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Selecting and Implementing Solder Paste Inspection for SMT Process Control

Rick Gunn
XeTel Corporation
Austin, TX

Bob Ries
CyberOptics Corporation
Minneapolis, MN

Abstract
This paper examines the process a major contract SMT manufacturer (XeTel Corporation), and the equipment supplier (CyberOptics Corporations) employed to evaluate, select and implement a new 100-percent, 3D post-print solder paste inspection system. This case study describes the manufacturer's need and requirements for a 100-percent solder paste inspection system. A thorough description of the evaluation and selection process is followed by descriptions of the actual evaluation and implementation that took place onsite at the contract manufacturer's facility. Initial results and process improvements are highlighted, including a 30% ICT yield improvement for high-density, high-complexity networking PCBs.

Why the Need for a New Solder Paste Inspection System?

Industry studies over the past two years have shown that approximately 50% of all electronics assembly errors (see Figure 1) and 65% of SMT-only defects (see Figure 2) are related to solder paste printing and solder joint formation.[1]

These and other studies have confirmed that effective and thorough paste inspection immediately after screen-printing is essential to ensure high yields, minimize rework/retest and reduce overall scrap costs.

With the advent of more high-technology components (such as CSP's and flip chips) and more complex, high-density PCBs (such as those used in telecommunications products), existing 3D sampling inspection is often not enough to sufficiently eliminate paste printing errors. Additionally, many contract SMT manufacturers have a market requirement to inspect 100% of the solder paste deposition and provide these inspection results to their customers.

These factors combined with the ongoing need for continuous process improvement influenced the contract manufacturer to upgrade one of their production lines with an in-line solder paste inspection system capable of 100-percent 3D inspection of most PCBs, including those with state-of the-art 8-mil diameter pad prints for flip chips.

A Review of The Solder Paste Inspection System Evaluation Process

The following paragraphs present the evaluation process used:

- A brief snapshot of existing SMT capabilities prior to installing the new solder paste inspection system
- Basic objectives and expectations for the inspection system
- Selection criteria for evaluating the inspection system
- Summary of the components used in the evaluation study

Paste Inspection in Current SMT Lines

The 120,000-square-foot-facility houses six SMT lines, including both high-volume and high-mix lines. Each line includes a sampling solder paste inspection system located directly after a screen printer. Typically, the sampling inspection system inspects 10 to 20 sites on every panel. This system inspects 100% of a 13” x 13”, 50-mil pitch BGA site in 8 seconds and inspects a 160-lead, 20-mil pitch QFP site in approximately 12 seconds. In-line cycle times vary from as low as 29 seconds per panel up to 4 minutes per panel. The SMT lines place components with sizes ranging from 0402 through ceramic column grid array (CCGA), plus flip chip and chip scale packages (μBGA).

Objectives and Expectations

By integrating a more capable inspection machine in an existing SMT line, the contract manufacturer hoped to achieve 100% solder paste inspection of PCBs without compromising line speed, repeatability, accuracy and overall throughput. 100% inspection was viewed as vitally important because it would help eliminate both systematic and random printing errors. There was also a need for the new inspection system to serve as a real-time quality check of the solder printing process, thus improving first-past test yield.

In contrast to the existing system, the manufacturer anticipated higher overall inspection rates and increased inspection coverage of ultra-fine-pitch and high technology board features with the new system – all without reducing the SMT line throughput.

