Power Amplifiers

7

CHAPTER OUTLINE

CHAPTER OBJECTIVES

- Explain and analyze the operation of class A amplifiers
- Explain and analyze the operation of class B and class AB amplifiers
- Explain and analyze the operation of class C amplifiers
- Troubleshoot power amplifiers

KEY TERMS

- Class A
- Power gain
- Efficiency
- Class B
- Push-pull
- Class AB
- Class C

APPLICATION ACTIVITY PREVIEW

The Application Activity in this chapter continues with the public address system started in Chapter 6. Recall that the complete system includes the preamplifier, a power amplifier, and a dc power supply. You will focus on the power amplifier in this chapter and complete the total system by combining the three component parts.

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INTRODUCTION

Power amplifiers are large-signal amplifiers. This generally means that a much larger portion of the load line is used during signal operation than in a small-signal amplifier. In this chapter, we will cover four classes of power amplifiers: class A, class B, class AB, and class C. These amplifier classifications are based on the percentage of the input cycle for which the amplifier operates in its linear region. Each class has a unique circuit configuration because of the way it must be operated. The emphasis is on power amplification.

Power amplifiers are normally used as the final stage of a communications receiver or transmitter to provide signal power to speakers or to a transmitting antenna. BJTs are used to illustrate power amplifier principles.

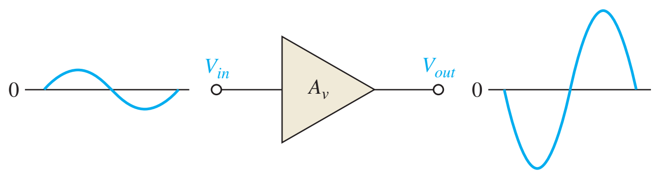
7–1 THE CLASS A POWER AMPLIFIER

When an amplifier is biased such that it always operates in the linear region where the output signal is an amplified replica of the input signal, it is a **class A** amplifier. The discussion of amplifiers in the previous chapters apply to class A operation. Power amplifiers are those amplifiers that have the objective of delivering power to a load. This means that components must be considered in terms of their ability to dissipate heat.

After completing this section, you should be able to

- **Explain and analyze the operation of class A amplifiers**
- Discuss transistor heat dissipation
  - Describe the purpose of a heat sink
- Discuss the importance of a centered Q-point
  - Describe the relationship of the dc and ac load lines with the Q-point
  - Describe the effects of a noncentered Q-point on the output waveform
- Determine power gain
- Define *dc quiescent power*
- Discuss and determine output signal power
- Define and determine the *efficiency* of a power amplifier

In a small-signal amplifier, the ac signal moves over a small percentage of the total ac load line. When the output signal is larger and approaches the limits of the ac load line, the amplifier is a **large-signal** type. Both large-signal and small-signal amplifiers are considered to be class A if they operate in the linear region at all times, as illustrated in Figure 7–1. Class A power amplifiers are large-signal amplifiers with the objective of providing power (rather than voltage) to a load. As a rule of thumb, an amplifier may be considered to be a power amplifier if it is rated for more than 1 W and it is necessary to consider the problem of heat dissipation in components.



▶ FIGURE 7–1

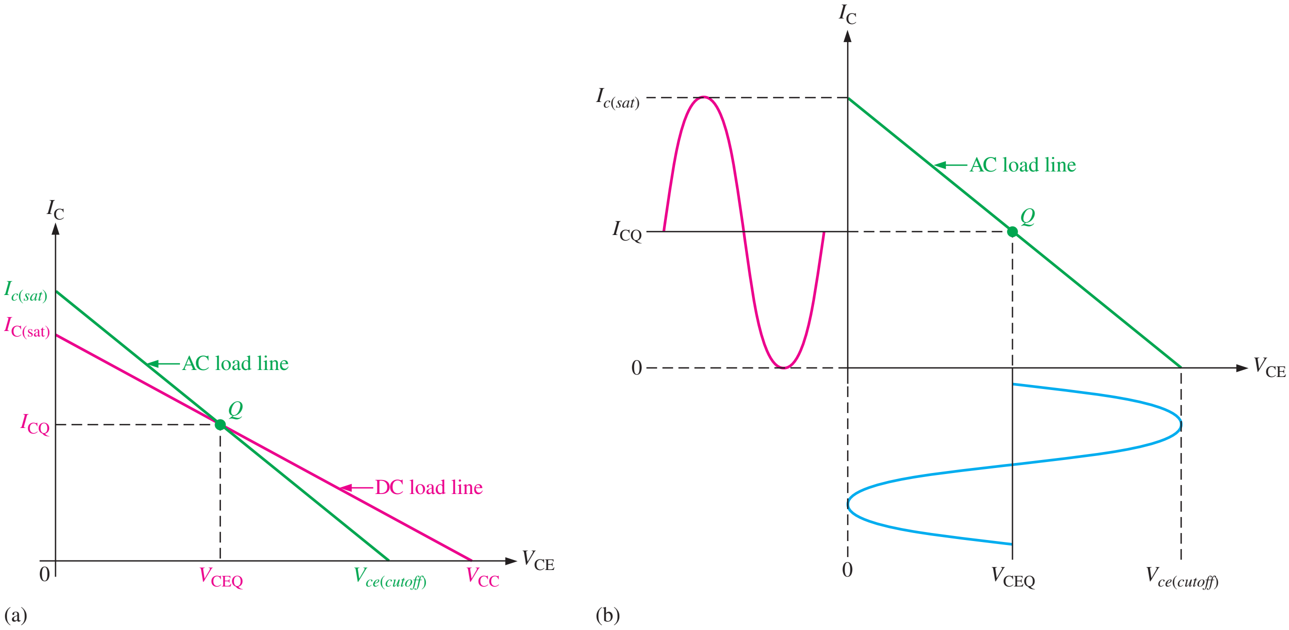
Basic class A amplifier operation. Output is shown 180° out of phase with the input (inverted).

Heat Dissipation

Power transistors (and other power devices) must dissipate a large amount of internally generated heat. For BJT power transistors, the collector terminal is the critical junction; for this reason, the transistor's case is always connected to the collector terminal. The case of all power transistors is designed to provide a large contact area between it and an external heat sink. Heat from the transistor flows through the case to the heat sink and then dissipates in the surrounding air. Heat sinks vary in size, number of fins, and type of material. Their size depends on the heat dissipation requirement and the maximum ambient temperature in which the transistor is to operate. In high-power applications (a few hundred watts), a cooling fan may be necessary.

Centered Q-Point

Recall that the dc and ac load lines intersect at the Q-point. When the Q-point is at the center of the ac load line, a maximum class A signal can be obtained. You can see this concept by examining the graph of the load line for a given amplifier in Figure 7–2(a). This graph shows the ac load line with the Q-point at its center. The collector current can vary from its

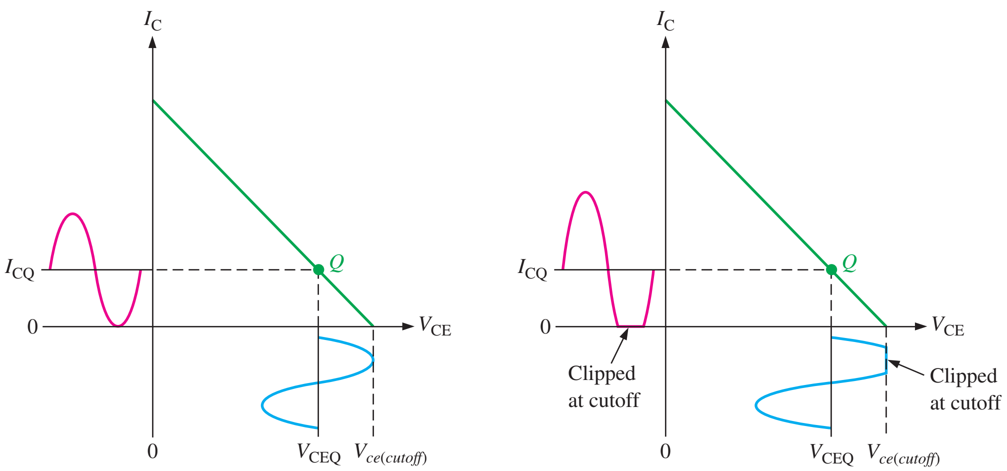


▲ **FIGURE 7–2**

Maximum class A output occurs when the Q-point is centered on the ac load line.

Q-point value, I_{CQ}, up to its saturation value, $I_{c(sat)}$, and down to its cutoff value of zero. Likewise, the collector-to-emitter voltage can swing from its Q-point value, V_{CEQ}, up to its cutoff value, $V_{ce(cutoff)}$, and down to its saturation value of near zero. This operation is indicated in Figure 7–2(b). The peak value of the collector current equals I_{CQ}, and the peak value of the collector-to-emitter voltage equals V_{CEQ} in this case. This signal is the maximum that can be obtained from the class A amplifier. Actually, the output cannot quite reach saturation or cutoff, so the practical maximum is slightly less.

If the Q-point is not centered on the ac load line, the output signal is limited. Figure 7–3 shows an ac load line with the Q-point moved away from center toward cutoff. The output variation is limited by cutoff in this case. The collector current can only swing down to near zero and an equal amount above I_{CQ}. The collector-to-emitter voltage can only swing up to its



(a) Amplitude of V_{ce} and I_c limited by cutoff

(b) Transistor driven into cutoff by a further increase in input amplitude

▲ **FIGURE 7–3**

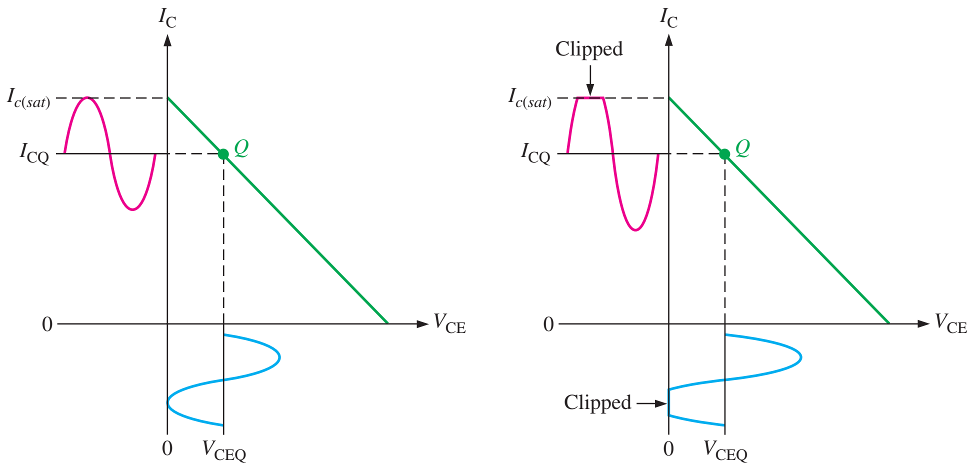
Q-point closer to cutoff.

cutoff value and an equal amount below V_{CEQ}. This situation is illustrated in Figure 7–3(a). If the amplifier is driven any further than this, it will "clip" at cutoff, as shown in Figure 7–3(b).

Figure 7–4 shows an ac load line with the Q-point moved away from center toward saturation. In this case, the output variation is limited by saturation. The collector current can only swing up to near saturation and an equal amount below I_{CQ}. The collector-to-emitter voltage can only swing down to its saturation value and an equal amount above V_{CEQ}. This situation is illustrated in Figure 7–4(a). If the amplifier is driven any further, it will "clip" at saturation, as shown in Figure 7–4(b).

FIGURE 7–4

Q-point closer to saturation.



(a) Amplitude of V_{ce} and I_c limited by saturation

(b) Transistor driven into saturation by a further increase in input amplitude

Power Gain

A power amplifier delivers power to a load. The **power gain** of an amplifier is the ratio of the output power (power delivered to the load) to the input power. In general, power gain is

Equation 7–1

$$A_p = \frac{P_L}{P_{in}}$$

where A_p is the power gain, P_L is signal power delivered to the load, and P_{in} is signal power delivered to the amplifier.

The power gain can be computed by any of several formulas, depending on what is known. Frequently, the easiest way to obtain power gain is from input resistance, load resistance, and voltage gain. To see how this is done, recall that power can be expressed in terms of voltage and resistance as

$$P = \frac{V^2}{R}$$

For ac power, the voltage is expressed as rms. The output power delivered to the load is

$$P_L = \frac{V_L^2}{R_L}$$

The input power delivered to the amplifier is

$$P_{in} = \frac{V_{in}^2}{R_{in}}$$

By substituting into Equation 7–1, the following useful relationship is produced:

$$A_p = \frac{V_L^2}{V_{in}^2}\left(\frac{R_{in}}{R_L}\right)$$

Since $V_L/V_{in} = A_v$,

$$\boldsymbol{A_p = A_v^2\left(\frac{R_{in}}{R_L}\right)}$$ Equation 7–2

Recall from Chapter 6 that for a voltage-divider biased amplifier,

$$R_{in(tot)} = R_1 \parallel R_2 \parallel R_{in(base)}$$

and that for a CE or CC amplifier,

$$R_{in(base)} = \beta_{ac}R_e$$

Equation 7–2 shows that the power gain of an amplifier is the voltage gain squared times the ratio of the input resistance to the output load resistance. The formula can be applied to any amplifier. For example, assume a common-collector (CC) amplifier has an input resistance of 5 kΩ and a load resistance of 100 Ω. Since a CC amplifier has a voltage gain of approximately 1, the power gain is

$$A_p = A_v^2\left(\frac{R_{in}}{R_L}\right) = 1^2\left(\frac{5\text{ k}\Omega}{100\ \Omega}\right) = 50$$

For a CC amplifier, A_p is just the ratio of the input resistance to the output load resistance.

DC Quiescent Power

The power dissipation of a transistor with no signal input is the product of its Q-point current and voltage.

$$\boldsymbol{P_{DQ} = I_{CQ}V_{CEQ}}$$ Equation 7–3

The only way a class A power amplifier can supply power to a load is to maintain a quiescent current that is at least as large as the peak current requirement for the load current. A signal will not increase the power dissipated by the transistor but actually causes less total power to be dissipated. The **dc quiescent power**, given in Equation 7–3, is the maximum power that a class A amplifier must handle. The transistor's power rating must exceed this value.

Output Power

In general, the output signal power is the product of the rms load current and the rms load voltage. The maximum unclipped ac signal occurs when the Q-point is centered on the ac load line. For a CE amplifier with a centered Q-point, the maximum peak voltage swing is

$$V_{c(max)} = I_{CQ}R_c$$

The rms value is $0.707V_{c(max)}$.

The maximum peak current swing is

$$I_{c(max)} = \frac{V_{CEQ}}{R_c}$$

The rms value is $0.707I_{c(max)}$.

