CHAPTER 5 –POWER AMPLIFIERS

NUMERICAL

EXAMPLE ON SERIES FED CLASS A POWER AMPLIFIER

Fig. 16.5 for an input voltage that results in a base current of 10 mA peak.

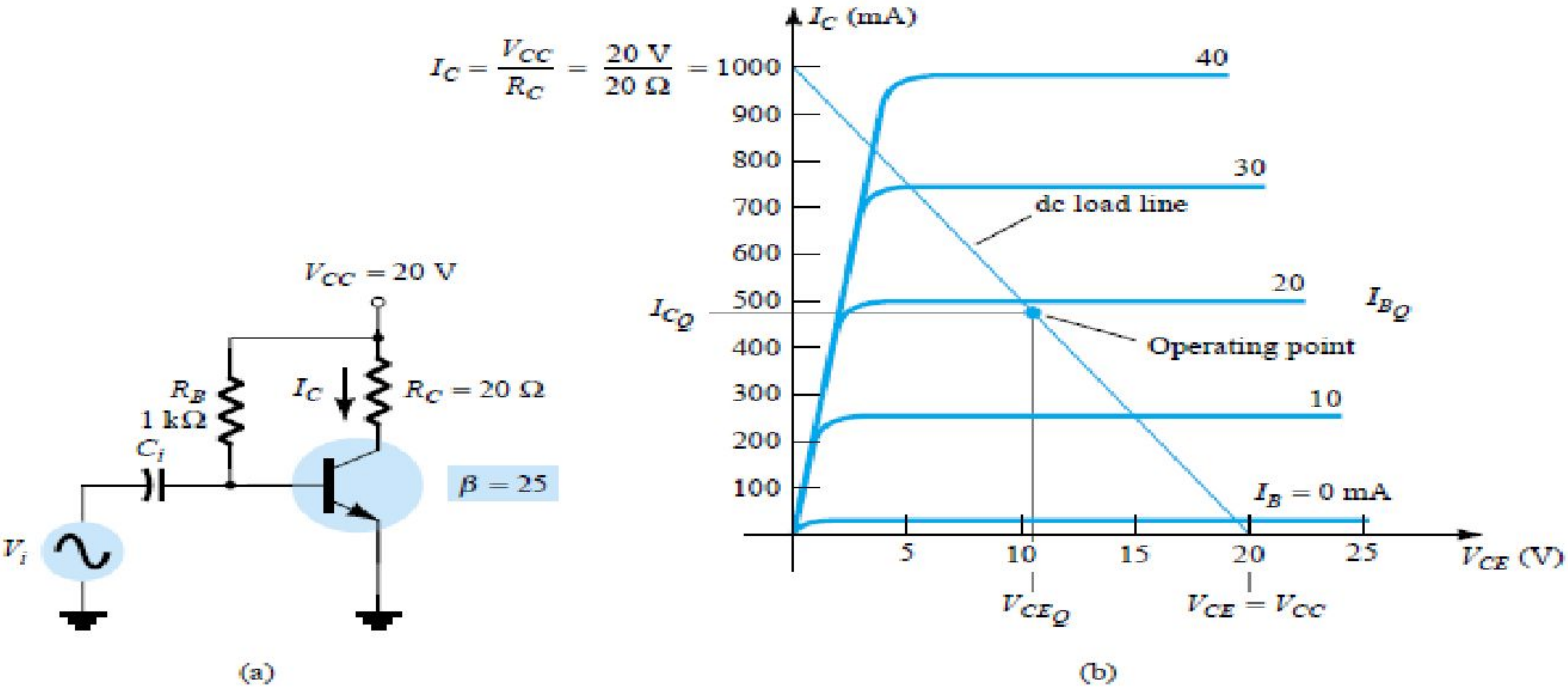


Figure 16.5 Operation of a series-fed circuit for Example 16.1.