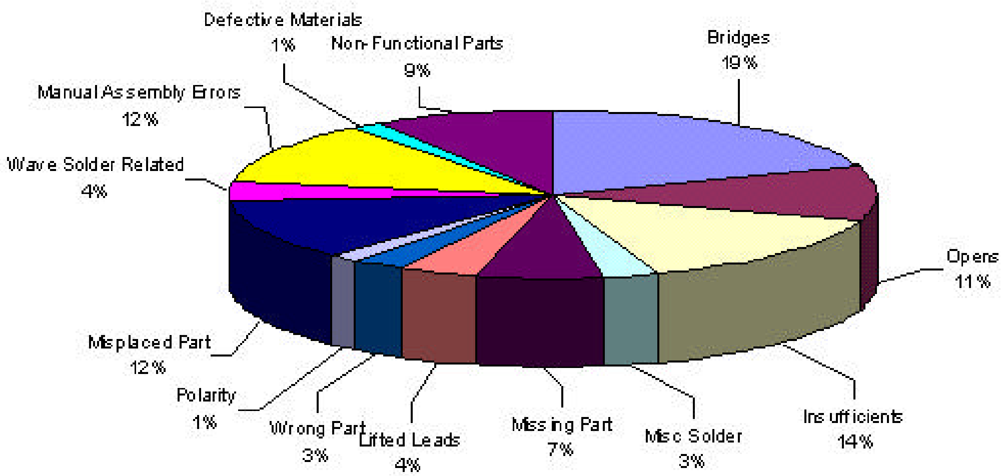

Figure 1 - Defect Chart for All Electronics Assemblies

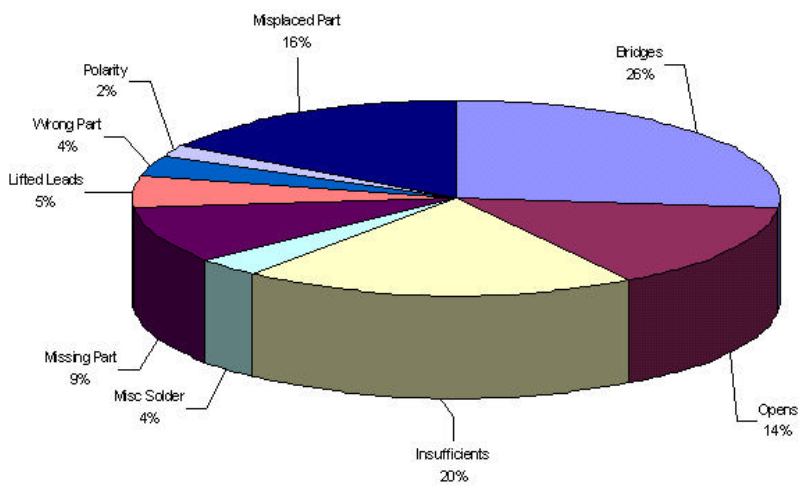

Figure 2 - Defect Chart for SMT-Only Assemblies

Criteria for Machine Performance, System and Price Selection Criteria

The contract manufacturer identified the following feature, performance, capability and price targets to the inspection system vendor:

- 100% solder paste inspection of PCBs at line speed, with inspection capabilities from 10 to 20 times faster than existing sampling inspection systems.
- 3D height, true volume and area measurement down to 8-mil diameter pads (i.e. flip chip and CSP).
- High-resolution, 12-bit height data to compute summary 3D measurements.
- Accurate results (CPk >= 1.67) for even the smallest features and/or components.
- High-resolution GR&R (gage repeatability and reproducibility) for height and volume measurements of <10% of typical 30-50% process tolerances.
- Ability to combine high-speed and high-resolution inspections within the same inspection program.
- Simple and intuitive Windows NT-based operator interface for panel display, trend charts, image views and online/off-line inspection programming.
- Minimum overhead for off-line machine programming from Gerber data, with less than 1 hour to program a simple PCB and less than 2 hours to program a complex board.
- Product changeover times of 15 minutes or less.

- Ability to collect and store all data for off-line analysis and report generation.
- Price less than $225K for inspection system hardware, software and training.
- Payback of less than one year.

Following a thorough evaluation study and acceptance process - as detailed in the next sections - the inspection system vendor met or exceeded the initial selection criteria, including a delivery price of $150K (beta system discount off $175,000 list price) for the in-line solder paste inspection system.

Summary Evaluation Study

The contrct manufacturer stipulated the following tasks to be performed onsite (with the exception of payback calculation and analysis) by the inspection system vendor during the actual inspection system evaluation process. Details of the actual evaluation tasks performed onsite are described below.

1. Machine programming and operation training
2. Off-line repeatability test to verify inspection machine performance
3. Cpk test on an idealized certification target
4. Off-line sampling of production
5. In-line installation
6. In-line operation, including independent review of defects to determine validity
7. Payback calculation and analysis

Implementation and Evaluation: Methods and Results

The onsite evaluation tasks and associated methods and applicable results are described here, corresponding to the tasks listed above.

Machine Programming and Operator Training

Hardware and software training took place over a period of one week at the contract manufacturer's site. This included an overview on the mechanical aspects of the machine and detailed operation instructions for the Teach and Solder Paste Inspection application software. (Figure 3 shows a typical Teach interface display. Figure 4 shows a representative Solder Paste Inspection interface display.) Additionally, one day was spent learning an after-market Gerber file-conversion software used for off-line programming. (Figure 5 shows a Gc-Place interface display.)

