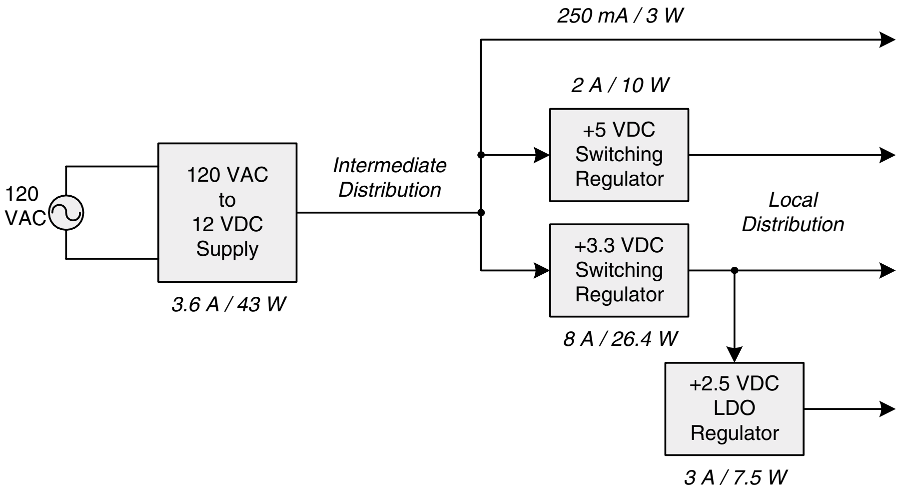

FIGURE 17.16 Distributed power regulation.

The fact that most systems can rely on an off-the-shelf AC power supply to provide an adequate level of safety enables a design style of selecting a certified AC supply with an adequate power rating and then using a custom combination of regulators to provide the desired logic-level voltages. The advantage to this approach is not requiring the perfect AC supply that provides every voltage at the correct current rating. Instead, an overall system power requirement is calculated and a supply is found that provides a suitable intermediate voltage at or above that level. In this example, the final voltages are needed as follows: 12 V at 250 mA, 5 V at 2 A, 3.3 V at 5 A, and 2.5 V at 3 A. It is decided to create the 5- and 3.3-V supplies with switching regulators and use a low dropout linear regulator to provide 2.5 V from 3.3 V, which is why the 3.3-V regulator must supply sufficient current for both the 3.3-V and 2.5-V needs. It is assumed that the switching regulators will operate with 90 percent efficiency and therefore require approximately 43 W from the AC power supply.

Taking a distributed approach means that, if the system specifications ever change to require different voltages, the proven AC supply is unaffected as long as the overall power level remains constant and the DC regulators can be adjusted as necessary. In many cases, adjusting the DC regulators is as simple as changing the value of a voltage-sensing feedback resistor.

A separate AC power supply module is often connected to the main circuit board with a wiring harness. In this case, wire must be chosen to safely carry 3.6 A at 12 V. Twenty-four gauge wire is adequate for the task and a more conservative choice is 22 gauge. The best results for distributing the regulated 5-, 3.3-, and 2.5-V supplies are achieved by using complete PCB planes or very wide copper paths to connect the regulator outputs to the various ICs and components that they serve. Distributing these final logic-level power supplies segues directly into electrical integrity issues.

17.8 ELECTRICAL INTEGRITY

An ideal power distribution system delivers a noise-free voltage supply at any current level required by the load. It performs this task regardless of how quickly the load's current demand changes and how much ambient noise is present. Electrical integrity is a measure of how close to the ideal a power distribution system really is. Factors that influence electrical integrity include the quality of the power conductors, the ability of the regulator to sense and respond to load variation, and the level of noise attenuation designed into the system. Electrical integrity should be considered only after the power distribution conductors have been adequately sized to carry the DC load with minimal voltage drop.

Assuming low enough resistance to adequately carry the current load, the quality of power conductors in the context of electrical integrity is a function of inductance and capacitance. Power is a signal like any other and is subject to degradation from noise created by components in the system, especially at high frequencies. Digital logic is infamous for creating high-amplitude and high-frequency noise because of the rapid binary switching characteristic of synchronous logic circuits. A sudden current spike is generated when a logic gate switches and charges its output node to a new state. A good power distribution system has low inductance so that the impedance between the power source and the switching load is minimal at the high logic switching frequencies. It also has sufficient capacitance near the load to attenuate the noise created by the switching event. The capacitance can be thought of as a tiny battery that briefly supplies the excess switching current until the power source can respond to the event.

Impedance at high frequency is minimized by increasing the surface area of a conductor, because high-frequency energy tends to travel along the surface of conductors according to a phenomenon known as *skin effect*. At DC, the entire cross section of a conductor carries current in a uniform distribution. As the frequency increases, the current distribution becomes nonuniform and moves out toward the conductor's surfaces. The inductance of a power supply wire is not going to be significantly reduced by moving to a lower gauge wire, because the surface areas of, for example, 22 and 18 gauge wires are not very different. A good way to distribute power in a low-inductance manner is with a solid sheet of metal. Modern PCBs are built up from individual copper layers, and it becomes very practical and cost effective to dedicate multiple layers as low-inductance power distribution planes.

Capacitance is distributed across a circuit board's power conductors using a variety of different capacitors. A typical system has a relatively small quantity of low frequency *bypass* capacitors, also called *bulk* bypass capacitors. Bypass capacitors are also called *decoupling* capacitors. Both terms refer to capacitors that help reduce power supply noise in a system. These are often aluminum or tantalum electrolytic capacitors, because electrolytics can pack a large capacitance into a small package. Standard aluminum electrolytic capacitors have a limited life span, because they use a wet electrolyte that gradually dries over time. Increased operating temperature shortens their life span. Tantalums use a solid electrolyte and are considered more reliable. New types of aluminum electrolytic capacitors have also been developed with extended life and temperature ratings.

The downside of electrolytics is their poor high-frequency response. Bulk bypass capacitors are placed at regular intervals on a circuit board to effectively lower the impedance of the voltage source (regulator). Values for bulk capacitors range from 10 to 1,000 μF. The specific quantity and type used and how they are placed varies greatly among system implementations. Some ICs recommend specific bulk bypass values. An engineer often errs on the side of conservatism and sprinkles 100-μF electrolytic capacitors around a circuit board so that there is one per supply voltage every few inches.

A larger quantity of high-frequency bypass capacitors are placed as close to the power pins of ICs as possible. These are ceramic capacitors, and they should be sized according to the expected noise frequencies. Historically, an individual 0.1-μF ceramic capacitor has been placed at each power and ground pin pair of each IC. It is important to minimize the inductance between each bypass capacitor and each power pin, because the resulting impedance at high frequency will limit the capacitor's effectiveness. This goal has given rise to the standard rules of placing capacitors as close as possible to their ICs and using surface mount components with much lower lead inductances as compared to