Using Eqs. (16.1) through (16.3), the Q-point can be determined to be

$$I_{B_Q} = \frac{V_{CC} - 0.7\text{ V}}{R_B} = \frac{20\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = 19.3\text{ mA}$$

$$I_{C_Q} = \beta I_B = 25(19.3\text{ mA}) = 482.5\text{ mA} \cong 0.48\text{ A}$$

$$V_{CE_Q} = V_{CC} - I_C R_C = 20\text{ V} - (0.48\ \Omega)(20\ \Omega) = 10.4\text{ V}$$

This bias point is marked on the transistor collector characteristic of Fig. 16.5b. The ac variation of the output signal can be obtained graphically using the dc load line drawn on Fig. 16.5b by connecting $V_{CE} = V_{CC} = 20$ V with $I_C = V_{CC}/R_C =$ 1000 mA = 1 A, as shown. When the input ac base current increases from its dc bias level, the collector current rises by

$$I_C(\text{p}) = \beta I_B(\text{p}) = 25(10\text{ mA peak}) = 250\text{ mA peak}$$

Using Eq. (16.6b) yields

$$P_o(\text{ac}) = \frac{I_C^2(\text{p})}{2} R_C = \frac{(250 \times 10^{-3}\ \text{A})^2}{2}(20\ \Omega) = 0.625\ \text{W}$$

Using Eq. (16.4) results in

$$P_i(\text{dc}) = V_{CC} I_{C_Q} = (20\ \text{V})(0.48\ \text{A}) = 9.6\ \text{W}$$

The amplifier's power efficiency can then be calculated using Eq. (16.8):

$$\%\ \eta = \frac{P_o(\text{ac})}{P_i(\text{dc})} \times 100\% = \frac{0.625\ \text{W}}{9.6\ \text{W}} \times 100\% = 6.5\%$$

TRANSFORMER COUPLED CLASS A POWER AMPLIFIER

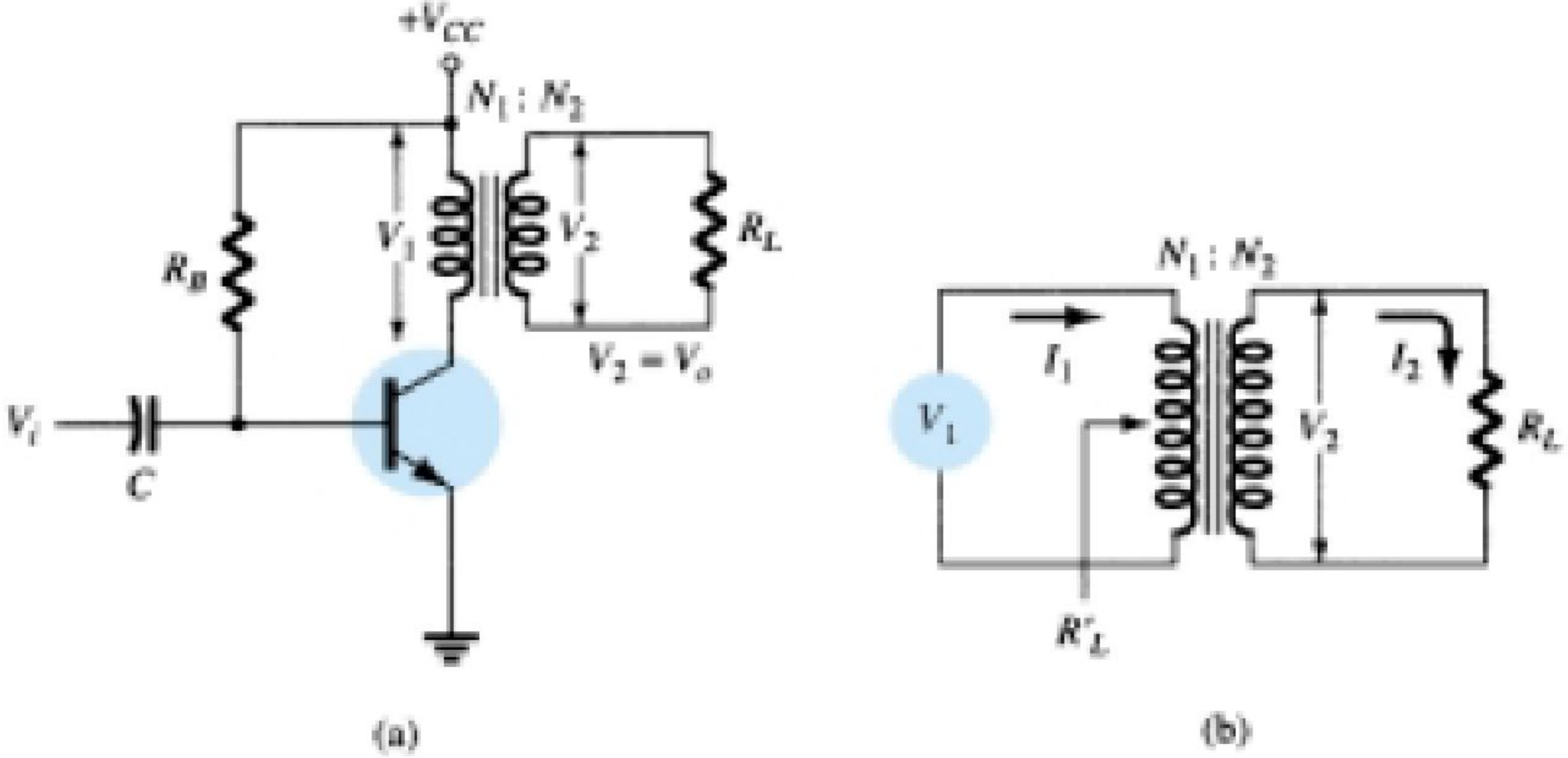
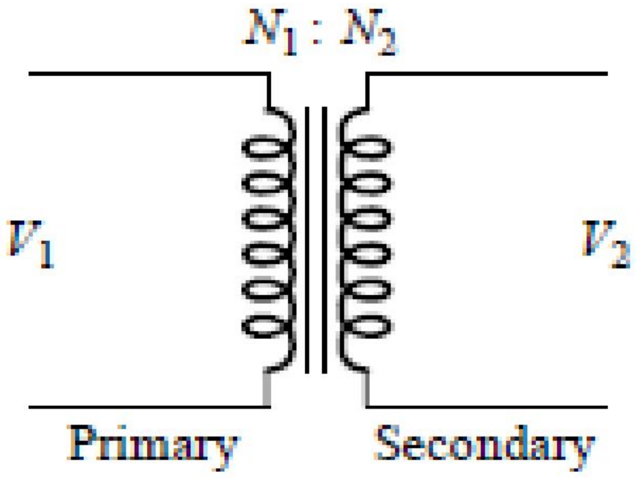


