Most of the power from the dc source is supplied to the output stage. The current in the output stage can be computed from the dc emitter voltage of Q_3.

$$V_{E(Q3)} \cong \left(\frac{22\text{ k}\Omega}{27.6\text{ k}\Omega}\right)12\text{ V} - 1.4\text{ V} = 8.2\text{ V}$$

$$I_{E(Q3)} = \frac{V_{E(Q3)}}{R_E} = \frac{8.2\text{ V}}{33\ \Omega} = 0.25\text{ A}$$

Neglecting the other transistor and bias currents, which are very small, the total dc supply current is about 0.25 A. The power from the dc source is

$$P_{DC} = I_{CC}V_{CC} = (0.25\text{ A})(12\text{ V}) = 3\text{ W}$$

Therefore, the efficiency of the amplifier for this input is

$$\eta = \frac{P_{out}}{P_{DC}} = \frac{122\text{ mW}}{3\text{ W}} \cong \mathbf{0.04}$$

This represents an efficiency of 4% and illustrates why class A is not a good choice for a power amplifier.

Related Problem Explain what happens to the efficiency if R_{E3} were replaced with the speaker. What problem does this have?

SECTION 7–1 CHECKUP
Answers can be found at www.pearsonhighered.com/floyd.

1. What is the purpose of a heat sink?
2. Which lead of a BJT is connected to the case?
3. What are the two types of clipping with a class A power amplifier?
4. What is the maximum efficiency for a class A amplifier?
5. How can the power gain of a CC amplifier be expressed in terms of a ratio of resistances?

7–2 THE CLASS B AND CLASS AB PUSH-PULL AMPLIFIERS

When an amplifier is biased at cutoff so that it operates in the linear region for 180° of the input cycle and is in cutoff for 180°, it is a **class B** amplifier. Class AB amplifiers are biased to conduct for slightly more than 180°. The primary advantage of a class B or class AB amplifier over a class A amplifier is that either one is more efficient than a class A amplifier; you can get more output power for a given amount of input power. A disadvantage of class B or class AB is that it is more difficult to implement the circuit in order to get a linear reproduction of the input waveform. The term *push-pull* refers to a common type of class B or class AB amplifier circuit in which two transistors are used on alternating half-cycles to reproduce the input waveform at the output.

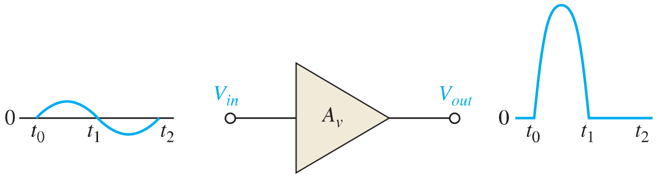
After completing this section, you should be able to

- ❑ **Explain and analyze the operation of class B and class AB amplifiers**
- ❑ Describe class B operation
  - ◆ Discuss Q-point location
- ❑ Describe class B push-pull operation
  - ◆ Discuss transformer coupling
  - ◆ Explain *complementary symmetry transistors*
  - ◆ Explain crossover distortion

- Bias a push-pull amplifier for class AB operation
  - Define *class AB*
  - Explain class AB ac signal operation
- Describe a single-supply push-pull amplifier
- Discuss class B/AB power
  - Calculate maximum output power
  - Calculate dc input power
  - Determine efficiency
- Determine the ac input resistance of a push-pull amplifier
- Discuss the Darlington class AB amplifier
  - Determine ac input resistance
- Describe the Darlington/complementary Darlington class AB amplifier

Class B Operation

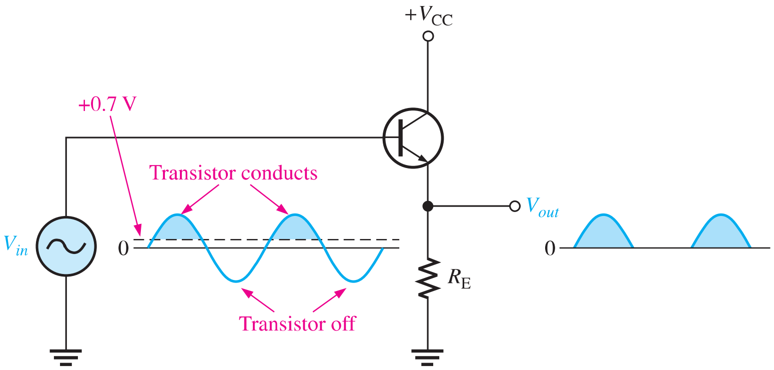
The class B operation is illustrated in Figure 7–6, where the output waveform is shown relative to the input in terms of time (t).



▲ FIGURE 7–6

Basic class B amplifier operation (noninverting).

The Q-Point Is at Cutoff The class B amplifier is biased at the cutoff point so that $I_{CQ} = 0$ and $V_{CEQ} = V_{CE(cutoff)}$. It is brought out of cutoff and operates in its linear region when the input signal drives the transistor into conduction. This is illustrated in Figure 7–7 with an emitter-follower circuit where the output is not a replica of the input.



▲ FIGURE 7–7

Common-collector class B amplifier.

Class B Push-Pull Operation

As you can see, the circuit in Figure 7–7 only conducts for the positive half of the cycle. To amplify the entire cycle, it is necessary to add a second class B amplifier that operates on the negative half of the cycle. The combination of two class B amplifiers working together is called **push-pull** operation.

There are two common approaches for using push-pull amplifiers to reproduce the entire waveform. The first approach uses transformer coupling. The second uses two **complementary symmetry transistors;** these are a matching pair of *npn*/*pnp* BJTs.

Transformer Coupling Transformer coupling is illustrated in Figure 7–8. The input transformer has a center-tapped secondary that is connected to ground, producing phase inversion of one side with respect to the other. The input transformer thus converts the input signal to two out-of-phase signals for the transistors. Notice that both transistors are *npn* types. Because of the signal inversion, Q_1 will conduct on the positive part of the cycle and Q_2 will conduct on the negative part. The output transformer combines the signals by permitting current in both directions, even though one transistor is always cut off. The positive power supply signal is connected to the center tap of the output transformer.

