

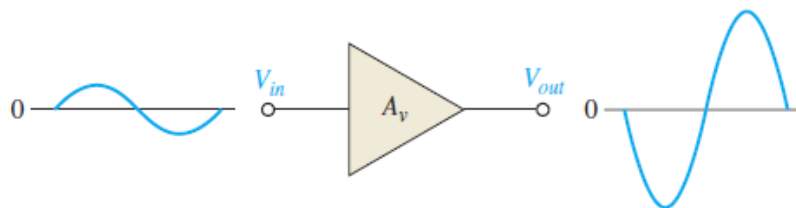
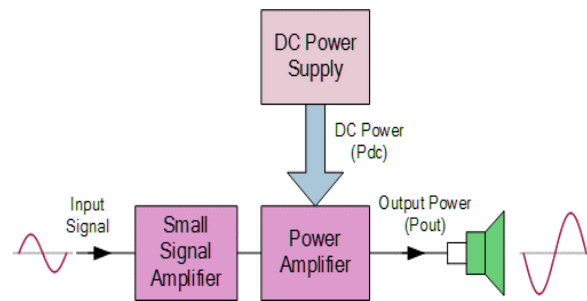
## LECTURE THREE

### POWER AMPLIFIER

#### 3.1 THE CLASS A POWER AMPLIFIER

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.

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 3. 1:** Basic class A amplifier operation.

#### 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

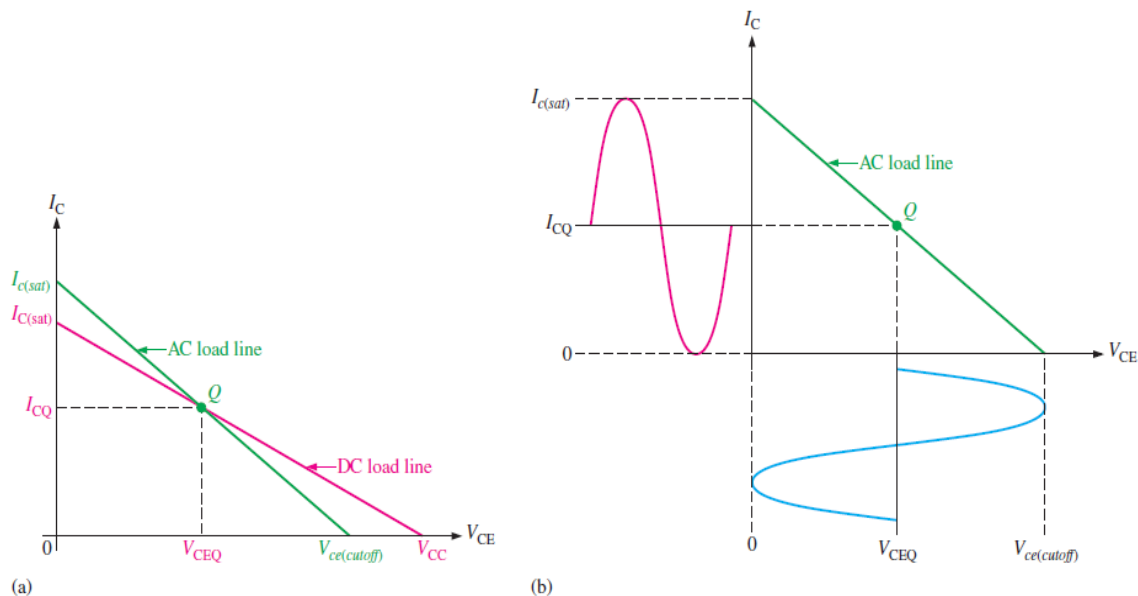
through the case to the heat sink and then dissipates in the surrounding air. Heat sinks vary in size, number of fins, and type of material.

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 3-2(a). The collector current can vary from its Q-point value,  $I_{CQ}$ , up to its saturation value,  $I_{c(sat)}$ , and down to its cutoff value of zero.

