11.1
Refer to Fig 11.2. The upper limit of the output voltage is determined by the saturation of \( Q_1 \) as:

\[
V_{O_{\text{max}}} = V_{CC} - V_{CE_{\text{sat}}}
\]

\[
= 5 - 0.3 = 4.7 \text{ V}
\]
The corresponding input is:

\[
v_I = 4.7 + 0.7 = 5.4 \text{ V}
\]
The bias current \( I \) is:

\[
I = \frac{0 - (-V_{CC} + V_{BE2})}{R}
\]

\[
= \frac{5 - 0.7}{1} = 4.3 \text{ mA}
\]
The lower limit of \( v_O \) is determined by either \( Q_1 \) cutting off,

\[
-\frac{V_{O}}{R_L} = I \Rightarrow v_O = -4.3 \text{ V}
\]
or by \( Q_2 \) saturating,

\[
v_O = -V_{CC} + V_{CE_{\text{sat}}} = -4.7 \text{ V}
\]
Obviously, \( v_{O_{\text{min}}} = -4.3 \text{ V} \)
and the corresponding input is:

\[
v_I = -4.3 + 0.7 = -3.6 \text{ V}
\]
If the emitter-base junction area of \( Q_3 \) is 14 made twice as large as that of \( Q_2 \), it becomes one half its previous value,

\[
I = \frac{4.3}{2} = 2.15 \text{ mA}
\]
and thus the lower limit of \( v_O \) changes to:

\[
v_{O_{\text{min}}} = -IR_L = -2.15 \text{ V}
\]
The corresponding value of \( v_I \) is:

\[
v_I = -2.15 + 0.7 = -1.45 \text{ V}
\]
The upper limit does not change.

11.2
First we determine the bias current \( I \) as follows:

\[
I = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_t)^2
\]
But \( V_{GS} = 5 - IR \)

\[
= 5 - I
\]
Thus:

\[
I = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (5 - I - V_t)^2
\]

\[
I = 10(5 - I - 1)^2
\]

\[
\Rightarrow I^2 - 8.1I + 16 = 0
\]

\[
I = 3.416 \text{ mA and } V_{GS} = 1.584 \text{ V}
\]
The upper limit on \( v_O \) is determined by \( Q_1 \) leaving the saturation region (and entering the triode region). This occurs when \( v_I \) exceeds \( V_{DS} \) by \( V_t \) volts,

\[
v_{O_{\text{max}}} = 5 + 1 = +6 \text{ V}
\]

To obtain the corresponding value of \( v_o \) we must find the corresponding value of \( V_{GS1} \), as follows:

\[
v_o = v_I - V_{GS1}
\]

\[
I_L = \frac{v_o}{R_L} = \frac{v_I - V_{GS1}}{1}
\]

\[
= v_I - V_{GS1} = 6 - V_{GS1}
\]

\[
i_t = I + i_L
\]

\[
= 3.416 + 6 - V_{GS1}
\]

\[
= 9.416 - V_{GS1}
\]

But \( i_t = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS1} - V_t)^2 \)

Thus, \( 9.416 - V_{GS1} = 10(V_{GS1} - 1)^2 \)

\[
\Rightarrow V_{GS1}^2 - 1.9 V_{GS1} + 0.0584 = 0
\]

\[
V_{GS1} = 1.869 \text{ V}
\]

\[
v_{O_{\text{max}}} = 6 - 1.869
\]

\[
= +4.131 \text{ V}
\]
The lower limit of \( v_o \) is determined either by \( Q_1 \) cutting off,

\[
v_o = -IR_L = -3.416 \times 1 = -3.416 \text{ V}
\]
or by \( Q_2 \) leaving saturation,

\[
v_o = V_{GS} - V_t
\]

\[
= 5 + 1.864 - 1 = -4.416 \text{ V}
\]
Thus, \( v_{O_{\text{min}}} = -3.416 \text{ V} \)

The corresponding value of \( v_I \) is determined by moving that since \( Q_1 \) is on the verge of cut-off,

\[
V_{GS1} = V_t = 1 \text{ V and}
\]

\[
v_I = -3.416 + 1 = -2.416 \text{ V}
\]
11.3
Refer to Fig. 11.2. With $V_{CC} = +9$ V, the upper limit on $v_o$ is 8.7 V, which is greater than the required value of +7 V. To obtain a lower limit of -7V, we select $I$ so that $IR_L = 7.

