Problem 4.11

\[ I_{B2} + I_{C1} + I_{B1} = 1 \text{ mA} \]

Because the transistors are identical and have equal \( V_{BE} \), we conclude that \( I_{B2} = I_{B1} \) and \( I_{C2} = I_{C1} \). Furthermore \( I_{C1} = \beta I_{B1} \).

\[ I_{B1} + 100I_{B1} + I_{B1} = 1 \text{ mA} \quad \Rightarrow \quad I_{B1} = 9.804 \mu\text{A} \]

\[ I_{C1} = I_{C2} = \beta I_{B1} = 0.9804 \text{ mA} \]

\[ I_{E1} = (\beta + 1)I_{B1} = 0.9902 \text{ mA} \]

Solving Equation 4.1 for \( V_{BE} \) we have

\[ V_{BE} = V_T \ln\left(\frac{I_E}{I_{ES}} + 1\right) \]

\[ = 0.026\ln\left(\frac{0.9902 \times 10^{-3}}{10^{-14}} + 1\right) \]

\[ = 0.6583 \text{ V} \]

Problem 4.33

<table>
<thead>
<tr>
<th>Circuit</th>
<th>( \beta )</th>
<th>Region</th>
<th>( I_C ) (mA)</th>
<th>( V_{CE} ) (V)</th>
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<tbody>
<tr>
<td>(a)</td>
<td>100</td>
<td>active</td>
<td>1.93</td>
<td>10.9</td>
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<tr>
<td>(a)</td>
<td>300</td>
<td>saturation</td>
<td>4.21</td>
<td>0.2</td>
</tr>
<tr>
<td>(b)</td>
<td>100</td>
<td>active</td>
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<td>5.00</td>
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<td>(c)</td>
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<td>cutoff</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>(c)</td>
<td>300</td>
<td>cutoff</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>(d)</td>
<td>100</td>
<td>active</td>
<td>6.5</td>
<td>8.5</td>
</tr>
<tr>
<td>(d)</td>
<td>300</td>
<td>saturation</td>
<td>14.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Problem 4.45

Dc circuit:

\[ \beta = 100 \]

\[ V_{BEQ} = 0.7 \text{ V} \]

\[ V_B = V_{CC} R_2 / (R_1 + R_2) = 4.80 \text{ V} \]

\[ R_B = R_1 \parallel R_2 = 3.20 \text{ k}\Omega \]

\[ I_BQ = \frac{V_B - V_{BEQ}}{R_B + (\beta + 1) R_E} = 0.0393 \text{ mA} \]

\[ I_{CQ} = \beta I_B = 3.93 \text{ mA} \]

\[ r_\pi = \beta V_T / I_{CQ} = 662 \text{ \Omega} \]

\[ R_L' = R_L \parallel R_C = 500 \text{ \Omega} \]

\[ A_V = -\beta R_L' / r_\pi = -75.5 \]

\[ A_{vo} = -\beta R_L / r_\pi = -151 \]

\[ Z_{in} = R_1 \parallel R_2 \parallel r_\pi = 548 \text{ \Omega} \]

\[ A_i = A_V Z_{in} / R_L = -41.4 \]

\[ g = A_V A_i = 3124 \]

\[ Z_o = R_C = 1 \text{ k}\Omega \]
Problem 4.49

(a)

(b)

(c)
Problem 4.59

(a)

\[ V_s = + \quad 0 \quad - \]

\[ R_2 \]

\[ R_1 \]

\[ r_\pi \]

\[ V_o \]

\[ V_{\text{hum}} \]

\[ \beta_{\lambda_b} \]

\[ R_c \]

\[ + \quad 0 \quad - \]

\[ V_o \]

\[ A_{\text{hum}} = \frac{V_o}{V_{\text{hum}}} = \frac{-\beta i_b R_C}{-r_\pi + b} = \frac{\beta R_C}{r_\pi} \]

(b)

Because \( V_s = 0 \) we have \( i_b = 0 \) and \( V_o = 0 \). Thus \( A_{\text{hum}} = 0 \).

Because of lower sensitivity to power-supply hum, the circuit of Figure P4.59b is preferable to that of Figure P4.59a. In other words, the emitter bypass capacitor should be connected from emitter to ground.
Problem 5.3

(a) Saturation because we have \( v_{GS} \geq v_{to} \) and \( v_{DS} \geq v_{GS} - v_{to} \).

(b) Triode because we have \( v_{DS} < v_{GS} - v_{to} \) and \( v_{GS} \geq v_{to} \).

(c) Cutoff because we have \( v_{GS} \leq v_{to} \).

