\[ A_{vb'} = V_o/V_\pi = -g_m R'_L \quad C_T = C_\pi + C_\mu (1 + g_m R'_L) \]

\[ f_H = \frac{1}{2\pi R'_S C_T} \]

Thus, we see that increasing \( R_L \) increases \( R'_L \), does not effect \( R'_S \), increases the gain \( A_{vb'} \), increases \( C_T \), and ultimately decreases the half-power frequency \( f_H \).

**Problem 8.40**

(a) \( I_{BQ} = I_{CQ}/\beta = 100 = 10 \, \mu A \quad R_B = (V_{CC} - V_{BEQ})/I_{BQ} = 1.43 \, \text{M} \Omega \)

\[ R_C = (V_{CC} - V_{CEQ})/I_{CQ} = 7 \, \text{k} \Omega \]

(b) \( r_\pi = \beta V_T/I_{CQ} = 2600 \, \Omega \quad R'_L = R_L || R_C || r_0 = 838 \, \Omega \)

\[ R'_S = r_\pi || [r_x + (R_B || R_S)] = 142 \, \Omega \]

\[ C_\pi \approx \frac{\beta}{2\pi r_\pi f_t} - C_\mu = 7.24 \, \text{pF} \quad g_m = \beta/r_\pi = 38.5 \, \text{mS} \]

\[ C_T = C_\pi + C_\mu (1 + g_m R'_L) = 173 \, \text{pF} \]

\[ f_H = \frac{1}{2\pi R'_S C_T} = 6.48 \, \text{MHz} \]

In the midband, we have \( R_{in} = R_B || r_\pi = 2.6 \, \text{k} \Omega \), \( A_v = -\beta r'_L/r_\pi = -32.2 \), and \( A_{VS} = A_v R_{in}/(R_S + R_{in}) = -31.0 \).

**Problem 8.41**

(a) \( I_{BQ} = I_{CQ}/\beta = 1.43 \, \mu A \)

\[ R_B = (V_{CC} - V_{BEQ})/I_{BQ} = 10.0 \, \text{M} \Omega \]

\[ R_C = (V_{CC} - V_{CEQ})/I_{CQ} = 7 \, \text{k} \Omega \]

(b) \( r_\pi = \beta V_T/I_{CQ} = 18.2 \, \text{k} \Omega \quad r_0 \approx V_A/I_{CQ} = 50 \, \text{k} \Omega \)

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common-base amplifier tends to be low and loading effects would be extreme.

**Problem 8.48**

See Figure 8.40 in the book.

**Problem 8.49**

Many correct choices exist for component values. We used 1 μF for each of the coupling capacitors, because the low-frequency region is not of interest in this problem. The following table gives choices of component values and results of the PSpice simulations for both Q points.

<table>
<thead>
<tr>
<th>( I_{CQ} )</th>
<th>( R_E )</th>
<th>( R_C )</th>
<th>( A_{Vsmid} )</th>
<th>( f_H )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mA</td>
<td>15 kΩ</td>
<td>5.6 kΩ</td>
<td>+5.1</td>
<td>3.9 MHz</td>
</tr>
<tr>
<td>10 μA</td>
<td>1.5 MΩ</td>
<td>560 kΩ</td>
<td>+22.6</td>
<td>248 kHz</td>
</tr>
</tbody>
</table>

The simulations are stored in P8.49a and P8.49b. The model for the 2N2222A is stored in the Device.lib file. Results will vary depending on the model used.

**Problem 8.50**

The circuit diagram is shown on the next page. Many correct choices exist for component values. We used 1 μF for each of the coupling capacitors and 100 μF for the bypass capacitor because the low-frequency region is not of interest in this problem. The table gives choices of component values and results of the PSpice simulations for both Q points.

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Many correct choices exist for component values. We used $C_1 = C_2 = 1 \, \mu F$ and $C_E = 100 \, \mu F$ because the low-frequency region is not of interest in this problem. The following table gives choices of component values and results of the PSpice simulations for both Q points.

<table>
<thead>
<tr>
<th>$I_{CQ}$</th>
<th>$R_B$</th>
<th>$R_{E1}$, $R_{E2}$</th>
<th>$R_C$</th>
<th>$A_{vsmid}$</th>
<th>$f_H$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mA</td>
<td>150 kΩ</td>
<td>15 kΩ</td>
<td>5.6 kΩ</td>
<td>+83</td>
<td>2.4 MHz</td>
</tr>
<tr>
<td>10 μA</td>
<td>15 MΩ</td>
<td>1.5 MΩ</td>
<td>560 kΩ</td>
<td>+14.7</td>
<td>250 kΩ</td>
</tr>
</tbody>
</table>

The simulations are stored in P8_51a and P8_51b. The model for the 2N2222A is stored in the Device.lib file. Results will vary depending on the model used.

