Electronic Circuits
Elektronik Devreler

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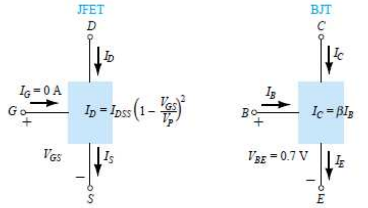

JFET		BJT
$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$	⇔	$I_C = \beta I_B$
$I_D = I_S$	⇔	$I_C \cong I_E$
$I_G \cong 0$ A	⇔	$V_{BE} \cong 0.7$ V

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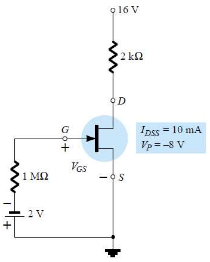
Example 17

- For the following network, determine:
  - (a) V_{GSQ}
  - (b) I_{DQ}
  - (c) V_{DS}
  - (d) V_D
  - (e) V_G
  - (f) V_S



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Solution 17

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

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

(d) $V_D = V_{DS} = \mathbf{4.75\ V}$

(e) $V_G = V_{GS} = \mathbf{-2\ V}$

(f) $V_S = \mathbf{0\ V}$

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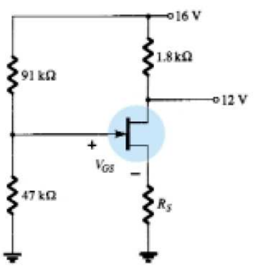
Example 18

- For the following network, if $V_D = 12$ V and $V_{GSQ} = -2$ V, determine the value of R_S



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Solution 18

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.

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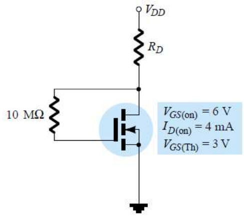
Example 19

- For the following network, the levels of V_{DS} and I_D are specified as V_{DS} = ½V_{DD} and I_D = $I_{D(on)}$.
  Determine the level of V_{DD} and R_D.



Solution 19

Given $I_D = I_{D(\text{on})} = 4$ mA and $V_{GS} = V_{GS(\text{on})} = 6$ V, for this configuration,

$$V_{DS} = V_{GS} = \tfrac{1}{2}V_{DD}$$

and

$$6\text{ V} = \tfrac{1}{2}V_{DD}$$

so that

$$V_{DD} = \mathbf{12\ V}$$

Applying Eq. (6.34) yields

$$R_D = \frac{V_{R_D}}{I_D} = \frac{V_{DD} - V_{DS}}{I_{D(\text{on})}} = \frac{V_{DD} - \frac{1}{2}V_{DD}}{I_{D(\text{on})}} = \frac{\frac{1}{2}V_{DD}}{I_{D(\text{on})}}$$

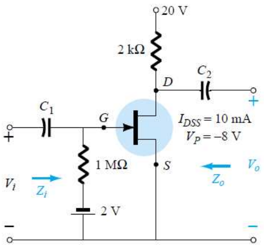
and

$$R_D = \frac{6\text{ V}}{4\text{ mA}} = \mathbf{1.5\ k\Omega}$$

which is a standard commercial value.

Example 20

- The following fixed-bias configuration has an operating point defined by V_{GSQ} = -2 V and I_{DQ} = 5.625 mA, with I_{DSS} =10 mA and V_P = -8 V. 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 20

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

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

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

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

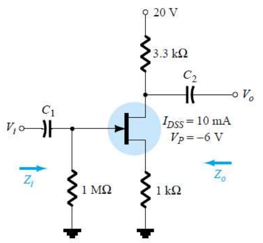
(d) $Z_o = R_D \| r_d = 2\text{ k}\Omega \| 25\text{ k}\Omega = \mathbf{1.85\ k\Omega}$

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

(f) $A_v = -g_m R_D = -(1.88\text{ mS})(2\text{ k}\Omega) = \mathbf{-3.76}$
As demonstrated in part (f), a ratio of 25 kΩ : 2 kΩ = 12.5 : 1 between r_d and R_D resulted in a difference of 8% in solution.

Example 21

- The following self-bias configuration has an operating point defined by V_{GSQ} = -2.6 V and I_{DQ} = 2.6 mA, with I_{DSS} =8 mA and V_P = -6 V. The value of y_{os} is given as 20 μS.
  (a) Determine g_m
  (b) Find r_d
  (c) Determine Z_i
  (d) Calculate Z_o with and without effects of r_d. Compare results.
  (e) Determine A_v with and without effects of r_d. Compare results.



Solution 21…

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

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

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

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

(d) With r_d:

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

Therefore,

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

If $r_d = \infty\ \Omega$

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

…Solution 21

(e) With r_d:

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

$$= \mathbf{-1.92}$$

Without r_d:

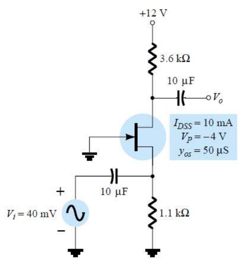
$$A_v = \frac{-g_m R_D}{1 + g_m R_S} = \frac{-(1.51\text{ mS})(3.3\text{ k}\Omega)}{1 + (1.51\text{ mS})(1\text{ k}\Omega)} = \mathbf{-1.98}$$

As above, the effect of r_d was minimal because the condition $r_d \geq 10(R_D + R_S)$ was satisfied.

Note also that the typical gain of a JFET amplifier is less than that generally encountered for BJTs of similar configurations. Keep in mind, however, that Z_i is magnitudes greater than the typical Z_i of a BJT, which will have a very positive effect on the overall gain of a system.