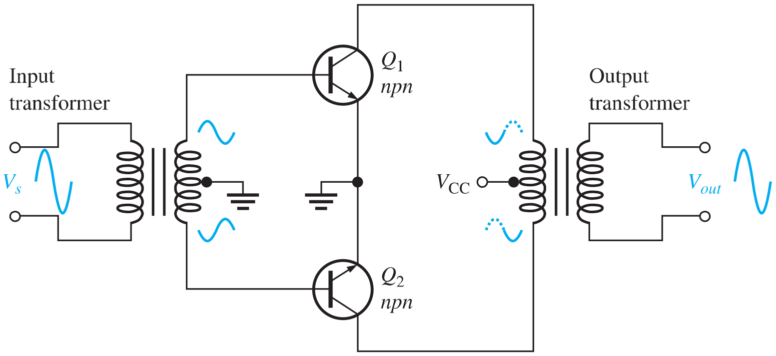
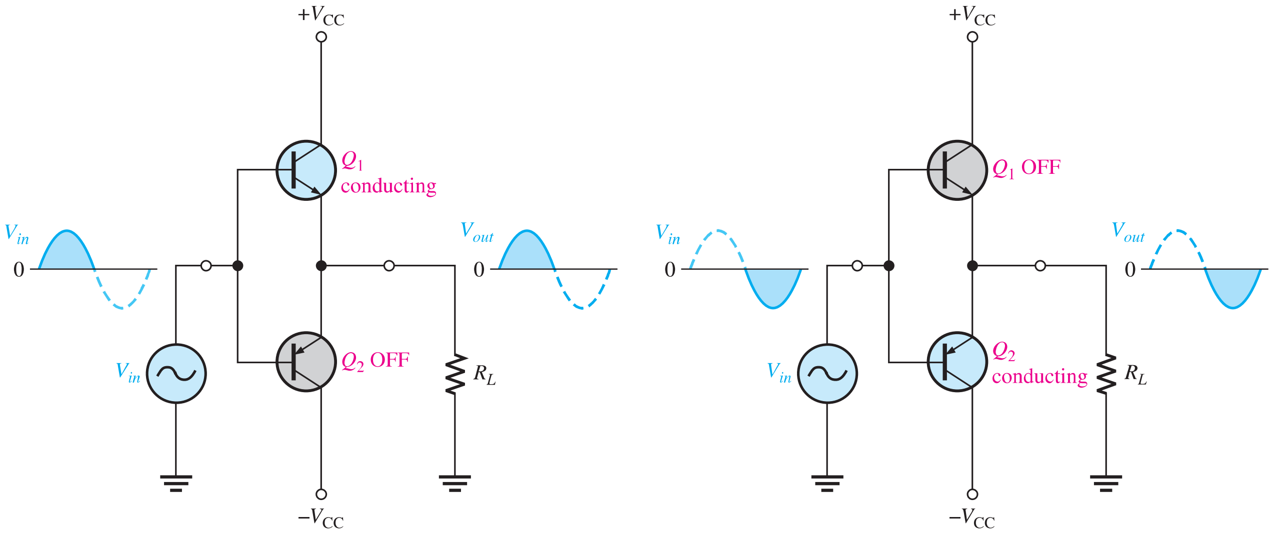


FIGURE 7–8

Transformer-coupled push-pull amplifiers. Q_1 conducts during the positive half-cycle; Q_2 conducts during the negative half-cycle. The two halves are combined by the output transformer.

Complementary Symmetry Transistors Figure 7–9 shows one of the most popular types of push-pull class B amplifiers using two emitter-followers and both positive and negative power supplies. This is a complementary amplifier because one emitter-follower uses an *npn* transistor and the other a *pnp,* which conduct on opposite alternations of the input cycle. Notice that there is no dc base bias voltage ($V_B = 0$). Thus, only the signal voltage drives the transistors into conduction. Transistor Q_1 conducts during the positive half of the input cycle, and Q_2 conducts during the negative half.



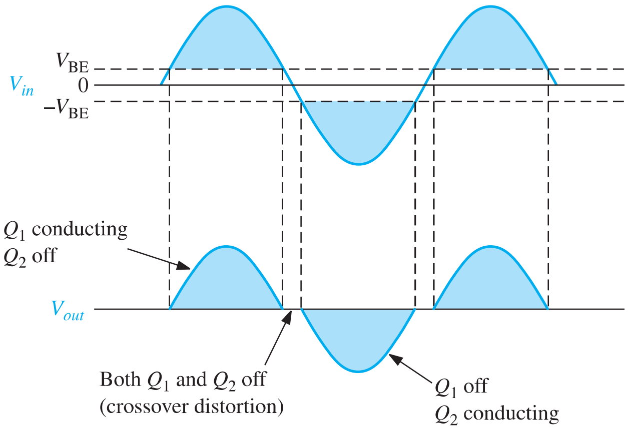
(a) During a positive half-cycle

(b) During a negative half-cycle

FIGURE 7–9

Class B push-pull ac operation.

Crossover Distortion When the dc base voltage is zero, both transistors are off and the input signal voltage must exceed V_{BE} before a transistor conducts. Because of this, there is a time interval between the positive and negative alternations of the input when neither transistor is conducting, as shown in Figure 7–10. The resulting distortion in the output waveform is called **crossover distortion.**

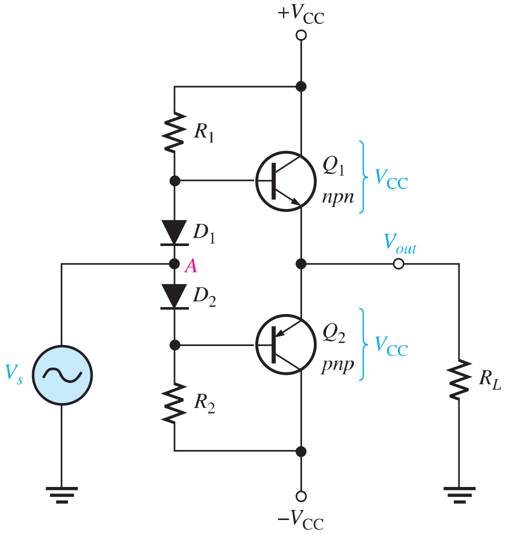


◀ FIGURE 7–10

Illustration of crossover distortion in a class B push-pull amplifier. The transistors conduct only during portions of the input indicated by the shaded areas.

