Problem 3.58

(a) \( r_d = \frac{nV_T}{I_{DQ}} = 26\ \Omega \)

(b) \( \Delta V_D = \Delta i_D r_d = (0.1\ mA) \times (26\ \Omega) = 2.6\ mV \)

(c) \( i_D = I_s \left[ \exp \left( \frac{V_D}{nV_T} \right) - 1 \right] \)

\[ V_D = nV_T \ln \left( \frac{i_D}{I_s} - 1 \right) \]

For \( i_D = 1\ mA \) we find \( V_D = 0.65854\ V \) and for \( i_D = 1.1\ mA \) we find \( V_D = 0.66102\ V \) for a difference of \( \Delta V_D = 2.48\ mV \) which is 4.8\% lower than the result using the dynamic resistance.

Problem 4.10

Equation 4.1 in the book states

\[ i_E = I_{ES} \left[ \exp \left( \frac{V_{BE}}{V_T} \right) - 1 \right] \]

Solving for \( V_{BE} \) we obtain

\[ V_{BE} = V_T \ln \left( \frac{i_E}{I_{ES}} + 1 \right) = 0.026 \ln \left( \frac{10^{-2}}{10^{-13}} + 1 \right) = 0.6585\ V \]

\[ V_{BC} = V_{BE} - V_{CE} = 10 - 0.6585 = -9.34\ V \]

\[ i_B = \frac{i_E}{(\beta + 1)} = 99.01\ \mu A \]

\[ i_C = i_E - i_B = 9.901\ mA \]

\[ \alpha = \frac{\beta}{(\beta + 1)} = 0.9901 \]
Because the transistors are identical and $v_{BE}$ is the same for both transistors, we conclude that $i_{C1} = i_{C2}$ and $i_{B1} = i_{B2}$. Thus we have

$$
\beta_{eq} = \frac{i_C}{i_B} = \frac{i_{C1} + i_{C2}}{i_{B1} + i_{B2}} = \frac{2i_{C1}}{2i_{B1}} = \beta_1 = 100
$$

$$
i_E = i_{E1} + i_{E2}
$$

$$
i_E = I_{ES1} \exp\left(\frac{v_{BE}}{V_T} - 1\right) + I_{ES2} \exp\left(\frac{v_{BE}}{V_T} - 1\right)
$$

$$
i_E = (I_{ES1} + I_{ES2}) \exp\left(\frac{v_{BE}}{V_T} - 1\right) = I_{ESeq} \exp\left(\frac{v_{BE}}{V_T} - 1\right)
$$

Thus we conclude that

$$
i_{PCeq} = I_{PC1} + I_{PC2} = 2 \times 10^{-13} \text{ A}
$$

**Problem 4.20**

The equation for the input load line is

$$
v_{BB} + v_{in}(t) = R_B i_B(t) + v_{BE}(t)
$$

Substituting values we have:

$$
0.8 + 0.2\sin(2000\pi t) = 40 \times 10^3 i_B + v_{BE}
$$

Load lines are shown on the input characteristic:
The equation for the output load line is

\[ V_{CC} = R_i C_i + V_{CE} \]

\[ 20 = 2000 i_C + V_{CE} \]

This is plotted below:
From these load lines we find:

<table>
<thead>
<tr>
<th>$v_{in} = +0.2 , V$</th>
<th>$v_{in} = 0$</th>
<th>$v_{in} = -0.2 , V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i_B (\mu A)$</td>
<td>10</td>
<td>5.5</td>
</tr>
<tr>
<td>$i_C (mA)$</td>
<td>4</td>
<td>2.2</td>
</tr>
<tr>
<td>$v_{CE} (V)$</td>
<td>12</td>
<td>15.6</td>
</tr>
</tbody>
</table>

The voltage gain is

$$A_v = -(V_{CE_{max}} - V_{CE_{min}})/0.4 \approx -(18.9 - 12)/0.4 = -17.25$$

Problem 4.28

(a) Active.
(b) Cutoff.
(c) Cutoff.
(d) Saturation.

Problem 4.34

<table>
<thead>
<tr>
<th>Circuit</th>
<th>$\beta$</th>
<th>Region</th>
<th>$I$ (mA)</th>
<th>$V$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>100</td>
<td>active</td>
<td>2.38</td>
<td>5.25</td>
</tr>
<tr>
<td>(a)</td>
<td>300</td>
<td>saturation</td>
<td>4.45</td>
<td>9.80</td>
</tr>
<tr>
<td>(a)</td>
<td>100</td>
<td>cutoff</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>(b)</td>
<td>300</td>
<td>cutoff</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>(c)</td>
<td>100</td>
<td>active</td>
<td>4.26</td>
<td>-10.74</td>
</tr>
<tr>
<td>(c)</td>
<td>300</td>
<td>active</td>
<td>4.29</td>
<td>-10.71</td>
</tr>
<tr>
<td>(d)</td>
<td>100</td>
<td>$Q_1$ active</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>(d)</td>
<td>300</td>
<td>$Q_2$ active</td>
<td>14.8</td>
<td>14.8</td>
</tr>
</tbody>
</table>