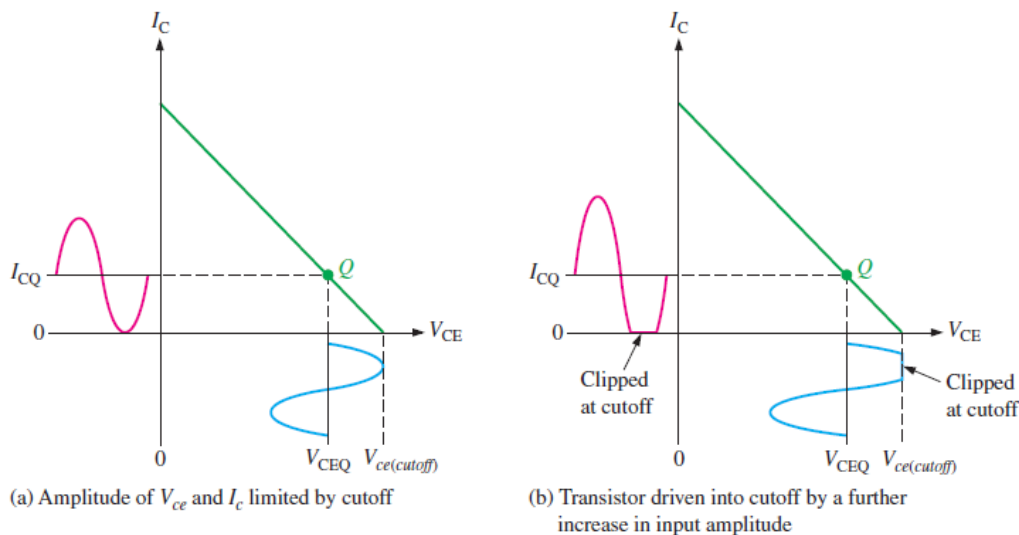
Likewise, the collector-to-emitter voltage can swing from its Q-point value,  $V_{CEQ}$ , up to its cutoff value,  $V_{ce(cutoff)}$ , and down to its saturation value of near zero. This operation is indicated in Figure 3-2(b). The peak value of the collector current equals  $I_{CQ}$ , and the peak value 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.



**Figure 3. 2:** Basic class A amplifier operation.

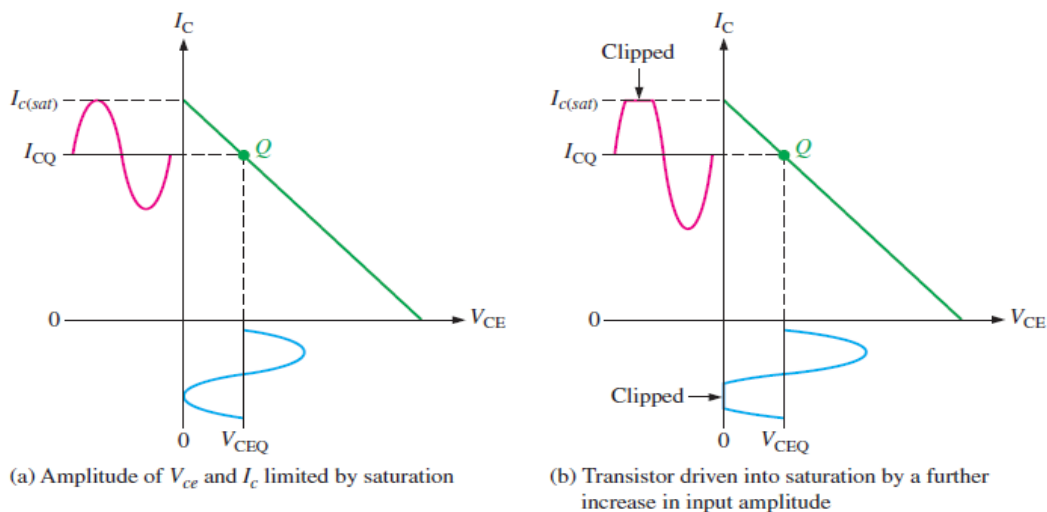
Actually, the output cannot quite reach saturation or cutoff, so the practical maximum is slightly less.

If the Q-point is not centered on the ac load line, the output signal is limited. Figure 3–3 shows an ac load line with the Q-point moved away from the center toward cutoff.