**Problem 8.52**

Here is one design that meets the requirements:

![Diagram](image)

The simulation, which is stored in the file named P8_52, yields $A_{vsmid} = 2.1$ and $f_H = 110$ MHz.
Equation 5.48 in the book gives the midband voltage gain as

\[ A_V = \frac{v_o}{v_{in}} = \frac{g_m R'_L}{1 + g_m R'_L} \]

where \( R'_L = r_d || R_s || R_L \)

However \( A_{VS} = A_V R_G/(R_{sig} + R_G) \).

Using the Miller effect and replacing \( v_{sig} \), \( R_{sig} \), and \( R_G \) with a Thévenin equivalent, we obtain the following equivalent input circuit.

\[ R_{sig}' = R_{sig} || R_D \]

\[ \frac{1}{C_{gd}} \quad \frac{1}{C_{gs}(1-A_V)} \]

This is a first-order lowpass filter having

\[ f_H = \frac{1}{2\pi R'_L [C_{gd} + C_{gs}(1 - A_V)]} \]

Evaluating for the parameters given in the problem we obtain

\[ R'_L = 1333 \ \Omega \]
\[ R'_{sig} = 4.98 \ \text{k\Omega} \]

\[ A_V = A_{VS} = 0.87 \]
\[ f_H = 56.5 \ \text{MHz} \]

**Problem 8.57**

This problem is similar to Example 8.10.
\[ I_{CQ} = I_{EQ} = 1 \text{ mA} \quad r_n = \beta V_T / I_{CQ} = 150(0.026) / 10^{-3} = 3900 \Omega \]

\[ f_t = \frac{\beta}{2 \pi r_n (C_\mu + C_\pi)} \Rightarrow C_\pi = 7.2 \text{ pF} \]

\[ R'_L = r_o || R_L = 990 \Omega \quad A_v = \frac{(\beta + 1)}{r_n + (\beta + 1) R'_L} = 0.975 \]

\[ R_{in} = R_B || [r_n + (\beta + 1) R'_L] = 60.5 \text{ k}\Omega \]

\[ A_{VS} = \frac{v_o}{v_s} = A_v \frac{R_{in}}{R_s + R_{in}} = 0.367 \]

\[ g_m = I_{CQ} / V_T = 38.5 \text{ mS} \quad C_T = C_\mu + \frac{C_\pi}{1 + g_m R'_L} = 5.18 \text{ pF} \]

\[ R_T = [r_x + (R_s || R_B)] || [r_n (1 + g_m R'_L)] = 37.7 \text{ k}\Omega \]

\[ f_H = \frac{1}{2 \pi R_T C_T} = 815 \text{ kHz} \quad \text{This is the upper half-power frequency for } A_{VS}. \quad \text{For } A_v \text{ we assume } R_s = 0 \text{ and recompute } R_T \text{ and } f_H. \quad \text{The upper half-power frequency for } A_v \text{ is } f_H = 1.02 \text{ GHz.} \]

**Problem 8.58**

See the circuit diagram on the next page. Many correct choices exist for component values. We used 1 \mu F each of the coupling capacitors because the low-frequency region is not of interest in this problem. The following table gives choices of component values and results of the PSpice simulations for both Q points.

<table>
<thead>
<tr>
<th>[ I_{CQ} ]</th>
<th>[ R_E ]</th>
<th>[ R_B ]</th>
<th>[ A_{Vsmid} ]</th>
<th>[ f_H ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mA</td>
<td>13 k\Omega</td>
<td>150 k\Omega</td>
<td>+0.435</td>
<td>455 kHz</td>
</tr>
<tr>
<td>10 \mu A</td>
<td>1.3 M\Omega</td>
<td>13 M\Omega</td>
<td>+0.22</td>
<td>69 kHz</td>
</tr>
</tbody>
</table>

The simulations are stored in P8_58a and P8_58b. The model for the 2N2222A is stored in the Device.lib file. Results will vary depending on the model used.
Problem 10.3

Sometimes we use a mica washer between the case of a power BJT and the heat sink to provide electrical insulation between the collector (which may be electrically connected to the case) and the heat sink.

Problem 10.4

Heat sinks should be mounted in a location and in an orientation that maximizes air flow over the fins of the sink.

