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AXI Applications with BTC and Connectors in Flextronics

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Abstract

Bottom Termination surface mount Components (BTC) are extremely popular because of their low cost, low stand-off height and excellent thermal and electrical properties. In this manufacturing arena, more and more connectors are utilizing the printed circuit board (PCB), due to its ability to allow convenient memory expansion in servers and embedded applications in communications. The challenge for the industry is to achieve the best possible BTC and connector solder joint quality. The following questions are keys to our discussion: What is the best way to use test and inspection techniques? How does one obtain accurate AXI (Automated X-ray Inspection) data and images for surface mount technology (SMT) process improvement? How does one minimize voiding in thermal pads caused by changing design rules in order to meet stringent customer requirements? How does one reduce the use of mechanical cross-sectioning, since it destroys costly PCBs and is time-consuming?

Identifying product defects associated with the manufacturing process is a critical part of electronics manufacturing. When faced with the need for high yields, especially for new product introduction (NPI), AXI faces challenges with new packages and processes, such as BTC and connectors. In this project, we will focus on how to use AXI to identify BTC and connectors, especially for voids from AXI testing of Mosfet and PQFN packages. The test methods include AXI, 2DX and cross-section. We would like to reduce destructive methods in order to have a high-accuracy, low-void percentage from DOE (Design of Experiments).

We analyzed data from Tomosynthesis of AXI3 machine, AXI4 machine and 2DX, cross-section (virtual and horizontal cross-sectioning) using QFN package types (Mosfet and PQFN). The goal is to look for a correlation between AXI and 2DX, 2DX and cross-section for improving accuracy levels with AXI data. The SMT process was improved, with good feedback of X-ray data and correlation results.

Introduction

With new component packages on PCBs, manufacturing technology faces challenges with new processes, including testing, when addressing the need for high yields. Detecting defects, and providing accurate product defect feedback to the manufacturing process, are vital parts of electronics manufacturing. In this paper, we will share a project in which an AXI application is used in conjunction with BTC, connectors and critical components, and show how to use AXI to improve the SMT process.

Current AXI capabilities have limits for detecting defects with these critical packages, including package on package (PoP), especially for zero percent error and connector false calls. In this project, we will focus on testing conditions, board defects of SMT connectors, Q (Mosfet) voids, PQFN thermal pad voids, false calls and undetected defects. We will first address testing conditions of machines and then algorithm optimization. We have been working with X-ray vendors to improve hardware and software status, calibrate machines with accurate standard samples and provide 2DX data/images to vendors for further fine tuning of the AXI program.

We use Gage repeatability and reproducibility (Gage R&R) regularly for all X-ray machines, using different component packages, and we know what each machine's repeatability and reproducibility capabilities are. Since 2DX is more accurate than AXI, it is important to compare the correlation studies with the Gage R&R results. Because AXI's measurement data output is automated, we prefer to have AXI measurement data with more accurate results comparable to 2DX data.

Beside AXI versus 2DX test methods, we also utilized 2DX versus cross-section, with both vertical and horizontal sections. We tried to minimize mechanical cross-section testing, since it was a destructive method during the design of experiments. By examining X-ray data and quickly applying its feedback to the manufacturing process, significant improvement was achieved, meeting our customer's requirements. The AXI algorithm of the Q (Mosfet) voids, PQFN thermal pad voids for the different AXI machines will be discussed for obtaining accurate measurement data. For reducing defects, the process improvement items, including stencil design, will also be discussed.

Motivation and Performance

This project is based on a high density printed circuit board assembly (PCBA). The size of the PCB is 8 X 16 X 0.130 $inch^3$ with 20 layers. The main SMT critical components are DDR3 DIMM (dual row in line memory module) connector, BTC's (PQFN, QFN, and Mosfet) and BGAs with larger socket 2011 I/O. The challenges we faced were SMT connector leads that were open and voiding under BTC's as shown in Figure 1.

