTAGE-DIVIDER CONFIGURATION



Figure



JFET SOURCE-FOLLOWER (COMMON-DRAIN) CONFIGURATION

EXAMPLE 9.9:

A dc analysis of the source-follower network of Fig. 9.28 will result in $V_{GS_Q} = -2.86$ V and $I_{D_Q} = 4.56$ mA.

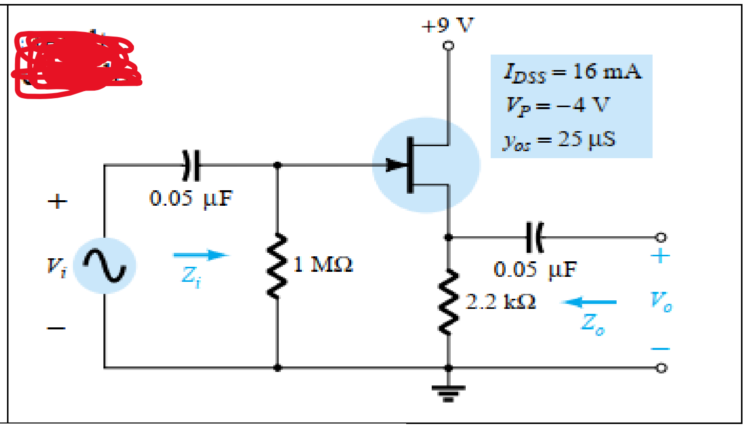
(a) Determining g_m.

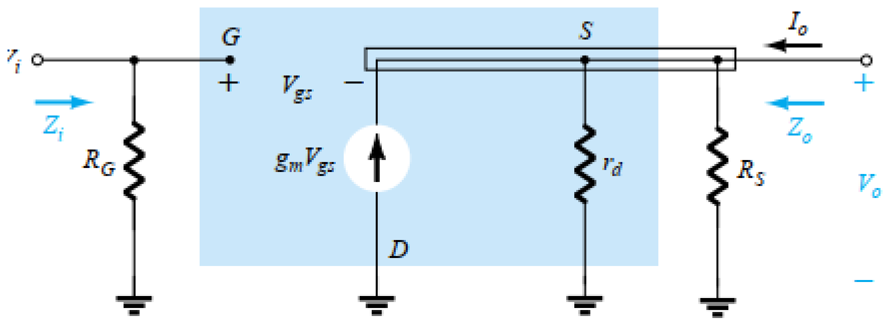
(b) Find r_d.

(c) Determine Z_i.

(d) Calculate Z_o with and without r_d. Compare results.

(e) Determine A_v with and without r_d. Compare results.





Solution

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

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

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

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

(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.

JFET COMMON-GATE CONFIGURATION

EXAMPLE 9.10:

Although the network of Fig. 9.32 may not initially appear to be of the common-gate variety, a close examination will reveal that it has all the characteristics of Fig. 9.29. If $V_{GS_Q} = -2.2$ V and $I_{D_Q} = 2.03$ mA:

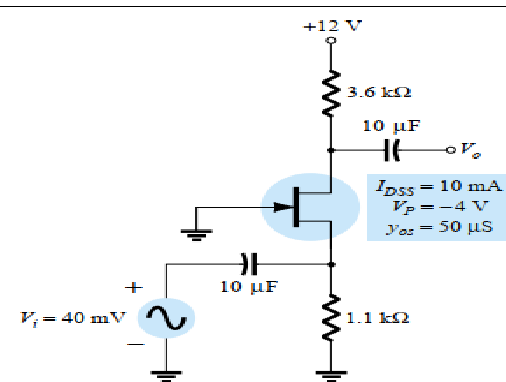
(a) Determine g_m.

(b) Find r_d.

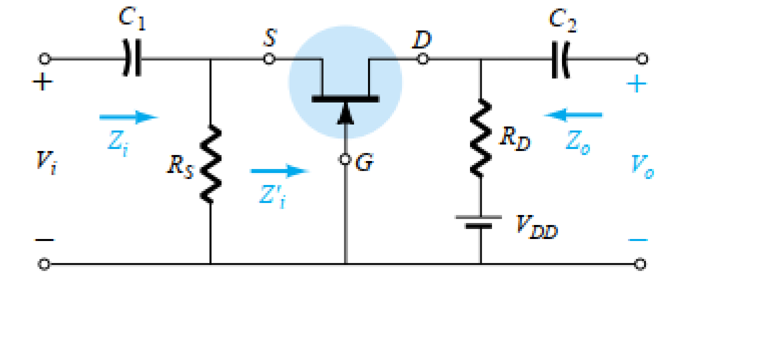
(c) Calculate Z_i with and without r_d. Compare results.