Biasing the Push-Pull Amplifier for Class AB Operation

To overcome crossover distortion, the biasing is adjusted to just overcome the V_{BE} of the transistors; this results in a modified form of operation called **class AB**. In class AB operation, the push-pull stages are biased into slight conduction, even when no input signal is present. This can be done with a voltage-divider and diode arrangement, as shown in Figure 7–11. When the diode characteristics of D_1 and D_2 are closely matched to the characteristics of the transistor base-emitter junctions, the current in the diodes and the current in the transistors are the same; this is called a **current mirror.** This current mirror produces the desired class AB operation and eliminates crossover distortion.



◀ FIGURE 7–11

Biasing the push-pull amplifier with current-mirror diode bias to eliminate crossover distortion. The transistors form a complementary pair (one *npn* and one *pnp*).

In the bias path of the circuit in Figure 7–11, R_1 and R_2 are of equal value, as are the positive and negative supply voltages. This forces the voltage at point *A* (between the diodes) to equal 0 V and eliminates the need for an input coupling capacitor. The dc voltage on the output is also 0 V. Assuming that both diodes and both complementary transistors are identical, the drop across D_1 equals the V_{BE} of Q_1, and the drop across D_2 equals the V_{BE} of Q_2. Since they are matched, the diode current will be the same as I_{CQ}. The diode current and I_{CQ} can be found by applying Ohm's law to either R_1 or R_2 as follows:

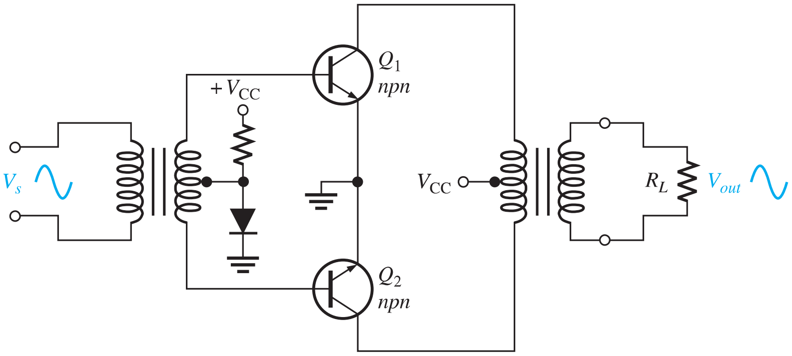
$$I_{CQ} = \frac{V_{CC} - 0.7\text{ V}}{R_1}$$

This small current required of class AB operation eliminates the crossover distortion but has the potential for thermal instability if the transistor's V_{BE} drops are not matched to the diode drops or if the diodes are not in thermal equilibrium with the transistors. Heat in the power transistors decreases the base-emitter voltage and tends to increase current. If the diodes are warmed the same amount, the current is stabilized; but if the diodes are in a cooler environment, they cause I_{CQ} to increase even more. More heat is produced in an unrestrained cycle known as *thermal runaway*. To keep this from happening, the diodes should have the same thermal environment as the transistors. In some cases, a small resistor in the emitter of each transistor can alleviate thermal runaway.

Crossover distortion also occurs in transformer-coupled amplifiers like the one shown in Figure 7–8. To eliminate it in this case, 0.7 V is applied to the input transformer's secondary that just biases both transistors into conduction. The bias voltage to produce this drop can be derived from the power supply using a single diode as shown in Figure 7–12.

▶ FIGURE 7–12

Eliminating crossover distortion in a transformer-coupled push-pull amplifier. The biased diode compensates for the base-emitter drop of the transistors and produces class AB operation.



AC Operation Consider the ac load line for Q_1 of the class AB amplifier in Figure 7–11. The Q-point is slightly above cutoff. (In a true class B amplifier, the Q-point is at cutoff.) The ac cutoff voltage for a two-supply operation is at V_{CC} with an I_{CQ} as given earlier. The ac saturation current for a two-supply operation with a push-pull amplifier is

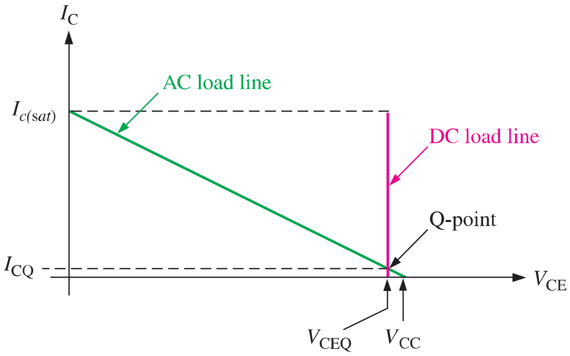
Equation 7–5

$$I_{c(sat)} = \frac{V_{CC}}{R_L}$$

The ac load line for the *npn* transistor is as shown in Figure 7–13. The dc load line can be found by drawing a line that passes through V_{CEQ} and the dc saturation current, $I_{C(sat)}$. However, the saturation current for dc is the current if the collector to emitter is shorted on

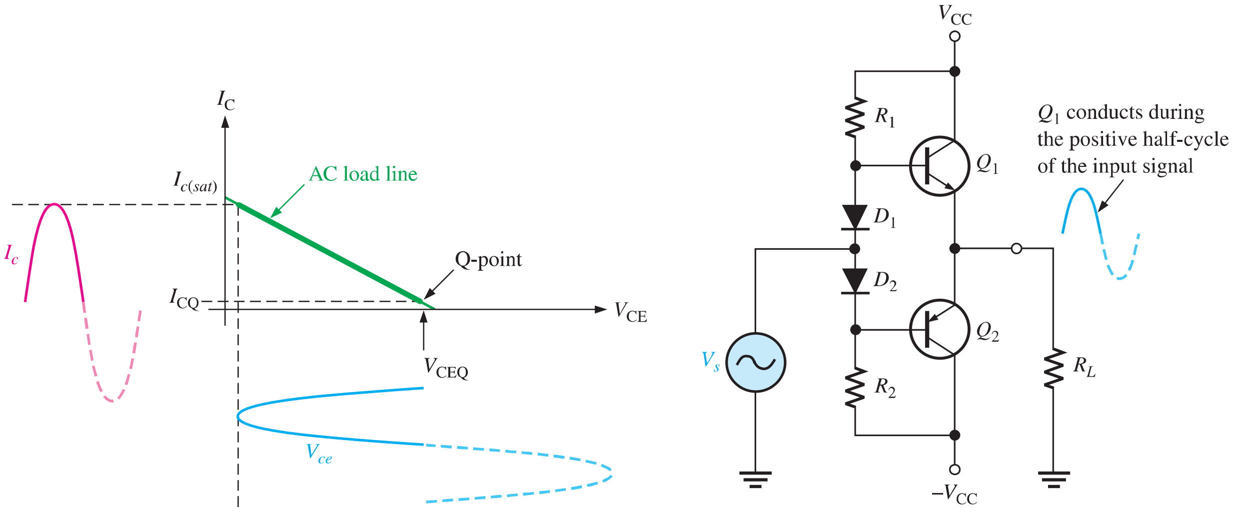
▶ FIGURE 7–13

Load lines for a complementary symmetry push-pull amplifier. Only the load lines for the ***npn*** transistor are shown.