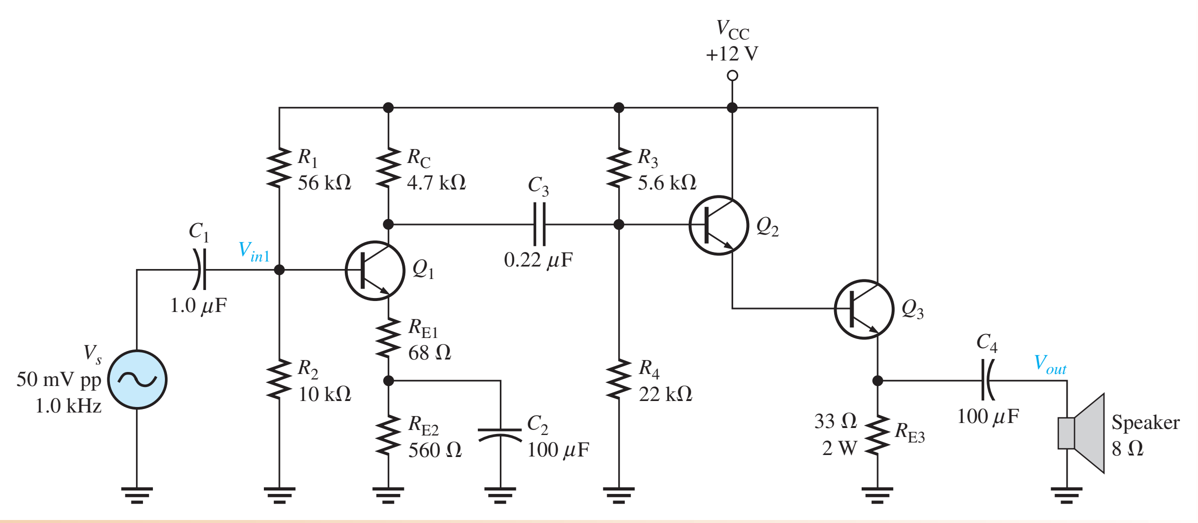
To find the maximum signal power output, use the rms values of maximum current and voltage. The maximum power out from a class A amplifier is

$$P_{out(max)} = (0.707I_c)(0.707V_c)$$

$$\boldsymbol{P_{out(max)} = 0.5I_{CQ}V_{CEQ}}$$ Equation 7–4

EXAMPLE 7–1

Determine the voltage gain and the power gain of the class A power amplifier in Figure 7–5. Assume $\beta_{ac} = 200$ for all transistors.



▲ FIGURE 7–5

Solution Notice that the first stage (Q_1) is a voltage-divider biased common-emitter with a swamping resistor (R_{E1}). The second stage (Q_2 and Q_3) is a Darlington voltage-follower configuration. The speaker is the load.

First stage: The ac collector resistance of the first stage is R_C in parallel with the input resistance to the second stage.

$$R_{c1} \cong R_C \| (R_3 \| R_4) = 4.7\text{ k}\Omega \| 5.6\text{ k}\Omega \| 22\text{ k}\Omega = 2.29\text{ k}\Omega$$

The voltage gain of the first stage is the ac collector resistance, R_{c1}, divided by the ac emitter resistance, which is the sum of $R_{E1} + r'_{e(Q1)}$. The approximate value of $r'_{e(Q1)}$ is determined by first finding I_E.

$$V_B \cong \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{10\text{ k}\Omega}{66\text{ k}\Omega}\right)12\text{ V} = 1.82\text{ V}$$

$$I_E = \frac{V_B - 0.7\text{ V}}{R_{E1} + R_{E2}} = \frac{1.82\text{ V} - 0.7\text{ V}}{628\ \Omega} = 1.78\text{ mA}$$

$$r'_{e(Q1)} = \frac{25\text{ mV}}{I_E} = \frac{25\text{ mV}}{1.78\text{ mA}} = 14\ \Omega$$

Using the value of r'_e, determine the voltage gain of the first stage with the loading of the second stage taken into account.

$$A_{v1} = -\frac{R_{c1}}{R_{E1} + r'_{e(Q1)}} = -\frac{2.29\text{ k}\Omega}{68\ \Omega + 14\ \Omega} = -27.9$$

The negative sign is for inversion.

The total input resistance of the first stage is equal to the bias resistors in parallel with the ac input resistance at the base of Q_1.

$$R_{in(tot)1} = R_1 \| R_2 \| \beta_{ac(Q1)}(R_{E1} + r'_{e(Q1)})$$
$$= 56\text{ k}\Omega \| 10\text{ k}\Omega \| 200(68\ \Omega + 14\ \Omega) = 8.4\text{ k}\Omega$$

Second stage: The voltage gain of the darlington emitter-follower is approximately equal to 1.

$$A_{v2} \cong 1$$

Overall amplifier: The overall voltage gain is the product of the first and second stage voltage gains. Since the second stage has a gain of approximately 1, the overall gain is approximately equal to the gain of the first stage.

$$A_{v(tot)} = A_{v1}A_{v2} = (-27.9)(1) = -27.9$$

Power gain: The power gain of the amplifier can be calculated using Equation 7–2.

$$A_p = A^2_{v(tot)}\left(\frac{R_{in(tot)1}}{R_L}\right) = (-27.9)^2\left(\frac{8.4\text{ k}\Omega}{8\ \Omega}\right) = \mathbf{817{,}330}$$

*Related Problem** What happens to the power gain if a second 8 Ω speaker is connected in parallel with the first one?

***Answers can be found at www.pearsonhighered.com/floyd.**

Efficiency

The **efficiency** of any amplifier is the ratio of the output signal power supplied to a load to the total power from the dc supply. The maximum output signal power that can be obtained is given by Equation 7–4. The average power supply current, I_{CC}, is equal to I_{CQ} and the supply voltage is at least $2V_{CEQ}$. Therefore, the total dc power is

$$P_{DC} = I_{CC}V_{CC} = 2I_{CQ}V_{CEQ}$$

The maximum efficiency, η_{max}, of a capacitively coupled class A amplifier is

$$\eta_{max} = \frac{P_{out}}{P_{DC}} = \frac{0.5I_{CQ}V_{CEQ}}{2I_{CQ}V_{CEQ}} = 0.25$$

The maximum efficiency of a capacitively coupled class A amplifier cannot be higher than 0.25, or 25%, and, in practice, is usually considerably less (about 10%). Although the efficiency can be made higher by transformer coupling the signal to the load, there are drawbacks to transformer coupling. These drawbacks include the size and cost of transformers as well as potential distortion problems when the transformer core begins to saturate. In general, the low efficiency of class A amplifiers limits their usefulness to small power applications that require usually less than 1 W.

EXAMPLE 7–2 Determine the efficiency of the power amplifier in Figure 7–5 (Example 7–1).

Solution The efficiency is the ratio of the signal power in the load to the power supplied by the dc source. The input voltage is 50 mV peak-to-peak which is 35.4 mV rms. The input power is, therefore,

$$P_{in} = \frac{V^2_{in}}{R_{in}} = \frac{(35.4\text{ mV})^2}{8.4\text{ k}\Omega} = 149\text{ nW}$$

The output power is

$$P_{out} = P_{in}A_p = (149\text{ nW})(817{,}330) = 122\text{ mW}$$

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.

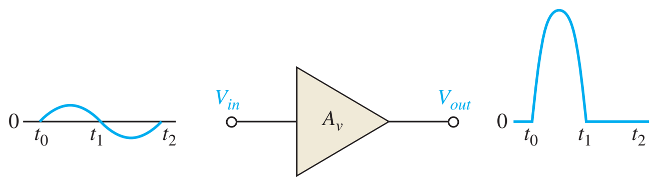
After completing this section, you should be able to

- **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

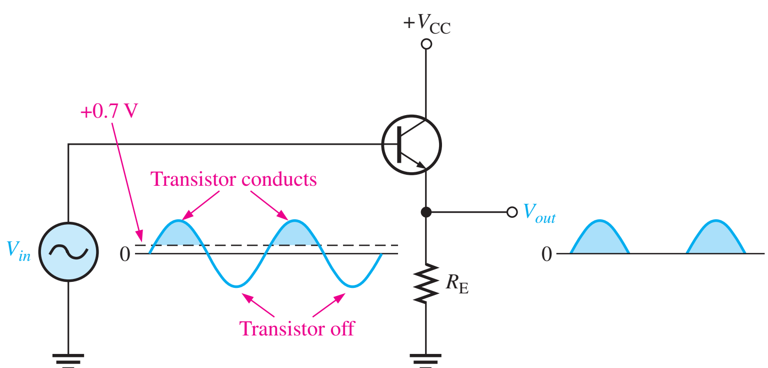
The class B operation is illustrated in Figure 7–6, where the output waveform is shown relative to the input in terms of time (t).



▲ 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

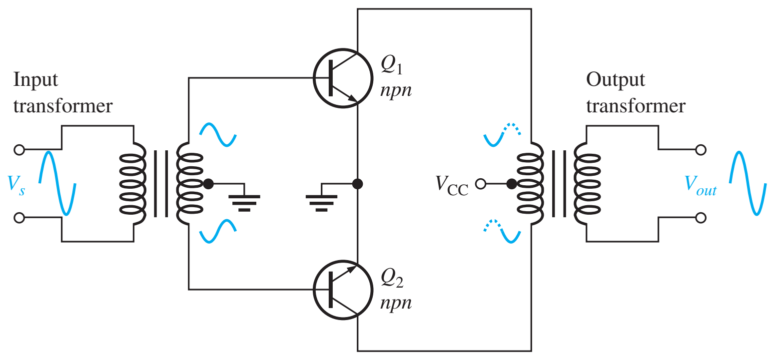
As you can see, the circuit in Figure 7–7 only conducts for the positive half of the cycle. To amplify the entire cycle, it is necessary to add a second class B amplifier that operates on the negative half of the cycle. The combination of two class B amplifiers working together is called **push-pull**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

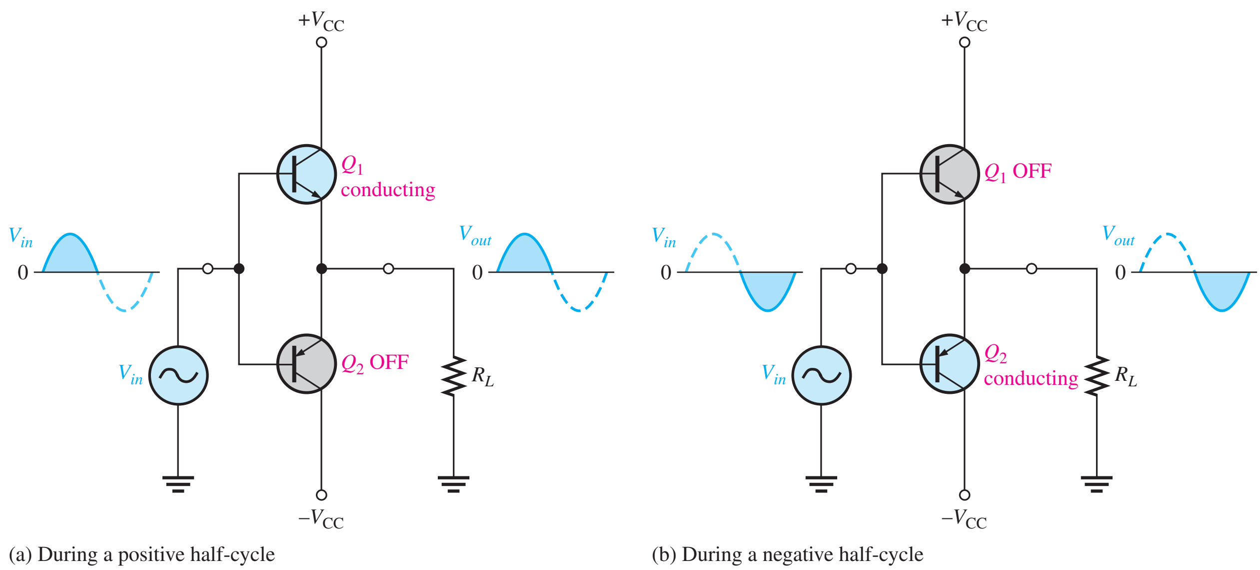
Transformer Coupling Transformer coupling is illustrated in Figure 7–8. The input transformer has a center-tapped secondary that is connected to ground, producing phase inversion of one side with respect to the other. The input transformer thus converts the input signal to two out-of-phase signals for 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.



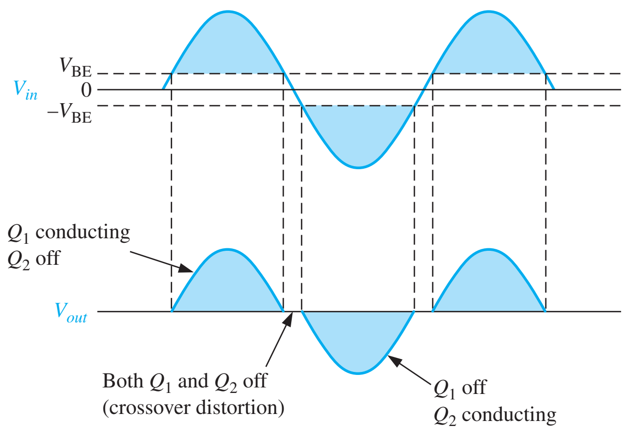
Complementary Symmetry Transistors Figure 7–9 shows one of the most popular types of push-pull class B amplifiers using two emitter-followers and both positive and negative power supplies. This is a complementary amplifier because one emitter-follower uses an *npn* transistor and the other a *pnp,* which 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.



▲ 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.**

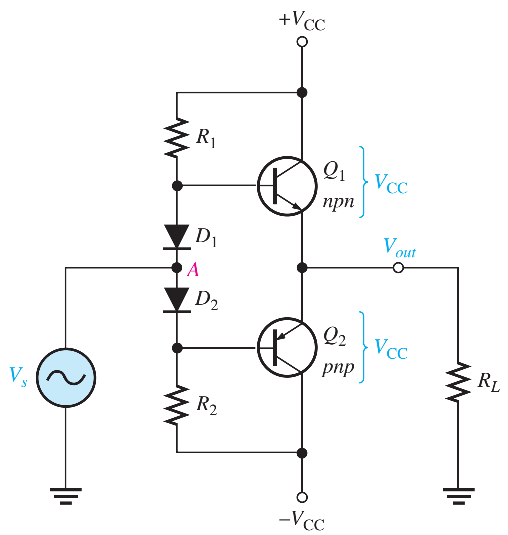


◀ FIGURE 7–10

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

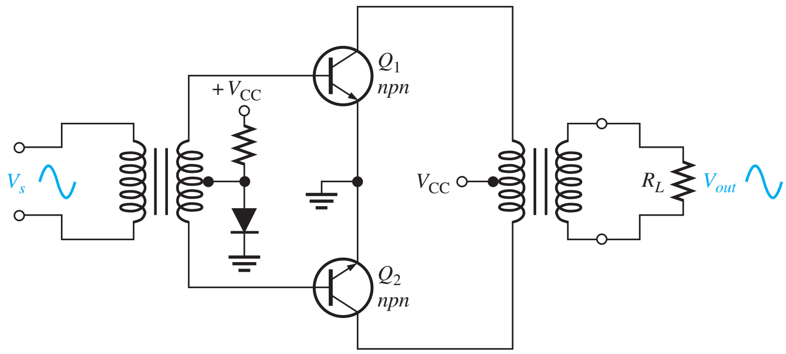
Biasing the push-pull amplifier with current-mirror diode bias to eliminate crossover distortion. The transistors form a complementary pair (one *npn* and one *pnp*).