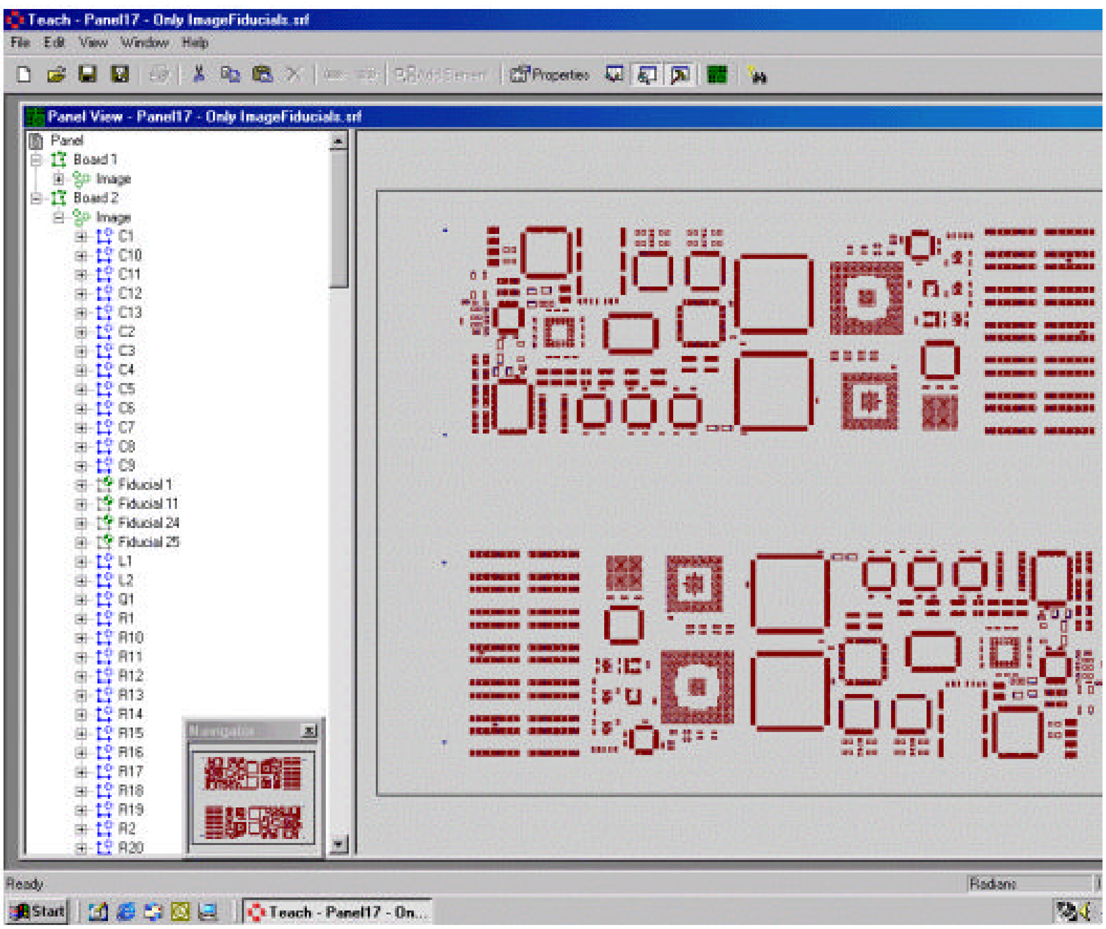

Figure 3 - TEACH Interface Display

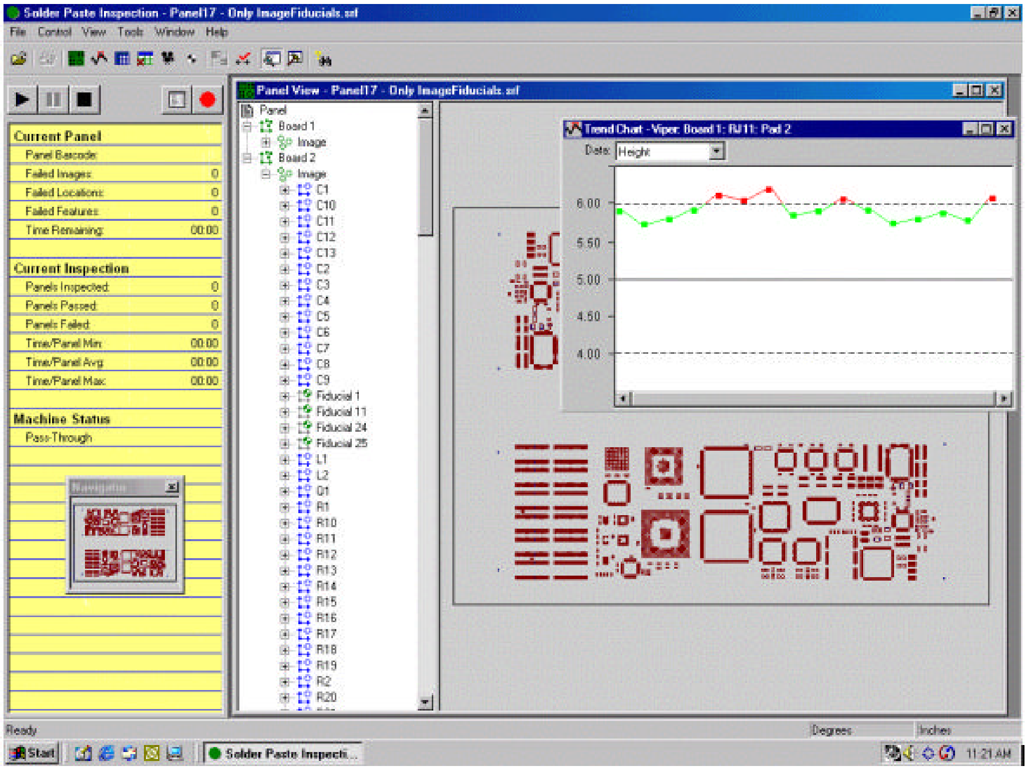

Figure 4 - Solder Paste Inspection Interface Display

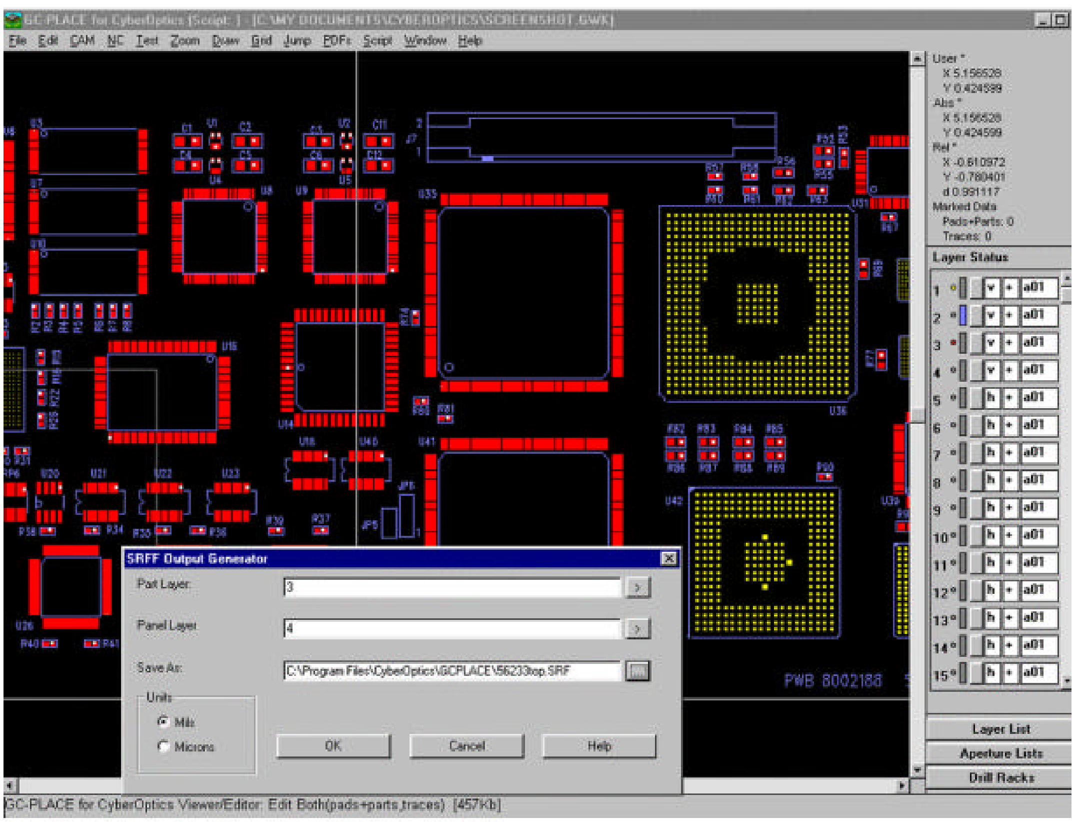

Figure 5 - Gerber Conversion Software Interface Display

Off-line Repeatability Test to Verify Machine Performance
A sample board was programmed and inspected 20+ times, logging all measurement data to the system hard drive in CSV format. This data was then input to a spreadsheet, where the standard deviation of the height and volume readings could be calculated for each different pad type. These numbers were compared to the GR&R specifications provided by the vendor to assure the inspection system met basic repeatability requirements on solder paste.

Cpk Test on an Idealized Certification Target
CPk testing of the inspection system is currently ongoing, with results forthcoming in the near future. The CPk method being employed is as follows: Calculating CPk, or machine process capability, is a method used to determine if a process (solder paste printing) is meeting specification limits and producing "good" parts. Capability is determined by comparing the width of the specification limits with the width of the process variation. Or, stated another way, a capability index is the ratio of the specification tolerance to the natural process variation. Typically, in electronics assembly, a process is deemed capable if this ratio is 1.67 or greater. To implement this type of CPk test, the process must be in control and "true" measurement values must be known. The best way to do this is to use an independently-measured, idealized target. In this case, a metal certification target is used with 16 different size and shape pads representing typical rectangular and round solder paste deposits.