both transistors! This assumed short across the power supplies obviously would cause maximum current from the supplies and implies the dc load line passes almost vertically through the cutoff as shown. Operation along the dc load line, such as caused by thermal runaway, could produce such a high current that the transistors are destroyed.

Figure 7–14(a) illustrates the ac load line for Q_1 of the class AB amplifier in Figure 7–14(b). In the case illustrated, a signal is applied that swings over the region of the ac load line shown in bold. At the upper end of the ac load line, the voltage across the transistor (V_{ce}) is a minimum, and the output voltage is maximum.



Q_1 conducts during the positive half-cycle of the input signal

(a) AC load line for Q_1

(b) Circuit

▲ FIGURE 7–14

Under maximum conditions, transistors Q_1 and Q_2 are alternately driven from near cutoff to near saturation. During the positive alternation of the input signal, the Q_1 emitter is driven from its Q-point value of 0 to nearly V_{CC}, producing a positive peak voltage a little less than V_{CC}. Likewise, during the negative alternation of the input signal, the Q_2 emitter is driven from its Q-point value of 0 V, to near $-V_{CC}$, producing a negative peak voltage almost equal to $-V_{CC}$. Although it is possible to operate close to the saturation current, this type of operation results in increased distortion of the signal.

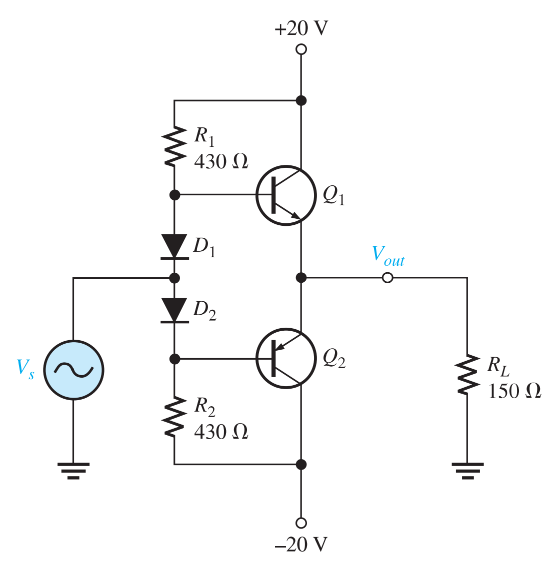
The ac saturation current (Equation 7–5) is also the peak output current. Each transistor can essentially operate over its entire load line. Recall that in class A operation, the transistor can also operate over the entire load line but with a significant difference. In class A operation, the Q-point is near the middle and there is significant current in the transistors even with no signal. In class B operation, when there is no signal, the transistors have only a very small current and therefore dissipate very little power. Thus, the efficiency of a class B amplifier can be much higher than a class A amplifier. It will be shown later that the maximum efficiency of a class B amplifier is 79%.

EXAMPLE 7–3 Determine the ideal maximum peak output voltage and current for the circuit shown in Figure 7–15.

Solution The ideal maximum peak output voltage is

$$V_{out(peak)} \cong V_{CEQ} \cong V_{CC} = \mathbf{20\ V}$$

▶ FIGURE 7–15



The ideal maximum peak current is

$$I_{out(peak)} \cong I_{c(sat)} \cong \frac{V_{CC}}{R_L} = \frac{20\text{ V}}{150\ \Omega} = \mathbf{133\ mA}$$

The actual maximum values of voltage and current are slightly smaller.

Related Problem What is the maximum peak output voltage and current if the supply voltages are changed to +15 V and −15 V?

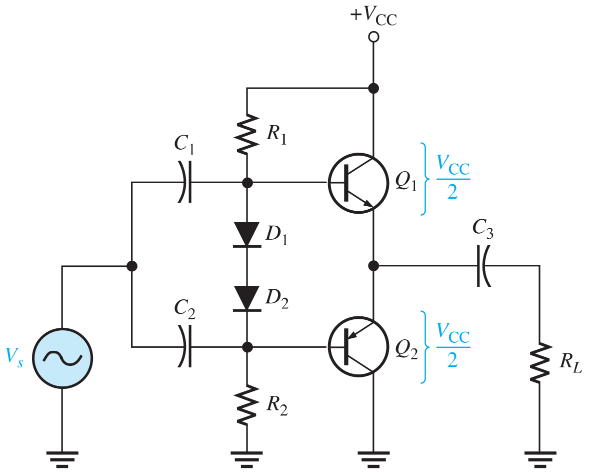
Open the Multisim file E07-03 in the Examples folder on the companion website. Measure the maximum peak-to-peak output voltage.

Single-Supply Push-Pull Amplifier

Push-pull amplifiers using complementary symmetry transistors can be operated from a single voltage source as shown in Figure 7–16. The circuit operation is the same as that described previously, except the bias is set to force the output emitter voltage to be $V_{CC}/2$ instead of zero volts used with two supplies. Because the output is not biased at zero volts,

▶ FIGURE 7–16

Single-ended push-pull amplifier.