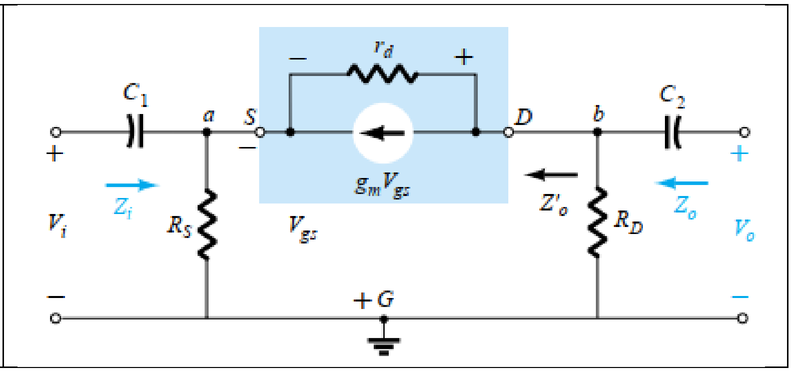
(d) Find Z_o with and without r_d. Compare results.

(e) Determine V_o with and without r_d. Compare results.



Bản chất:





Solution

(a) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(10\text{ mA})}{4\text{ V}} = 5\text{ mS}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 5\text{ mS}\left(1 - \frac{(-2.2\text{ V})}{(-4\text{ V})}\right) = \mathbf{2.25\text{ mS}}$$

(b) $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{50\ \mu\text{S}} = \mathbf{20\text{ k}\Omega}$

(c) With r_d:

$$Z_i = R_S \| \left[\frac{r_d + R_D}{1 + g_m r_d}\right] = 1.1\text{ k}\Omega \| \left[\frac{20\text{ k}\Omega + 3.6\text{ k}\Omega}{1 + (2.25\text{ ms})(20\text{ k}\Omega)}\right]$$
$$= 1.1\text{ k}\Omega \| 0.51\text{ k}\Omega = \mathbf{0.35\text{ k}\Omega}$$

Without r_d:

$$Z_i = R_S \| 1/g_m = 1.1\text{ k}\Omega \| 1/2.25\text{ ms} = 1.1\text{ k}\Omega \| 0.44\text{ k}\Omega = \mathbf{0.31\text{ k}\Omega}$$

Even though the condition,

$$r_d \geq 10R_D => 20\text{ k}\Omega \geq 10(3.6\text{ k}\Omega) => 20\text{ k}\Omega \geq 36\text{ k}\Omega$$

is *not* satisfied, both equations result in essentially the same level of impedance. In this case, $1/g_m$ was the predominant factor.

(d) With r_d:

$$Z_o = R_D \| r_d = 3.6\text{ k}\Omega \| 20\text{ k}\Omega = \mathbf{3.05\text{ k}\Omega}$$

Without r_d:

$$Z_o = R_D = \mathbf{3.6\text{ k}\Omega}$$

Again the condition $r_d \geq 10R_D$ is *not* satisfied, but both results are reasonably close. R_D is certainly the predominant factor in this example.

(e) With r_d:

$$A_v = \frac{\left[g_m R_D + \dfrac{R_D}{r_d}\right]}{\left[1 + \dfrac{R_D}{r_d}\right]} = \frac{\left[(2.25\text{ mS})(3.6\text{ k}\Omega) + \dfrac{3.6\text{ k}\Omega}{20\text{ k}\Omega}\right]}{\left[1 + \dfrac{3.6\text{ k}\Omega}{20\text{ k}\Omega}\right]}$$
$$= \frac{8.1 + 0.18}{1 + 0.18} = \mathbf{7.02}$$

and $A_v = \dfrac{V_o}{V_i} => V_o = A_v V_i = (7.02)(40\text{ mV}) = \mathbf{280.8\text{ mV}}$

Without r_d:

$$A_v = g_m R_D = (2.25\text{ mS})(3.6\text{ k}\Omega) = \mathbf{8.1}$$

with $V_o = A_v V_i = (8.1)(40\text{ mV}) = \mathbf{324\text{ mV}}$

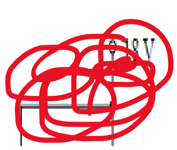
In this case, the difference is a little more noticeable but not dramatically so.

