MACHINE DESIGN

EDITED BY JOHN R. GYORKI

DECEMBER 7, 2000 www.machinedesign.com

X-rays spot circuit-board flaws

X-rays can go deeper into PC-board inspection than traditional vision systems to uncover component placement and soldering errors.

Doug McClure
Nicolet Imaging Systems
Sierra Research &
Technology
San Diego, Calif.

Self-contained X-ray systems can perform numerous inspection functions including failure analysis, process analysis, and repair verification. Systems range from manual to fully automatic and various combinations in between. One challenge is selecting an optimum X-ray unit to match a specific process.

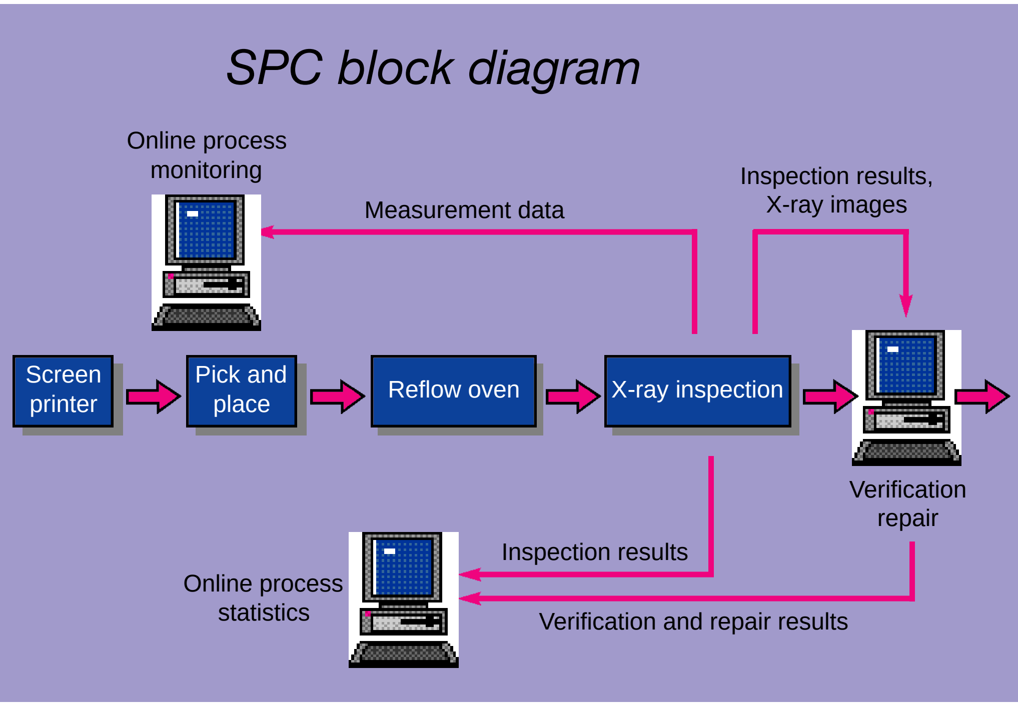
The proliferation of cell phones, pagers and miniaturized personal-logic devices (PLDs) has added more pressure for faster throughput to an already overloaded electronics manufacturing industry. Shrinking PC boards encourage more use of ICs with denser circuits and more pinouts, including surface-mount technology (SMT) devices such as ball-grid arrays (BGA and µBGA), chip-scale packages (CSPs), and flip-chips.

These miniature devices are more reliable than former counterparts, but the large quantities currently needed present formidable challenges to the SMT industry. For one, the manufacturing process must be optimized for maximum yield and minimum waste. Secondly, PC-board components must be properly assembled and verified that the boards are error-free. Only the most sophisticated and accurate inspection systems can find defects without slowing production. Although more expensive than in-circuit testers, X-ray inspection systems require little programming and no special test fixtures.

X-RAY SYSTEMS

Real-time X-ray technology is the most effective method for detecting PCB faults around these miniature components. Although ordinary vision systems are widely used, the observed parts often have connections that can be hidden from view. Moreover, X-ray methods also

Automated X-ray systems can work with equipment from a variety of vendors. The system produces a uniform means of monitoring critical manufacturing variables in real time to correct for process shift and drift. The information collected also helps establish control limits and pass/fail conditions.



help verify the process and test the product.

