run through the component's axis. A radial leaded component is also cylindrical but has both leads protruding from the same face—the two leads are at equal radii from the component's center. Other components that do not have 0.1-in lead pitch also require lead bending: TO-92 packages (used for transistors and low-power voltage regulators) and common connectors including DB-9, DB-25, and RJ-45. These days, it may be impossible to find some desirable ICs in DIP packages. PLCCs are a popular low-cost surface mount package for lower-lead-count ICs. PLCC sockets are available with leads on 0.1-in centers, making it possible to prototype a circuit with PLCCs on a standard breadboard.

Sockets are desirable for manually wired circuits, not only for mating incompatible IC packages but also for component protection during soldering and for ease of component replacement. If a soldering iron is applied to an IC pin for too long, the IC may be damaged. Careful soldering is necessary to ensure that ICs are not damaged during construction. Additionally, static control measures must be taken when handling CMOS components because of the risk of damaging the MOSFET gate oxide. Both of these problems are eliminated when using IC sockets, because the sockets are not as sensitive to heat, and they are insensitive to ESD. A further benefit is gained if an IC is damaged during the initial prototype debugging process. Rather than having to unsolder all of the IC's pins, a socket allows a new IC to be easily installed.

Soldering a circuit on a breadboard can be done with minimal planning, but it is important to consider power distribution ahead of time. Adequate wires should be used so that components at one end of the board are not operating at a significantly different DC level from those at the other end. It may be prudent to run smaller gauge power bus wires around the board before beginning the more dense signal wiring; 24- or 26-gauge wire will ensure negligible DC voltage drop across a typical board. Implementing a mesh power distribution scheme will also marginally lower the inductance between IC power pins and bulk bypass capacitance. The absence of low-inductance power planes is a critical limitation of breadboards. Each IC should have adequate bypassing with ceramic disc capacitors arranged so that their lead length is minimized. A common scheme for bypassing a DIP IC is to directly connect the capacitor leads to the power pins. This often results in a diagonal configuration in which the capacitor runs from one corner of the IC to the other, because power pins in a DIP are often at opposing corners of the package. Pins 7 and 14 are ground and V_{CC}, respectively, for most 14-pin DIP logic ICs. Figure 19.4 shows a power distribution scheme for a breadboard in which the power buses are formed with meshed wires, high-frequency bypass capacitors are wired

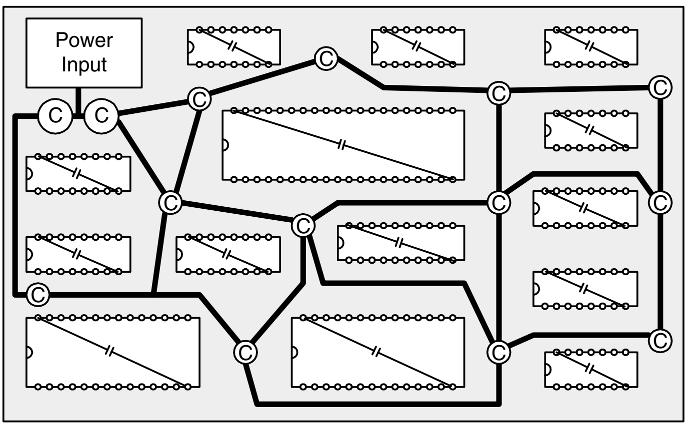

FIGURE 19.4 Breadboard power distribution.

directly to power pins, and low-frequency bulk electrolytic capacitors are arranged throughout the board. This hypothetical circuit contains 7400-type logic ICs in 14-, 16-, and 20-pin DIPs as well as VLSI memory and microprocessor ICs in 28- and 40-pin DIPs.

An alternative to conventional breadboards for temporary prototypes of small circuits is the *solderless breadboard*. A solderless breadboard isn't a fiberglass board, but a plastic frame in which many small spring-clips are embedded. Holes are on 0.1-in centers, and the spring clips are typically arranged in rows of five contacts separated by a gap, or channel, across which a standard 0.3-in (76.2 mm) wide DIP is inserted. Figure 19.5 shows a small solderless breadboard. Power distribution is often assisted by means of a continuous spring-clip bus running across the top and bottom of the breadboard. Connections are made by inserting solid wires between various spring clips. Since each spring clip has five contacts, a maximum of five connections can be made to a single node. If more are necessary, an unoccupied spring clip nearby must be used for the excess connections and then bridged to the other spring clip via a wire. Solderless breadboards are perfect for small experiments and are used in many academic lab settings, because solder irons and other assembly tools are not necessary. Clearly, solderless breadboards are not for every circuit. Aside from electrical integrity issues, they cannot accept common PLCC packages without a special breakout product that essentially converts a PLCC to a DIP. Nevertheless, substantial digital circuits can be prototyped on a solderless breadboard, including low-speed microprocessors with memory and basic peripherals.

Soldering is not the only way to prototype a digital system with permanent connections. *Wire-wrapping* is a technique that has been around for decades and was actually used for production assembly in many minicomputers and mainframes during the 1960s and 1970s. The wire-wrapping process establishes electrical connections by tightly wrapping small wire, typically 30 gauge, around square pins. Several turns of wire are made as shown in Fig. 19.6, resulting in a surprisingly durable electromechanical connection, even without the benefit of insulation that is often stripped off. Wire-wrapping requires the use of special IC sockets with long, square posts that protrude through the bot-

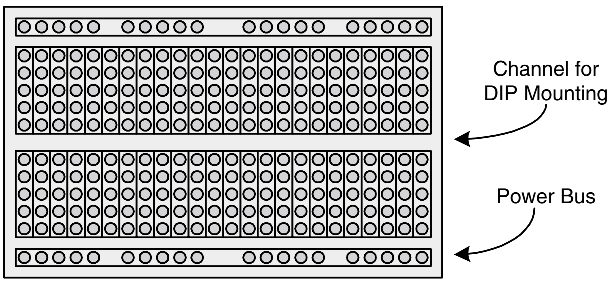

FIGURE 19.5 Solderless breadboard.

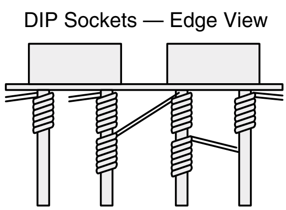

FIGURE 19.6 Wire-wrap connections.