\( \beta = \frac{i_C}{i_E} = \frac{9 \text{ mA}}{0.3 \text{ mA}} = 30 \)

\( \alpha = \frac{\beta}{(\beta + 1)} = \frac{30}{31} = 0.9677 \)

\( i_E = i_C + i_B = 9.3 \text{ mA} \)

Problem 4.9

\( \alpha = \frac{\beta}{(\beta + 1)} = \frac{50}{51} = 0.9804 \)

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

\[ V_{BE} = V_T \ln\left( \frac{i_E}{I_{ES}} + 1 \right) = 0.0266 \ln\left( \frac{10^{-3}}{10^{-13}} + 1 \right) = 0.6585 \text{ V} \]

\[ V_{BC} = V_{BE} - V_{CE} = 9.3 - 0.6585 = 9.34 \text{ V} \]

\[ i_B = i_E / (\beta + 1) = 9.901 \mu\text{A} \]

\[ i_C = i_E - i_B = 9.901 \text{ mA} \]

\( \alpha = \frac{\beta}{(\beta + 1)} = 0.9801 \)

Problem 4.11

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

Because the transistors are identical and have equal \( V_{BE} \), we conclude that \( I_{E1} = I_{B1} \) and \( I_{E2} = I_{C1} \). Furthermore \( I_{C1} = \beta I_{B1} \).

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

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

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

Solving Equation 4.1 for $V_{BE}$, we have

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

\[ = 0.0261\ln\left(\frac{0.9902 \times 10^{-3}}{10^{-14}} + 1\right) \]

\[ = 0.6583 \text{ V} \]

**Problem 4.12**

\[ V_{BE1} = V_{BE2} \]

\[ V_T \ln\left(\frac{I_{E1}}{I_{ES1}} + 1\right) = V_T \ln\left(\frac{I_{E2}}{I_{ES2}} + 1\right) \]

\[ \frac{I_{ES1}}{I_{E2}} = \frac{I_{ES1}}{I_{ES2}} = 0.1 \]

Therefore, we can write

\[ I_{B1}/I_{B2} = I_{C1}/I_{C2} = 0.1 \]

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

\[ 10I_{B1} + 100I_{B1} + I_{B1} = 1 \text{ mA} \]

\[ I_{B1} = 9.009 \mu \text{A} \]

\[ I_{C1} = \beta I_{B1} = 0.9009 \text{ mA} \]

\[ I_{C2} = 10I_{C1} = 9.009 \text{ mA} \]

\[ I_{E1} = (\beta + 1)I_{B1} = 0.9099 \text{ mA} \]

\[ V_{BE1} = V_{BE1} = V_T \ln\left(\frac{I_{E1}}{I_{ES1}} + 1\right) \]

\[ = 0.0261\ln\left(0.9099 \times 10^{-7}/10^{-14} + 1\right) \]

\[ = 0.6561 \text{ V} \]

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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

\[
\begin{align*}
I_{E_{eq}} &= i_C = i_{C1} + i_{C2} = \frac{i_{C1}}{I_{B1}} + \frac{i_{C2}}{I_{B2}} = 2\frac{i_{C1}}{I_{B1}} = \beta_1 = 100 \\
\beta &= i_{E1} + i_{E2} \\
i_{E} &= I_{ES1} \exp (\frac{v_{BE}/V_T - 1}{}) + I_{ES2} \exp (\frac{v_{BE}/V_T - 1}{}) \\
i_{E} &= (I_{ES1} + I_{ES2}) \exp (\frac{v_{BE}/V_T - 1}{}) = I_{E_{eq}} \exp (\frac{v_{BE}/V_T - 1}{})
\end{align*}
\]

Thus we conclude that

\[I_{E_{eq}} = I_{ES1} + I_{ES2} = 2 \times 10^{-13} \text{ A}\]
\[ I_B = \frac{(15 - 0.7)}{(680 \text{ K})} = 21.0 \mu\text{A} \]
\[ I_C = \frac{(15 - 7)}{(10 \text{ K})} = 0.800 \text{ mA} \]
\[ \beta = \frac{I_C}{I_B} = 38.1 \]