Figure 16.6 Transformer-coupled audio power amplifier.

TRANSFORMER COUPLED CLASS A POWER AMPLIFIER

VOLTAGE TRANSFORMATION

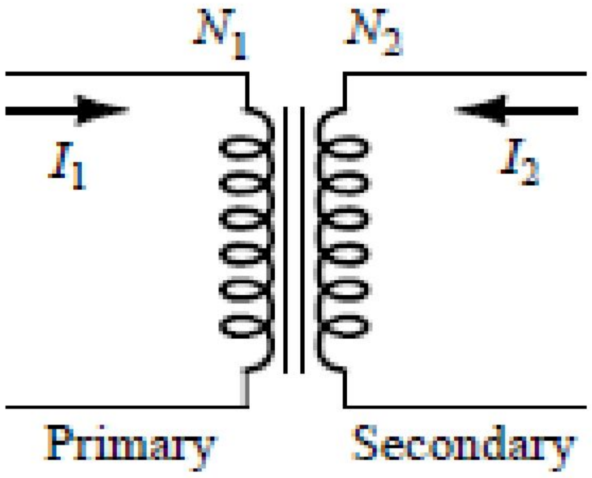
$$\boxed{\frac{V_2}{V_1} = \frac{N_2}{N_1}}$$



$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

CURRENT TRANSFORMATION

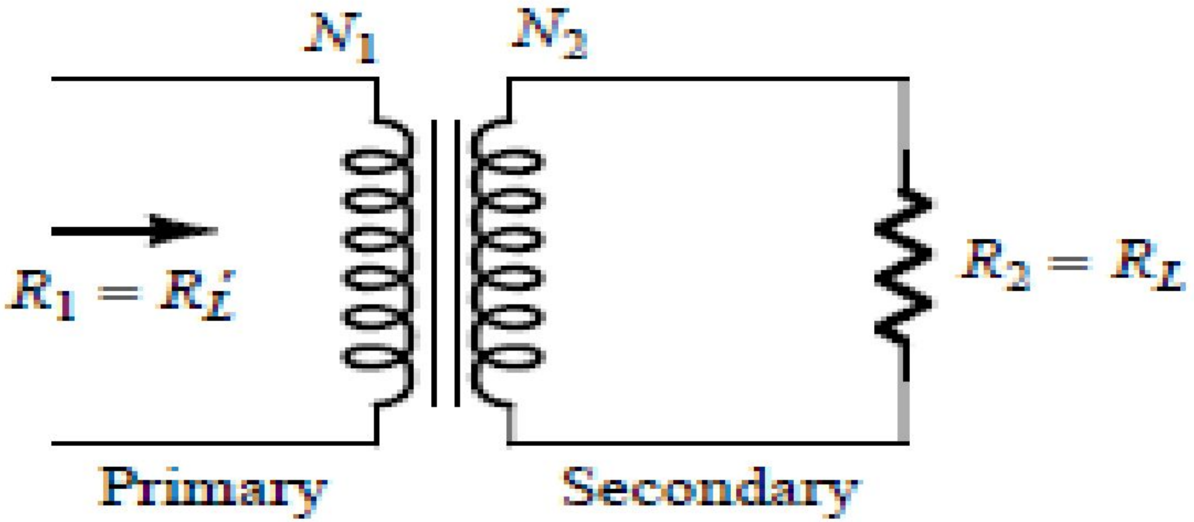
$$\boxed{\frac{I_2}{I_1} = \frac{N_1}{N_2}}$$



$$\frac{I_2}{I_1} = \frac{N_1}{N_2}$$

TRANSFORMER COUPLED CLASS A POWER AMPLIFIER

IMPEDANCE MATCHING



$$R_L' = a^2 R_L = \left(\frac{N_1}{N_2}\right)^2 R_L$$

Since the voltage and current can be changed by a transformer, an impedance "seen" from either side (primary or secondary) can also be changed. As shown in Fig. 16.7c, an impedance R_L is connected across the transformer secondary. This impedance is changed by the transformer when viewed at the primary side (R_L'). This can be shown as follows:

$$\frac{R_L}{R_L'} = \frac{R_2}{R_1} = \frac{V_2/I_2}{V_1/I_1} = \frac{V_2}{I_2}\,\frac{I_1}{V_1} = \frac{V_2}{V_1}\,\frac{I_1}{I_2} = \frac{N_2}{N_1}\,\frac{N_2}{N_1} = \left(\frac{N_2}{N_1}\right)^2$$

IMPEDANCE MATCHING

If we define $a = N_1/N_2$, where a is the turns ratio of the transformer, the above equation becomes

$$\boxed{\frac{R_L'}{R_L} = \frac{R_1}{R_2} = \left(\frac{N_1}{N_2}\right)^2 = a^2} \qquad (16.11)$$

We can express the load resistance reflected to the primary side as:

$$\boxed{R_1 = a^2 R_2} \quad \text{or} \quad \boxed{R_L' = a^2 R_L} \qquad (16.12)$$

where R_L' is the reflected impedance. As shown in Eq. (16.12), the reflected impedance is related directly to the square of the turns ratio. If the number of turns of the secondary is smaller than that of the primary, the impedance seen looking into the primary is larger than that of the secondary by the square of the turns ratio.

EXAMPLES

1 Calculate the effective resistance seen looking into the primary of a 15:1 transformer connected to an 8-Ω load.

Solution

$$\text{Eq. (16.12):} \quad R'_L = a^2 R_L = (15)^2(8\ \Omega) = 1800\ \Omega = \mathbf{1.8\ k\Omega}$$

2 What transformer turns ratio is required to match a 16-Ω speaker load so that the effective load resistance seen at the primary is 10 kΩ?

Solution

$$\text{Eq. (16.11):} \quad \left(\frac{N_1}{N_2}\right)^2 = \frac{R'_L}{R_L} = \frac{10\ \text{k}\Omega}{16\ \Omega} = 625$$

$$\frac{N_1}{N_2} = \sqrt{625} = \mathbf{25:1}$$

EXAMPLES

Calculate the ac power delivered to the 8-Ω speaker for the circuit of Fig. 16.10. The circuit component values result in a dc base current of 6 mA, and the input signal (V_i) results in a peak base current swing of 4 mA.