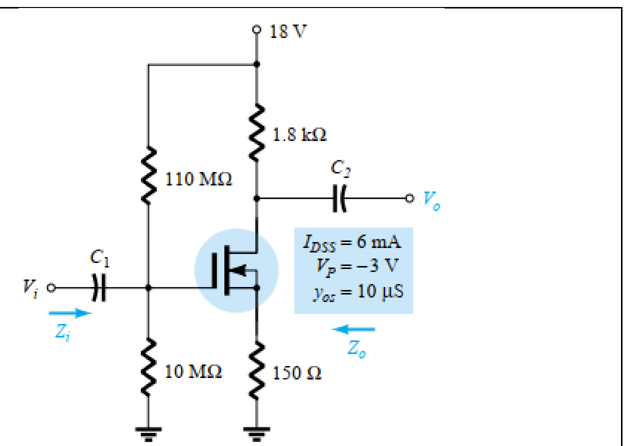
DEPLETION-TYPE MOSFETs

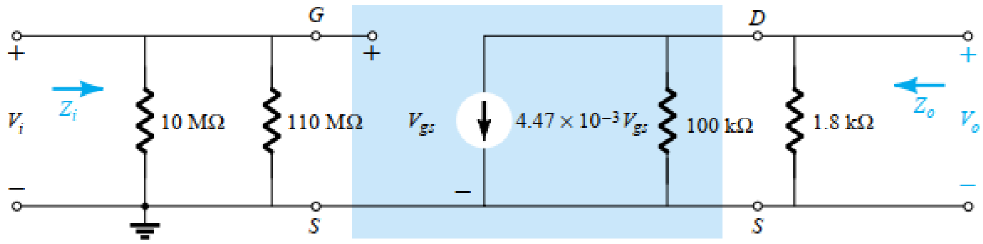
EXAMPLE 9.11:

The network of Fig. 9.34 was analyzed as Example 6.8, resulting in $V_{GS_Q} = 0.35$ V and $I_{D_Q} = 7.6$ mA.

(a) Determine g_m and compare to g_{m0}.
(b) Find r_d.
(c) Sketch the ac equivalent network for Fig. 9.34.
(d) Find Z_i.
(e) Calculate Z_o.
(f) Find A_v.







Solution

(a) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(6\text{ mA})}{3\text{ V}} = 4\text{ mS}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 4\text{ mS}\left(1 - \frac{(+0.35\text{ V})}{(-3\text{ V})}\right) = 4\text{ mS}(1 + 0.117) = \mathbf{4.47\text{ mS}}$$

(b) $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{10\ \mu S} = \mathbf{100\text{ k}\Omega}$

(d) Eq. (9.28): $Z_i = R_1\|R_2 = 10\text{ M}\Omega\|110\text{ M}\Omega = \mathbf{9.17\text{ M}\Omega}$

(e) Eq. (9.29): $Z_o = r_d\|R_D = 100\text{ k}\Omega\|1.8\text{ k}\Omega = \mathbf{1.77\text{ k}\Omega} \cong R_D = \mathbf{1.8\text{ k}\Omega}$

(f) $r_d \geq 10R_D \rightarrow 100\text{ k}\Omega \geq 18\text{ k}\Omega$

Eq. (9.32): $A_v = -g_mR_D = -(4.47\text{ mS})(1.8\text{ k}\Omega) = \mathbf{8.05}$

E-MOSFET DRAIN-FEEDBACK CONFIGURATION

<u>EXAMPLE 9.12:</u>

The E-MOSFET of Fig. 9.40 was analyzed in Example 6.11, with the result that $k = 0.24 \times 10^{-3}\text{ A/V}^2$, $V_{GS_Q} = 6.4$ V, and $I_{D_Q} = 2.75$ mA.