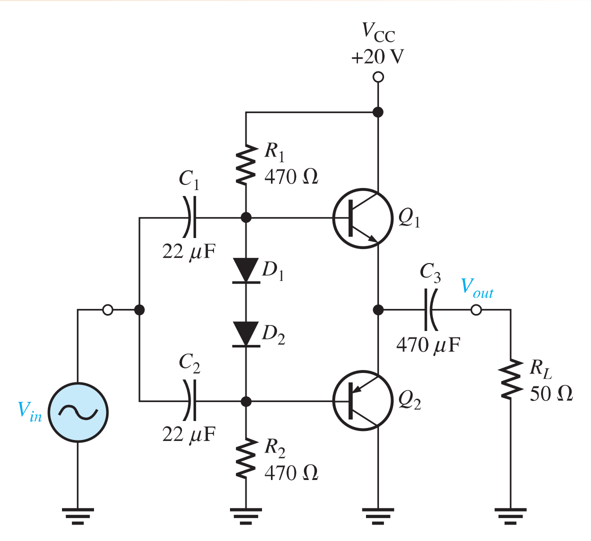


capacitive coupling for the input and output is necessary to block the bias voltage from the source and the load resistor. Ideally, the output voltage can swing from zero to V_{CC}, but in practice it does not quite reach these ideal values.

EXAMPLE 7–4

Determine the maximum ideal peak values for the output voltage and current in Figure 7–17.

▶ FIGURE 7–17



Solution The maximum peak output voltage is

$$V_{out(peak)} \cong V_{CEQ} = \frac{V_{CC}}{2} = \frac{20\text{ V}}{2} = \mathbf{10\text{ V}}$$

The maximum peak output current is

$$I_{out(peak)} \cong I_{c(sat)} = \frac{V_{CEQ}}{R_L} = \frac{10\text{ V}}{50\ \Omega} = \mathbf{200\text{ mA}}$$

Related Problem Find the maximum peak values for the output voltage and current in Figure 7–17 if V_{CC} is lowered to 15 V and the load resistance is changed to 30 Ω.

Open the Multisim file E07-04 in the Examples folder on the companion website. Measure the maximum peak-to-peak output voltage.

Class B/AB Power

Maximum Output Power You have seen that the ideal maximum peak output current for both dual-supply and single-supply push-pull amplifiers is approximately $I_{c(sat)}$, and the maximum peak output voltage is approximately V_{CEQ}. Ideally, the maximum *average* output power is, therefore,

$$P_{out} = I_{out(rms)}V_{out(rms)}$$

Since

$$I_{out(rms)} = 0.707I_{out(peak)} = 0.707I_{c(sat)}$$

and

$$V_{out(rms)} = 0.707V_{out(peak)} = 0.707V_{\text{CEQ}}$$

then

$$P_{out} = 0.5I_{c(sat)}V_{\text{CEQ}}$$

Substituting $V_{\text{CC}}/2$ for V_{CEQ}, the maximum average output power is

Equation 7–6

$$\mathbf{P_{out} = 0.25I_{c(sat)}V_{CC}}$$

DC Input Power The dc input power comes from the V_{CC} supply and is

$$P_{\text{DC}} = I_{\text{CC}}V_{\text{CC}}$$

Since each transistor draws current for a half-cycle, the current is a half-wave signal with an average value of

$$I_{\text{CC}} = \frac{I_{c(sat)}}{\pi}$$

So,

$$P_{\text{DC}} = \frac{I_{c(sat)}V_{\text{CC}}}{\pi}$$

Efficiency An advantage of push-pull class B and class AB amplifiers over class A is a much higher efficiency. This advantage usually overrides the difficulty of biasing the class AB push-pull amplifier to eliminate crossover distortion. Recall that efficiency, η is defined as the ratio of ac output power to dc input power.

$$\eta = \frac{P_{out}}{P_{\text{DC}}}$$

The maximum efficiency, $\eta_{\max}$, for a class B amplifier (class AB is slightly less) is developed as follows, starting with Equation 7–6.

$$P_{out} = 0.25I_{c(sat)}V_{\text{CC}}$$

$$\eta_{\max} = \frac{P_{out}}{P_{\text{DC}}} = \frac{0.25I_{c(sat)}V_{\text{CC}}}{I_{c(sat)}V_{\text{CC}}/\pi} = 0.25\pi$$

Equation 7–7

$$\boldsymbol{\eta_{\max} = 0.79}$$

or, as a percentage,

$$\eta_{\max} = 79\%$$

Recall that the maximum efficiency for class A is 0.25 (25 percent).

EXAMPLE 7–5

Find the maximum ac output power and the dc input power of the amplifier in Figure 7–18.

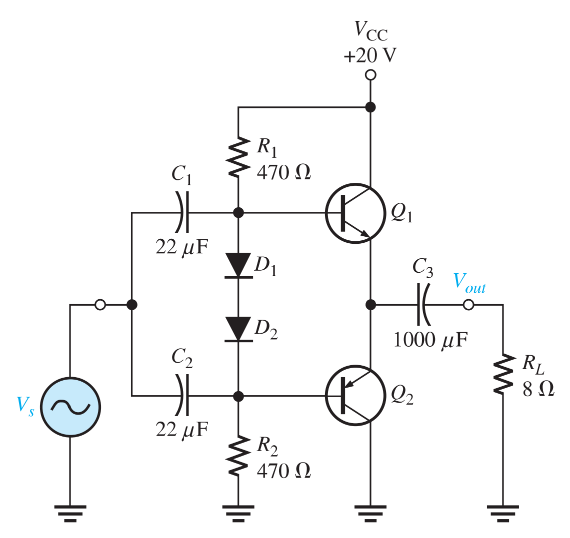
Solution The ideal maximum peak output voltage is

$$V_{out(peak)} \cong V_{\text{CEQ}} = \frac{V_{\text{CC}}}{2} = \frac{20\text{ V}}{2} = 10\text{ V}$$

The maximum peak output current is

$$I_{out(peak)} \cong I_{c(sat)} = \frac{V_{\text{CEQ}}}{R_L} = \frac{10\text{ V}}{8\ \Omega} = 1.25\text{ A}$$

▶ **FIGURE 7–18**



The ac output power and the dc input power are

$$P_{out} = 0.25I_{c(sat)}V_{CC} = 0.25(1.25\text{ A})(20\text{ V}) = \mathbf{6.25\text{ W}}$$

$$P_{DC} = \frac{I_{c(sat)}V_{CC}}{\pi} = \frac{(1.25\text{ A})(20\text{ V})}{\pi} = \mathbf{7.96\text{ W}}$$

Related Problem Determine the maximum ac output power and the dc input power in Figure 7–18 for $V_{CC} = 15$ V and $R_L = 16\ \Omega$.