**Figure 3. 3: Q-point closer to cutoff.**

Figure 3–4 shows an ac load line with the Q-point moved away from the center toward saturation.



**Figure 3. 4: Q-point closer to saturation.**



## 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

$$A_p = \frac{P_L}{P_{in}} \quad \text{Equation 3-1}$$

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

The power gain can be computed by any of several formulas, depending on what is known.

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

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 3-1, the following useful relationship is produced:

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

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

$$A_p = A_v^2 \left( \frac{R_{in}}{R_L} \right) \quad \text{Equation 3-2}$$

Recall from Lecture 2, that for a voltage-divider biased amplifier

$$R_{in}(tot) = R1 // R2 // R_{in}(base) \quad \text{Where } R_{in}(base) = \beta_{ac} R_e$$

## DC Quiescent Power

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

$$P_{DQ} = I_{CQ}V_{CEQ} \quad \text{Equation 3-3}$$

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 3-3, is the maximum power that a class A amplifier must handle.

### EXAMPLE 3-1

Determine the voltage gain and the power gain of the class A power amplifier in Figure 3-5. Assume  $\beta_{ac} = 200$  for all transistors.

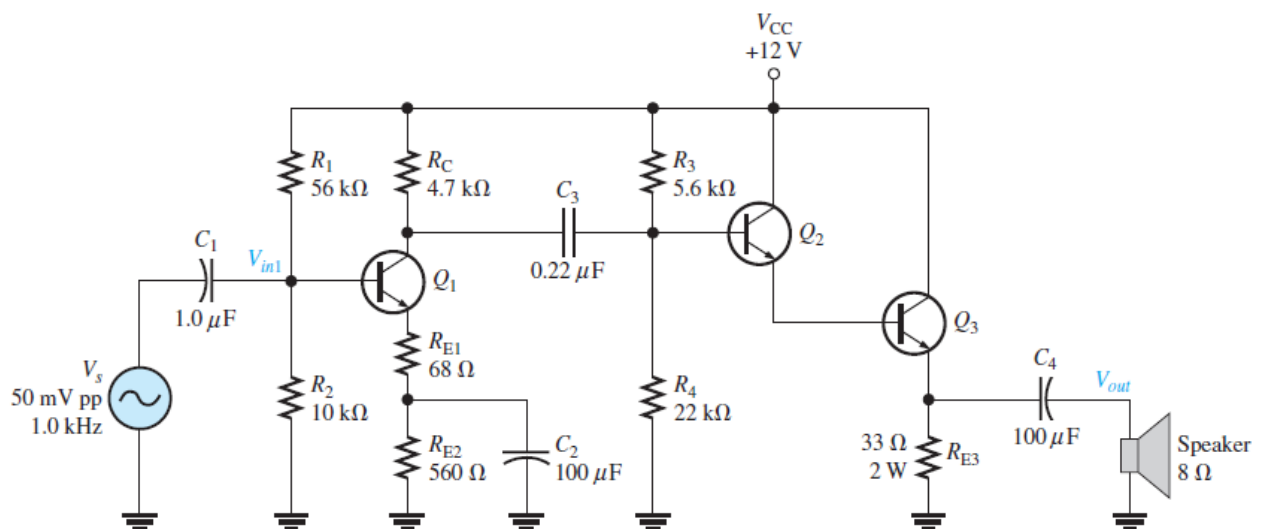


Figure 3. 5



### Solution

Notice that the first stage ( $Q1$ ) is a voltage-divider biased common-emitter with a swamping resistor ( $R_{E1}$ ). The second stage ( $Q2$  and  $Q3$ ) is a **Darlington** voltage follower configuration. The speaker is the load.

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

$$R_{c1} = RC \parallel (R3 \parallel R4) = 4.7k\Omega \parallel 5.6k\Omega \parallel 22k\Omega = 2.29k\Omega$$

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  $I_E$ .