X-ray inspection systems display grayscale images which represent variations in the shape and thickness of an object. High-density parts produce darker images than less dense or thinner parts. Automated inspection algorithms analyze these grayscale images of soldered features to show acceptable or unacceptable joints. This eliminates questionable human interpretations of quality.

VERIFICATION AND OPTIMIZATION

X-rays work well with process verification and optimization, functions which collect data, evaluate processes, and report process performance. The process should be automated and operate as near to real-time as possible to correct for process-drift and improve efficiency.

Automated X-ray inspection systems monitor real-time, critical manufacturing variables, including line speed and inspection. This information sets control limits and determines pass/fail conditions. An alarm can identify process variations and correct them before out-of-tolerance conditions cause defects, affect product quality, or reduce yield.

X-ray inspection systems can detect insufficient solder, skewed parts, and voids in the solder reflow. More importantly, as an automated X-ray system collects measurement information on each joint, it immediately feeds back information to the controller on the assembly process. For chip-scale packages, measurements also include bridging, opens missing balls, poor or no reflow, and lifted leads.

A FEW GUIDELINES

BGA solder-joint inspection using X-rays should start at the center of the BGA. This is the most likely place to find voids, solder balls, or delaminated components. All BGA solder joints should be circular and relatively uniform in size.

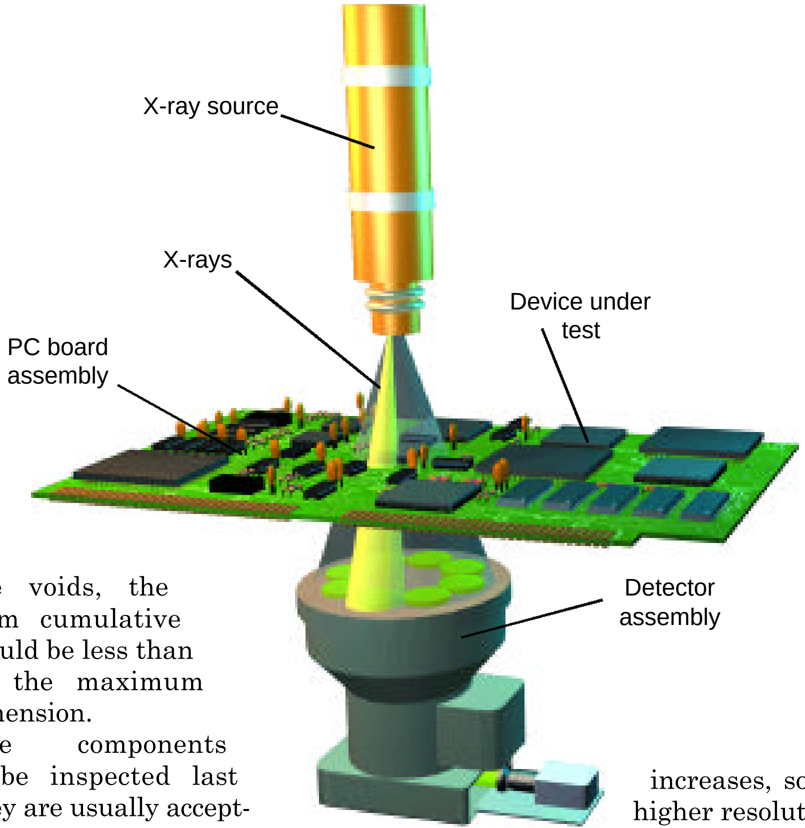
The maximum permissible void size should be less than 10% of the minimum joint dimension. In the case of multiple voids, the maximum cumulative area should be less than 10% of the maximum joint dimension. However, this is only a rule of thumb. If the component has been reworked, an X-ray scan of the entire region below the component should be performed to verify that it has been successful.

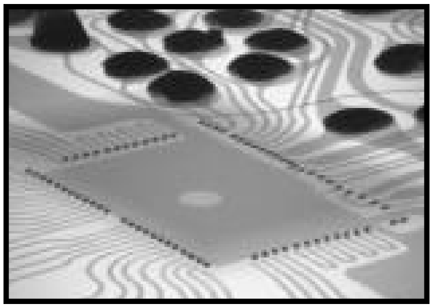
Plastic-leaded chip-carrier (PLCC) solder joints should be inspected from one corner of the component, then scanned around all four sides. Heel, toe, and side fillets on gull-wing leads should be clearly visible.

The heel fillets should have consistently sized, well-formed castellation (built up) regions. The heel fillet is the region subjected to most mechanical and thermal stresses. Toe fillets are not always visible because the lead tip has no wettable area.