Input Resistance

The complementary push-pull configuration used in class B/class AB amplifiers is, in effect, two emitter-followers. The input resistance for the emitter-follower, where R_1 and R_2 are the bias resistors, is

$$R_{in} = \beta_{ac}(r'_e + R_E) \parallel R_1 \parallel R_2$$

Since $R_E = R_L$, the formula is

$$\boldsymbol{R_{in} = \beta_{ac}(r'_e + R_L) \parallel R_1 \parallel R_2}$$

Equation 7–8

EXAMPLE 7–6

Assume that a preamplifier stage with an output signal voltage of 3 V rms and an output resistance of 50 Ω is driving the push-pull power amplifier in Figure 7–18 (Example 7–5). Q_1 and Q_2 in the power amplifier have a β_{ac} of 100 and an r'_e of 1.6 Ω. Determine the loading effect that the power amplifier has on the preamp stage.

Solution Looking from the input signal source, the bias resistors appear in parallel because both go to ac ground and the ac resistance of the forward-biased diodes is very small and can be ignored. The input resistance at the emitter of either transistor is $\beta_{ac}(r'_e + R_L)$. So, the signal source sees R_1, R_2, and $\beta_{ac}(r'_e + R_L)$ all in parallel.

The ac input resistance of the power amplifier is

$$R_{in} = \beta_{ac}(r'_e + R_L) \parallel R_1 \parallel R_2 = 100(9.6\ \Omega) \parallel 470\ \Omega \parallel 470\ \Omega = 188\ \Omega$$

Obviously, this will have an effect on the preamp driver stage. The output resistance of the preamp stage and the input resistance of the power amp effectively form a voltage divider that reduces the output signal from the preamp. The actual signal at the power amp is

$$V_{in} = \left(\frac{R_{in}}{R_s + R_{in}}\right)V_s = \left(\frac{188\ \Omega}{238\ \Omega}\right)3\text{ V} = 2.37\text{ V}$$

Related Problem What would be the effect of raising the bias resistors in the circuit?

Darlington Class AB Amplifier

In many applications where the push-pull configuration is used, the load resistance is relatively small. For example, an 8 Ω speaker is a common load for a class AB push-pull amplifier.

As you saw in the previous example, push-pull amplifiers can present a quite low input resistance to the preceding amplifier that drives it. Depending on the output resistance of the preceding amplifier, the low push-pull input resistance can load it severely and significantly reduce the voltage gain. As an example, if each bias resistor is 1 kΩ and if the complementary transistors in a push-pull amplifier exhibit an ac beta of 50 and the load resistance is 8 Ω, the input resistance (assuming $r'_e = 1\ \Omega$) is

$$R_{in} = \beta_{ac}(r'_e + R_L) \parallel R_1 \parallel R_2 = 50(1\ \Omega + 8\ \Omega) \parallel 1\text{ k}\Omega \parallel 1\text{ k}\Omega = 236\ \Omega$$

If the collector resistance of the driving amplifier is, for example, 1.0 kΩ, the input resistance of the push-pull amplifier reduces the effective collector resistance of the driving amplifier (assuming a common-emitter) to $R_c = R_C \parallel R_{in} = 1.0\text{ k}\Omega \parallel 236\ \Omega = 190\ \Omega$. This drastically reduces the voltage gain of the driving amplifier because its gain is R_c/r'_e.

In certain applications with low-resistance loads, a push-pull amplifier using Darlington transistors can be used to increase the input resistance presented to the driving amplifier and avoid severely reducing the voltage gain. The overall ac beta of a Darlington pair is generally in excess of a thousand. Also, the bias resistors can be greater because less base current is required.

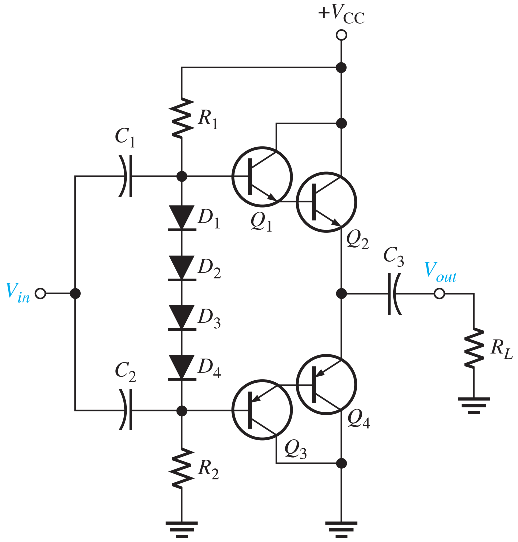
In the previous case, for example, if $\beta_{ac} = 50$ for each transistor in a Darlington pair, the overall ac beta is $\beta_{ac} = (50)(50) = 2500$. If the bias resistors are 10 kΩ, the input resistance is greatly increased, as the following calculation shows.

$$R_{in} = \beta_{ac}(r'_e + R_L) \parallel R_1 \parallel R_2 = 2500(1\ \Omega + 8\ \Omega) \parallel 10\text{ k}\Omega \parallel 10\text{ k}\Omega = 4.09\text{ k}\Omega$$

A Darlington class AB push-pull amplifier is shown in Figure 7–19. Four diodes are required in the bias circuit to match the four base-emitter junctions of the two Darlington pairs.

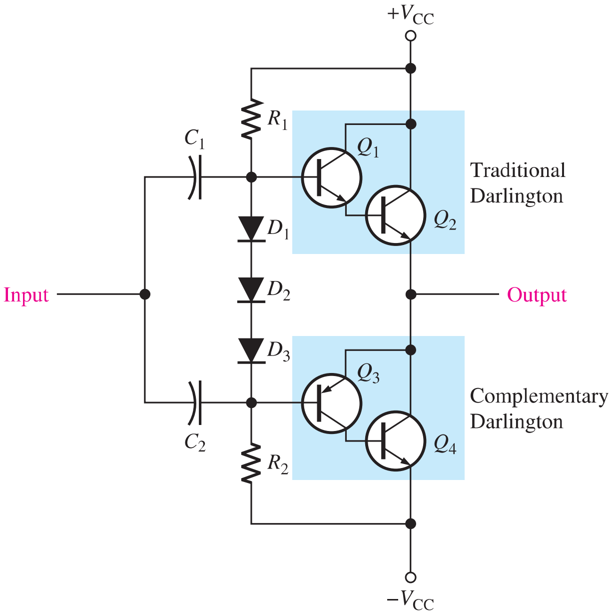
▶ FIGURE 7–19

A Darlington class AB push-pull amplifier.



