17.1 VOLTAGE REGULATION BASICS

Power usually enters a system in a form dictated by its generation and distribution characteristics rather than in a form required by the components within that system. Plugging a computer into a 120 VAC wall outlet provides it with power in a form that was deemed efficient for generation and distribution in the early twentieth century. Unlike light bulbs, digital logic chips do not run very well if connected directly to 120 VAC, although they may emit a bright light for a brief period if connected in this manner! Rectifiers and the conversion between AC to DC has already been discussed, but this is only part of the solution to providing usable power to system components. Once the AC has been rectified to DC and filtered, the voltage probably does not meet the specifications of the circuit. A rectified power input may not only have the wrong DC level, it probably has a good deal of ripple artifacts from the original AC input, as shown in Fig. 17.1.

An ideal voltage regulator provides a constant DC output without ripple regardless of the input voltage's DC level and ripple. This applies not only to rectified AC power but also to power provided by batteries, solar cells, DC generators, and so on. Any time a system's power input does not provide the supply voltage required by its components, a voltage regulator is necessary to perform this conversion. Most digital systems require at least one voltage regulator, because it is rare to find a power source that provides the exact voltage required by digital and analog circuits. There are, however, some special-purpose ICs designed with wide supply voltage specifications so that they can be directly connected to batteries without an intermediate voltage regulator. On the flip side, there are systems that require multiple voltage regulators, because they contain circuitry with multiple supply voltage specifications. At one time, it was common to have a single +5-V digital supply. Now, it is not uncommon to have 3.3-, 2.5-, 1.8-, and 1.5-V supplies in myriad configurations.

Most voltage regulators are the *step-down* variety—they provide a constant output voltage that is lower than the input. There are many types of step-down regulators, as will be shown in the course of this chapter. Some applications require *step-up* regulators that provide a constant output that is higher than the input. These applications are often low-power battery-operated devices in which a 1.5- to 3-V battery is moderately stepped up to power a small circuit.

A voltage regulator must have access to some form of voltage reference to which it can compare its output to determine if the level is correct. Without a known reference, the regulator has no means of measuring its output. This is analogous to measuring an object with a ruler, which is a known length reference. Without the reference, the object's length remains unknown. The structure of a general voltage regulator is shown in Fig. 17.2.

The reference is powered directly by the arbitrary input voltage but maintains a constant output voltage subject to certain minimum operating conditions. A reference cannot maintain an output voltage higher than the input. Therefore, references usually provide low voltages that are compared against a scaled-down feedback voltage from the output. This enables the regulator to function over a wider range of input levels. The two resistors implement a basic voltage divider that drives a feedback comparator. These resistors are chosen to provide a feedback voltage equal to the reference at the desired output voltage. When the feedback voltage falls below the reference, the comparator sig-

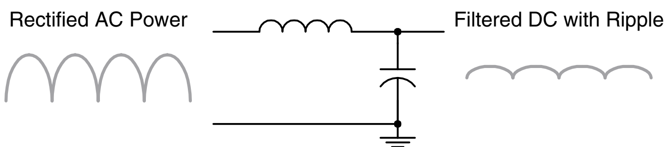

FIGURE 17.1 Ripple on a rectified AC power input.

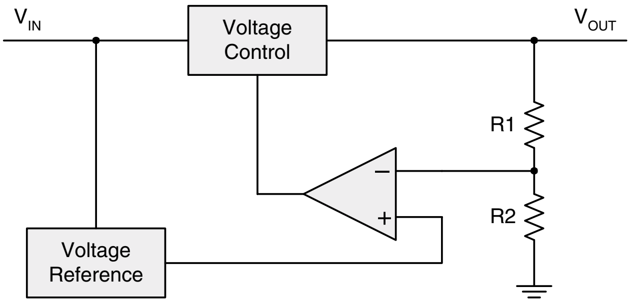

FIGURE 17.2 General voltage regulator.

nals the voltage control circuit to increase V_{OUT}. Similarly, once the feedback voltage rises above the reference, the voltage control circuit must reduce its output. This feedback loop is subject to stability problems unless special allowances are made in the design. An unstable voltage regulator can oscillate, which is very undesirable. Voltage regulator stability problems have long been dealt with in reliable and effective manners.

From the brief description of a regulator's operation, it is apparent that the accuracy of the reference directly affects the accuracy of the generated output voltage. Diodes of various types serve as voltage references, because semiconductor junctions exhibit nonlinear voltage drops that are not very sensitive to current changes—Ohm's law does not apply. However, current and temperature do affect this voltage drop, which causes variation. A standard small-signal silicon diode exhibits a drop of between 0.6 and 0.7 V at low currents. A crude regulator could be constructed using such a reference, but the degree of accuracy would be unacceptable for many applications. More specialized diodes with integrated compensation elements designed explicitly to serve as stable voltage references can achieve tolerances of 0.1 percent over temperature and part-to-part variations.

Voltage regulators are characterized using a wide range of parameters. Some of the metrics that might first come to mind are how much current can be supplied and what restrictions exist on the input and output voltages. Other specifications that are just as important involve the accuracy to which the output voltage is maintained and how the output is affected by a variety of ambient conditions.

The relationship of input and output voltages is usually the first order of business. A regulator has minimum and maximum input and output voltage limits as well as a *dropout voltage*, which is the minimum difference between input and output that can exist while guaranteeing a regulated output. When designing a particular regulator into a system, it is important to ensure that the regulator's specifications will not be violated and that any dropout voltage restriction will be met. Some types of switching regulators do not have a dropout voltage, but most regulators do require a certain minimum overhead between input and output. Output current and power specifications must also be observed. Each regulator has maximum current and power ratings beyond which it will overheat and damage itself and, possibly, surrounding circuitry. Some regulators have minimum current ratings, below which the device is incapable of guaranteeing a regulated output.

Adherence to these rules may sound obvious at first, but many an engineer has picked an inadequate voltage regulator as an afterthought, only to waste time and money later in solving problems of poorly regulated voltages and overheating regulator components.

Once the basic input/output conditions have been satisfied, regulation accuracy becomes the prime concern. Among others, there are three basic specifications: *line regulation*, *load regulation*, and *ripple rejection*.