As with BGAs, the maximum permissible void size should be less than 10% of the minimum joint dimension. In the case of

Transmissive X-rays





Transmissive X-ray methods provide 2D images of the object between source and detector. The technique is used for inspecting single-sided PC boards and assemblies. But when used with a multiaxis manipulator, it can simulate 3D images.

multiple voids, the maximum cumulative area should be less than 10% of the maximum joint dimension.

Passive components should be inspected last since they are usually acceptable when all other component connections are accepted. Because passive components are comparatively smaller, they are more likely to reflow before the other components and less likely to contain voids. However, they may show voids during second-side reflowing. When a chip component has been reflowed successfully, it will have a well-formed fillet at end and side terminations.

Miniature active components such as small outline transistors (SOTs) and small outline ICs (SOICs) are less likely to show poor reflow because of their low mass. For small active and passive components, the maximum permissible void size should be less than 10% of the minimum joint dimension. In the case of multiple voids, the maximum cumulative area should be less than 10% of the maximum joint dimension.

X-RAY SYSTEM SELECTION

A high resolution source is required when selecting an X-ray system to test CSPs, flip-chips, BGAs and other high-density packages. X-ray tube resolution is determined primarily by spot size, measured in microns.

The lower the micron number, the higher the resolution. Most systems have at least an 8-micron X-ray tube, but as package density increases, so does the need for higher resolution.

X-ray systems should uncover subtle defects under high magnification. For example, a 0.05 to 0.250-mil field-of-view can detect openings in component leads, while lower magnification improves throughput and detects bridging, missing balls, excessive solder, and poor reflow.

Throughput versus accuracy: Whether the X-ray system is manual, semiautomatic, or fully automatic, expect a few trade-offs. A larger field-of-view provides higher throughputs because more joints are inspected simultaneously. At a magnification of five or 10 times, the cross-sectional view is about the size of a BGA component. It's easy to see bridging, missing balls, excessive solder, and poor reflow.

Most X-ray inspection-system makers specify throughput at these low magnification levels. Yet, to detect voids, misshapen balls, or unreflowed solder, they recommend a higher magnification, rotating boards, or 3D imaging. But the latter two processes take time and reduce throughput.

X-ray penetration: Power, rated in kilovolts of the X-ray source, is relative to the viewing subject and obstructions between the source and region of interest. Increasing power lets X-rays penetrate chip packages to acquire images of solder connections. However, lower X-ray intensity is required to view traces and lead carriers. Manual and semiautomatic systems typically select intensity. Fully automatic systems usually are set for a particular Z-height measurement.

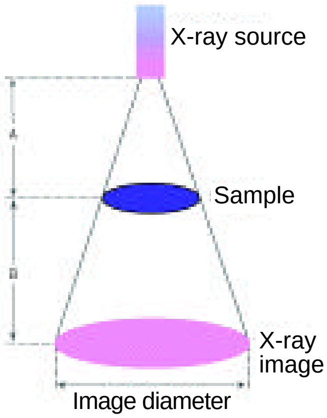
BEST FIT: SYSTEM TYPES

Basic X-ray systems can be manual, semiautomatic, or automatic. Each has advantages and disadvantages.

Manual systems work best at off-line failure analysis, sample process verification, process ramp-up, prototyping, and rework verification. A multiaxis sample manipulator is only available on manual and semiautomatic systems. This lets operators view samples from numerous places and removes obscuring artifacts. These systems are easy to use in high-mix contract-manufacturing environments. The drawback, however, is a lack of process analysis data. Manual systems rely on the operator to determine errors.

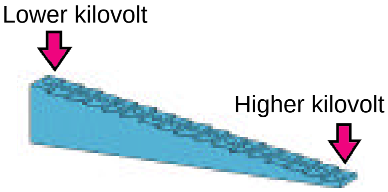
These systems also should be able to rotate a sample for optimum viewing and separate solder artifacts in the X-ray image. Although most systems offer 360° rotation, most users have found +45° of board travel optimum for both throughput and inspection quality.

X-ray image magnification



A large field of view lets inspectors see more joints at one time. At a magnification of five or 10 times, it's easy to see solder bridges, missing balls, excessive solder, and poor reflow. Magnification equals the distance from the X-ray source to the sample (A) plus the distance from the sample to the X-ray image (B) divided by distance A. Also, the image diameter equals the product of sample diameter and magnification.