Darlington/Complementary Darlington Class AB Amplifier

The complementary Darlington, also known as the Sziklai pair, was introduced in Chapter 6. Recall that it is similar to the traditional Darlington pair except it uses complementary transistors (one *npn* and one *pnp*). The complementary Darlington is used when it is determined that output power transistors of the same type should be used (both *npn* or both *pnp*). Figure 7–20 shows a class AB push-pull amplifier with two *npn* output power transistors (Q_2 and Q_4). The upper part of the push-pull configuration is a traditional Darlington, and the lower part is a complementary Darlington.



◀ FIGURE 7–20

A Darlington/complementary Darlington class AB push-pull amplifier.

SECTION 7–2 CHECKUP

1. Where is the Q-point for a class B amplifier?
2. What causes crossover distortion?
3. What is the maximum efficiency of a push-pull class B amplifier?
4. Explain the purpose of the push-pull configuration for class B.
5. How does a class AB differ from a class B amplifier?

7–3 THE CLASS C AMPLIFIER

Class C amplifiers are biased so that conduction occurs for much less than 180°. Class C amplifiers are more efficient than either class A or push-pull class B and class AB, which means that more output power can be obtained from class C operation. The output amplitude is a nonlinear function of the input, so class C amplifiers are not used for linear amplification. They are generally used in radio frequency (RF) applications, including circuits, such as oscillators, that have a constant output amplitude, and modulators, where a high-frequency signal is controlled by a low-frequency signal.

After completing this section, you should be able to

- ❑ **Explain and analyze the operation of class C amplifiers**
- ❑ Describe basic class C operation
  - ◆ Discuss the bias of the transistor

- ❑ Discuss class C power dissipation
- ❑ Explain tuned operation
- ❑ Determine maximum output power
- ❑ Explain clamper bias for a class C amplifier

Basic Class C Operation

The basic concept of class C operation is illustrated in Figure 7–21. A common-emitter class C amplifier with a resistive load is shown in Figure 7–22(a). A class C amplifier is normally operated with a resonant circuit load, so the resistive load is used only for the purpose of illustrating the concept. It is biased below cutoff with the negative V_{BB} supply. The ac source voltage has a peak value that is slightly greater than $|V_{BB}| + V_{BE}$ so that the base voltage exceeds the barrier potential of the base-emitter junction for a short time near the positive peak of each cycle, as illustrated in Figure 7–22(b). During this short interval, the transistor is turned on. When the entire ac load line is used, as shown in Figure 7–22(c), the ideal maximum collector current is $I_{c(sat)}$, and the ideal minimum collector voltage is $V_{ce(sat)}$.

FIGURE 7–21

Basic class C amplifier operation (noninverting).

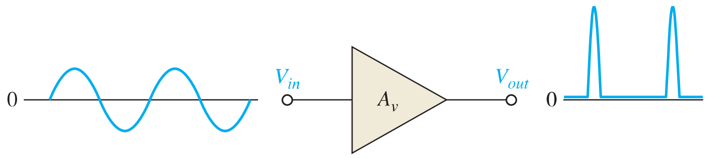
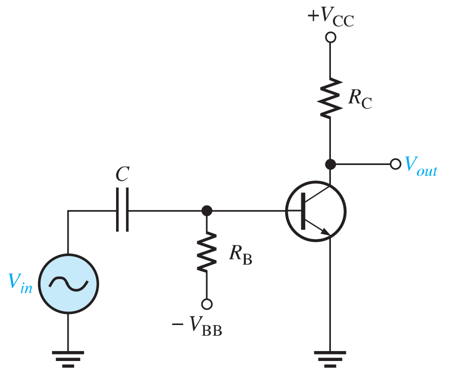
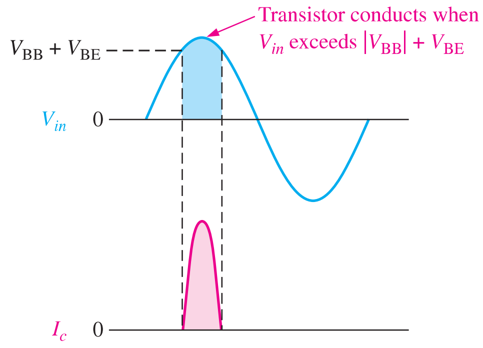


FIGURE 7–22

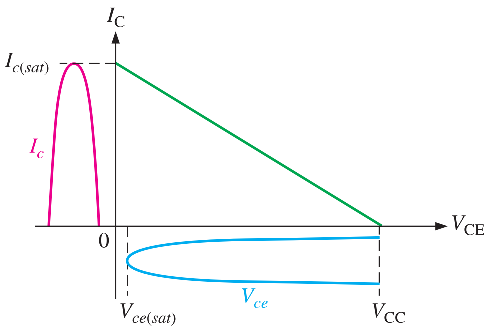
Basic class C operation.



(a) Basic class C amplifier circuit



(b) Input voltage and output current waveforms



(c) Load line operation

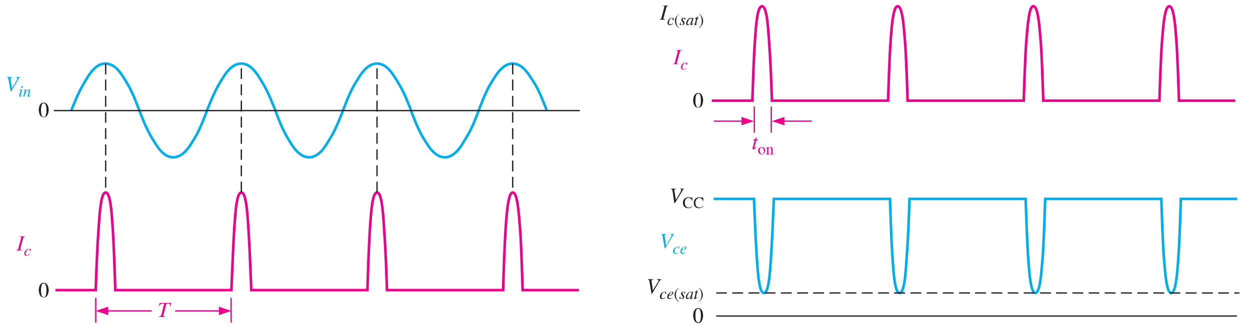
Power Dissipation

The power dissipation of the transistor in a class C amplifier is low because it is on for only a small percentage of the input cycle. Figure 7–23(a) shows the collector current pulses. The time between the pulses is the period (T) of the ac input voltage. The collector current and the collector voltage during the *on* time of the transistor are shown in Figure 7–23(b). To avoid complex mathematics, we will assume ideal pulse approximations. Using this simplification, if the output swings over the entire load, the maximum current amplitude is $I_{c(sat)}$ and the minimum voltage amplitude is $V_{ce(sat)}$ during the time the transistor is on. The power dissipation during the *on* time is, therefore,