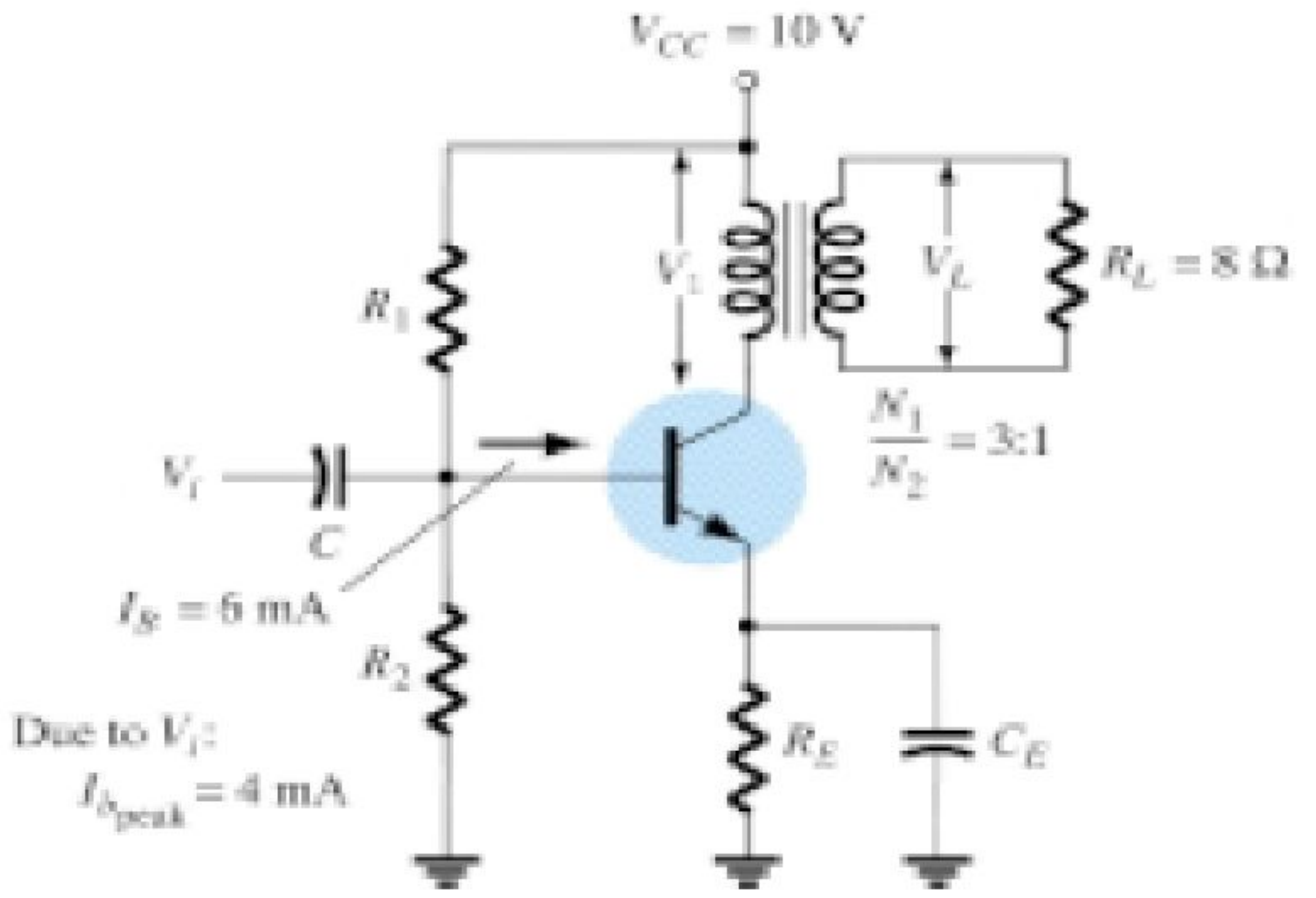


Figure 16.10 Transformer-coupled class A amplifier for Example 16.4.