X-ray penetration



High-power X-rays penetrate chip packages and shields to acquire images of solder connections underneath. But lower power is needed to view the printed-circuit-board traces and lead carriers.

Semiautomatic systems are often manual systems with semiautomatic positioning and image processors to reduce human error, increase throughput, and provide analysis and measurement capabilities. With the ability to quickly feed back data for verifying designs, analyzing failures and monitoring processes, these systems are cost effective, highly flexible and becoming more widely used.

Image processors using advanced software improve an X-ray image for viewing anomalies or taking measurements to quantify them. A common inspection technique uses image averaging to reduce noise. This helps define the edges and detects the defects. Also, by calibrating the number of pixels for a known distance, the operator can quantify measurements of void areas and diameters of solder bumps and balls. Since the operator makes the defect decision, these tools greatly aid human eyes and reduce the chances of false calls.

Automatic systems are best suited for in-line, high-volume, low-mix production. This approach provides assembly line performance data to provide continual process efficiency feedback and repeatable failure analysis.

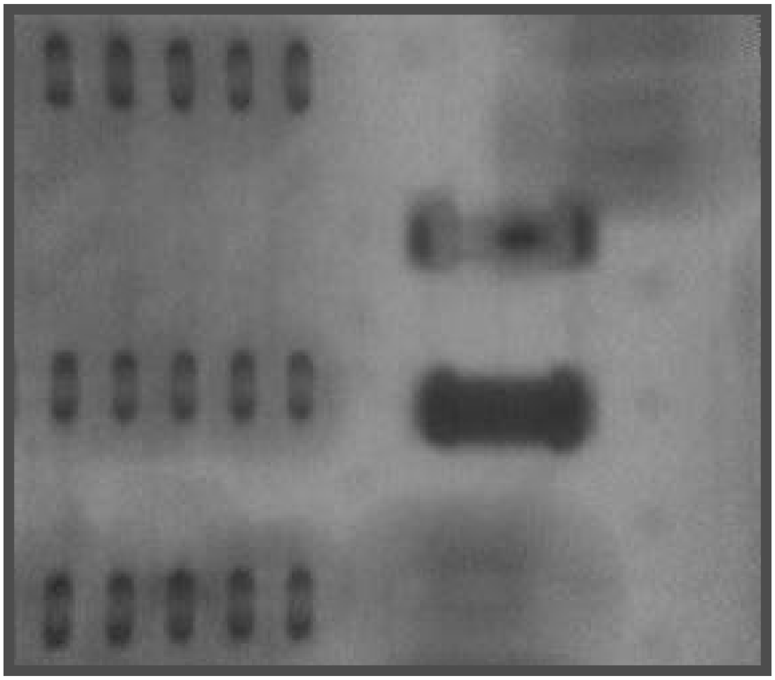
Automatic systems use conveyors to handle samples, which moves products through inspection and routes defective units to a rework or reject area. More importantly, automated-systems' image processing and analysis software can accurately identify production anomalies without relying on an operator's interpretations.

With a machine processor making the defect call, visual enhancement tools are not needed. The image is examined at speeds based on CPU clock frequencies and the number of processors. Resulting measurement data, when compared to a set of rules, makes quality assessments and out-of-tolerance report calls. If the data is accumulated over a period of time, drifts in the manufacturing process can be compensated to prevent faults.

A manual system offers more variables in the analytical examination but at the expense of throughput. Automated systems provide throughput and repeatability at the expense of the initial setup, plus the measurement details that need to be defined.

Automatic systems may perform 100% inspection, lot sampling, or critical component inspection. These depend on line speed and inspection-coverage requirements. Even

Laminographic X-ray image



3D laminography, also called scanned-beam laminography, uses a steered X-ray source and a moving detector to create artifacts in the background of a 256-shade grayscale image. The area mapped is of the surface of a PC board at the component pad level.