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

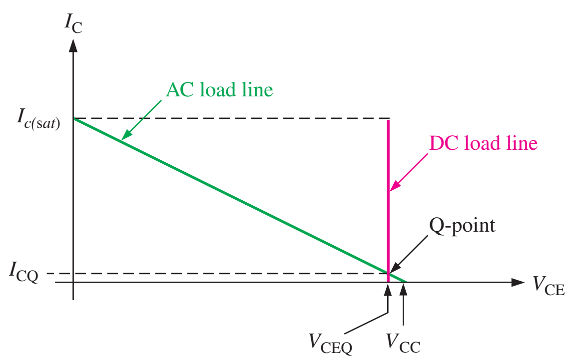
Equation 7–5

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

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

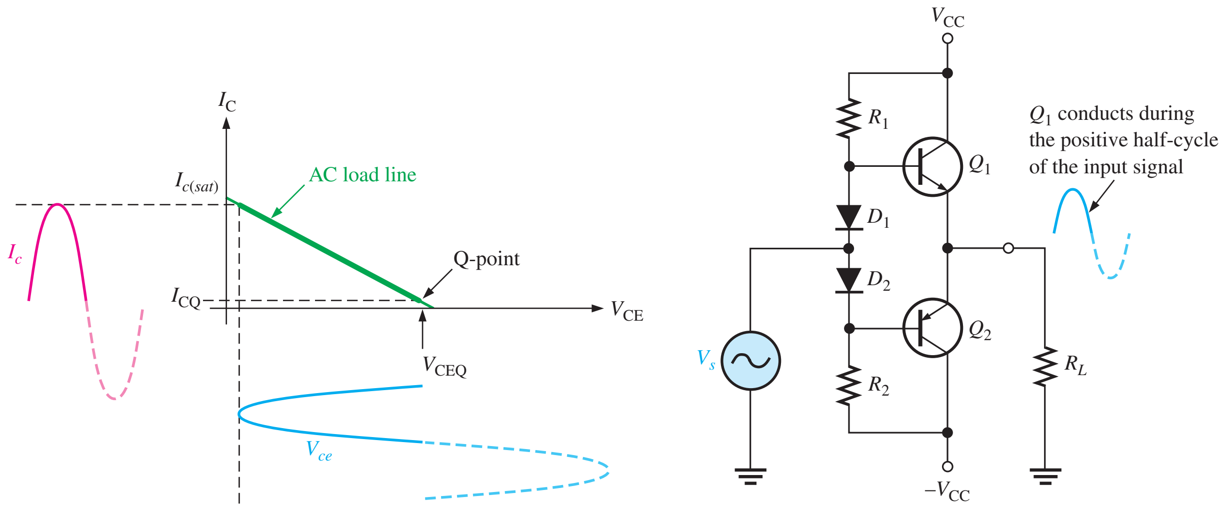
▶ **FIGURE 7–13**

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.



(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 cut-off 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%.

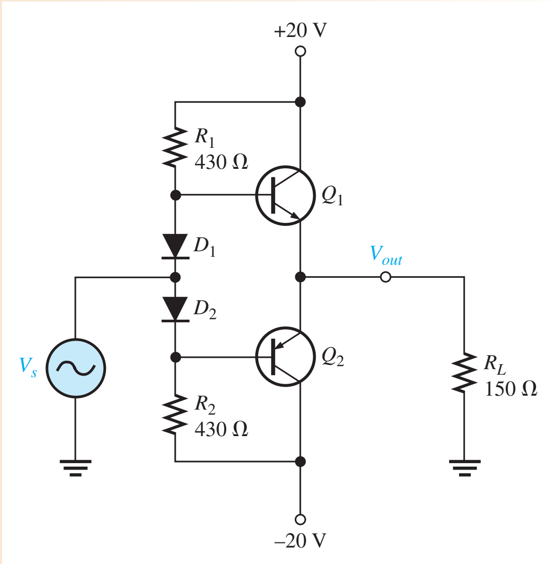
EXAMPLE 7–3

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?

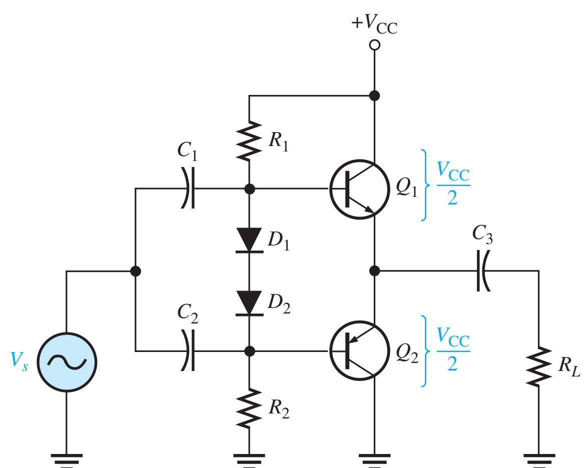
Open the Multisim file E07-03 in the Examples folder on the companion website. Measure the maximum peak-to-peak output voltage.

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.

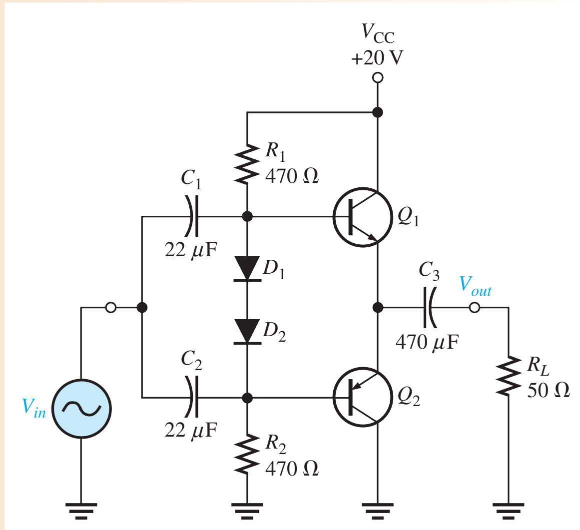


capacitive coupling for the input and output is necessary to block the bias voltage from the source and the load resistor. Ideally, the output voltage can swing from zero to V_{CC}, but in practice it does not quite reach these ideal values.

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

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

The maximum peak output current is

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

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

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

then

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

Substituting $V_{CC}/2$ 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

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

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

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

So,

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

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.

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

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

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

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

Equation 7–7

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

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.

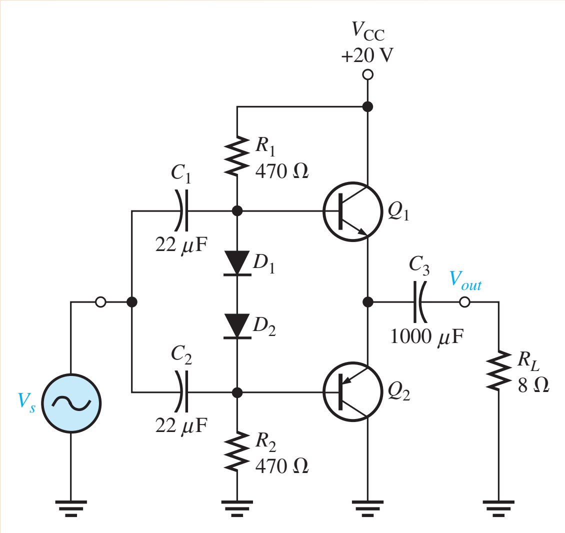
Solution The ideal maximum peak output voltage is

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

The maximum peak output current is

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

▶ FIGURE 7–18



The ac output power and the dc input power are

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

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

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

$$\mathbf{R_{in} = \beta_{ac}(r'_e + R_L) \parallel R_1 \parallel R_2} \qquad \text{Equation 7–8}$$

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.

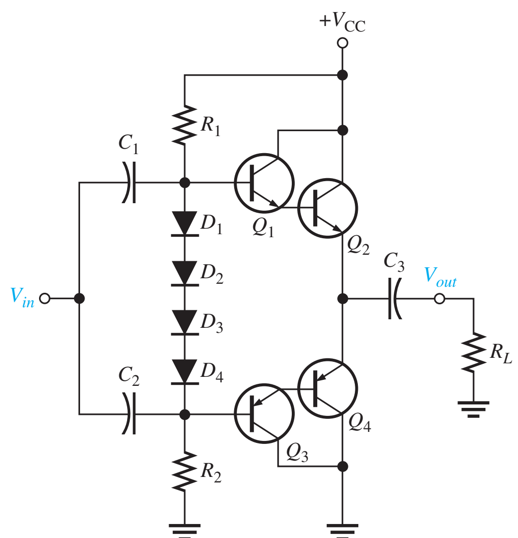
In the previous case, for example, if $\beta_{ac} = 50$ for each transistor in a Darlington pair, the overall ac beta is $\beta_{ac} = (50)(50) = 2500$. If the bias resistors are 10 kΩ, the input resistance is greatly increased, as the following calculation shows.

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

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.

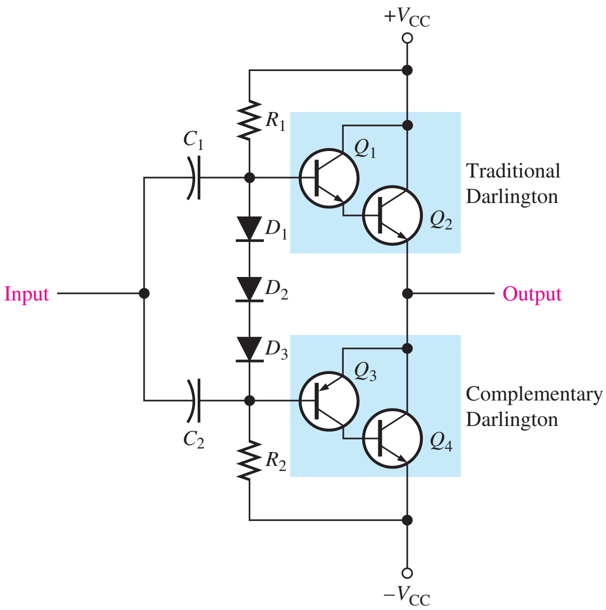
▶ **FIGURE 7–19**

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

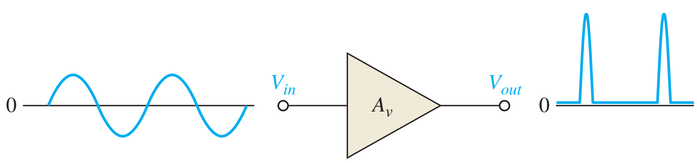
- Discuss class C power dissipation
- Explain tuned operation
- Determine maximum output power
- Explain clamper bias for a class C amplifier

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 $V_{ce(sat)}$.

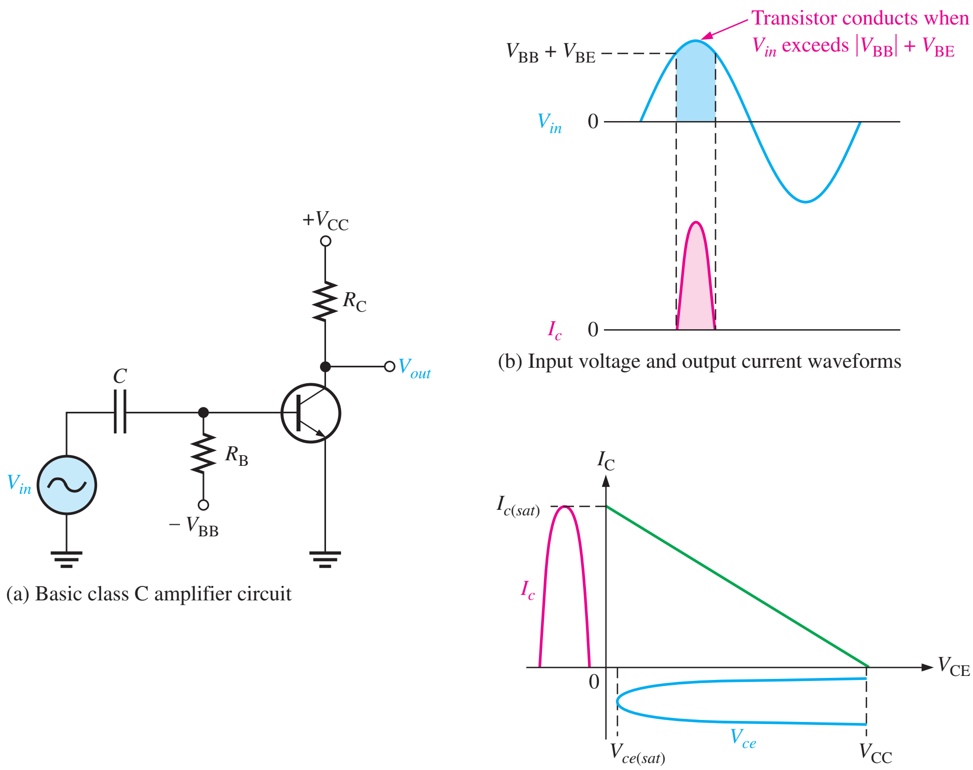
▶ **FIGURE 7–21**

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

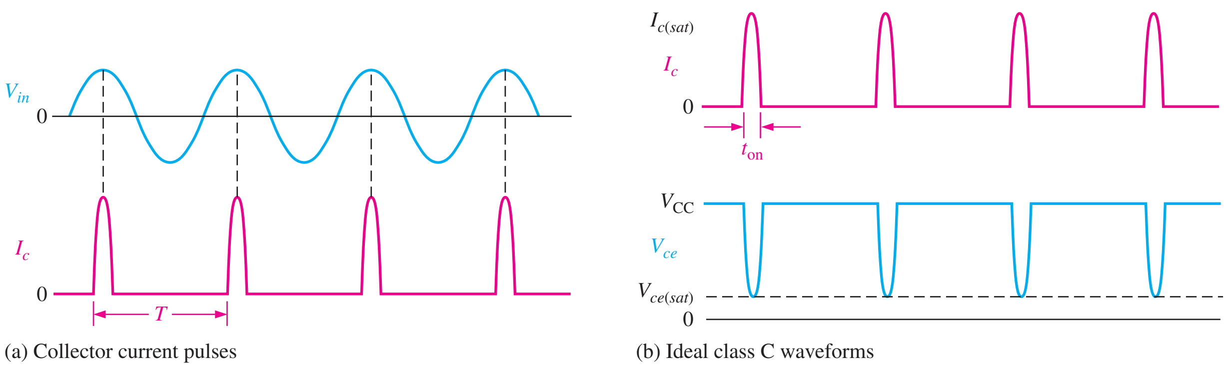
Power Dissipation

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,

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

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

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



▲ **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

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

Therefore,

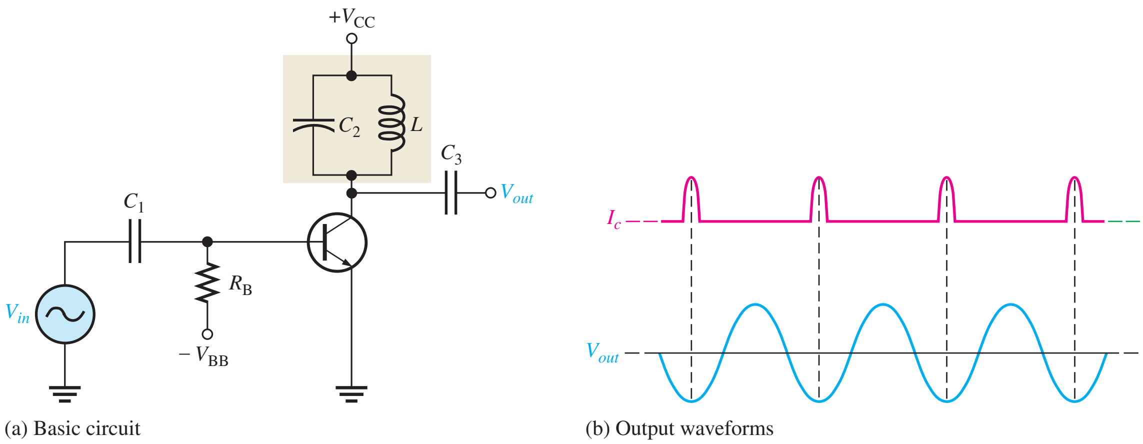
$$P_{\text{D(avg)}} = \left(\frac{t_{\text{on}}}{T}\right)I_{c(sat)}V_{ce(sat)} = (0.2)(100\text{ mA})(0.2\text{ V}) = \mathbf{4\ mW}$$

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.