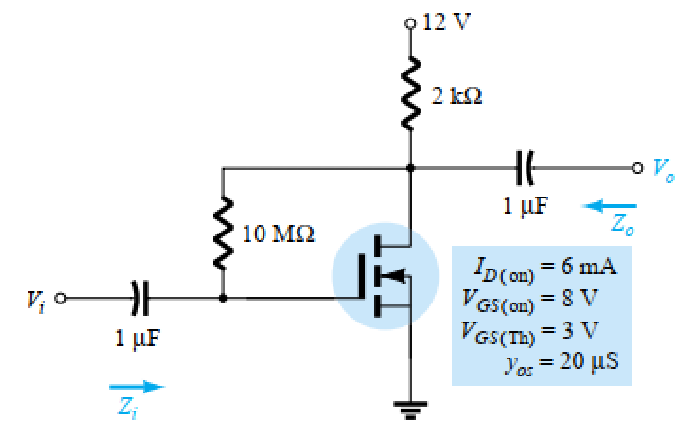
(a) Determine g_m.

(b) Find r_d.

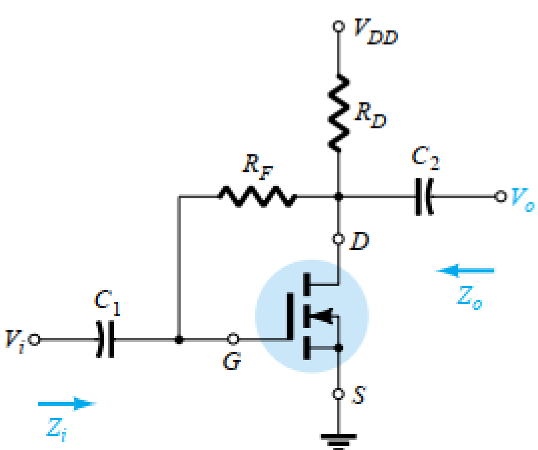
(c) Calculate Z_i with and without r_d. Compare results.

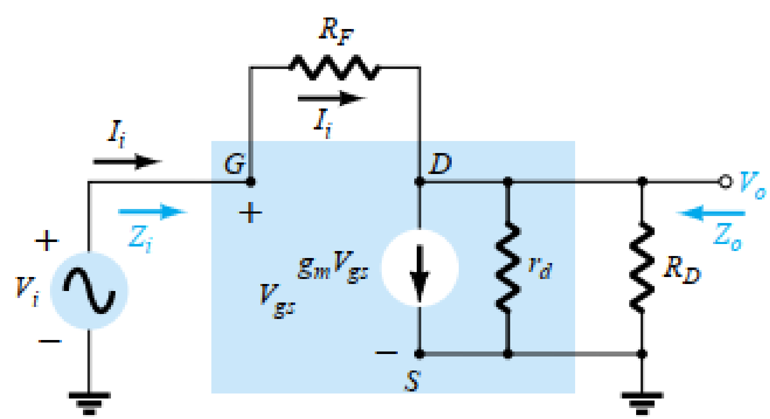
(d) Find Z_o with and without r_d. Compare results.

(e) Find A_v with and without r_d. Compare results.



Bản chất:





Solution

(a) $g_m = 2k(V_{GS_Q} - V_{GS(\text{Th})}) = 2(0.24 \times 10^{-3}\ \text{A/V}^2)(6.4\ \text{V} - 3\ \text{V})$
$= \mathbf{1.63\ mS}$

(b) $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{20\ \mu\text{S}} = \mathbf{50\ k\Omega}$

(c) With r_d:

$$Z_i = \frac{R_F + r_d \| R_D}{1 + g_m(r_d \| R_D)} = \frac{10\ \text{M}\Omega + 50\ \text{k}\Omega \| 2\ \text{k}\Omega}{1 + (1.63\ \text{mS})(50\ \text{k}\Omega \| 2\ \text{k}\Omega)}$$
$$= \frac{10\ \text{M}\Omega + 1.92\ \text{k}\Omega}{1 + 3.13} = \mathbf{2.42\ M\Omega}$$

Without r_d:

$$Z_i \cong \frac{R_F}{1 + g_m R_D} = \frac{10\ \text{M}\Omega}{1 + (1.63\ \text{mS})(2\ \text{k}\Omega)} = \mathbf{2.53\ M\Omega}$$

revealing that since the condition $r_d \geq 10R_D = 50\ \text{k}\Omega \geq 40\ \text{k}\Omega$ is satisfied, the results for Z_o with or without r_d will be quite close.