$\Rightarrow I = 7$ mA

Since we are provided with four devices, we can minimize the total supply current by paralleling two devices to form $Q_2$ as shown below.

The resulting supply current will be $3 \times \frac{I}{2}$ rather than $2I$ which is the value obtained in the circuit of Fig. 11.2. Then the supply current is 10.5 mA.

The value of $R$ is found from

$$R = \frac{8.3 \text{ V}}{3.5 \text{ mA}} = 2.37 \text{ k}\Omega$$

In a practical design we would select a standard value for $R$ that results in $I$ somewhat larger than 7 mA. Say, $R=2.2k\Omega$

11.4
Refer to Fig. 11.2. For a load resistance of 100 $\Omega$ and $v_o$ ranging between -5 V and +5 V, the maximum current through $Q_1$ is

$$I + \frac{5}{0.1} = I + 50 \text{ mA}$$

and the minimum current is

$$I = \frac{5}{0.1} = I - 50 \text{ mA}.$$
Devices have $|V_i| = 0.5$ V

$$\mu C_{os} \frac{W}{L} = 2 \text{ mA/V}^2$$

For $R_L = \infty$, the current is normally zero, so

$$V_{gs} = V_i$$

$$\therefore v_o = v_i - V_{gs} = 5 - 0.5 = 4.5 \text{ V}$$

The peak output voltage will be 4.5 V

$$\sin \theta = \frac{0.5}{5} \Rightarrow \theta = 5.74^\circ$$

Crossover interval $= 4\theta = 22.96^\circ$

$$= \frac{22.96}{360} \times 100$$

$$= 6.4\%$$

For $v_i = 5$ V, $v_o = 2.5$ V

$$\therefore V_{gs} = 5 - 2.5 = 2.5 \text{ V}$$

$$i_o = \frac{1}{2} \mu C_{os} \frac{W}{L} (V_{gs} - V_i)^2$$

$$= \frac{1}{2} \times 2 \times (2.5 - 0.5)^3$$

$$i_o = 4 \text{ mA and } R_L = \frac{2.5 \text{ V}}{4 \text{ mA}} = 625 \Omega$$

11.11

For $V_{CC} = 10$ V and $R_L = 100 \Omega$, the maximum sine-wave output power occurs when $V_o = V_{CC}$

and is $P_{L_{\text{max}}} = \frac{1}{2} \frac{V_{CC}^2}{R_L}$

$$= \frac{1}{2} \frac{100}{100} = 0.5 \text{ W}$$

Correspondingly,

$$P_{S+} = P_{S-} = \frac{V_o^2}{\pi R_L} V_{CC}$$

$$= \frac{1}{\pi} \times \frac{100}{100} \times 10 = 0.318 \text{ W}$$

For a total supply power of

$$P_s = 2 \times 0.318 = 0.637 \text{ W}$$

The power conversion efficiency $\eta$ is

$$\eta = \frac{P_L}{P_s} \times 100 = \frac{0.5}{0.637} \times 100 = 78.5\%$$

For $V_o = 5$ V,

$$P_L = \frac{V_o^2}{2R_L} = \frac{1}{2} \times \frac{25}{100} = \frac{1}{8} \text{ W}$$

$$P_{S+} = P_{S-} = \frac{V_o^2}{\pi R_L} V_{CC}$$

$$= \frac{1}{\pi} \times \frac{5}{100} \times 10 = \frac{1}{2\pi} \text{ W}$$

$$P_s = \frac{1}{\pi} \text{ W} = 0.318 \text{ W}$$

$$\eta = \frac{P_L}{P_s} \times 100 = \frac{\pi}{8} \times 100 = 39.3\%$$
11.12

\[ V_{CC} = 5 \text{ V} \]

For maximum \( \eta \),

\[ \dot{V}_o = V_{CC} = 5 \text{ V} \]

The output voltage that results in maximum device dissipation is given by Eq. (12.20),

\[ \dot{V}_o = \frac{2}{\pi} V_{CC} \]
\[ = \frac{2}{\pi} \times 5 = 3.18 \text{ V} \]

If operation is always at full output voltage, \( \eta = 78.5\% \) and thus

\[ P_{\text{dissipation}} = (1 - \eta) P_s \]
\[ = (1 - 0.785) \frac{P_L}{0.785} = 0.274 P_L \]

\[ P_{\text{dissipation/device}} = \frac{1}{2} \times 0.274 P_L = 0.137 P_L \]