The certification target is first measured with a white-light interferometer to establish "true" height values from which upper and lower specification limits (i.e. USL and LSL) could be calculated. Next, the target is measured by the solder paste inspection system 30 times to generate the data required to determine the mean reading and process variation (i.e. sigma). Finally, CPk for height was calculated per the formula the following formula:

CPk = minimum of either (USL – mean)/3 sigma or (LSL – mean)/3 sigma

Off-line Sampling of Production
With the machine still in off-line mode, PCBs were taken from the production line and run through the inspection system. This was done to verify that the program data generated for these assemblies was executing correctly. Measurement data was also saved so that it could be fed back into the *TEACH* software to adjust nominal values for height, volume and area, accordingly.

In-line Installation
Installation of the inspection equipment was accomplished in approximately half-day (4 hours). A 100-percent solder paste inspection system was installed in a high-volume SMT line directly following the screen printer and the masking and epoxy dispensers. (The solder paste inspection system replaced a sampling, solder paste inspection system.) Installation also included removing a 1-meter section of conveyor, positioning the inspection system in this location in the line, and connecting up/down stream SMEMA communications. A network connection was also made to the inspection system's computer so that programs generated off-line could be easily downloaded to the production system (See Figure 6).

Figure 6 - The 100-Percent Solder Paste Inspection Machine Installed In-Line at SMT Facility

In-line Operation
Initial in-line operation consisted of adjusting conveyor width for production assemblies, loading pre-existing programs and executing them. Gross defects were introduced on some assemblies by manually removing solder paste to assure that the inspection equipment was detecting all failures. Process engineers verified more subtle failures by using both the inspection systems built-in 2D and 3D image views and by taking questionable boards to a off-line solder paste inspection system for independent measurement of solder paste height.

In-line Speed Testing
Initial in-line testing was performed on one of the most complex PCBs manufactured by the contract manufacturer. Specifications and results were as follows:

- Board type: containing CSP's
- Board size: 16" x 11"
- Number of pads: 16,454
- Number of cards: single-up
- Inspection time: 3 minutes, 6 seconds
- Cycle time: 3 minutes, 15 seconds

Payback Calculation and Analysis

Note: The following paragraphs describe a *typical* payback analysis, not necessarily that of XeTel.

The first step in a financial justification is to define a sample production scenario and costs. Table 1 shows the required production input data and typical values as determined by the inspection vendor. Key elements in this table are initial yield, solder paste defect rates and test/labor costs.

Table 2 illustrates a payback is calculation. The total cost of ownership is input, and savings in rework, test and scrap are calculated. Overall payback, rate of return and net present value are output. Typically a payback of less than one year is achieved, along with a rate of return much greater than the cost of capital for the user.