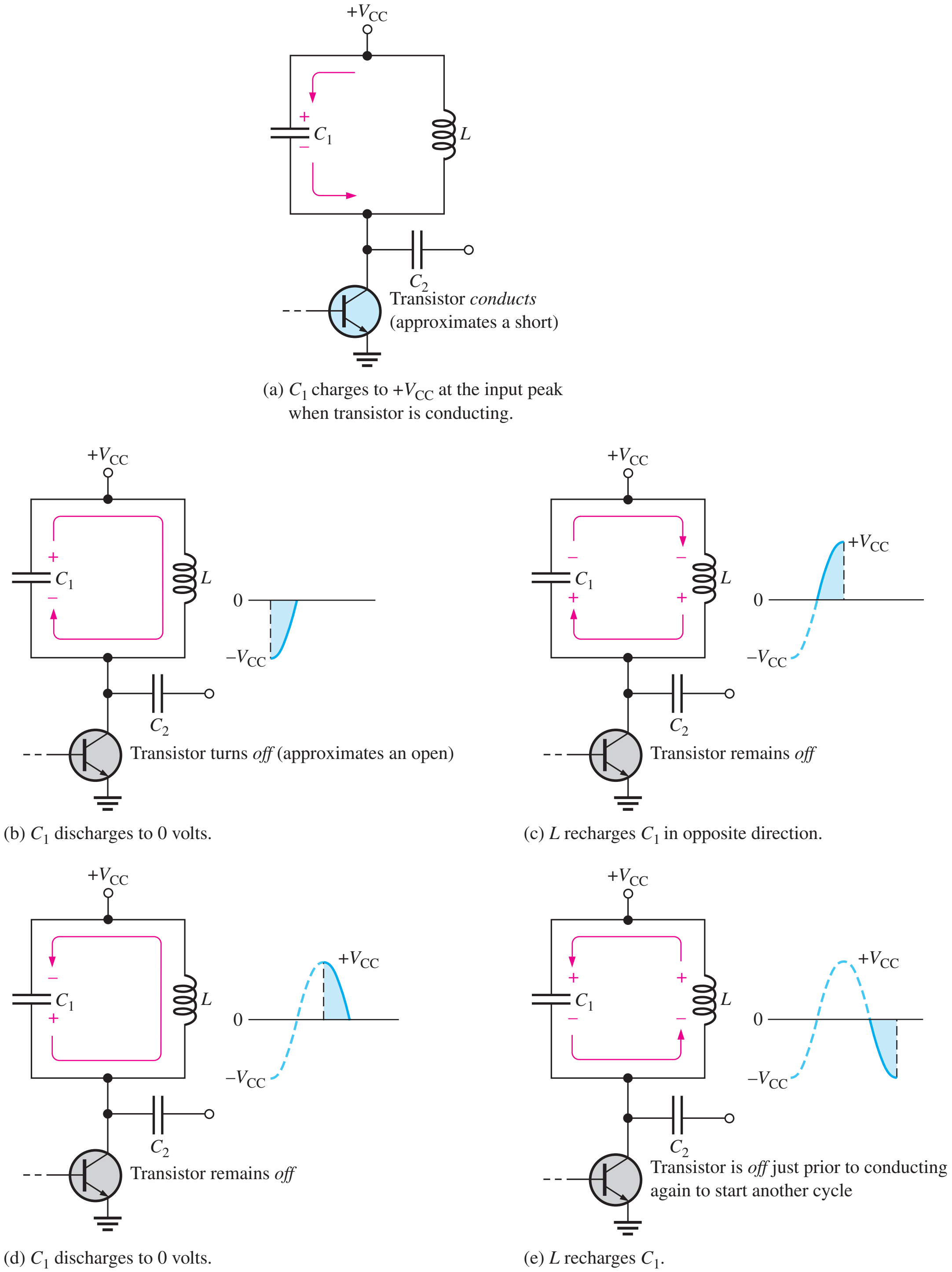
▲ FIGURE 7–24

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.

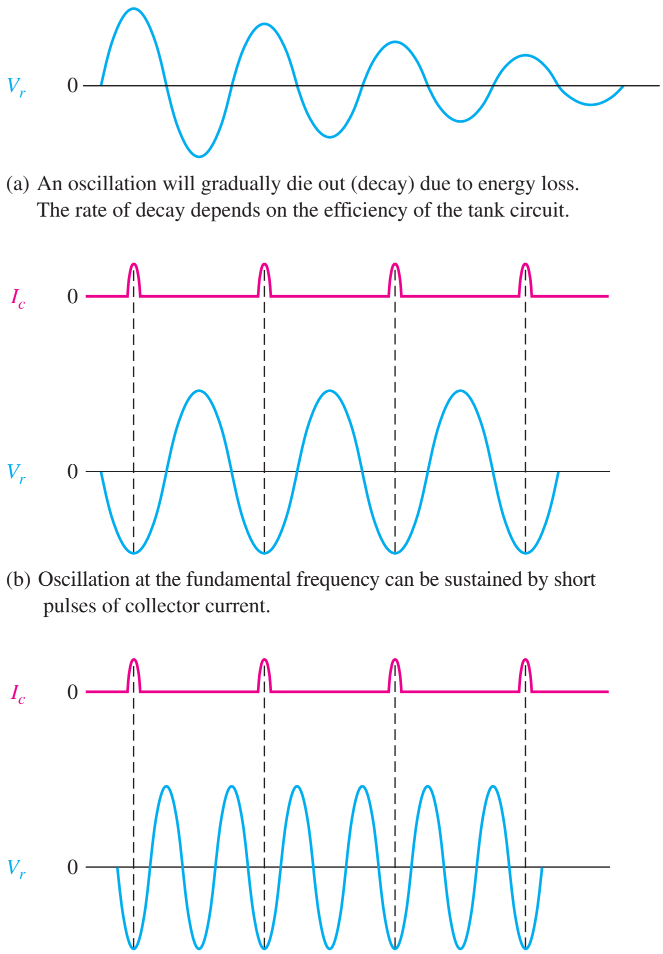


▲ **FIGURE 7–25**

Resonant circuit action.

FIGURE 7–26

Tank circuit oscillations. V_r is the voltage across the tank circuit.



(a) An oscillation will gradually die out (decay) due to energy loss. The rate of decay depends on the efficiency of the tank circuit.

(b) Oscillation at the fundamental frequency can be sustained by short pulses of collector current.

(c) Oscillation at the second harmonic frequency

Maximum Output Power

Since the voltage developed across the tank circuit has a peak-to-peak value of approximately $2V_{CC}$, the maximum output power can be expressed as

$$P_{out} = \frac{V_{rms}^2}{R_c} = \frac{(0.707V_{CC})^2}{R_c}$$

Equation 7–9

$$\boldsymbol{P_{out} = \frac{0.5V_{CC}^2}{R_c}}$$

R_c is the equivalent parallel resistance of the collector tank circuit at resonance and represents the parallel combination of the coil resistance and the load resistance. It usually has a low value. The total power that must be supplied to the amplifier is

$$P_T = P_{out} + P_{D(avg)}$$

Therefore, the efficiency is

Equation 7–10

$$\boldsymbol{\eta = \frac{P_{out}}{P_{out} + P_{D(avg)}}}$$

When $P_{out} >> P_{D(avg)}$, the class C efficiency closely approaches 1 (100 percent).

EXAMPLE 7–8

Suppose the class C amplifier described in Example 7–7 has a V_{CC} equal to 24 V and the R_c is 100 Ω. Determine the efficiency.

Solution From Example 7–7, $P_{D(avg)} = 4$ mW.

$$P_{out} = \frac{0.5V_{CC}^2}{R_c} = \frac{0.5(24\text{ V})^2}{100\ \Omega} = 2.88\text{ W}$$

Therefore,

$$\eta = \frac{P_{out}}{P_{out} + P_{D(avg)}} = \frac{2.88\text{ W}}{2.88\text{ W} + 4\text{ mW}} = \mathbf{0.999}$$

or, as a percentage, 99.9%.

Related Problem What happens to the efficiency of the amplifier if R_c is increased?

Clamper Bias for a Class C Amplifier

Figure 7–27 shows a class C amplifier with a base bias clamping circuit. The base-emitter junction functions as a diode.

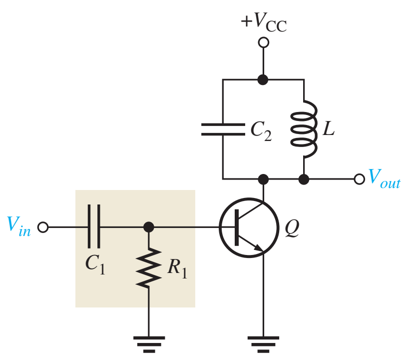
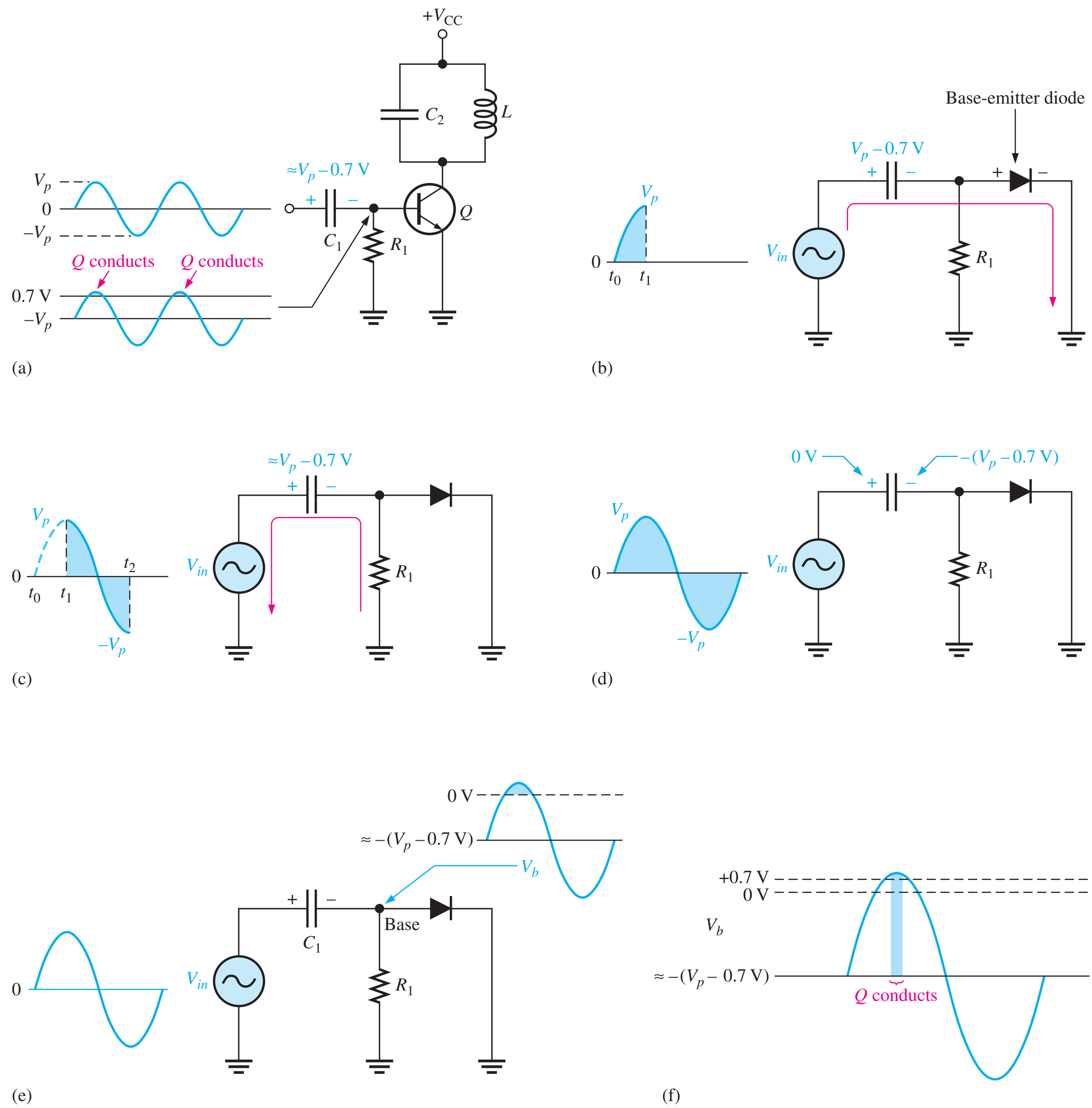


FIGURE 7–27

Tuned class C amplifier with clamper bias.

When the input signal goes positive, capacitor C_1 is charged to the peak value with the polarity shown in Figure 7–28(a). This action produces an average voltage at the base of approximately $-V_p$. This places the transistor in cutoff except at the positive peaks, when the transistor conducts for a short interval. For good clamping action, the R_1C_1 time constant of the clamping circuit must be much greater than the period of the input signal. Parts (b) through (f) of Figure 7–28 illustrate the bias clamping action in more detail. During the time up to the positive peak of the input (t_0 to t_1), the capacitor charges to $V_p - 0.7$ V through the base-emitter diode, as shown in part (b). During the time from t_1 to t_2, as shown in part (c), the capacitor discharges very little because of the large RC time constant. The capacitor, therefore, maintains an average charge slightly less than $V_p - 0.7$ V.

Since the dc value of the input signal is zero (positive side of C_1), the dc voltage at the base (negative side of C_1) is slightly more positive than $-(V_p - 0.7\text{ V})$, as indicated in Figure 7–28(d). As shown in Figure 7–28(e), the capacitor couples the ac input signal through to the base so that the voltage at the transistor's base is the ac signal riding on a dc level slightly more positive than $-(V_p - 0.7\text{ V})$. Near the positive peaks of the input voltage, the base voltage goes slightly above 0.7 V and causes the transistor to conduct for a short time, as shown in Figure 7–28(f).



▲ **FIGURE 7–28**

Clamper bias action.

EXAMPLE 7–9

Determine the voltage at the base of the transistor, the resonant frequency, and the peak-to-peak value of the output signal voltage for the class C amplifier in Figure 7–29.

Solution

$$V_{s(p)} = (1.414)(1\text{ V}) \cong 1.4\text{ V}$$

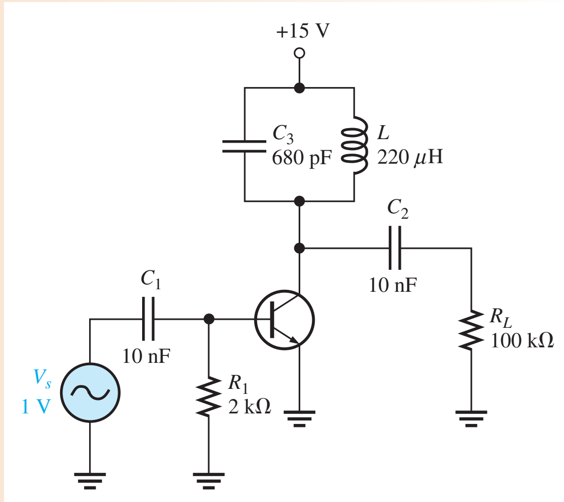
The base is clamped at

$$-(V_{s(p)} - 0.7) = \mathbf{-0.7\text{ V dc}}$$

The signal at the base has a positive peak of +0.7 V and a negative peak of

$$-V_{s(p)} + (-0.7\text{ V}) = -1.4\text{ V} - 0.7\text{ V} = \mathbf{-2.1\text{ V}}$$

▶ FIGURE 7–29



The resonant frequency is

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(220\ \mu\text{H})(680\ \text{pF})}} = \mathbf{411\ kHz}$$

The output signal has a peak-to-peak value of

$$V_{pp} = 2V_{CC} = 2(15\ \text{V}) = \mathbf{30\ V}$$

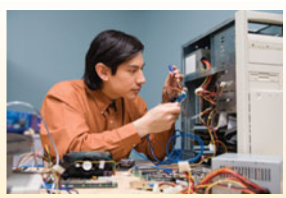
Related Problem How could you make the circuit in Figure 7–29 a frequency doubler?