Problem 10.5

A typical power-derating curve for a power transistor is shown in Figure 10.3 on page 670 in the book.

Problem 10.6

We assume that the junction is at its maximum allowed temperature for $T_C = 25^\circ$ and $P_D = 40$ W. Thus we have

$$\theta_{JC} = (T_J - T_C)/P_D = 3.75^\circ C/W$$

Problem 10.7

(a) The junction-to-case thermal resistance is minus the inverse of the slope of the derating curve, which is $150^\circ/(100 \text{ W}) = 1.5 \text{ } ^\circ C/W$.

(b) The maximum junction is the intersection of the derating curve with the temperature axis. Thus $T_{J\text{max}} = 200^\circ C$.

Problem 10.8

(a) $\theta_{JC} = (T_{J\text{max}} - T_C)/P_{D\text{max}} = (200 - 25)/15 = 11.67^\circ C/W$

(b) $T_{J\text{max}} = (\theta_{JC} + \theta_{CS} + \theta_{SA})P_D + T_A$

$\theta_{SA} = (T_{J\text{max}} - T_A)/P_D - \theta_{JC} - \theta_{CS}$

$= (200 - 75)/5 - 11.67 - 1$

$= 12.33^\circ C/W$

(c) $T_C = T_A + P_D(\theta_{CS} + \theta_{SA}) = 75 + 5(1 + 12.33) = 141.7^\circ C$
Problem 10.9

(a) \[ P_{J_{\text{max}}} = 50 \text{ W} \]
\[ \text{Slope} = -\frac{1}{\theta_{JC}} = -0.2 \text{ W/°C} \]
\[ T_{J_{\text{max}}} = 275^\circ\text{C} \]

(b) \( T_{J_{\text{max}}} = 275^\circ\text{C} \) (This is a very high value.)

(c) \( \theta_{JC} = 5^\circ\text{C/W} \)

Problem 10.10

The third sentence of the problem should read: "The case-to-sink thermal resistance is \( \theta_{CS} = 0.5^\circ\text{C/W} \)." Then we have
\[ \theta_{JC} = (T_{J_{\text{max}}} - T_C)/P_D = (200 - 25)/20 = 8.75^\circ\text{C/W} \]
\[ \theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA} = (T_J - T_A)/P_D \]
\[ \theta_{SA} = 10.75^\circ\text{C/W} \]
\[ \theta_{JA} = 8.75 + 0.5 + \theta_{SA} = (150 - 50)/5 = 20 \]

Problem 10.11

\[ T_J = (0.7 - 0.5)/0.0025) + 25 = 105^\circ\text{C} \]
\[ \theta_{JA} = (T_J - T_A)/P_D = (105 - 30)/(0.5) = 45^\circ\text{C/W} \]

Problem 10.12

(a) From page 867 we find that \( P_{D_{\text{max}}} = 1.2 \text{ W} \) at a case temperature of 25°C. This is to be derated at 6.85 mW/°C. The junction-to-case thermal resistance is \( \theta_{JC} = 1/(6.85 \times 10^{-3}) = 146^\circ\text{C/W} \). (The thermal resistances are denoted as \( R_{\theta JC} \) and \( R_{\theta JA} \) on the data sheet, and their values are interchanged.)
(b) For an ambient temperature of 25°C, $P_{D\text{max}} = 0.4$ W derated by 2.28 mW/°C. Thus the junction to ambient thermal resistance is $\theta_{JA} = \frac{1}{2.28 \times 10^{-3}} = 439$°C/W.

(c) $P_{D\text{max}} = 0.4 - (75 - 25)(2.28 \times 10^{-3}) = 0.286$ W

Compared to small-signal BJTs, power BJTs have larger junction areas, larger junction capacitances, lower $\beta$s, larger leakage currents, lower $f_t$'s, and larger more massive cases.

As temperature increases, $V_{BEQ}$ decreases, the leakage current $I_{CBO}$ increases, and $\beta$ increases. In most power amplifiers, all of these effects tend to raise $I_{CQ}$ and dissipated power which leads to higher temperature and even higher values of $I_{CQ}$ and $P_D$. In extreme cases, this can lead to thermal runaway and destruction of the device.

The maximum ratings to consider for a power BJT include junction temperature, collector current, collector-to-emitter voltage, and second breakdown.

Second breakdown occurs in BJTs with higher collector-to-emitter voltages that concentrate the current in a small part of the junction. This causes localized overheating of part of the junction.