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

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

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

Using the value of  $r'_{e}$ , determine the voltage gain of the first stage with the loading of the second stage taken into account

$$A_{V1} = \left(\frac{R_{C1}}{R_{E1} + r'_{e(Q1)}}\right) = \left(\frac{2.29k\Omega}{68\Omega + 14\Omega}\right) = 27.9$$

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  $Q1$ .



$$\begin{aligned}R_{in(tot)1} &= R1 // R2 // \beta_{ac(Q1)}(R_{E1} + r'_{e(Q1)}) \\ &= 56k\Omega // 10k\Omega // 200(68 \Omega + 14 \Omega) = 8.4k\Omega\end{aligned}$$

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

$$A_{v2} \approx 1$$

**Overall amplifier:**

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

**Power gain:**

The power gain of the amplifier can be calculated using Equation 3–2.

$$A_P = A_{v(tot)}^2 \left( \frac{R_{in(tot)}}{R_L} \right) = (27.9)^2 \left( \frac{8.4k\Omega}{8\Omega} \right) = 817,330$$

**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 3–4.

The maximum efficiency,  $\eta_{max}$  of a capacitively coupled class A amplifier is

$$\eta_{max} = \frac{P_{out}}{P_{DC}}$$

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%)



### EXAMPLE 3–2

Determine the efficiency of the power amplifier in (Example 3–1).

#### *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,

$$P_{in} = \frac{v_{in}^2}{R_{in}} = \frac{33.4mV^2}{8.4k\Omega} = 149nW$$

The output power is

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

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  $Q_3$ .

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

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

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

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

Therefore, the efficiency of the amplifier for this input is

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

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

### 3.2 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  $180^\circ$  of the input cycle and is in cutoff for  $180^\circ$ , it is a **class B** amplifier. Class AB amplifiers are biased to conduct for slightly more than  $180^\circ$ . 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 to get a linear reproduction of the input waveform.

#### Class B Operation

The class B operation is illustrated in Figure 3–6, where the output waveform is shown relative to the input in terms of time ( $t$ ).

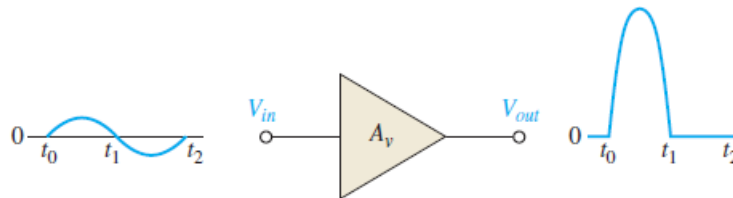
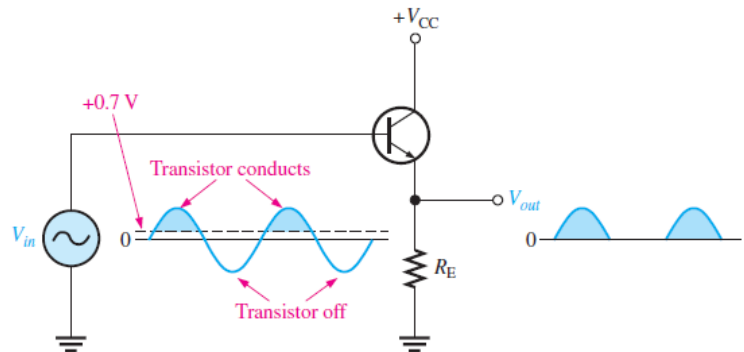


Figure 3. 6: Basic class B amplifier operation (noninverting).

### 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 3–7 with an emitter-follower circuit where the output is not a replica of the input.