Table 1 - Production Input Data and Values

Production Inputs					
Days of Operation Per Week	5	*Notes:*	Inputs cells in white		
Weeks of Operation Per Year	50		Calcuations in blue		
Number of Shifts Per day	3				
Hours Per Shift	8				
Non Production Hours Per Shift	2				
Typical Cycle Time Per Board (seconds)	90				
Boards Scrapped Per Shift ($ value)	$500				
Run Time Per Year (hours)	4500				
Annual Board Volume per Line	180,000				
Typical Board Length (inches)	10				
Typical Board Width (inches)	12				
Typical Board Area ($inches^2$)	120				
First Pass Yield at Test (pre-inspection)	70 %				
Test Cycle Time (seconds)	120				
Test Cost Per Hour	$150				
Solder Related Defects (% of total defects)	50 %				
Placement Related Defects (% of total defects)	30 %				
Pre-Reflow Rework Cost Input/Summary	Defect Rates (% Of Boards)	Rework Time (Minutes)	Total Rework Cost Per Hour	Repair Cost Per Board	Total Cost Per Year
Solder Related Defects	15 %	2	$20.00	$0.67	$18,000
Placement Related Defects	9 %	5	$20.00	$1.67	$27,000
Post-Reflow Rework Cost Input/Summary					
Solder Related Defects	15 %	10	$25.00	$4.17	$112,500
Placement Related Defects	9 %	30	$25.00	$12.50	$202,500
	1st Pass	2nd Pass	Total Cost Per Year		
ICT Cost Summary	$900,000	$270,000	$1,170,000		
	Per Day	Per Year			
Scrap Cost Summary	$1,500	$375,000			

Table 2 - Payback Calculation and Analysis

Inputs					
List Price	$175,000	*Notes:*	Inputs cells in white		
Options (GC-Place, SPC, cert target)	$18,250		Calculations in blue		
Residual Value After Three Years	$20,000				
Installation and Training	$0				
Maintenance Per Year	$17,500				
Engineer/Operator Cost Per Year	$70,000				
	Defective Boards Per Year	Rework Cost Per Year			
Pre-Reflow Rework Cost Increase					
Solder Related Defects	27,000	$18,000			
	New Yield	Cost/Year			
ICT Cost Decrease With Improved Yield	85 %	$135,000			
	Defective Boards Per Year	Cost/Year			
Post-Reflow Rework Cost Decrease					
Solder Related Defects	27,000	$112,500			
Scrap Reduction Per Year	$56,250				
Payback Analysis		**Year 0**	**Year 1**	**Year 2**	**Year 3**
Equipment, Installation and Training		-$193,250			$20,000
Maintenance and Engineer/Operator			-$87,500	-$87,500	-$87,500
Rework Costs			-$18,000	-$18,000	-$18,000
Scrap Savings			$56,250	$56,250	$56,250
Rework Savings			$112,500	$112,500	$112,500
ICT Savings			$135,000	$135,000	$135,000
Projected Cash Flows		-$193,250	$198,250	$198,250	$218,250
Payback Period (years)		0.97			
Internal Rate of Return		88.68 %			
Cost of Capital	20 %				
Net Present Value		$196,612			

Initial Process Improvements

During initial runs on the modified SMT line with the SE 300 solder paste inspection system, The contract manufacturer reported 30-percent ICT yield improvements for high-density, high-complexity networking cards with 20,000 apertures on the top side. This yield improvement compares favorably with the defect charts highlighted earlier in this paper (Figures 1 and 2) that showed approximately 50% of all electronics assembly errors and 65% of SMT-only defects are related to solder paste printing and solder joint formation. SMT operators are now routinely using the 100-percent inspection results to detect printing errors and correct them prior to component placement.

Conclusion

With the advent of more high-technology components and more complex high-density PCBs, many contract SMT manufacturers now realize a market requirement to increase line speeds for improved throughput and to inspect 100% of the solder paste for improved PCB coverage and, as a result, improved ICT yields. Following a thorough selection, evaluation and implementation process (as detailed in this paper), the contract manufacturer has initially realized significant ICT yield improvements of 30% for these complex PCBs when run on the modified SMT line that incorporates the 100-percent solder paste inspection system.

References

1. Source data for the assembly defect studies were derived from CyberOptics Corp internal data collected from 36 worldwide manufacturers representing 458 lines.
2. Detailed information about the solder paste inspection gage repeatability and reproducibility (GR&R) procedure and results can be found at www.cyberoptics.com.