SECTION 7–3 CHECKUP

1. At what point is a class C amplifier normally biased?
2. What is the purpose of the tuned circuit in a class C amplifier?
3. A certain class C amplifier has a power dissipation of 100 mW and an output power of 1 W. What is its percent efficiency?

7–4 TROUBLESHOOTING

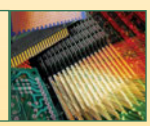
In this section, examples of isolating a component failure in a circuit are presented. We will use a class A amplifier and a class AB amplifier with the output voltage monitored by an oscilloscope. Several incorrect output waveforms will be examined and the most likely faults will be discussed.



After completing this section, you should be able to

- **Troubleshoot power amplifiers**
- Troubleshoot a class A amplifier for various faults
- Troubleshoot a class AB amplifier for various faults

Chapter 18: Basic Programming Concepts for Automated Testing
Selected sections from Chapter 18 may be introduced as part of this troubleshooting coverage or, optionally, the entire Chapter 18 may be covered later or not at all.

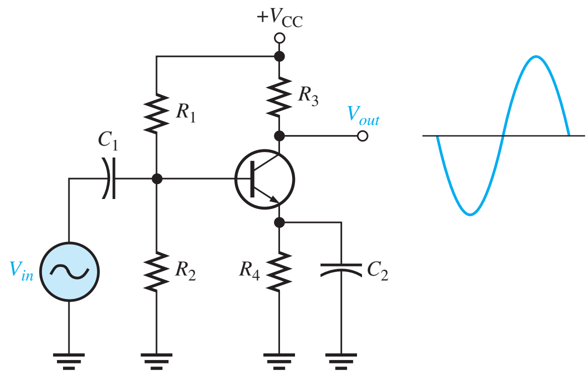


Case 1: Class A

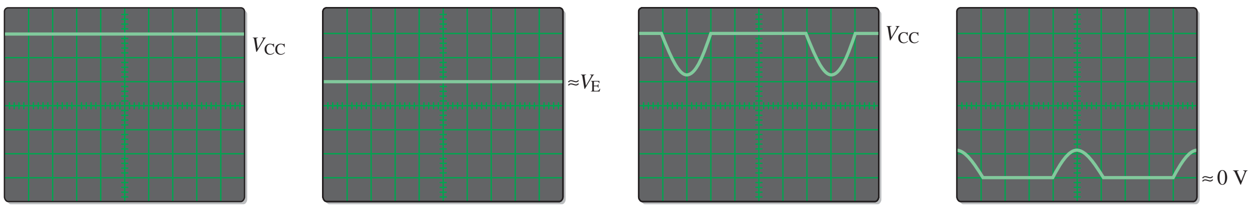
As shown in Figure 7–30, the class A power amplifier should have a normal sinusoidal output when a sinusoidal input signal is applied.

▶ FIGURE 7–30

Class A power amplifier with correct output voltage swing.



Now let's consider four incorrect output waveforms and the most likely causes in each case. In Figure 7–31(a), the scope displays a dc level equal to the dc supply voltage, indicating that the transistor is in cutoff. The two most likely causes of this condition are (1) the transistor has an open *pn* junction, or (2) R_4 is open, preventing collector and emitter current.



(a) Transistor in cutoff (b) CE short or R_2 open (c) Q-point shift or R_1 open (d) Transistor in saturation

▲ FIGURE 7–31

Oscilloscope displays showing output voltage for the amplifier in Figure 7–30 for several types of failures.

In Figure 7–31(b), the scope displays a dc level at the collector approximately equal to the dc emitter voltage. The two probable causes of this indication are (1) the transistor is shorted from collector to emitter, or (2) R_2 is open, causing the transistor to be biased in saturation. In the second case, a sufficiently large input signal can bring the transistor out of saturation on its negative peaks, resulting in short pulses on the output.

In Figure 7–31(c), the scope displays an output waveform that indicates the transistor is in cutoff except during a small portion of the input cycle. Possible causes of this indication are (1) the Q-point has shifted down due to a drastic out-of-tolerance change in a resistor value, or (2) R_1 is open, biasing the transistor in cutoff. The display shows that the input signal is sufficient to bring it out of cutoff for a small portion of the cycle.

In Figure 7–31(d), the scope displays an output waveform that indicates the transistor is saturated except during a small portion of the input cycle. Again, it is possible that an incorrect resistance value has caused a drastic shift in the Q-point up toward saturation, or R_2 is open, causing the transistor to be biased in saturation, and the input signal is bringing it out of saturation for a small portion of the cycle.

Case 2: Class AB

As shown in Figure 7–32, the class AB push-pull amplifier should have a sinusoidal output when a sinusoidal input signal is applied.

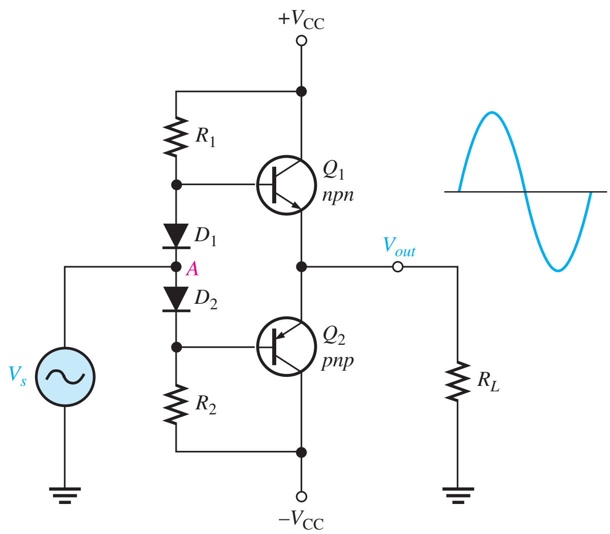
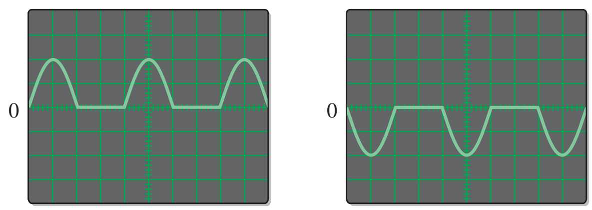


FIGURE 7–32

A class AB push-pull amplifier with correct output voltage.

Two incorrect output waveforms are shown in Figure 7–33. The waveform in part (a) shows that only the positive half of the input signal is present on the output. One possible cause is that diode D_1 is open. If this is the fault, the positive half of the input signal forward-biases D_2 and causes transistor Q_2 to conduct. Another possible cause is that the base-emitter junction of Q_2 is open so only the positive half of the input signal appears on the output because Q_1 is still working.



(a) D_1 open or Q_2 base-emitter open

(b) D_2 open or Q_1 base-emitter open

FIGURE 7–33

Incorrect output waveforms for the amplifier in Figure 7–32.

The waveform in Figure 7–33(b) shows that only the negative half of the input signal is present on the output. One possible cause is that diode D_2 is open. If this is the fault, the negative half of the input signal forward-biases D_1 and places the half-wave signal on the base of Q_1. Another possible cause is that the base-emitter junction of Q_1 is open so only the negative half of the input signal appears on the output because Q_2 is still working.

Multisim Troubleshooting Exercises

These file circuits are in the Troubleshooting Exercises folder on the companion website. Open each file and determine if the circuit is working properly. If it is not working properly, determine the fault.

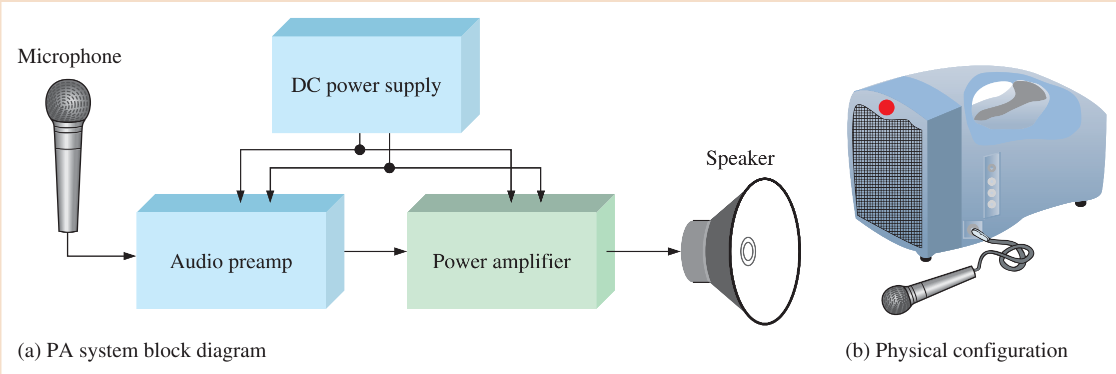
1. Multisim file TSE07-01
2. Multisim file TSE07-02
3. Multisim file TSE07-03
4. Multisim file TSE07-04

SECTION 7–4 CHECKUP

1. What would you check for if you noticed clipping at both peaks of the output waveform?
2. A significant loss of gain in the amplifier of Figure 7–30 would most likely be caused by what type of failure?

Application Activity: *The Complete PA System*

The class AB power amplifier follows the audio preamp and drives the speaker as shown in the PA system block diagram in Figure 7–34. In this application, the power amplifier is developed and interfaced with the preamp that was developed in Chapter 6. The maximum signal power to the speaker should be approximately 6 W for a frequency range of 70 Hz to 5 kHz. The dynamic range for the input voltage is up to 40 mV. Finally, the complete PA system is put together.



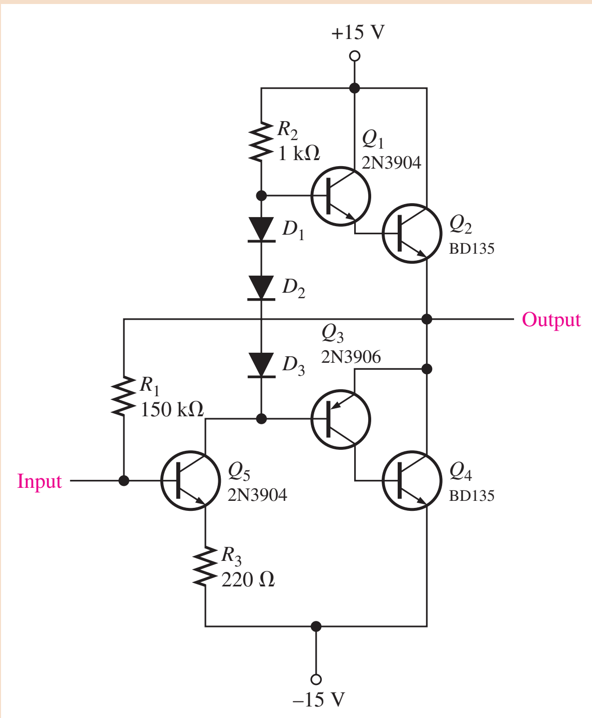
▲ FIGURE 7–34

The Power Amplifier Circuit

The schematic of the push-pull power amplifier is shown in Figure 7–35. The circuit is a class AB amplifier implemented with Darlington configurations and diode current mirror bias. Both a traditional Darlington pair and a complementary Darlington (Sziklai) pair are used to provide sufficient current to an 8 Ω speaker load. The signal from the preamp is

▶ FIGURE 7–35

Class AB power push-pull amplifier.



capacitively coupled to the driver stage, Q_5, which is used to prevent excessive loading on the preamp and provide additional gain. Notice that Q_5 is biased with the dc output voltage (0 V) fed back through R_1. Also, the signal voltage fed back to the base of Q_5 is out-of-phase with the signal from the preamp and has the effect of stabilizing the gain. This is called *negative feedback.* The amplifier will deliver up to 5 W to an 8 Ω speaker.

A partial datasheet for the BD135 power transistor is shown in Figure 7–36.

1. Estimate the input resistance of the power amplifier in Figure 7–35.
2. Calculate the approximate voltage gain of the power amplifier in Figure 7–35?

▶ **FIGURE 7–36**

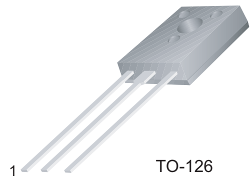
Partial datasheet for the BD135 power transistors. Copyright Fairchild semiconductor corporation. Used by permission.

FAIRCHILD SEMICONDUCTOR™

BD135/137/139

Medium Power Linear and Switching Applications

- Complement to BD136, BD138 and BD140 respectively



TO-126

1. Emitter 2.Collector 3.Base

NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_C = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage : BD135 : BD137 : BD139	45 60 80	V V V
V_{CEO}	Collector-Emitter Voltage : BD135 : BD137 : BD139	45 60 80	V V V
V_{EBO}	Emitter-Base Voltage	5	V
I_C	Collector Current (DC)	1.5	A
I_{CP}	Collector Current (Pulse)	3.0	A
I_B	Base Current	0.5	A
P_C	Collector Dissipation (T_C = 25°C)	12.5	W
P_C	Collector Dissipation (T_a = 25°C)	1.25	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 55 ~ 150	°C

Electrical Characteristics T_C = 25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Units
$V_{CEO}(sus)$	Collector-Emitter Sustaining Voltage : BD135 : BD137 : BD139	I_C = 30mA, I_B = 0	45 60 80			V V V
I_{CBO}	Collector Cut-off Current	V_{CB} = 30V, I_E = 0			0.1	μA
I_{EBO}	Emitter Cut-off Current	V_{EB} = 5V, I_C = 0			10	μA
h_{FE1} h_{FE2} h_{FE3}	DC Current Gain : ALL DEVICE : ALL DEVICE : BD135 : BD137, BD139	V_{CE} = 2V, I_C = 5mA V_{CE} = 2V, I_C = 0.5A V_{CE} = 2V, I_C = 150mA	25 25 40 40		 250 160	
$V_{CE}(sat)$	Collector-Emitter Saturation Voltage	I_C = 500mA, I_B = 50mA			0.5	V
$V_{BE}(on)$	Base-Emitter ON Voltage	V_{CE} = 2V, I_C = 0.5A			1	V