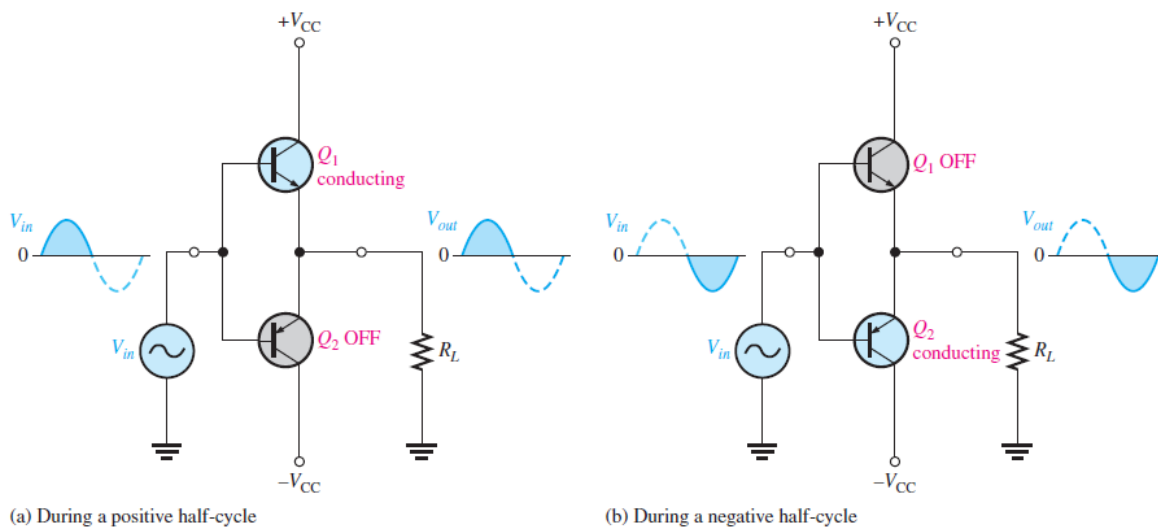


**Figure 3. 7**

### Class B Push-Pull Operation

As you can see, the circuit in Figure 3–7 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.

**Complementary Symmetry Transistors:** One of the most popular types of push-pull class B amplifiers using two emitter-followers and both positive and negative



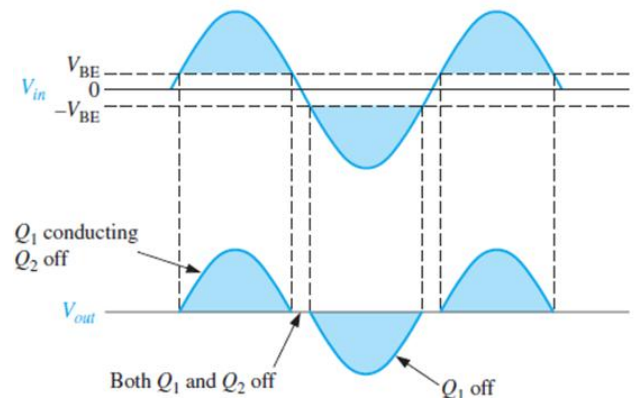
**Figure 3. 8: Class B push-pull ac operation**

power supplies. This is a complementary amplifier because one emitter-follower uses a *nnp* transistor and the other a *npn*, which conduct on opposite alternations of the input cycle

### 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.

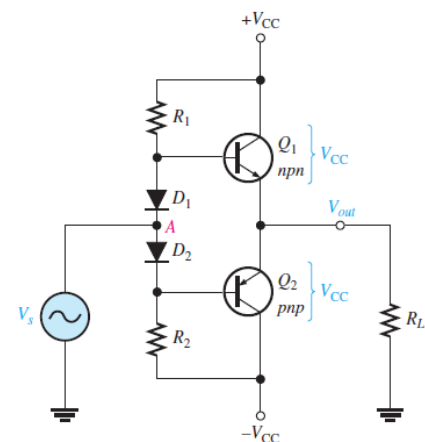
Because of this, there is a time interval between the positive and negative alternations of the input when neither transistor is conducting, as shown in Figure 3–9. The resulting distortion in the output waveform is called **crossover distortion**.



*Figure 3. 9: Illustration of crossover distortion in a class B push-pull amplifier.*

### 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 3–10. When the diode characteristics of  $D1$  and  $D2$  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**.