Power MOSFETs require very little drive current (i.e., gate current) compared to that of power BJTs. Switching times are generally shorter for power MOSFETs than for power BJTs. Furthermore, at higher currents, drain current of a power MOSFET tends to decrease with temperature, which makes MOSFETs less likely than BJTs to experience thermal runaway.
Problem 10.18

\[ P_{D \text{max}} = I_{C \text{max}}V_{CE} = (T_{J \text{max}} - T_A)/\theta_{JA} \]
\[ I_{C \text{max}} = (T_{J \text{max}} - T_A)/(\theta_{JA}V_{CE}) = (150 - 50)/(3 \times 25) = 1.33 \text{ A} \]

Problem 10.19

In a class-A amplifier, current flows through the transistors for the entire signal cycle (360°).

Problem 10.20

See Figure 10.11 on page 680 in the book.

Problem 10.21

If either the current or the voltage is constant with time, the average power is the product of the average current and the average voltage. If both the current and the voltage vary with time, the average power dissipation is not equal to the product of average current and average voltage in general.

Problem 10.22

\[ I_{CQ2} = (15 - 0.7)/(5 \text{ k}\Omega) = 2.86 \text{ mA} = I_{CQ3} = I_{CQ1}. \]

For \( Q_1 \) at cutoff, \( v_L = -2.86 \text{ mA} \times 1 \text{ k}\Omega = -2.86 \text{ V} \).

For \( Q_1 \) in saturation, \( v_L = V_{CC} - V_{CE\text{sat}} = 14.8 \text{ V} \).

\[ A_3 = 2A_2 \]

When \( A_3 = 2A_2 \), \( I_{CQ3} = 2 \times 2.86 = 5.72 \text{ mA} \).
Problem 10.23

\[ P_{Q1} = \frac{1}{T} \int_{0}^{T} V_{CE1}(t)i_{C1}(t) \, dt \]

\[ P_{Q1} = \frac{1}{T} \int_{0}^{T} [12.65 - 12.65 \sin(2000\pi t)][1.58 \sin(2000\pi t) + 1.58] \, dt \]

\[ P_{Q1} = \frac{1}{T} \int_{0}^{T} 20 \, dt - \frac{1}{T} \int_{0}^{T} 20 \sin^2(2000\pi t) \, dt \]

[We have made use of the fact that \( \frac{1}{T} \int_{0}^{T} \sin(2000\pi t) \, dt = 0 \).]

Using the trigonometric identity \( 2\sin^2(x) = 1 - \sin(2x) \), we have

\[ P_{Q1} = \frac{1}{T} \int_{0}^{T} 20 \, dt - \frac{1}{T} \int_{0}^{T} 10 - 10\sin(4000\pi t) \, dt \]

\[ = 20 - 10 \]

\[ = 10 \, \text{W} \]

We have \( I_{Clavg} = 1.58 \) and \( V_{CEavg} = 12.65 \). Thus \( I_{Clavg}V_{CEavg} = 20 \, \text{W} \) which is not equal to \( P_{Q1} \).

Problem 10.24

See the circuit diagram on the next page. For \( V_O = \pm 5 \, \text{V} \) we have \( i_O = \pm 10 \, \text{mA} \). Therefore we must choose \( I_{CQ3} = 10 \, \text{mA} \). (We are designing for minimum supply current, however in a more realistic situation, we would allow significant design margin.) We choose \( I_{ref} = 1 \, \text{mA}, A_2 = 1 \) and \( A_1 = A_3 = 10 \). The resistance is \( R = (10 - V_{BE2})/(1 \, \text{mA}) = 9.3 \, \text{k}\Omega \).
Problem 10.25

(a)

\[ I_{C_1} = 30 \text{mA} \]

\[ V_{CE1} = V_{CC} - V_0 \]

\[
P_{Q1} = \frac{1}{T} \int_{0}^{T} V_{CE1}(t) i_{C1}(t) \, dt = 0
\]

\[
P_{CC} = V_{CC} I_{C1\text{avg}} = (15 \text{ V}) \times (15 \text{ mA}) = 225 \text{ mW}
\]

\[
P_{EE} = V_{EE} I_{bias} = 225 \text{ mW}
\]
Problem 10.34

The capacitor is included so the feedback ratio is unity for dc, which results in unity closed-loop gain for any dc offsets that may be present, thereby reducing the dc voltage applied to the load.