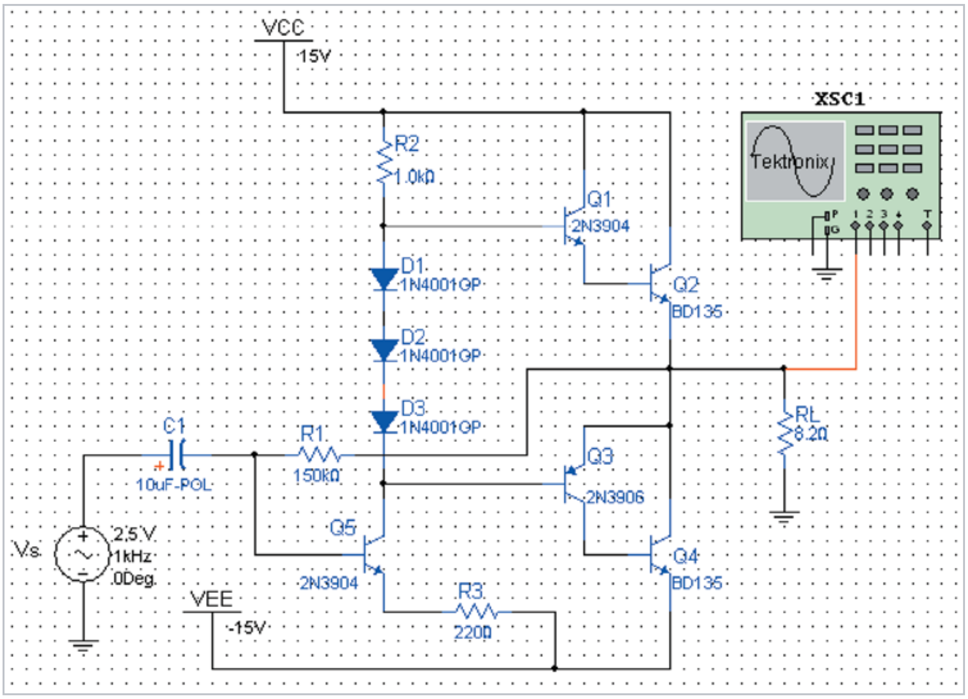
h_{FE} Classification

Classification	6	10	16
h_{FE3}	40 ~ 100	63 ~ 160	100 ~ 250

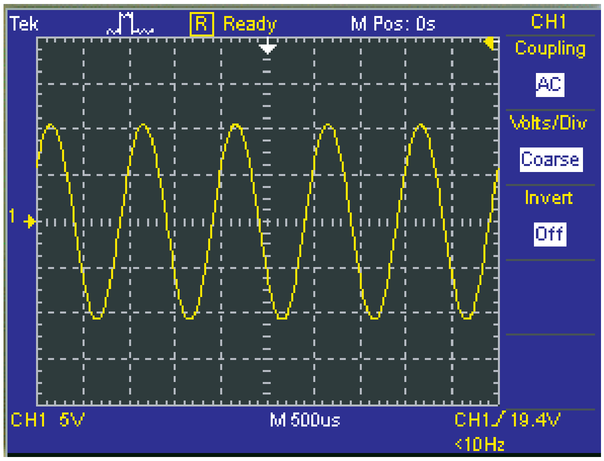
Simulation

The power amplifier is simulated using Multisim with a 1 kHz input signal at near its maximum linear operation. The results are shown in Figure 7–37 where an 8.2 Ω resistor is used to closely approximate the 8 Ω speaker.

3. Calculate the power to the load in Figure 7–37.
4. What is the measured voltage gain? The input is a peak value.
5. Compare the measured gain to the calculated gain for the amplifier in Figure 7–35.



(a) Circuit screen



(b) Output signal

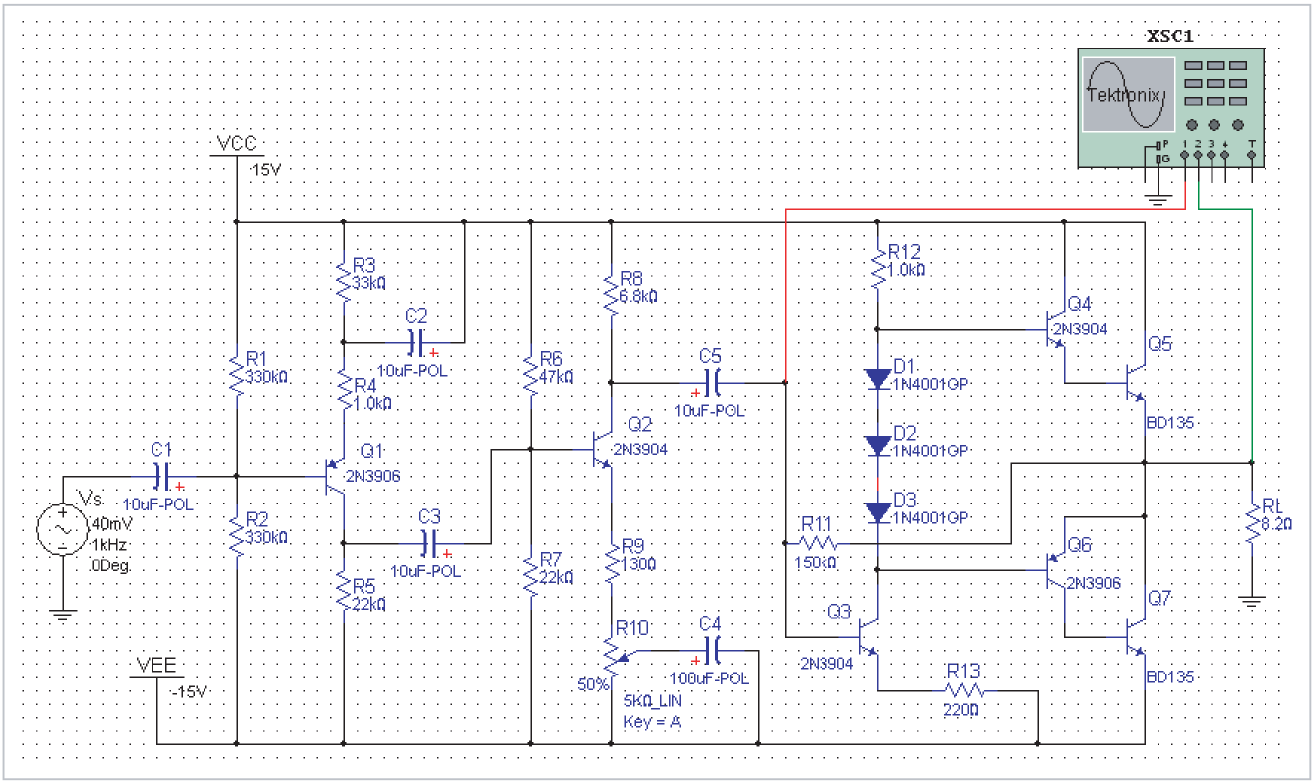
▲ FIGURE 7–37

Simulation of the power amplifier.

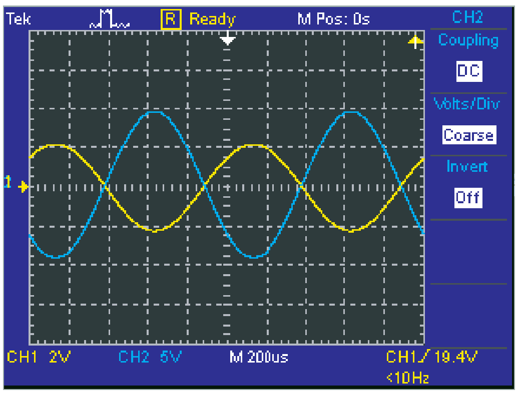
The Complete Audio Amplifier

Both the preamp and the power amp have been simulated individually. Now, they must work together to produce the required signal power to the speaker. Figure 7–38 is the simulation of the combined audio preamp and power amp. Components in the power amplifier are now numbered sequentially with the preamp components.

6. Calculate the power to the load in Figure 7–38.
7. What is the measured voltage gain of the power amplifier?
8. What is the measured overall voltage gain?



(a) Circuit screen



(b) Preamp output and final output

▲ **FIGURE 7–38**

Simulation of the complete audio amplifier.

Simulate the audio amplifier using your Multisim software. Observe the operation with the virtual oscilloscope.

Prototyping and Testing

Now that the circuit has been simulated, the prototype circuit is constructed and tested. After the circuit is successfully tested on a protoboard, it is ready to be finalized on a printed circuit board.

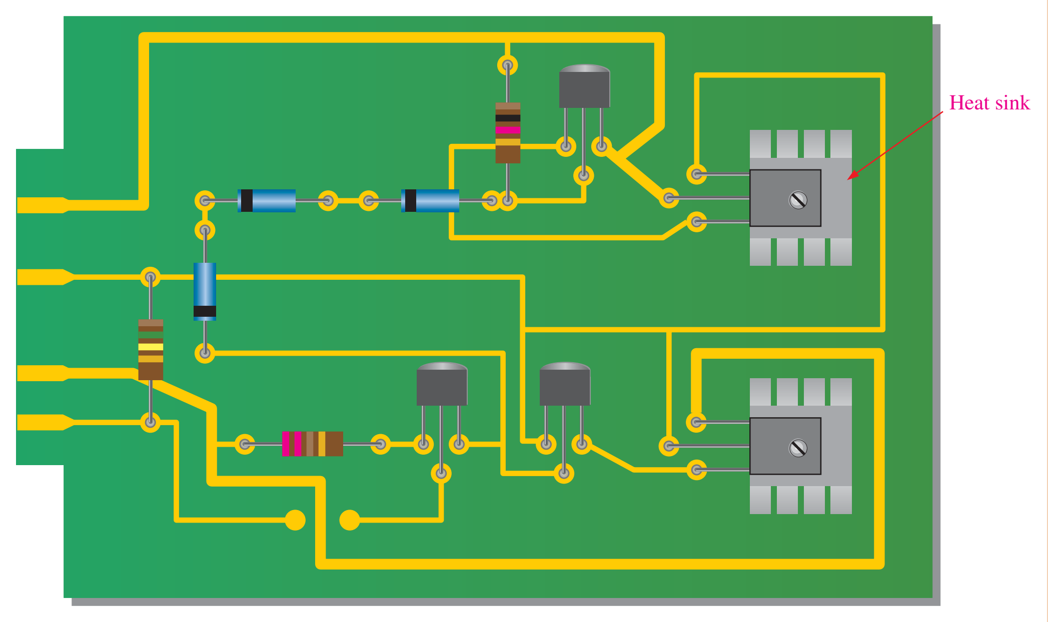
Lab Experiment

To build and test a similar circuit, go to Experiment 7 in your lab manual (*Laboratory Exercises for Electronic Devices* by David Buchla and Steven Wetterling).

Circuit Board

The power amplifier is implemented on a printed circuit board as shown in Figure 7–39. Heat sinks are used to provide additional heat dissipation from the power transistors.

9. Check the printed circuit board and verify that it agrees with the schematic in Figure 7–35. The volume control potentiometer is mounted off the PC board for easy access.
10. Label each input and output pin according to function. Locate the single back-side trace.



▲ **FIGURE 7–39**

Power amplifier circuit board.

Troubleshooting the Power Amplifier Board

A power amplifier circuit board has failed the production test. Test results are shown in Figure 7–40.

11. Based on the scope displays, list possible faults for the circuit board.

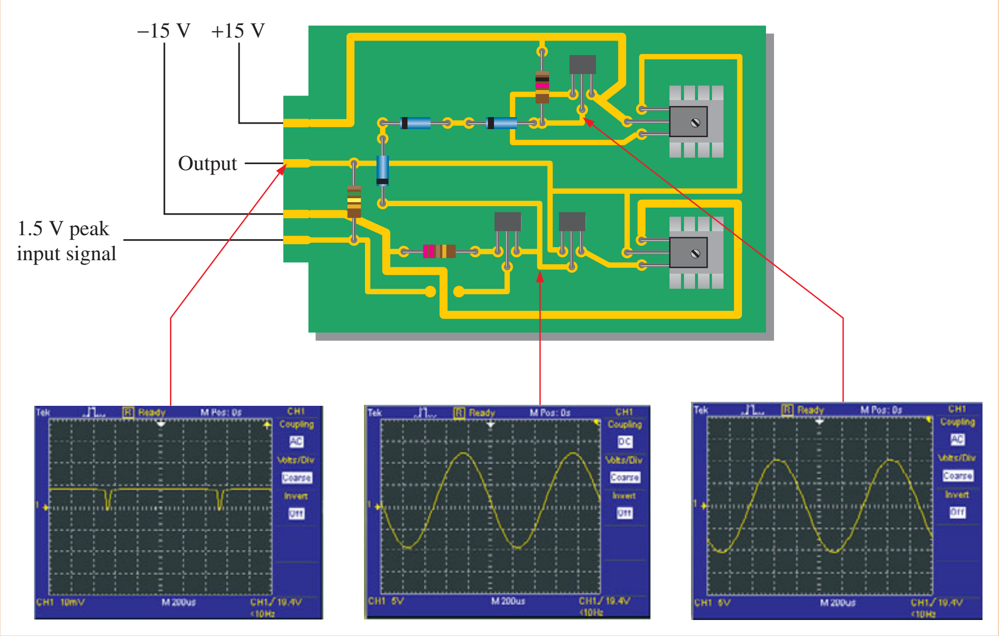
Putting the System Together

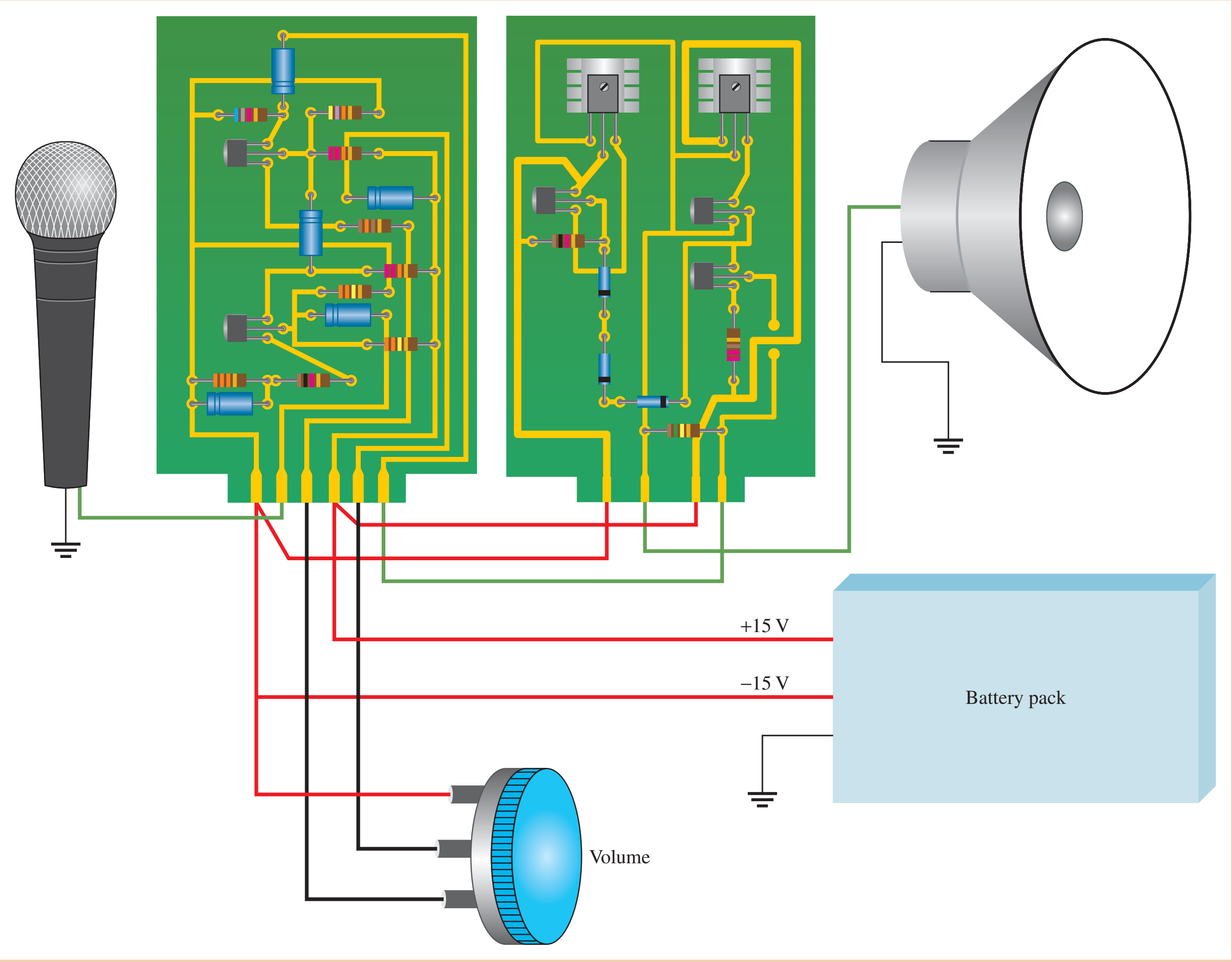
The preamp circuit board and the power amplifier circuit board are interconnected and the dc power supply (battery pack), microphone, speaker, and volume control potentiometer are attached, as shown in Figure 7–41.