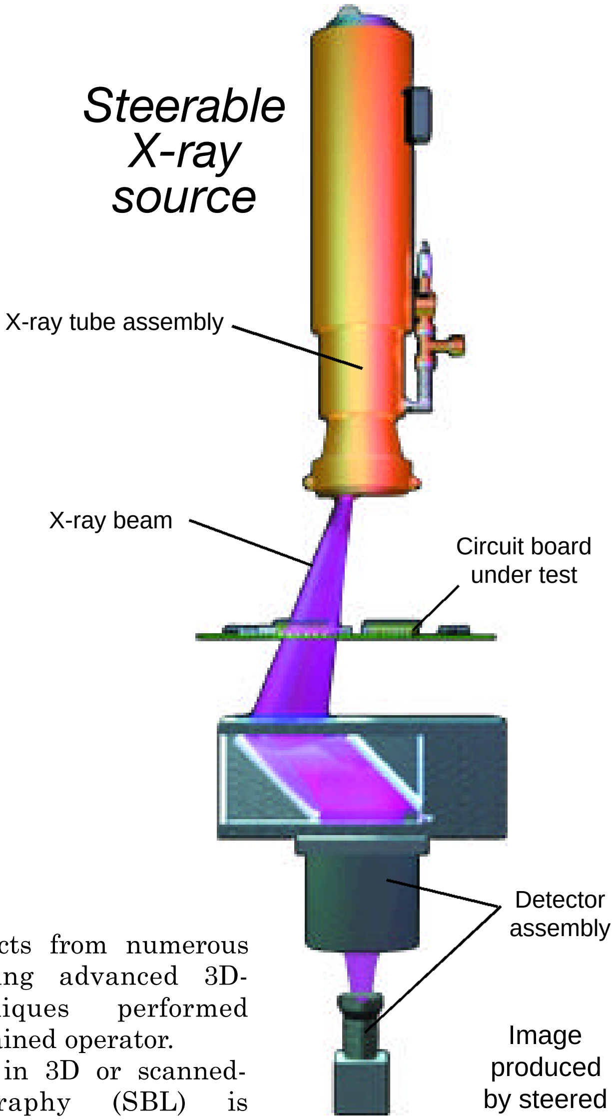


Image produced by steered X-ray source and movable detector.

partial component inspection will identify proper component placement and typical failures, such as shorts. Monitoring can provide fault coverage and process statistics. Detailed X-ray analysis can identify a myriad of faults at specific component solder joints, and pinpoint the area in the manufacturing process that created the defect.

Some manufacturers put X-ray inspection systems at the end of the production line to replace in-circuit test (ICT), while others position systems at postwave soldering and postreflow positions to maintain maximum throughput.

IMAGING TECHNIQUES

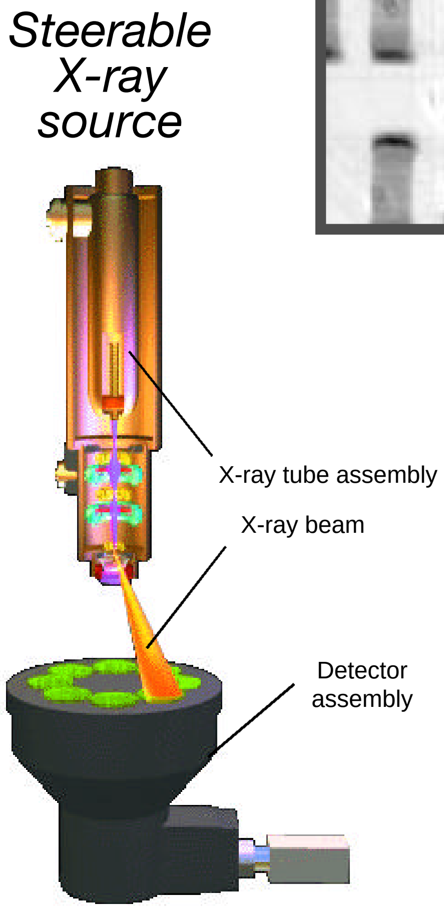
Imaging techniques can be classified as 2D-transmissive, 3D-laminography, and 3D-digital tomosynthesis. Laminography and digital tomosynthesis acquire focal plane slices from several off-axis vantage points and combine these X-ray views to reconstruct all or selected portions of an X-ray image.