Problem 10.35

(a) Neglecting saturation voltages, the peak output voltage is equal to $V_{CC}$. Thus we have

$$P_o = 50 = \left(\frac{V_{CC}}{\sqrt{2}}\right)R_L$$

$$V_{CC} = 28.3 \, V$$

(b) The peak collector current equals the peak load current which is $(28.3 \, V)/(8 \, \Omega) = 3.54 \, A$. The peak current rating of the transistors should be larger than this value.

(c) When the load voltage reaches its peak value $V_{CC}$, we have

$$|V_{CE2\text{max}}| = V_{CC} + V_{EE} = 56.6 \, V$$

The peak $V_{CE}$ ratings of the transistors should exceed this value.

(d) The peak power dissipated in the transistors (assuming a sinusoidal signal) is given by Equation 10.40 on page 696 in the book.

$$P_{DQ1\text{max}} = P_{DQ2\text{max}} = \left(\frac{2}{\pi^2}\right)P_{o\text{max}}$$

$$= \left(\frac{2}{\pi^2}\right)50$$

$$= 10.1 \, W$$

Thus the thermal design should accommodate at least 10.1 W without exceeding the maximum junction temperatures of the devices.

Problem 10.36

Following the approach of Problem 10.35 for $R_L = 50 \, \Omega$, we find $V_{CC} = 70.7 \, V$, $I_{C\text{peak}} = 1.41 \, A$, $V_{CE\text{max}} = 141 \, V$, and $P_{DQ\text{max}} = 10.1 \, W$. 

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Problem 7.48

In a small-signal equivalent circuit, an ideal dc voltage source is replaced with a short circuit because there is no change in the source voltage even if the current through it is changing. An ideal dc current source is replaced with an open circuit because there is no change in the source current even if the voltage across it changes.

Problem 7.49

By symmetry, we conclude that $I_{CQ1} = I_{CQ2} = 5$ mA. Then we have $r_\pi = r_\pi = \beta V_T / I_C = 1040 \Omega$. Also the differential input voltage is $v_d = v_{in}$. From Table 7.2 on page 450 in the book, we have

$$A_{vds} = \frac{V_{o}}{v_d} = \frac{V_o}{v_{in}} = \frac{R \rho}{2[r_\pi + (\beta + 1)R_{EF}]}$$

$$= \frac{1000 \times 200}{2[1040 + 201 \times 20]} = 19.8$$

$$R_i = R_{id} = 2[r_\pi + (\beta + 1)R_{EF}] = 10.1 \, k\Omega$$

Problem 7.50

Because the 1-mA sources become open circuits in the equivalent circuit, the common-mode gain is zero, and the common-mode input impedance is infinite. Thus we can compute the input impedance and gain using the formulas for the differential signal.

Comparing Figure F7.50 to the equivalent circuit shown in Figure 7.33, we have $R_{EB} = \infty$ and $2R_{EF} = 100$. Thus $R_{EF} = 50$.

$I_{CQ1} = I_{CQ2} = 1$ mA

$r_\pi = \beta V_T / I_C = 5.2 \, k\Omega$

$$A_{vds} = \frac{V_o}{v_{in}} = \frac{V_o}{v_d} = \frac{R \rho}{2[r_\pi + (\beta + 1)R_{EF}]}$$
\[ A_{vds} = \frac{10^4 \times 200}{2(5200 + 201 \times 50)} = 65.6 \]

\[ R_i = R_{id} = 2[r_{\pi} + (\beta + 1)R_E] = 30.5 \text{ k}\Omega \]

**Problem 7.51**

(a) \[ I_{CQ1} = I_{CQ2} = (5 \text{ mA})\beta/(\beta + 1) = 4.975 \text{ mA} \]

\[ r_{\pi} = \beta V_T/I_{CQ} = 1045 \text{ k}\Omega \]

\[ A_{vds} = \frac{V_o}{V_{in}} = \frac{V_o}{V_d} = \frac{R_C}{2[r_{\pi} + (\beta + 1)R_E]} \]

\[ A_{vds} = \frac{1000 \times 200}{2(1045 + 201 \times 0)} = 95.7 \]

(b) and (c)

\[ v_{il} \text{ is a } 1-\text{kHz sine wave with peak amplitude of } 10 \text{ mV.} \]

\[ i_{C1} = I_{CQ} + A_{vds}v_{il}/R_C = 4.975 + 0.957\sin(2000\pi t) \]

\[ i_{C2} = I_{CQ} - A_{vds}v_{il}/R_C = 4.975 - 0.957\sin(2000\pi t) \]

The simulation is stored in the file named P7_51. The simulation yields the following plots of the currents.