For a rated device dissipation of 1 W, and using a factor of 2 safety margin,

\[ P_{\text{dissipation/device}} = 0.5 \text{ W} \]
\[ = 0.137 P_L \]
\[ \Rightarrow P_L = 3.65 \text{ W} \]

\[ 3.65 = \frac{1}{2} \times \frac{25}{R_L} \]
\[ \Rightarrow R_L = 3.425 \Omega \text{ (i.e. } R_L \geq 3.425 \Omega \text{) } \]

The corresponding output power (i.e., greatest possible output power) is 3.65 W.

If operation is allowed at \( \dot{V}_o = \frac{1}{2} V_{CC} = 2.5 \text{ V}, \)

\[ \eta = \frac{\pi \dot{V}_o}{4 V_{CC}} \text{ (Eq. 12.15)} \]
\[ = \frac{\pi \times 2.5}{4} = 0.393 \]

\[ P_{\text{dissipation/device}} = \frac{1}{2} \left( 1 - \frac{1}{\eta} \right) P_L = 0.772 P_L \]

\[ 0.5 = 0.772 P_L \]
\[ \Rightarrow P_L = 0.647 \text{ W} \]
\[ = \frac{1}{2} \frac{25}{R_L} \]
\[ \Rightarrow R_L = 4.83 \Omega \text{ (i.e., } R_L \geq 4.83 \Omega \text{) } \]

11.13

\[ P_L = \frac{1}{2} \frac{\dot{V}_o^2}{R_L} \]
\[ 100 = \frac{1}{2} \frac{\dot{V}_o^2}{16} \]
\[ \dot{V}_o = 56.6 \text{ V} \]
\[ V_{CC} = 56.6 + 4 = 60.6 \rightarrow 61 \text{ V} \]

Peak current from each supply \[ = \frac{\dot{V}_o}{R_L} = \frac{56.6}{16} \]
\[ = 3.54 \text{ A} \]

\[ P_s = P_s = \frac{1}{\pi} \times 3.54 \times 61 \]

Thus, \( P_s = \frac{2}{\pi} \times 3.54 \times 61 \]
\[ = 137.4 \text{ W} \]

\[ \frac{P_L}{P_s} = \frac{100}{137.4} = 73\% \]

Using Eq. (12.22),

\[ P_{DN \text{ max}} = P_{DP \text{ max}} = \frac{\dot{V}_o^2}{\pi^2 R_L} = \frac{61^2}{\pi^2 \times 16} \]
\[ = 23.6 \text{ W} \]

11.14

\[ P_L = \frac{\dot{V}_o^2}{R_L} \]

\[ P_s = \frac{1}{2} \frac{\dot{V}_o}{R_L} \]

\[ P_s = \frac{\dot{V}_o}{R_L} \]

\[ \eta = \frac{P_L}{P_s} = \frac{V_{SS}}{2(V_{SS} R_L)} = \frac{\dot{V}_o}{V_{SS}} \]

\[ \eta_{\text{max}} = 1(100\%), \text{ obtained for } \dot{V}_o = V_{SS} \]

\[ P_{L \text{ max}} = \frac{V_{SS}^2}{R_L} \]

\[ P_{\text{dissipation}} = P_s - P_L \]

\[ = \frac{\dot{V}_o}{V_{SS} R_L} \]

\[ \frac{\partial P_{\text{dissipation}}}{\partial \dot{V}_o} = \frac{V_{SS} - 2\dot{V}_o}{R_L} \]

\[ = 0 \text{ for } \dot{V}_o = \frac{V_{SS}}{2} \]

Correspondingly, \( \eta = \frac{V_{SS}/2}{V_{SS}} = \frac{1}{2} \text{ or } 50\% \)

11.15

\[ A_v = \frac{R_L}{R_L + R_{\text{out}}} \text{ and } R_{\text{out}} = \frac{R_i}{2} = \frac{V_i}{2I_Q} \]

Now \( A_v \geq 0.98 \text{ for } R_i \geq 100 \Omega \)

\[ \therefore 0.98 = \frac{100}{100 + R_{\text{out}}} \]
\[ \Rightarrow R_{\text{out}} \geq 2 \Omega \]

\[ R_{\text{out}} = \frac{2}{2I_Q} \]