(b)

\[ I_B = \frac{(15 - 0.7)}{(56 \text{ K})} = 0.255 \text{ mA} \]
\[ I_C = \frac{5}{(1 \text{ K})} = 5 \text{ mA} \]
\[ \beta = \frac{I_C}{I_B} = 19.6 \]

**Problem 4.15**

Solving Equation 4.1 for \( I_{ES} \) we have:

\[ I_{ES} = \frac{I_E}{\left[ \exp \left( \frac{V_{BE}}{V_T} \right) - 1 \right]} = \frac{10 \times 10^{-3}}{\left[ \exp \left( \frac{0.700}{0.026} \right) - 1 \right]} = 2.03 \times 10^{-14} \text{ A} \]

Then for \( I_E = 1 \text{ mA} \) we have:

\[ V_{BE} = V_T \ln \left( I_E / I_{ES} + 1 \right) \]
\[ = 0.026 \ln \left( \frac{10^{-3}}{2.03 \times 10^{-14}} + 1 \right) \]
\[ = 0.640 \text{ V} \]

Similarly for \( I_E = 0.1 \text{ mA} \) we obtain \( V_{BE} = 0.586 \text{ V} \).
Problem 4.18

The schematic is stored in the file named P4_18. The input characteristic is shown above.

Problem 4.19

Distortion occurs in BJT amplifiers mainly because of the curvature of the input characteristic. Nonuniform spacing and curvature of the output characteristics also contributes to distortion. If the BJT is driven into cutoff or saturation, clipping (which is a severe form of distortion) occurs.

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:

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The equation for the output load line is

\[ V_{CC} = R_C i_C + V_{CE} \]

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

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

<table>
<thead>
<tr>
<th>( V_{in} = +0.2 \text{ V} )</th>
<th>( V_{in} = 0 )</th>
<th>( V_{in} = -0.2 \text{ 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

\[
A_v = \frac{-V_{CE\text{max}} - V_{CE\text{min}}}{0.4} = \frac{-(18.9 - 12)}{0.4} = -17.25
\]

**Problem 4.21**

The input load line is the same as in Problem 4.20. The output load line is

From these load lines we find:

<table>
<thead>
<tr>
<th>( V_{in} = +0.2 \text{ V} )</th>
<th>( V_{in} = 0 )</th>
<th>( V_{in} = -0.2 \text{ V} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( i_B (\mu A) )</td>
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<td>5.5</td>
</tr>
<tr>
<td>( i_C (mA) )</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>( V_{CE} (V) )</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

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Because $V_{CE\text{min}} = V_{CE\text{EQ}}$ the waveform is severely distorted. The circuit schematic is stored in the file named P4.21. A plot of $V_{CE}(t)$ is:

![Waveform Plot]

**Problem 4.22**

The equation for the input load line is

$$0.3 + v_{\text{in}(t)} = 40 \times 10^3 i_B + v_{BE}$$

Plotting load lines for $v_{\text{in}} = -0.2$, 0 and $+0.2$ V results in

![Load Lines Plot]

We have $I_{\text{Emax}} = I_{BQ} = I_{B\text{min}}$, so there is virtually no signal at the output. Furthermore, $V_{CE\text{min}} = V_{CE\text{EQ}} = V_{CE\text{max}} = 20$ V.
Problem 4.23

See Figure 4.16 in the book.