(d) With r_d:

$$Z_o = R_F \| r_d \| R_D = 10\ \text{M}\Omega \| 50\ \text{k}\Omega \| 2\ \text{k}\Omega = 49.75\ \text{k}\Omega \| 2\ \text{k}\Omega$$
$$= \mathbf{1.92\ k\Omega}$$

Without r_d:

$$Z_o \cong R_D = \mathbf{2\ k\Omega}$$

again providing very close results.

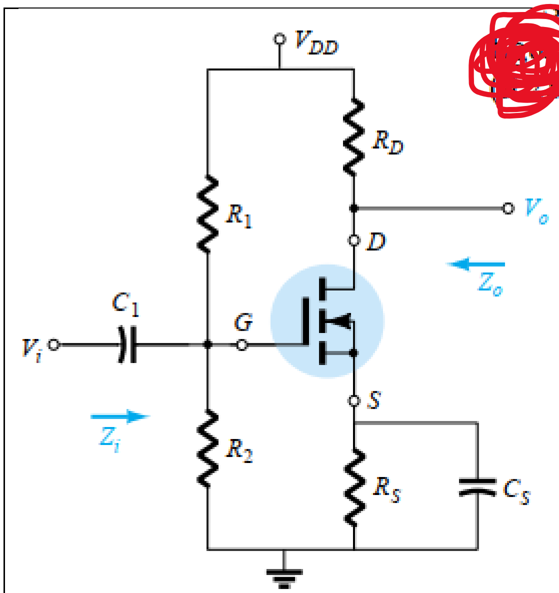
(e) With r_d:

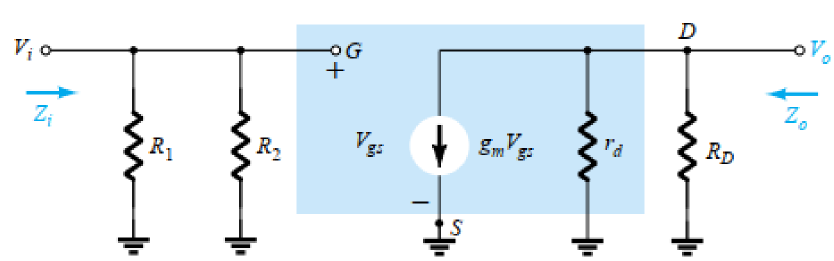
$$A_v = -g_m(R_F \| r_d \| R_D)$$
$$= -(1.63\ \text{mS})(10\ \text{M}\Omega \| 50\ \text{k}\Omega \| 2\ \text{k}\Omega)$$
$$= -(1.63\ \text{mS})(1.92\ \text{k}\Omega)$$
$$= \mathbf{-3.21}$$

Without r_d:

$$A_v = -g_m R_D = -(1.63\ \text{mS})(2\ \text{k}\Omega)$$
$$= \mathbf{-3.26}$$

E-MOSFET VOLTAGE-DIVIDER CONFIGURATION

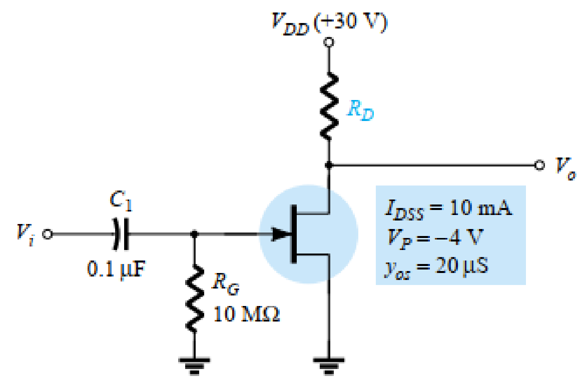




DESIGNING FET AMPLIFIER NETWORKS

EXAMPLE 9.13:

Design the fixed-bias network of Fig. 9.43 to have an ac gain of 10. That is, determine the value of R_D.