$$P_{\mathrm{D(on)}} = I_{c(sat)}V_{ce(sat)}$$

The transistor is on for a short time, t_{on}, and off for the rest of the input cycle. Therefore, assuming the entire load line is used, the power dissipation averaged over the entire cycle is

$$P_{\mathrm{D(avg)}} = \left(\frac{t_{\mathrm{on}}}{T}\right)P_{\mathrm{D(on)}} = \left(\frac{t_{\mathrm{on}}}{T}\right)I_{c(sat)}V_{ce(sat)}$$



(a) Collector current pulses

(b) Ideal class C waveforms

▲ FIGURE 7–23

Class C waveforms.

EXAMPLE 7–7

A class C amplifier is driven by a 200 kHz signal. The transistor is on for 1 μs, and the amplifier is operating over 100 percent of its load line. If $I_{c(sat)} = 100$ mA and $V_{ce(sat)} =$ 0.2 V, what is the average power dissipation of the transistor?

Solution The period is

$$T = \frac{1}{200\ \mathrm{kHz}} = 5\ \mu\mathrm{s}$$

Therefore,

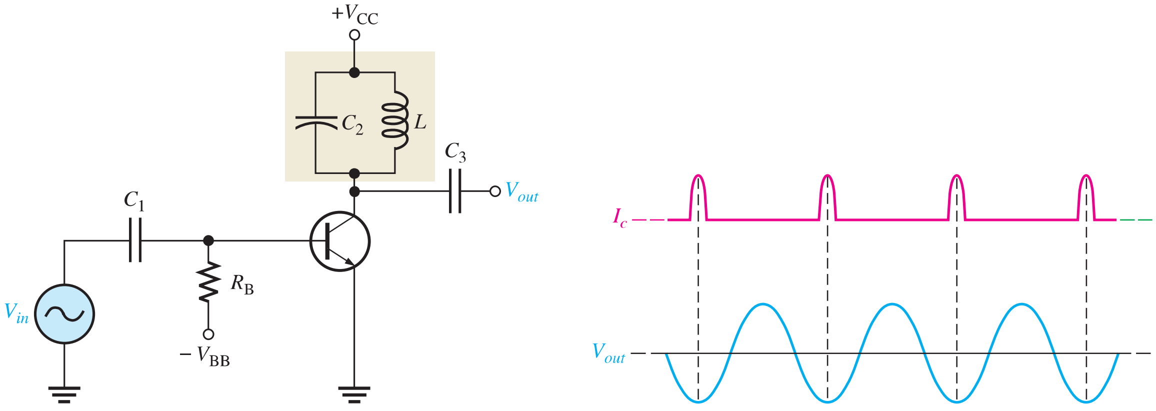
$$P_{\mathrm{D(avg)}} = \left(\frac{t_{\mathrm{on}}}{T}\right)I_{c(sat)}V_{ce(sat)} = (0.2)(100\ \mathrm{mA})(0.2\ \mathrm{V}) = \mathbf{4\ mW}$$

The low power dissipation of the transistor operated in class C is important because, as you will see later, it leads to a very high efficiency when it is operated as a tuned class C amplifier in which relatively high power is achieved in the resonant circuit.

Related Problem If the frequency is reduced from 200 kHz to 150 kHz with the same *on* time, what is the average power dissipation of the transistor?

Tuned Operation

Because the collector voltage (output) is not a replica of the input, the resistively loaded class C amplifier alone is of no value in linear applications. It is therefore necessary to use a class C amplifier with a parallel resonant circuit (tank), as shown in Figure 7–24(a). The resonant frequency of the tank circuit is determined by the formula $f_r = 1/(2\pi\sqrt{LC})$. The short pulse of collector current on each cycle of the input initiates and sustains the oscillation of the tank circuit so that an output sinusoidal voltage is produced, as illustrated in Figure 7–24(b). The tank circuit has high impedance only near the resonant frequency, so the gain is large only at this frequency.



(a) Basic circuit

(b) Output waveforms

▲ **FIGURE 7–24**

Tuned class C amplifier.

The current pulse charges the capacitor to approximately $+V_{CC}$, as shown in Figure 7–25(a). After the pulse, the capacitor quickly discharges, thus charging the inductor. Then, after the capacitor completely discharges, the inductor's magnetic field collapses and then quickly recharges C to near V_{CC} in a direction opposite to the previous charge. This completes one half-cycle of the oscillation, as shown in parts (b) and (c) of Figure 7–25. Next, the capacitor discharges again, increasing the inductor's magnetic field. The inductor then quickly recharges the capacitor back to a positive peak slightly less than the previous one, due to energy loss in the winding resistance. This completes one full cycle, as shown in parts (d) and (e) of Figure 7–25. The peak-to-peak output voltage is therefore approximately equal to $2V_{CC}$.

The amplitude of each successive cycle of the oscillation will be less than that of the previous cycle because of energy loss in the resistance of the tank circuit, as shown in Figure 7–26(a), and the oscillation will eventually die out. However, the regular recurrences of the collector current pulse re-energizes the resonant circuit and sustains the oscillations at a constant amplitude.

When the tank circuit is tuned to the frequency of the input signal (fundamental), re-energizing occurs on each cycle of the tank voltage, V_r, as shown in Figure 7–26(b). When the tank circuit is tuned to the second harmonic of the input signal, re-energizing occurs on alternate cycles as shown in Figure 7–26(c). In this case, a class C amplifier operates as a frequency multiplier ($\times 2$). By tuning the resonant tank circuit to higher harmonics, further frequency multiplication factors are achieved.