Table 24-1 shows a typical ripple rejection of 72 dB for the LM7812. If we convert 72 dB mentally (60 dB + 12 dB), we get approximately 4000. With a scientific calculator, the exact ripple rejection is:

$$RR = \text{antilog}\,\frac{72\text{ dB}}{20} = 3981$$

The peak-to-peak output ripple is approximately:

$$V_R = \frac{1\text{ V}}{4000} = 0.25\text{ mV}$$

PRACTICE PROBLEM 24-12 Repeat Example 24-12 using an LM7815 voltage regulator and a 2000 μF capacitor.

Example 24-13

If $R_1 = 2\text{ k}\Omega$ and $R_2 = 22\text{ k}\Omega$ in Fig. 24-20, what is the output voltage? If R_2 is increased to 46 kΩ, what is the output voltage?

SOLUTION With Eq. (24-19):

$$V_{out} = \frac{2\text{ k}\Omega + 22\text{ k}\Omega}{2\text{ k}\Omega}(1.25\text{ V}) = 15\text{ V}$$

When R_2 is increased to 46 kΩ, the output voltage increases to:

$$V_{out} = \frac{2\text{ k}\Omega + 46\text{ k}\Omega}{2\text{ k}\Omega}(1.25\text{ V}) = 30\text{ V}$$

PRACTICE PROBLEM 24-13 In Fig. 24-20, what is the output voltage if $R_1 = 330\ \Omega$ and $R_2 = 2\text{ k}\Omega$?

Example 24-14

The LM7805 can regulate to specifications with an input voltage between 7.5 and 20 V. What is the maximum efficiency? What is the minimum efficiency?

SOLUTION The LM7805 produces an output of 5 V. With Eq. (24-13), the maximum efficiency is:

$$\text{Efficiency} \cong \frac{V_{out}}{V_{in}} \times 100\% = \frac{5\text{ V}}{7.5\text{ V}} \times 100\% = 67\%$$

This high efficiency is possible only because the headroom voltage is approaching the dropout voltage.

On the other hand, the minimum efficiency occurs when the input voltage is maximum. For this condition, the headroom voltage is maximum and the power dissipation in the pass transistor is maximum. The minimum efficiency is:

$$\text{Efficiency} \cong \frac{5\text{ V}}{20\text{ V}} \times 100\% = 25\%$$

Since the unregulated input voltage is usually somewhere between the extremes in input voltage, the efficiency we can expect with an LM7805 is in the range of 40 to 50 percent.

24-5 Current Boosters

Even though the 78XX regulators of Table 24-1 have a maximum load current of 1.5 A, the data sheet shows many parameters measured at 1 A. For instance, a load current of 1 A is used for measuring line regulation, ripple rejection, and output resistance. For this reason, we will establish 1 A as a practical limit on the load current when using a 78XX device.

The Outboard Transistor

One way to get more load current is to use a **current booster**. The idea is similar to what we did to boost the output current of an op amp. Recall that we used the op amp to supply the base current for an external transistor, which produced a much larger output current.

Figure 24-22 shows how we can use an external transistor to boost the output current. The external transistor, called an **outboard transistor,** is a power transistor. R_1 is a current-sensing resistor of 0.7 Ω. Notice that we are using 0.7 Ω instead of 0.6 Ω. We are using 0.7 Ω because a power transistor needs more base voltage than does a small-signal transistor (used in the previous discussion).

When the current is less than 1 A, the voltage across the current-sensing resistor is less than 0.7 V and the transistor is off. When the load current is greater than 1 A, the transistor turns on and supplies almost all the load current above 1 A. Here is why: When the load current increases, the current through the 78XX increases slightly. This produces more voltage across the current-sensing resistor, which makes the outboard transistor conduct more heavily.

Each time we increase the load current, the current through the 78XX device increases slightly, producing more voltage across the current-sensing resistor. In this way, the outboard transistor produces the bulk of any increase in load current above 1 A, with only a small increase in the current through the 78XX.

For large load currents, the base current in the outboard transistor becomes large. The 78XX chip has to supply this base current in addition to its share of load current. When the large base current becomes a problem, a designer may use a Darlington connection for the outboard transistor. In this case, the current-sensing voltage is approximately 1.4 V, which means that R_1 should be increased to approximately 1.4 Ω.

Short-Circuit Protection

Figure 24-23 shows how to add short-circuit protection to the circuit. We are using two current-sensing resistors, one to drive the outboard transistor Q_2 and a second to turn on Q_1 for short-circuit protection. For this discussion, 1 A is where Q_2 conducts, and 10 A is where Q_1 provides short-circuit protection.

Figure 24-22 Outboard transistor increases load current.