all components. These keep-outs make the PCB easier to handle and allow it to ride on rails through the pick-and-place, wave, and reflow machines. A typical component-to-edge keep-out is 0.2 in (5 mm). Very dense PCBs that cannot tolerate such keep-outs may require snap-off rails fabricated as part of the PCB. Such rails are not uncommon and are almost free, because they are formed by routing slots at the edges of a PCB as shown in Fig. 19.1. A related assembly rule is the inclusion of tooling holes at several locations around the PCB perimeter. These holes provide alignment and attachment points for the assembly machines.

Pick-and-place machines generally require assistance in perfectly aligning a high-pin-count SMT package to its designated location on the PCB. Most passive components and small multilead SMT packages can be automatically aligned once the PCB is locked into the machine. The alignment of packages such as QFPs and BGAs is aided with fiducial markers that are designed into the PCB in the vicinity of these IC locations. Fiducials are typically small circles or bull's eye symbols etched in the surface copper layer that can be optically detected by the pick-and-place machine as the dispenser head closes in on the desired location. Figure 19.2 illustrates fiducial placement around QFP

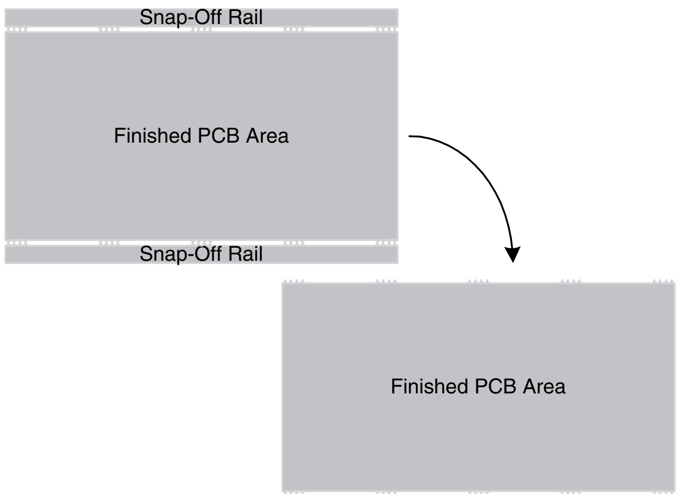

FIGURE 19.1 Removable PCB rails.

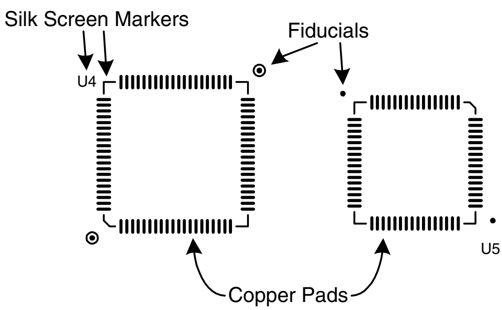

FIGURE 19.2 Fiducial markers for SMT alignment.

footprints. Also shown are visual inked silk-screen markers for people's benefit that are created to identify different components with unique reference designators and to draw shapes that assist in circuit assembly and troubleshooting. The fiducials do not have to be in a standard location. What is important is that their exact location is known and entered into the machine so that an absolute location can be determined once the fiducials are optically detected.

19.3 MANUALLY WIRED CIRCUITS

PCBs are an excellent solution for high-speed and production systems, but manual wiring may be suitable for building small quantities of lower-speed circuits. Manual wiring can be performed in a variety of ways and has the benefits of low material cost and less support infrastructure, and it is the quickest way to start building a circuit. The time and money spent designing a PCB can be amortized across multiple units built, but each manually wired circuit consumes the same construction resources. It is important to understand the limitations of manual circuit wiring, because it can take days of tedious work to build a single circuit board. For an engineer on a budget, it may be the cheapest and quickest way to prototype a lower-speed digital system.

Breadboard is an industry term for a blank circuit board that consists solely of equally spaced holes. A breadboard is generally made of fiberglass and has hundreds or thousands of holes aligned on 0.1-in (2.54-mm) centers to match the common pin spacing of DIPs and many other electronic components. The term breadboard comes from a loose similarity to a slice of bread that is permeated with holes. If the breadboard is designed for solder assembly, it is built with thin copper pads around each hole so that solder will adhere to the board. Some breadboards contain plated holes with pads on both sides of the board for increased solder adhesion. As shown in Fig. 19.3, some breadboards add thin mesh planes by taking advantage of the small spaces between copper pads. These planes are not as effective as a PCB's continuous plane, but they have less inductance than discrete wires. The presence of a mesh plane is not bad, but it should not lead to the false impression that high-quality transmission lines can be constructed.

Building a circuit from scratch on a breadboard is done by inserting components into the board and then running small wires, usually 30 gauge, point to point between their leads. DIPs and other components with preformed leads on 0.1-in centers can be directly inserted into the board. Some connectors, as well as TO-220 voltage regulators, transistors, and diodes, have a compatible 0.1-in lead pitch. Resistors, capacitors, and inductors with axial or radial lead configurations may require bending their leads so that they can lie flat on the board. An axial leaded component is most commonly in a cylindrical package with one lead protruding from the center of each face—the two leads

FIGURE 19.3 Breadboard with plated holes and mesh plane.