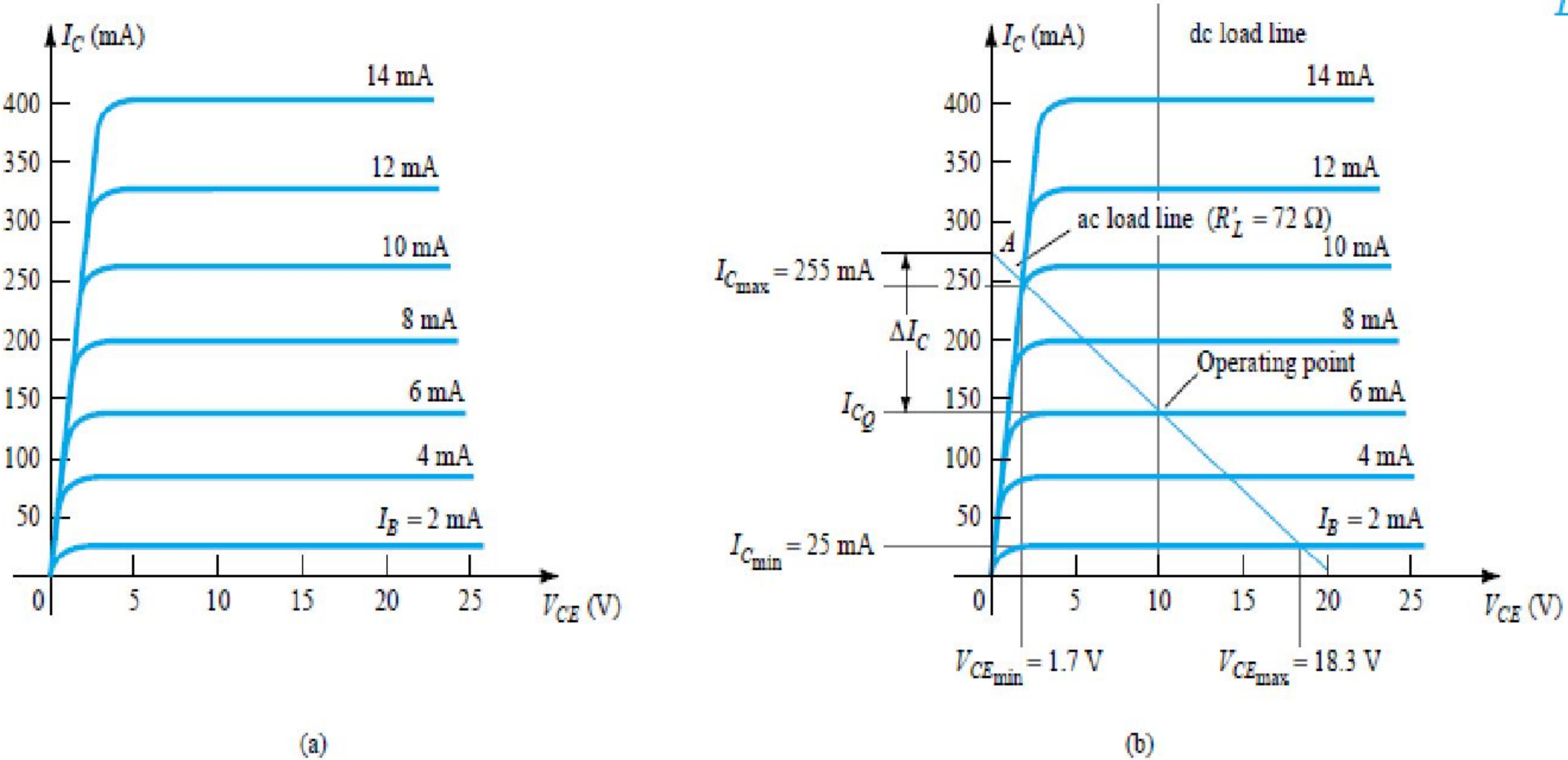


Figure 16.11 Transformer-coupled class A transistor characteristic for Examples 16.4 and 16.5: (a) device characteristic; (b) dc and ac load lines.