Solution

Since $V_{GS_Q} = 0$ V, the level of g_m is g_{m0}. The gain is therefore determined by

$$A_v = -g_m(R_D \| r_d) = -g_{m0}(R_D \| r_d)$$

with
$$g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(10\text{ mA})}{4\text{ V}} = 5\text{ mS}$$

The result is
$$-10 = -5\text{ mS}(R_D \| r_d)$$

and
$$R_D \| r_d = \frac{10}{5\text{ mS}} = 2\text{ k}\Omega$$

From the device specifications,

$$r_d = \frac{1}{y_{os}} = \frac{1}{20 \times 10^{-6}\text{ S}} = 50\text{ k}\Omega$$

Substituting, we find

$$R_D \| r_d = R_D \| 50\text{ k}\Omega = 2\text{ k}\Omega$$

and
$$\frac{R_D(50\text{ k}\Omega)}{R_D + 50\text{ k}\Omega} = 2\text{ k}\Omega$$

or
$$50R_D = 2(R_D + 50\text{ k}\Omega) = 2R_D + 100\text{ k}\Omega$$

with
$$48R_D = 100\text{ k}\Omega$$

and
$$R_D = \frac{100\text{ k}\Omega}{48} \cong 2.08\text{ k}\Omega$$

The closest standard value is **2 kΩ** (Appendix C), which would be employed for this design.

The resulting level of V_{DS_Q} would then be determined as follows:

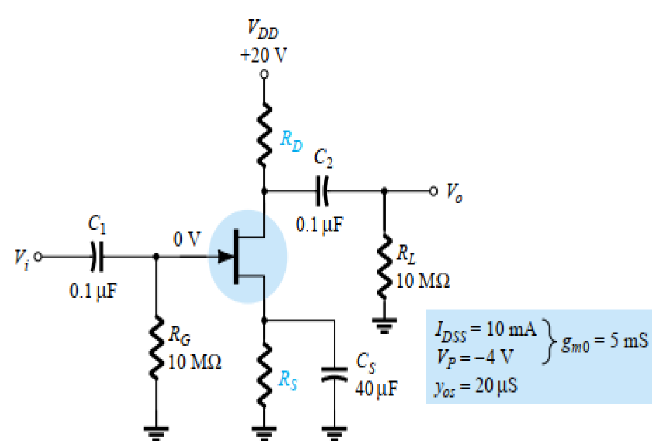
$$V_{DS_Q} = V_{DD} - I_{D_Q}R_D = 30\text{ V} - (10\text{ mA})(2\text{ k}\Omega) = \mathbf{10\text{ V}}$$

The levels of Z_i and Z_o are set by the levels of R_G and R_D, respectively. That is,

$$Z_i = R_G = \mathbf{10\text{ M}\Omega}$$
$$Z_o = R_D \| r_d = 2\text{ k}\Omega \| 50\text{ k}\Omega = \mathbf{1.92\text{ k}\Omega} \cong R_D = 2\text{ k}\Omega.$$

EXAMPLE 9.14:

Choose the values of R_D and R_S for the network of Fig. 9.44 that will result in a gain of 8 using a relatively high level of g_m for this device defined at $V_{GS_Q} = \frac{1}{4}V_P$.



Solution

The operating point is defined by

$$V_{GS_Q} = \frac{1}{4}V_P = \frac{1}{4}(-4\text{ V}) = -1\text{ V}$$

and $$I_D = I_{DSS}\left(1 - \frac{V_{GS_Q}}{V_P}\right)^2 = 10\text{ mA}\left(1 - \frac{(-1\text{ V})}{(-4\text{ V})}\right)^2 = 5.625\text{ mA}$$

Determining g_m,

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right)$$

$$= 5\text{ mS}\left(1 - \frac{(-1\text{ V})}{(-4\text{ V})}\right) = 3.75\text{ mS}$$

The magnitude of the ac voltage gain is determined by

$$|A_v| = g_m(R_D \| r_d)$$

Substituting known values will result in

$$8 = (3.75\text{ mS})(R_D \| r_d)$$

so that $$R_D \| r_d = \frac{8}{3.75\text{ mS}} = 2.13\text{ k}\Omega$$

The level of r_d is defined by

$$r_d = \frac{1}{y_{os}} = \frac{1}{20\ \mu\text{S}} = 50\text{ k}\Omega$$

and $$R_D \| 50\text{ k}\Omega = 2.13\text{ k}\Omega$$

with the result that

$$\mathbf{R_D = 2.2\text{ k}\Omega}$$

which is a standard value.

The level of R_S is determined by the dc operating conditions as follows:

$$V_{GS_Q} = -I_D R_S$$

$$-1\text{ V} = -(5.625\text{ mA})R_S$$

and $$R_S = \frac{1\text{ V}}{5.625\text{ mA}} = 177.8\ \Omega$$

The closest standard value is 180 Ω. In this example, R_S does not appear in the ac design because of the shorting effect of C_S.