12. Verify that the system interconnections are correct.

▶ FIGURE 7–40

Test of faulty power amplifier board.





▲ FIGURE 7–41

The complete public address system.

SUMMARY

Section 7–1

- A class A power amplifier operates entirely in the linear region of the transistor's characteristic curves. The transistor conducts during the full 360° of the input cycle.
- The Q-point must be centered on the load line for maximum class A output signal swing.
- The maximum efficiency of a class A power amplifier is 25 percent.

Section 7–2

- A class B amplifier operates in the linear region for half of the input cycle (180°), and it is in cutoff for the other half.
- The Q-point is at cutoff for class B operation.
- Class B amplifiers are normally operated in a push-pull configuration in order to produce an output that is a replica of the input.
- The maximum efficiency of a class B amplifier is 79 percent.
- A class AB amplifier is biased slightly above cutoff and operates in the linear region for slightly more than 180° of the input cycle.
- Class AB eliminates crossover distortion found in pure class B.

Section 7–3

- A class C amplifier operates in the linear region for only a small part of the input cycle.
- The class C amplifier is biased below cutoff.
- Class C amplifiers are normally operated as tuned amplifiers to produce a sinusoidal output.
- The maximum efficiency of a class C amplifier is higher than that of either class A or class B amplifiers. Under conditions of low power dissipation and high output power, the efficiency can approach 100 percent.

KEY TERMS

Key terms and other bold terms in the chapter are defined in the end-of-book glossary.

Class A A type of amplifier that operates entirely in its linear (active) region.

Class AB A type of amplifier that is biased into slight conduction.

Class B A type of amplifier that operates in the linear region for 180° of the input cycle because it is biased at cutoff.

Class C A type of amplifier that operates only for a small portion of the input cycle.

Efficiency The ratio of the signal power delivered to a load to the power from the power supply of an amplifier.

Power gain The ratio of output power to input power of an amplifier.

Push-Pull A type of class B amplifier with two transistors in which one transistor conducts for one half-cycle and the other conducts for the other half-cycle.

KEY FORMULAS

The Class A Power Amplifier

7–1	$A_p = \dfrac{P_L}{P_{in}}$	Power gain
7–2	$A_p = A_v^2\left(\dfrac{R_{in}}{R_L}\right)$	Power gain in terms of voltage gain
7–3	$P_{DQ} = I_{CQ}V_{CEQ}$	DC quiescent power
7–4	$P_{out(max)} = 0.5I_{CQ}V_{CEQ}$	Maximum output power

The Class B/AB Push-Pull Amplifiers

7–5	$I_{c(sat)} = \dfrac{V_{CC}}{R_L}$	AC saturation current
7–6	$P_{out} = 0.25I_{c(sat)}V_{CC}$	Maximum average output power

7–7	$\eta_{max} = 0.79$	Maximum efficiency
7–8	$R_{in} = \beta_{ac}(r'_e + R_L) \parallel R_1 \parallel R_2$	Input resistance

The Class C Amplifier

7–9	$P_{out} = \dfrac{0.5V^2_{CC}}{R_c}$	Output power
7–10	$\eta = \dfrac{P_{out}}{P_{out} + P_{D(avg)}}$	Efficiency

TRUE/FALSE QUIZ

Answers can be found at www.pearsonhighered.com/floyd.

1. Class A power amplifiers are a type of large-signal amplifier.
2. Ideally, the Q-point should be centered on the load line in a class A amplifier.
3. The quiescent power dissipation occurs when the maximum signal is applied.
4. Efficiency is the ratio of output signal power to total power.
5. Each transistor in a class B amplifier conducts for the entire input cycle.
6. Class AB operation overcomes the problem of crossover distortion.
7. Complementary symmetry transistors must be used in a class AB amplifier.
8. A current mirror is implemented with a laser diode.
9. Darlington transistors can be used to increase the input resistance of a class AB amplifier.
10. The transistor in a class C amplifier conducts for a small portion of the input cycle.
11. The output of a class C amplifier is a replica of the input signal.
12. A class C amplifier usually employs a tuned circuit.

CIRCUIT-ACTION QUIZ

Answers can be found at www.pearsonhighered.com/floyd.

1. If the value of R_3 in Figure 7–5 is decreased, the voltage gain of the first stage will
   (a) increase **(b)** decrease **(c)** not change
2. If the value of R_{E2} in Figure 7–5 is increased, the voltage gain of the first stage will
   (a) increase **(b)** decrease **(c)** not change
3. If C_2 in Figure 7–5 opens, the dc voltage at the emitter of Q_1 will
   (a) increase **(b)** decrease **(c)** not change
4. If the value of R_4 in Figure 7–5 is increased, the dc voltage at the base of Q_3 will
   (a) increase **(b)** decrease **(c)** not change
5. If V_{CC} in Figure 7–18 is increased, the peak output voltage will
   (a) increase **(b)** decrease **(c)** not change
6. If the value of R_L in Figure 7–18 is increased, the ac output power will
   (a) increase **(b)** decrease **(c)** not change
7. If the value of R_L in Figure 7–19 is decreased, the voltage gain will
   (a) increase **(b)** decrease **(c)** not change
8. If the value of V_{CC} in Figure 7–19 is increased, the ac output power will
   (a) increase **(b)** decrease **(c)** not change
9. If the values of R_1 and R_2 in Figure 7–19 are increased, the voltage gain will
   (a) increase **(b)** decrease **(c)** not change
10. If the value of C_2 in Figure 7–24 is decreased, the resonant frequency will
    (a) increase **(b)** decrease **(c)** not change

SELF-TEST

Answers can be found at www.pearsonhighered.com/floyd.

Section 7–1

1. An amplifier that operates in the linear region at all times is

(a) Class A **(b)** Class AB **(c)** Class B **(d)** Class C

2. A certain class A power amplifier delivers 5 W to a load with an input signal power of 100 mW. The power gain is

(a) 100 **(b)** 50 **(c)** 250 **(d)** 5

3. The peak current a class A power amplifier can deliver to a load depends on the

(a) maximum rating of the power supply **(b)** quiescent current
(c) current in the bias resistors **(d)** size of the heat sink

4. For maximum output, a class A power amplifier must maintain a value of quiescent current that is

(a) one-half the peak load current **(b)** twice the peak load current
(c) at least as large as the peak load current **(d)** just above the cutoff value

5. A certain class A power amplifier has $V_{CEQ} = 12$ V and $I_{CQ} = 1$ A. The maximum signal power output is

(a) 6 W **(b)** 12 W **(c)** 1 W **(d)** 0.707 W

6. The efficiency of a power amplifier is the ratio of the power delivered to the load to the

(a) input signal power **(b)** power dissipated in the last stage
(c) power from the dc power supply **(d)** none of these answers

7. The maximum efficiency of a class A power amplifier is

(a) 25% **(b)** 50% **(c)** 79% **(d)** 98%

Section 7–2

8. The transistors in a class B amplifier are biased

(a) into cutoff **(b)** in saturation
(c) at midpoint of the load line **(d)** right at cutoff

9. Crossover distortion is a problem for

(a) class A amplifiers **(b)** class AB amplifiers
(c) class B amplifiers **(d)** all of these amplifiers

10. A BJT class B push-pull amplifier with no transformer coupling uses

(a) two *npn* transistors **(b)** two *pnp* transistors
(c) complementary symmetry transitors **(d)** none of these

11. A current mirror in a push-pull amplifier should give an I_{CQ} that is

(a) equal to the current in the bias resistors and diodes
(b) twice the current in the bias resistors and diodes
(c) half the current in the bias resistors and diodes
(d) zero

12. The maximum efficiency of a class B push-pull amplifier is

(a) 25% **(b)** 50% **(c)** 79% **(d)** 98%

13. The output of a certain two-supply class B push-pull amplifier has a V_{CC} of 20 V. If the load resistance is 50 Ω, the value of $I_{c(sat)}$ is

(a) 5 mA **(b)** 0.4 A **(c)** 4 mA **(d)** 40 mA

14. The maximum efficiency of a class AB amplifier is

(a) higher than a class B **(b)** the same as a class B
(c) about the same as a class A **(d)** slightly less than a class B

Section 7–3

15. The power dissipation of a class C amplifier is normally

(a) very low **(b)** very high **(c)** the same as a class B **(d)** the same as a class A

16. The efficiency of a class C amplifier is

(a) less than class A **(b)** less than class B
(c) less than class AB **(d)** greater than classes A, B, or AB

17. The transistor in a class C amplifier conducts for
   (a) more than 180° of the input cycle
   (b) one-half of the input cycle
   (c) a very small percentage of the input cycle
   (d) all of the input cycle

PROBLEMS

Answers to all odd-numbered problems are at the end of the book.

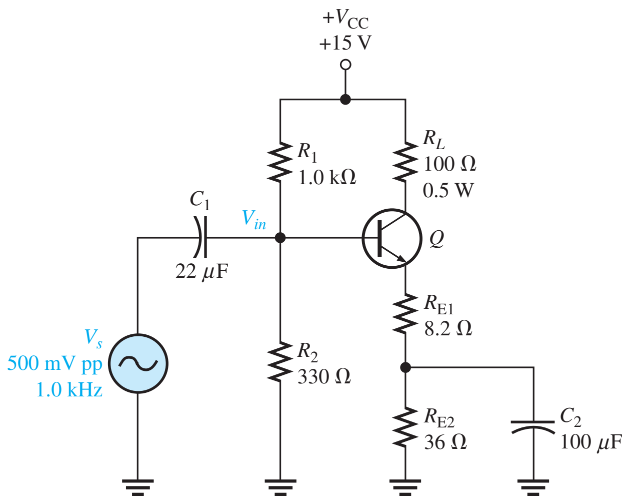
BASIC PROBLEMS

Section 7–1 **The Class A Power Amplifier**

1. Figure 7–42 shows a CE power amplifier in which the collector resistor serves also as the load resistor. Assume $\beta_{DC} = \beta_{ac} = 100$.
   (a) Determine the dc Q-point (I_{CQ} and V_{CEQ}).
   (b) Determine the voltage gain and the power gain.

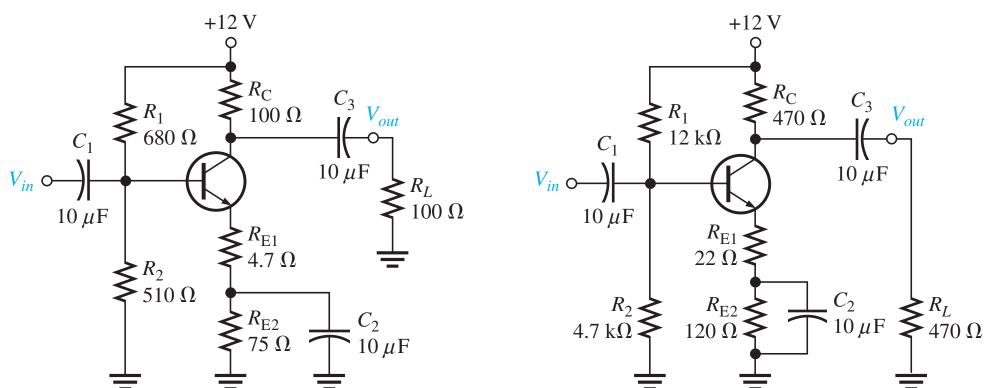
▶ FIGURE 7–42

Multisim file circuits are identified with a logo and are in the Problems folder on the companion website. Filenames correspond to figure numbers (e.g., F07-42).



2. For the circuit in Figure 7–42, determine the following:
   (a) the power dissipated in the transistor with no load
   (b) the total power from the power supply with no load
   (c) the signal power in the load with a 500 mV input
3. Refer to the circuit in Figure 7–42. What changes would be necessary to convert the circuit to a *pnp* transistor with a positive supply? What advantage would this have?
4. Assume a CC amplifier has an input resistance of 2.2 kΩ and drives an output load of 50 Ω. What is the power gain?
5. Determine the Q-point for each amplifier in Figure 7–43.

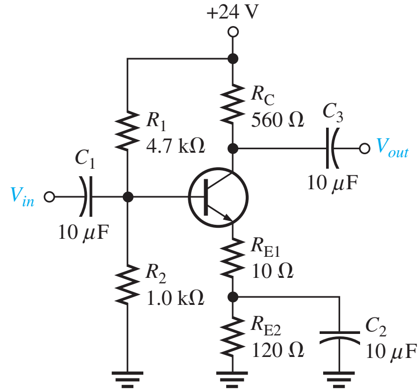
▶ FIGURE 7–43



(a) $\beta_{ac} = \beta_{DC} = 125$ (b) $\beta_{ac} = \beta_{DC} = 120$

6. If the load resistor in Figure 7–43(a) is changed to 50 Ω, how much does the Q-point change?
7. What is the maximum peak value of collector current that can be realized in each circuit of Figure 7–43? What is the maximum peak value of output voltage in each circuit?
8. Find the power gain for each circuit in Figure 7–43. Neglect r'_e.
9. Determine the minimum power rating for the transistor in Figure 7–44.
10. Find the maximum output signal power to the load and efficiency for the amplifier in Figure 7–44 with a 500 Ω load resistor.

▶ **FIGURE 7–44**

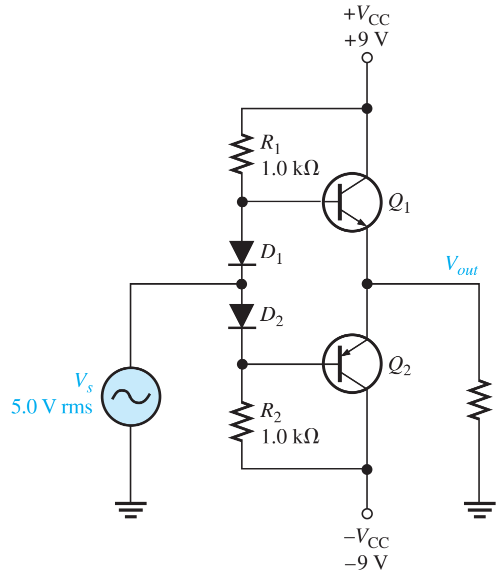


$\beta_{ac} = \beta_{DC} = 90$; $r'_e = 10\ \Omega$

Section 7–2 **The Class B and Class AB Push-Pull Amplifiers**

11. Refer to the class AB amplifier in Figure 7–45.
    (a) Determine the dc parameters $V_{B(Q1)}$, $V_{B(Q2)}$, V_E, I_{CQ}, $V_{CEQ(Q1)}$, $V_{CEQ(Q2)}$.
    (b) For the 5 V rms input, determine the power delivered to the load resistor.