Solution

The dc load line is drawn vertically (see Fig. 16.11) from the voltage point:

$$V_{CE_Q} = V_{CC} = 10 \text{ V}$$

For $I_B = 6$ mA, the operating point on Fig. 16.11 is

$$V_{CE_Q} = 10 \text{ V} \qquad \text{and} \qquad I_{C_Q} = 140 \text{ mA}$$

The effective ac resistance seen at the primary is

$$R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L = (3)^2(8) = 72 \ \Omega$$

The ac load line can then be drawn of slope $-1/72$ going through the indicated operating point. To help draw the load line, consider the following procedure. For a current swing of

$$I_C = \frac{V_{CE}}{R'_L} = \frac{10\text{ V}}{72\ \Omega} = 139\text{ mA}$$

mark a point (A):

$$I_{CE_Q} + I_C = 140\text{ mA} + 139\text{ mA} = 279\text{ mA along the } y\text{-axis}$$

Connect point A through the Q-point to obtain the ac load line. For the given base current swing of 4 mA peak, the maximum and minimum collector current and collector−emitter voltage obtained from Fig. 16.11 are

$$V_{CE_{\min}} = 1.7\text{ V} \qquad I_{C_{\min}} = 25\text{ mA}$$

$$V_{CE_{\max}} = 18.3\text{ V} \qquad I_{C_{\max}} = 255\text{ mA}$$

The ac power delivered to the load can then be calculated using Eq. (16.13):

$$P_o\text{ (ac)} = \frac{(V_{CE_{\max}} - V_{CE_{\min}})(I_{C_{\max}} - I_{C_{\min}})}{8}$$

$$= \frac{(18.3\text{ V} - 1.7\text{ V})(255\text{ mA} - 25\text{ mA})}{8} = \mathbf{0.477\ W}$$

~~For the circuit of Fig. 16.10 and results of Example 16.4, calculate the dc input power,~~ power dissipated by the transistor, and efficiency of the circuit for the input signal of Example 16.4.

Solution

$$\text{Eq. (16.14):}\quad P_i(\text{dc}) = V_{CC}I_{C_Q} = (10\text{ V})(140\text{ mA}) = \mathbf{1.4\text{ W}}$$

$$\text{Eq. (16.15):}\quad P_Q = P_i(\text{dc}) - P_o(\text{ac}) = 1.4\text{ W} - 0.477\text{ W} = \mathbf{0.92\text{ W}}$$

The efficiency of the amplifier is then

$$\%\ \eta = \frac{P_o(\text{ac})}{P_i(\text{dc})} \times 100\% = \frac{0.477\text{ W}}{1.4\text{ W}} \times 100\% = \mathbf{34.1\%}$$

Calculate the efficiency of a transformer coupled class A amplifier for a supply of 12 V and outputs of:

(a) $V(\mathrm{p}) = 12$ V.

(b) $V(\mathrm{p}) = 6$ V.

(c) $V(\mathrm{p}) = 2$ V.

Solution

Since $V_{CE_Q} = V_{CC} = 12$ V, the maximum and minimum of the voltage swing are

(a) $V_{CE_{\max}} = V_{CE_Q} + V(\mathrm{p}) = 12\text{ V} + 12\text{ V} = 24\text{ V}$

$V_{CE_{\min}} = V_{CE_Q} - V(\mathrm{p}) = 12\text{ V} - 12\text{ V} = 0\text{ V}$

resulting in

$$\% \, \eta = 50\left(\frac{24 \text{ V} - 0 \text{ V}}{24 \text{ V} + 0 \text{ V}}\right)^2 \% = \mathbf{50\%}$$

(b) $V_{CE_{max}} = V_{CE_Q} + V(\text{p}) = 12 \text{ V} + 6 \text{ V} = 18 \text{ V}$
$V_{CE_{min}} = V_{CE_Q} - V(\text{p}) = 12 \text{ V} - 6 \text{ V} = 6 \text{ V}$

resulting in

$$\% \, \eta = 50\left(\frac{18 \text{ V} - 6 \text{ V}}{18 \text{ V} + 6 \text{ V}}\right)^2 \% = \mathbf{12.5\%}$$

(c) $V_{CE_{max}} = V_{CE_Q} + V(\text{p}) = 12 \text{ V} + 2 \text{ V} = 14 \text{ V}$
$V_{CE_{min}} = V_{CE_Q} - V(\text{p}) = 12 \text{ V} - 2 \text{ V} = 10 \text{ V}$

resulting in

$$\% \, \eta = 50\left(\frac{14 \text{ V} - 10 \text{ V}}{14 \text{ V} + 10 \text{ V}}\right)^2 \% = \mathbf{1.39\%}$$

Notice how dramatically the amplifier efficiency drops from a maximum of 50% for $V(\text{p}) = V_{CC}$ to slightly over 1% for $V(\text{p}) = 2$ V.