Problem 4.24

![Diagram](image)

Problem 4.25

Assuming that current is constant at 2 mA we have

\[ V_{\text{BET2}} = V_{\text{BET1}} + (2 \text{ mV})(T_2 - T_1) \]

\[ = -0.7 + 0.002(180 - 30) \]

\[ = -0.4 \text{ V} \]

At 180° we have \( V_T = kT/q = \frac{1.38 \times 10^{-23}(273 + 180)}{1.60 \times 10^{-19}} = 39.1 \text{ mV.} \)

Now we compute the value of \( I_s \) for a temperature of 180°.

\[ I_s = \frac{I_C}{\exp(V_{\text{BE}}/V_T) - 1} = \frac{2 \times 10^{-3}}{\exp(0.4/0.0391) - 1} = 71.6 \text{ mA} \]

Finally we compute \( V_{\text{BE}} \) for a current of 0.1 mA at 180°C.

\[ V_{\text{BE}} = V_T \ln\left(\frac{I_C/I_s}{1}\right) = 0.0391 \ln\left(\frac{10^{-4}}{(71.6 \times 10^{-3} + 1)}\right) \]

\[ = 0.283 \text{ V} \]

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To determine the output resistance of an amplifier:

1. Replace the load with a test voltage (or current) source.
2. Write circuit equations involving the current $i_x$ and voltage $v_x$ of the test source.

3. Eliminate current and voltage variables until one equation remains that relates $i_x$ and $v_x$.

4. The output impedance is $Z_o = v_x/i_x$.

**Problem 4.51**

Dc circuit:

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

\[ V_B = V_{CC} R_2 / (R_1 + R_2) = 7.5 \text{ V} \]
\[ R_B = R_1 || R_2 = 5 \text{ k\Omega} \]

\[ I_{BO} = \frac{V_B - V_{RDQ}}{R_B + (\beta + 1) R_E} = 64.1 \mu\text{A} \]
\[ I_{CQ} = \beta I_B = 6.41 \text{ mA} \]

\[ r_n = \rho V_{PD}/I_{CQ} = 405 \Omega \]
\[ R'_L = R_L || R_E = 333 \Omega \]

\[ R_V = \frac{R'_L (\beta + 1)}{r_n + R'_L (\beta + 1)} = 0.988 \]
\[ A_{vo} = \frac{R_E (\beta + 1)}{r_n + R_E (\beta + 1)} = 0.986 \]

\[ Z_{in} = R_B || [r_n + R'_L (\beta + 1)] = 4.36 \text{ k\Omega} \]
\[ A_1 = A_{vo} V_{2n}/R_L = 8.61 \]
\[ G = A_1 A_1 = 8.51 \]
\[ R'_S = R_E || R_S = 833 \Omega \]

\[ Z_o = R_E || [(R'_S + i_o)/(\beta + 1)] = 12.1 \Omega \]

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Circuit (b) is a better voltage reference because $I_o$ is much smaller.

**Problem 4.62**

See Figure 4.41 in the book. The transistor operates in saturation if the input is high and in cutoff if the input is low.

**Problem 4.63**

See Figure 4.45 in the book.

**Problem 4.64**

When the transistor is in the active region we have:

$$V_o = V_{CC} - R_C \frac{V_{in} - 0.7}{V_{B}} = 14.1 - 3V_{in}$$

![Graph](a)
(d) In part (b) the circuit acts as a linear amplifier.

For $V_o = 6$ V we have $I_{RE} = (12 - 6)/R_E = 2.73$ mA and $I_B (6 - 0.7)/(22 \text{ k}\Omega) = 0.241$ mA. Thus the maximum fanout is the largest integer that does not exceed $I_{RE}/I_B = 11.39$. Thus the maximum fanout is 11.
Problem 4.66

\[ I_B = \left( V_{in} - 0.7 \right) / R_B = 0.241 \text{ mA} \]
\[ I_C = \left( V_{CC} - 0.2 \right) / R_C = 5.37 \text{ mA} \]

For the circuit to remain in saturation we must have \( \beta I_B > I_C \) which implies that \( \beta > 22.3 \).

Problem 4.67

For \( V_o = 0.5 \text{ V} \), we have \( I_B = 0 \). Therefore there is no limit on fanout imposed by the conditions of this problem.