Example 22

- The following network has an operating point defined by V_{GSQ} = -2.2 V and I_{DQ} = 2.03 mA.
  (a) Determine g_m
  (b) Find r_d
  (c) Calculate Z_i with and without r_d. Compare results.
  (d) Calculate Z_o with and without r_d. Compare results.
  (e) Determine V_o with and without r_d. Compare results.



Solution 22

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

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

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

(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:

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

$$= \frac{8.1 + 0.18}{1 + 0.18} = \mathbf{7.02}$$

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

Without r_d:

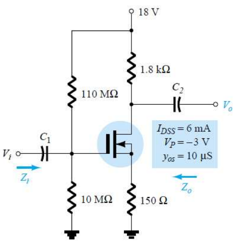
$$A_v = g_m R_D = (2.25\text{ mS})(3.6\text{ k}\Omega) = \mathbf{8.1}$$

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.

Example 23

- The following network has an operating point defined by V_{GSQ} = 0.35 V and I_{DQ} = 7.6 mA.
  (a) Determine g_m and compare to g_{m0}
  (b) Find r_d
  (c) Sketch the ac equivalent network
  (d) Calculate Z_i
  (e) Calculate Z_o
  (f) Determine A_v



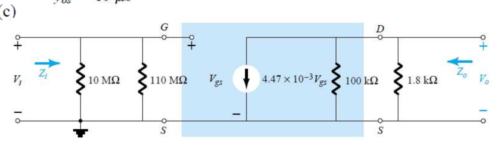
Solution 23

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

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

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

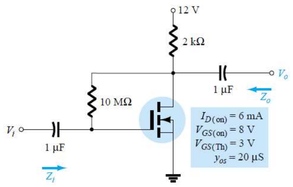
(c)



(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): $A_v = -g_m R_D = -(4.47\text{ mS})(1.8\text{ k}\Omega) = \mathbf{8.05}$

Example 24

- In the following network ; $k = 0.24 \times 10^{-3}$ A/V², $V_{GSQ} = 6.4$ V and $I_{DQ} = 2.75$ mA.
  (a) Determine g_m
  (b) Find r_d
  (c) Calculate Z_i with and without r_d. Compare results.
  (d) Calculate Z_o with and without r_d. Compare results.
  (e) Determine A_v with and without r_d. Compare results.



Solution 24

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

(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:

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

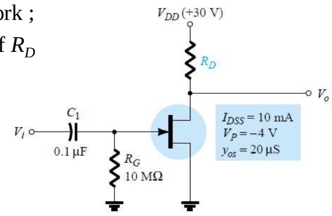
Without r_d:

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

which is very close to the above result.

Example 25

- In the following network ;
  Determine the value of R_D



Solution 25

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

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

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

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 $\quad \dfrac{R_D(50\ \text{k}\Omega)}{R_D + 50\ \text{k}\Omega} = 2\ \text{k}\Omega$

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

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

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

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:

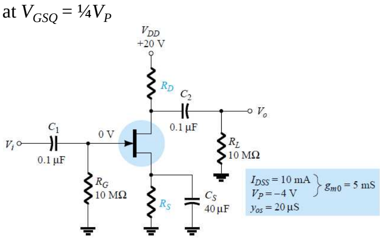
$$V_{DS_Q} = V_{DD} - I_{D_Q}R_D = 30\ \text{V} - (10\ \text{mA})(2\ \text{k}\Omega) = \mathbf{10\ V}$$

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

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

Example 26

- In the following network, chose the values of R_D and R_S that will result in a gain of 8 using relatively high level of g_m for this device defined at $V_{GSQ} = ¼V_P$



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Solution 26

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

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

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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

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

which is a standard value.

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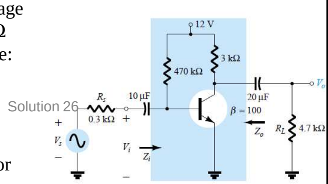
Example 27

- For the following single stage amplifier, with R_D = 4.7 kΩ and R_S = 0.3 kΩ, determine:
  - (a) A_{vs}
  - (b) $A_v = V_o/V_i$
  - (c) A_i

  The two-port parameters for the fixed-bias configuration are Z_i = 1.071 kΩ , Z_o = 3 kΩ and $A_{v_{NL}}$ = -280.11



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Solution 27

(a) Eq. (10.14): $A_{v_s} = \frac{V_o}{V_s} = \frac{R_i}{R_i + R_s}\frac{R_L}{R_L + R_o}A_{v_{NL}}$

$$= \left(\frac{1.071\text{ k}\Omega}{1.071\text{ k}\Omega + 0.3\text{ k}\Omega}\right)\left(\frac{4.7\text{ k}\Omega}{4.7\text{ k}\Omega + 3\text{ k}\Omega}\right)(-280.11)$$
$$= (0.7812)(0.6104)(-280.11)$$
$$= (0.4768)(-280.11)$$
$$= \mathbf{-133.57}$$

(b) $A_v = \frac{V_o}{V_i} = \frac{R_L A_{v_{NL}}}{R_L + R_o} = \frac{(4.7\text{ k}\Omega)(-280.11)}{4.7\text{ k}\Omega + 3\text{ k}\Omega}$

$= (0.6104)(-280.11) = \mathbf{-170.98}$

(c) $A_i = -A_v\frac{R_i}{R_L} = -(-170.98)\left(\frac{1.071\text{ k}\Omega}{4.7\text{ k}\Omega}\right)$

$= \mathbf{38.96}$

or $A_{i_s} = -A_{v_s}\frac{R_s + R_i}{R_L} = -(-133.57)\left(\frac{1.071\text{ k}\Omega + 0.3\text{ k}\Omega}{4.7\text{ k}\Omega}\right)$

$= \mathbf{38.96}$

as above.

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