For a class B amplifier providing a 20-V peak signal to a 16-Ω load (speaker) and a power supply of $V_{CC} = 30$ V, determine the input power, output power, and circuit efficiency.

Solution

A 20-V peak signal across a 16-Ω load provides a peak load current of

$$I_L(\text{p}) = \frac{V_L(\text{p})}{R_L} = \frac{20\ \text{V}}{16\ \Omega} = 1.25\ \text{A}$$

The dc value of the current drawn from the power supply is then

$$I_{\text{dc}} = \frac{2}{\pi} I_L(\text{p}) = \frac{2}{\pi}(1.25\ \text{A}) = 0.796\ \text{A}$$

and the input power delivered by the supply voltage is

$$P_i(\mathrm{dc}) = V_{CC} I_{\mathrm{dc}} = (30\ \mathrm{V})(0.796\ \mathrm{A}) = \mathbf{23.9\ W}$$

The output power delivered to the load is

$$P_o(\mathrm{ac}) = \frac{V_L^2(\mathrm{p})}{2R_L} = \frac{(20\ \mathrm{V})^2}{2(16\ \Omega)} = \mathbf{12.5\ W}$$

for a resulting efficiency of

$$\%\ \eta = \frac{P_o(\mathrm{ac})}{P_i(\mathrm{dc})} \times 100\% = \frac{12.5\ \mathrm{W}}{23.9\ \mathrm{W}} \times 100\% = \mathbf{52.3\%}$$

For a class B amplifier using a supply of $V_{CC} = 30$ V and driving a load of 16 Ω, determine the maximum input power, output power, and transistor dissipation.

Solution

The maximum output power is

$$\text{maximum } P_o(\text{ac}) = \frac{V_{CC}^2}{2R_L} = \frac{(30\text{ V})^2}{2(16\ \Omega)} = \mathbf{28.125\ W}$$

The maximum input power drawn from the voltage supply is

$$\text{maximum } P_i(\text{dc}) = \frac{2V_{CC}^2}{\pi RL} = \frac{2(30\text{ V})^2}{\pi(16\ \Omega)} = \mathbf{35.81\ W}$$

The circuit efficiency is then

$$\text{maximum } \%\ \eta = \frac{P_o(\text{ac})}{P_i(\text{dc})} \times 100\% = \frac{28.125\text{ W}}{35.81\text{ W}} \times 100\% = 78.54\%$$

as expected. The maximum power dissipated by each transistor is

$$\text{maximum } P_Q = \frac{\text{maximum } P_{2Q}}{2} = 0.5\left(\frac{2V_{CC}^2}{\pi^2 R_L}\right) = 0.5\left[\frac{2(30\text{ V})^2}{\pi^2 16\ \Omega}\right] = \mathbf{5.7\ W}$$

Under maximum conditions a pair of transistors, each handling 5.7 W at most, can deliver 28.125 W to a 16-Ω load while drawing 35.81 W from the supply.

Calculate the efficiency of a class B amplifier for a supply voltage of $V_{CC} = 24$ V with peak output voltages of:

(a) $V_L(\text{p}) = 22$ V.

(b) $V_L(\text{p}) = 6$ V.

Solution

Using Eq. (16.29) gives

(a) $\%\ \eta = 78.54\,\dfrac{V_L(\text{p})}{V_{CC}}\% = 78.54\left(\dfrac{22\text{ V}}{24\text{ V}}\right) = \mathbf{72\%}$

(b) $\%\ \eta = 78.54\left(\dfrac{6\text{ V}}{24\text{ V}}\right)\% = \mathbf{19.6\%}$

Notice that a voltage near the maximum [22 V in part (a)] results in an efficiency near the maximum, while a small voltage swing [6 V in part (b)] still provides an efficiency near 20%. Similar power supply and signal swings would have resulted in much poorer efficiency in a class A amplifier.