Problem 4.42

<table>
<thead>
<tr>
<th>$I_{CQ}$</th>
<th>$r_n$</th>
<th>$g_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 $\mu$A</td>
<td>2.6 M$\Omega$</td>
<td>38.5 $\mu$S</td>
</tr>
<tr>
<td>0.1 mA</td>
<td>26 k$\Omega$</td>
<td>3.85 ms</td>
</tr>
<tr>
<td>1 mA</td>
<td>2.6 k$\Omega$</td>
<td>38.5 ms</td>
</tr>
</tbody>
</table>
Problem 4.39

Many answers exist for this problem. Here is one of them:

We use $\beta = 100$ (which is the average value) in the design calculations. We design so $V_{CE} = \frac{20}{3} = 6.67 \text{ V}$, $R_E I_E = 6.67 \text{ V}$ and $R_C I_C = 6.67 \text{ V}$. Then we have $R_C = 6.67/I_C = 1.333 \text{ kΩ}$ and $R_E = 6.67/I_E = 6.67/I_C = 1.333 \text{ kΩ}$. We select the closest nominal values of 1.3 kΩ.

We have $V_2 = V_{BE} + I_E R_E = 0.7 + 6.67 = 7.37 \text{ V}$. $I_B = I_C/\beta = 50 \mu\text{A}$. We design so that $I_2 = 20 I_B = 1 \text{ mA}$. Then we have $R_2 = V_2/I_2 = 7.37 \text{ kΩ}$ and $R_1 = (V_{CC} - V_2)/(I_2 + I_B) = 12.03 \text{ kΩ}$.

Finally we select the nominal values $R_2 = 7.5 \text{ kΩ}$ and $R_1 = 12 \text{ kΩ}$.

Problem 4.45

**Dc circuit:**

\[ \beta = 100 \]

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

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

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

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

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

\[ r_\pi = \frac{\beta V_T}{I_{CQ}} = 662 \text{ Ω} \]

\[ R'_L = R_L \parallel R_C = 500 \text{ Ω} \]

\[ A_v = -\beta R'_L/r_\pi = -75.5 \]

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

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

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

\[ G = A_v A_i = 3124 \]

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

(a) [circuit diagram]

(b) [circuit diagram]

(c) [circuit diagram]

Problem 4.51

Dc circuit:

\[ V_{BEQ} = 0.7 \text{ V} \]
\[ \beta = 100 \]

\[ V_B = V_{CC} \frac{R_2}{R_1 + R_2} = 7.5 \text{ V} \]
\[ R_B = R_1 || R_2 = 5 \text{ k}\Omega \]
\[ I_{BQ} = \frac{V_B - V_{BEQ}}{R_B + (\beta + 1)R_E} = 64.1 \, \mu A \quad I_{CQ} = \beta I_B = 6.41 \, mA \]

\[ r_i = \beta V_T / I_{CQ} = 405 \, \Omega \quad R_L' = R_L || R_E = 333 \, \Omega \]

\[ A_V = \frac{R_L' (\beta + 1)}{r_i + R_L' (\beta + 1)} = 0.988 \quad A_{VO} = \frac{R_E (\beta + 1)}{r_i + R_E (\beta + 1)} = 0.996 \]

\[ Z_{in} = R_B || (r_i + R_L' (\beta + 1)) = 4.36 \, k\Omega \]

\[ A_1 = A_V Z_{in} / R_L = 8.61 \quad G = A_V A_1 = 8.51 \]

\[ R_s' = R_B || R_s = 833 \, \Omega \]

\[ Z_o = R_E || [(R_s' + r_i) / (\beta + 1)] = 12.1 \, \Omega \]

**Problem 4.60**

\[ V_{BEQ} / R_2 = 1 \, mA \quad I_1 = I_2 + I_{BEQ} \]

\[ 5 \, mA = I_1 + I_{CQ} = I_2 + (\beta + 1) I_{BQ} \]

Using the first two equations to substitute for \( I_1 \) and \( I_2 \) and solving, we find \( I_{BEQ} = 39.6 \, \mu A \). Then we have

\[ V_{CEQ} = R_1 I_1 + V_{BEQ} = 7.25 \, V \]

Furthermore we have \( I_{CQ} = \beta I_{BEQ} = 3.96 \, mA \) and \( r_i = \beta V_T / I_{CQ} = 657 \, \Omega \).

The small signal equivalent circuit used to find the output impedance is:
\[ v_{\text{test}} = R_1(i_b + r_\pi i_b/R_2) + r_\pi i_b \]
\[ i_{\text{test}} = \beta i_b + i_b + r_\pi i_b/R_2 \]
\[ R_0 = \frac{v_{\text{test}}}{i_{\text{test}}} = \frac{r_\pi + R_1 (1 + r_\pi/R_2)}{1 + \beta + r_\pi/R_2} = 126 \, \Omega \]

This circuit is sometimes used as a voltage reference (similar to a Zener diode regulator).

**Problem 4.64**

When the transistor is in the active region we have:

\[ V_o = V_{CC} - R_C \frac{V_{\text{in}} - 0.7}{R_B} = 14.1 - 3V_{\text{in}} \]

![Graph](image)

(a)