Problem 5.7

With \( v_{GS} = v_{DS} = 5 \text{ V} \) the transistor operates in the saturation region for which we have \( i_D = K(v_{GS} - v_{to})^2(1 + \lambda v_{DS}) \).

Solving for \( K \) and substituting values we obtain \( K = 31.25 \text{ \mu A/V}^2 \). However we have \( K = (W/L)(K_P/2) \). Solving for \( W/L \) and substituting values we obtain \( W/L = 1.25 \). Thus for \( L = 2 \text{ \mu m} \), we need \( W = 2.5 \text{ \mu m} \).

Repeating the calculations with \( \lambda = 0.05 \), we obtain \( K = 25 \), \( W/L = 1 \) and \( W = 2 \text{ \mu m} \).

Problem 5.19

For \( v_{in} = +1 \text{ V} \) we have \( v_{GS} = 4 \text{ V} \). For the FET to remain in saturation, we must have \( V_{DMin} \geq 3 \text{ V} \) at which point the drain current is 4.5 mA. Thus the maximum value of \( R_D \) is

\[
R_{Dmax} = (20 - 3)/4.5 \text{ mA} = 3.778 \text{ k\Omega}.
\]
A)

\[ v_o = R'_L (i_{in} - g_m v_{in}) \quad i_{in} = (v_{in} - v_o)/R_f \]

\[ A_v = \frac{v_o}{v_{in}} = \frac{R'_L - g_m R'_L R_f}{R'_L + R_f} \]

\[ R_{in} = \frac{v_{in}}{i_{in}} = \frac{R_f}{1 - A_v} \]

The circuit used to determine output impedance is:

\[ v_{gs} = v_x \frac{R}{R + R_f} \quad i_x = \frac{v_x}{R_D} + g_m v_{gs} \]
\[ R_O = \frac{v_x}{i_x} = \frac{1}{\frac{R'}{R_D} + \frac{g_m R}{R_f + R}} \]

(c) The dc circuit is:

\[ V_{GSQ} = V_{DSQ} \quad I_{DQ} = K(V_{DSQ} - V_{to})^2 \quad I_{DQ} = (V_{DD} - V_{DSQ})/R_D \]

Using the above equations we obtain

\[ 3V_{DSQ}^2 - 29V_{DSQ} + 55 = 0 \]

\[ V_{DSQ} = 7.08 \text{ V and } I_{DQ} = 4.31 \text{ mA} \]

\[ q_m = \frac{\partial i_D}{\partial v_{GS}} \bigg|_{Q-point} = 2K(V_{GSQ} - V_{to}) = 4.16 \times 10^{-3} \text{ s} \]

(d) \[ R'_L = R_D || R_L = 2.31 \text{ k}\Omega \]

\[ A_V = -9.37 \]

\[ R_{in} = 9.64 \text{ k}\Omega \]

\[ R_O = 414 \text{ } \Omega \]

(e) \[ v_o(t) = v(t) \frac{R_{in}}{R + R_{in}} A_V = -0.164 \sin(2000\pi t) \]

(f) This is an inverting amplifier that has a very low input impedance compared to many other FET amplifiers.
We have

\[ K = \left( \frac{W}{L} \right) \frac{K_P}{2} = 400 \ \mu A/V^2 \]

Assuming operation in saturation, we have

\[ I_{DQ} = K(V_{GSQ} - V_{to})^2 \]

Solving for \( V_{GSQ} \) and evaluating we have

\[ V_{GSQ} = V_{to} + \sqrt{\frac{I_{DQ}}{K}} = 3.236 \ \text{V} \]

\[ V_G = V_{DD} \frac{R_2}{R_1 + R_2} = 10 \ \text{V} \]

\[ V_G = V_{GSQ} + R_S I_{DQ} \]

Solving for \( R_S \) and substituting values we have

\[ R_S = \frac{(V_G - V_{GSQ})}{I_{DQ}} = 3.382 \ \text{k\Omega} \]

We have \( g_m = \sqrt{K I_{DQ}} = 0.8944 \ \text{mS} \)

\[ R_L' = \frac{1}{\frac{1}{R_d} + \frac{1}{R_S} + \frac{1}{R_L}} = 1.257 \ \text{k\Omega} \]
\[ A_v = \frac{v_o}{v_{in}} = \frac{g_m R'_L}{1 + g_m R'_L} = 0.5293 \]

\[ R_{in} = \frac{v_{in}}{i_{in}} = R_G = R_1 || R_2 = 666.7 \text{ k}\Omega \]

\[ R_o = \frac{1}{g_m + \frac{1}{R_s} + \frac{1}{r_d}} = 840.0 \text{ \Omega} \]