*Figure 3. 10: Biasing the push-pull amplifier*

In the bias path of the circuit in Figure 3–10,  $R_1$  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:

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

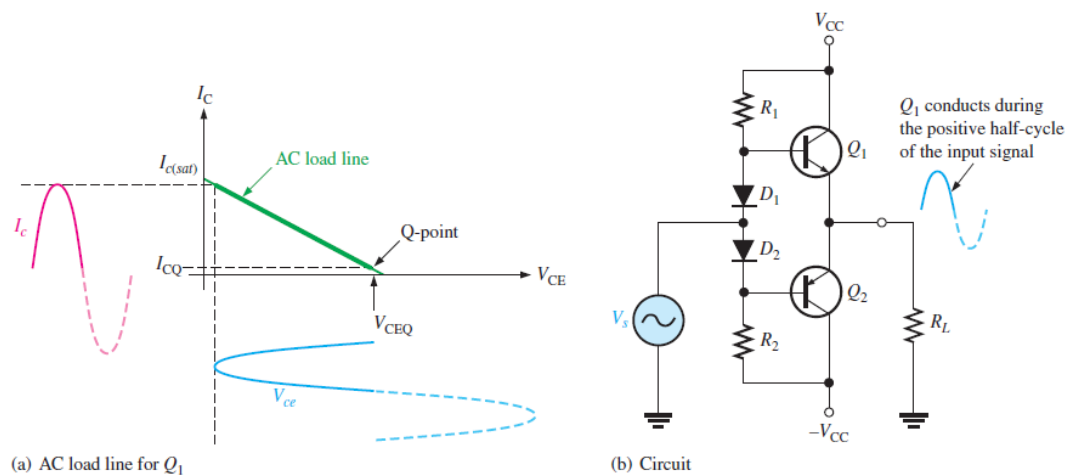
### AC Operation

Consider the ac load line for  $Q_1$  of the class AB amplifier in Figure 3–10. The Q-point is slightly above the cutoff.

The ac saturation current for a two-supply operation with a push-pull amplifier is

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

Figure 3–11(a) illustrates the ac load line for  $Q_1$  of the class AB amplifier in Figure 3–11(b).



**Figure 3. 11**

### EXAMPLE 7-3

Determine the ideal maximum peak output voltage and current for the circuit shown in Figure 7-12.

#### Solution

The ideal maximum peak output voltage is

$$V_{out(peak)} \approx V_{CEQ} \approx V_{CC} = 20 \text{ V}$$

The ideal maximum peak current is

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

The actual maximum values of voltage and current are slightly smaller

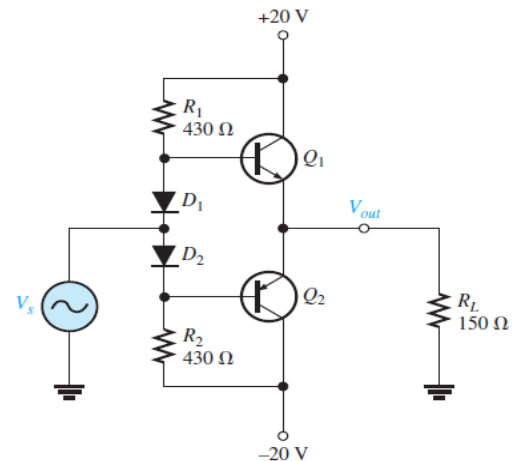


Figure 3. 12

### Single-Supply Push-Pull Amplifier

Push-pull amplifiers using complementary symmetry transistors can be operated from a single voltage source as shown in Figure 3-13. 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, capacitive coupling for the input and output is necessary to block the bias voltage from the source and the load resistor.

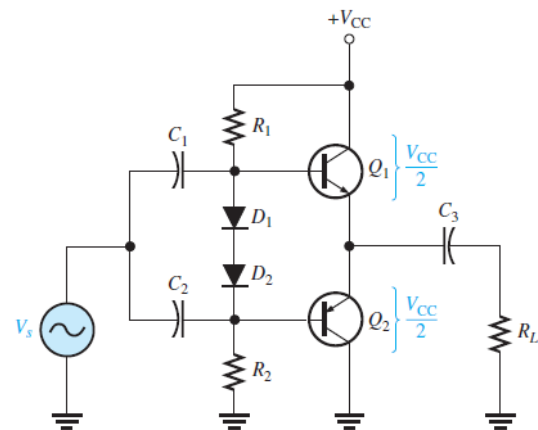


Figure 3. 13: Single-ended push-pull amplifier

### EXAMPLE 3–4

Determine the maximum ideal peak values for the output voltage and current in Figure 3–14.

#### Solution

The maximum peak output voltage is

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

The maximum peak output current is

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