▶ **FIGURE 7–45**



12. Draw the load line for the *npn* transistor in Figure 7–45. Label the saturation current, $I_{c(sat)}$, and show the Q-point.

13. Determine the approximate input resistance seen by the signal source for the amplifier of Figure 7–45 if $\beta_{ac} = 100$.

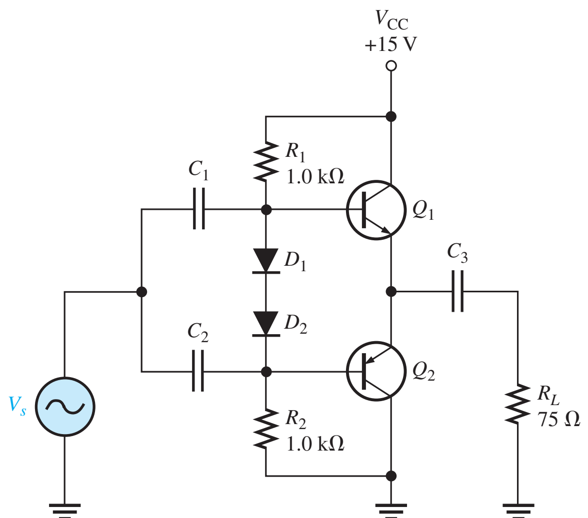
14. If D_2 has more voltage drop than D_1, what effect does this have on the output?

15. Refer to the class AB amplifier in Figure 7–46 operating with a single power supply.
    - **(a)** Determine the dc parameters $V_{B(Q1)}$, $V_{B(Q2)}$, V_E, I_{CQ}, $V_{CEQ(Q1)}$, $V_{CEQ(Q2)}$.
    - **(b)** Assuming the input voltage is 10 V pp, determine the power delivered to the load resistor.

16. Refer to the class AB amplifier in Figure 7–46.
    - **(a)** What is the maximum power that could be delivered to the load resistor?
    - **(b)** Assume the power supply voltage is raised to 24 V. What is the new maximum power that could be delivered to the load resistor?

17. Refer to the class AB amplifier in Figure 7–46. What fault or faults could account for each of the following troubles?
    - **(a)** a positive half-wave output signal
    - **(b)** zero volts on both bases and the emitters
    - **(c)** no output: emitter voltage = +15 V
    - **(d)** crossover distortion observed on the output waveform

18. If a 1 V rms signal source with an internal resistance of 50 Ω is connected to the amplifier in Figure 7–46, what is the actual rms signal applied to the amplifier input? Assume $\beta_{ac} = 200$.



▲ FIGURE 7–46

Section 7–3 The Class C Amplifier

19. A certain class C amplifier transistor is on for 10 percent of the input cycle. If $V_{ce(sat)} = 0.18$ V and $I_{c(sat)} = 25$ mA, what is the average power dissipation for maximum output?

20. What is the resonant frequency of a tank circuit with $L = 10$ mH and $C = 0.001\ \mu$F?

21. What is the maximum peak-to-peak output voltage of a tuned class C amplifier with $V_{CC} = 12$ V?

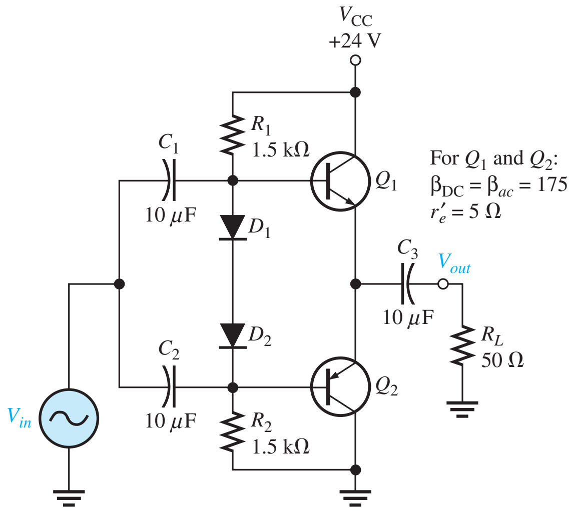
22. Determine the efficiency of the class C amplifier described in Problem 21 if $V_{CC} = 15$ V and the equivalent parallel resistance in the collector tank circuit is 50 Ω. Assume that the transistor is on for 10% of the period.

Section 7–4 Troubleshooting

23. Refer to Figure 7–47. What would you expect to observe across R_L if C_1 opened?

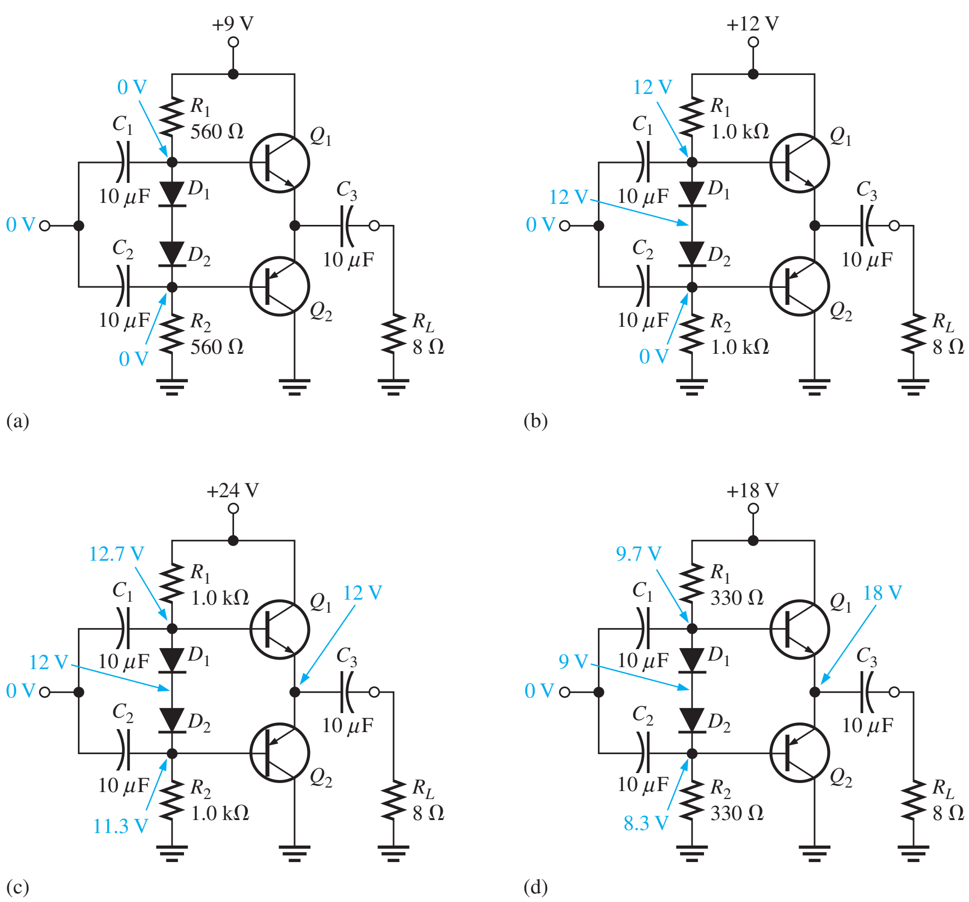
24. Your oscilloscope displays a half-wave output when connected across R_L in Figure 7–47. What is the probable cause?

▶ FIGURE 7–47



25. Determine the possible fault or faults, if any, for each circuit in Figure 7–48 based on the indicated dc voltage measurements.

▶ FIGURE 7–48



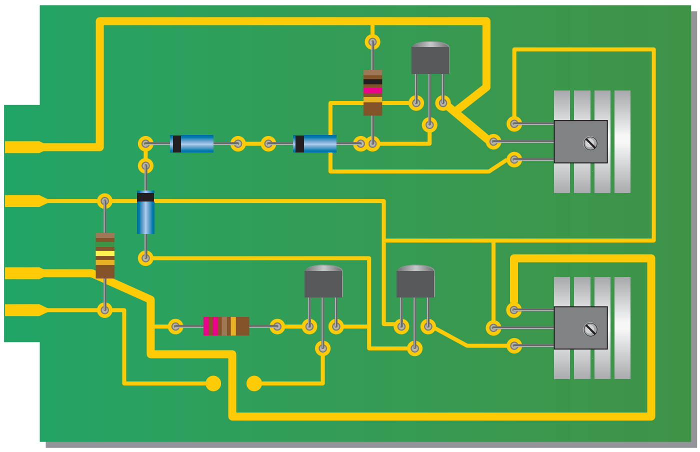
APPLICATION ACTIVITY PROBLEMS

26. Assume that the public address system represented by the block diagram in Figure 7–34 has quit working. You find there is no signal output from the power amplifier or the preamplifier, but you have verified that the microphone is working. Which two blocks are the most likely to be the problem? How would you narrow the choice down to one block?

27. Describe the output that would be observed in the push-pull amplifier of Figure 7–35 with a 2 V rms sinusoidal input voltage if the base-emitter junction of Q_2 opened.

28. Describe the output that would be observed in Figure 7–35 if the collector-emitter junction of Q_5 opened for the same input as in Problem 27.

29. After visually inspecting the power amplifier circuit board in Figure 7–49, describe any problems.



▲ FIGURE 7–49

DATASHEET PROBLEMS

30. Referring to the datasheet in Figure 7–50, determine the following:

(a) minimum β_{DC} for the BD135 and the conditions

(b) maximum collector-to-emitter voltage for the BD135

(c) maximum power dissipation for the BD135 at a case temperature of 25°C

(d) maximum continuous collector current for the BD135

31. Determine the maximum power dissipation for a BD135 at a case temperature of 50°C.

32. Determine the maximum power dissipation for a BD135 at an ambient temperature of 50°C.

33. Describe what happens to the dc current gain as the collector current increases.

34. Determine the approximate h_{FE} for the BD135 at $I_C = 20$ mA.

ADVANCED PROBLEMS

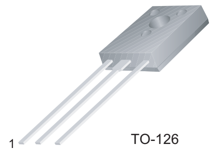
35. Explain why the specified maximum power dissipation of a power transistor at an ambient temperature of 25°C is much less than maximum power dissipation at a case temperature of 25°C.

FAIRCHILD SEMICONDUCTOR™

BD135/137/139

Medium Power Linear and Switching Applications

- Complement to BD136, BD138 and BD140 respectively



NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_C = 25°C unless otherwise noted

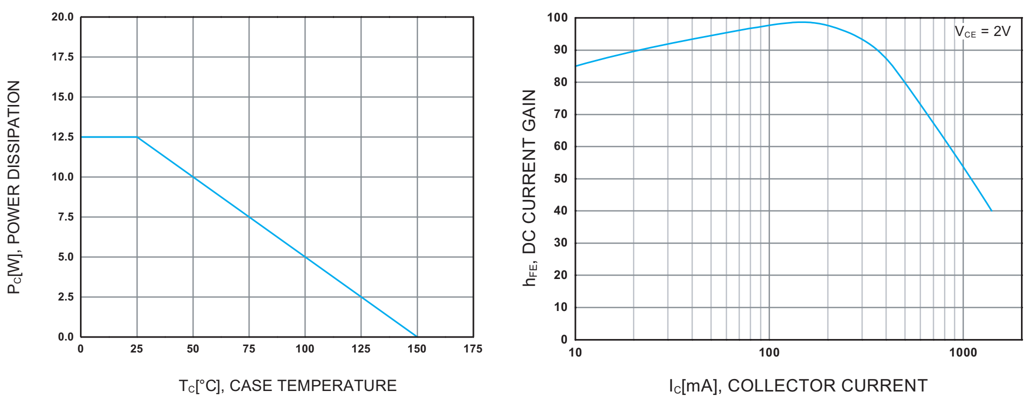
Symbol	Parameter		Value	Units
V_{CBO}	Collector-Base Voltage	: BD135 : BD137 : BD139	45 60 80	V V V
V_{CEO}	Collector-Emitter Voltage	: BD135 : BD137 : BD139	45 60 80	V V V
V_{EBO}	Emitter-Base Voltage		5	V
I_C	Collector Current (DC)		1.5	A
I_{CP}	Collector Current (Pulse)		3.0	A
I_B	Base Current		0.5	A
P_C	Collector Dissipation (T_C = 25°C)		12.5	W
P_C	Collector Dissipation (T_a = 25°C)		1.25	W
T_J	Junction Temperature		150	°C
T_{STG}	Storage Temperature		- 55 ~ 150	°C

Electrical Characteristics T_C = 25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Units
V_{CEO}(sus)	Collector-Emitter Sustaining Voltage : BD135 : BD137 : BD139	I_C = 30mA, I_B = 0	 45 60 80			 V V V
I_{CBO}	Collector Cut-off Current	V_{CB} = 30V, I_E = 0			0.1	μA
I_{EBO}	Emitter Cut-off Current	V_{EB} = 5V, I_C = 0			10	μA
h_{FE1} h_{FE2} h_{FE3}	DC Current Gain : ALL DEVICE : ALL DEVICE : BD135 : BD137, BD139	V_{CE} = 2V, I_C = 5mA V_{CE} = 2V, I_C = 0.5A V_{CE} = 2V, I_C = 150mA	25 25 40 40		 250 160	
V_{CE}(sat)	Collector-Emitter Saturation Voltage	I_C = 500mA, I_B = 50mA			0.5	V
V_{BE}(on)	Base-Emitter ON Voltage	V_{CE} = 2V, I_C = 0.5A			1	V

h_{FE} Classification

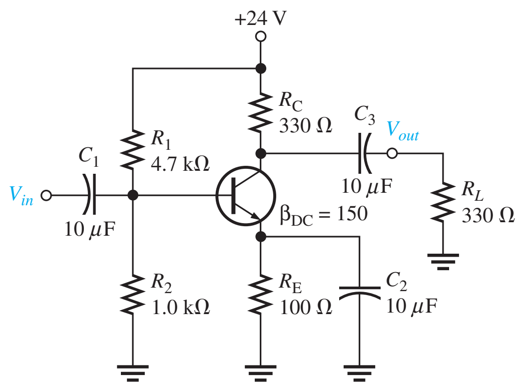
Classification	6	10	16
h_{FE3}	40 ~ 100	63 ~ 160	100 ~ 250



▲ **FIGURE 7–50**

36. Draw the dc and the ac load lines for the amplifier in Figure 7–51.

▶ FIGURE 7–51



37. Design a swamped class A power amplifier that will operate from a dc supply of +15 V with an approximate voltage gain of 50. The quiescent collector current should be approximately 500 mA, and the total dc current from the supply should not exceed 750 mA. The output power must be at least 1 W.

38. The public address system in Figure 7–34 is a portable unit that is independent of 115 V ac. Determine the ampere-hour rating for the +15 V and the −15 V battery supply necessary for the system to operate for 4 hours on a continuous basis.

MULTISIM TROUBLESHOOTING PROBLEMS

These file circuits are in the Troubleshooting Problems folder on the companion website.

39. Open file TSP07-39 and determine the fault.

40. Open file TSP07-40 and determine the fault.

41. Open file TSP07-41 and determine the fault.

42. Open file TSP07-42 and determine the fault.

43. Open file TSP07-43 and determine the fault.