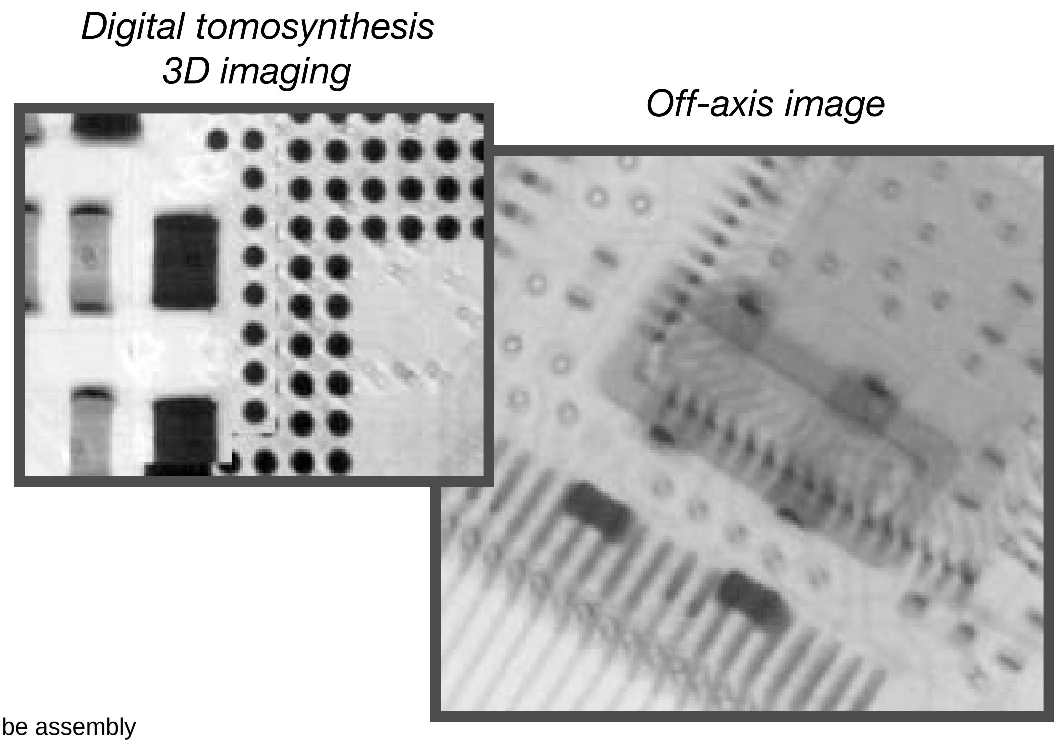
Transmissive X-ray imaging provides 2D silhouette-type imaging of an object between the source and detector. This is for inspecting single-sided PC assemblies or components. When used with a multiaxis manipulator it can inspect objects from numerous angles, simulating advanced 3D-imaging techniques performed manually by a trained operator.

Laminography in 3D or scanned-beam laminography (SBL) is mechanical image integration process. The combination of a steered X-ray source and moving detector smears artifacts into the background of a 256-shade grayscale image. Images are acquired in a ±5 mil region above the PC board where the solder sits. This area is defined after mapping 50 or more boards to acquire an average or normalized Z-reference, known as Z-axis transform.

The benefits of using laminography instead of transmissive systems include the ability to analyze double-sided boards, and programming time is less than that needed to program ICT systems. ICTs cannot identify voids or verify solder quality, and has limited or no physical access to the component.

On the other hand, the liabilities include a medium-high cost, and Z-height transform mapping is required. Transform mapping is a problem even with minimal board warpage, component shielding, or visual





In digital tomosynthesis, the X-ray source is projected from a number of predetermined off-axis positions onto a stationary detector. This can provide numerous slices which are then analyzed to find the best view for finding solder defects.

access to the board surface. In addition, CAD programming is required to determine component orientation and pad and pin locations, and algorithm threshold tuning is required to establish control limits and evaluate and determine best-practice pass/fail conditions.

Digital tomosynthesis uses a steerable X-ray source projected from off-axis positions onto a stationary detector. Because the source and detector do not move during image capture, tomosysnthesis images have as much as 50% better resolution than laminography images. Many slices can be produced from the original set of off-axis images, and then analyzed to find the best slice for determining solder defects. Since multiple slices and Z-heights are acquired simultaneously, there is no need to perform Z-height transform mapping.

Benefits include:

- The ability to analyze double-sided boards
- Digital tomosynthesis does not degrade the image to isolate regions of interest as laminography does.
- Programming time is less than that needed to program ICT systems. ICTs cannot identify voids or verify solder quality and, without test points, have limited or no physical access to the component.
- Multiple Z-height locations are taken in one test pass. Therefore, a board does not have to be reinserted to acquire data for alternate testing scenarios.

Liabilities include:

- Medium-high cost
- CAD programming to determine component orientation, pad and pin locations.
- Algorithm threshold tuning to establish control limits and evaluate and determine best practice pass/fail conditions. ■

As printed in MACHINE DESIGN DECEMBER 7, 2000
www.machinedesign.com