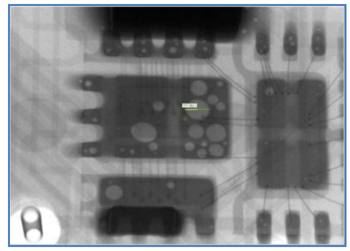


Figure 1. Open Solder on SMT Connector **Voids on QFN**

The PCBA has a total of 24 DDR3 DIMM connectors populated on the bottom and top sides. The DDR3 DIMM is a high-speed memory connector with 1mm pitch size for 240 pins. The DIMMs are mirrored top to bottom, with a slight offset for rework purposes. AXI is used to inspect solder joints.

We used AXI3 machine for this assembly. It has capabilities to detect open connectors with high false calls, and more escaped BTC voids with poor Algorithm threshold settings. Because of stringent requirements from the customer, we requested an AXI4 machine as a back-up to the project. This gave us opportunities to conduct AXI comparison studies using the same boards. To this day, the AXI3 machine is still on the manufacturing line, and its re-aligned hardware and software settings have improved its performance over the past six months. AXI4 machine had also improved its performance in this challenging industry.

1. **Testing conditions**

Because the 2DX machine is used as the reference for the AXI measurement, it is imperative that the 2DX machine be used with accuracy[1]. 2DX machine calibration comes with very high accuracy standard void samples from the vendor's engineering group. We suggest that AXI machine vendors themselves also soon maintain the same accuracy standard void samples as the 2DX machine, in order to increase the AXI machines' level of accuracy.

Keeping AXI machines aligned with normal testing conditions is also important. When we see unexpected issues, such as an alignment shift or wide discrepancies in testing defects, we stop and evaluate the machine. Usually these problems are due to hardware issues, such as conveyors/orbits, a camera, etc. We determine the root cause first, fix it, and then keep going for optimized programming.

2. **Gage R&R**

It is good to know the Gage repeatability and reproducibility (Gage R&R) of the AXI machines which are on the line. At the company, we suggest using the same board for Gage R&R, and keeping the records for the AXI machine. For this project, collection data included new connectors on NPI boards from two AXI machines, AXI 3 and AXI 4. Table 1 lists the package types, and their information. All Gage R&R data collection was from three operators: each operator tested three times. In total there were nine sets of data, which were analyzed with a SPC software tool with a tolerance of plus or minus 20 percent.

Table 2 lists Gage R&R results of AXI3 and AXI4 machines for BGA, CSP, FP Gullwing, QFN, Resistor, Press Fit, and SMT Connectors respectively. From the data, it is best to have most of Gage R&R at less than 20 percent. It is important to remember that Gage R&R is just a repeatable parameter. Another parameter which we need to consider is accuracy, which we will discuss next.

Table 1 – Package List for AXI Gage R & R

Package	Component	# of Pins	Pitch Size (mil)	Pin #	Pad length (mil)	Pad width (mil)
BGA	U907	196	39.4	1 -196	20	20
QFN	U506	52	19.6	28 - 31	63	10
				19	33	10
				1 - 20, 21 - 27, 32 - 52	26	10
QFN	U506 (thermal pad)	3		55	168	89
				54	154	115
				53	126	80
201	R1, R2, …	2	21	1, 2	13	11
CSP	U303	97	15.8	1 - 97	13	13.4
Gullwing	U20	100	19.7	1 - 100	63	12
Press Fit	J288	120	53.1	1 - 120	28	28
STM connector	J1-J25	240	39.4	1 - 240	83	28

Table 2 – Gage R & R for AXI3, and AXI4

Gage R&R - BGA

Gage R&R	Package-Location	AXI3 Gage R & R						AXI4 Gage R & R					
		Ball Diameter (mil)			Void %			Ball Diameter (mil)			Void %		
		Middle	Pad	Package	Middle	Pad	Package	Middle	Pad	Package	Middle	Pad	Package
Gage RR %	BGA-U907	2.05	4.23	7.68	7.77	9.08	5.89	2.68	10.24	8.95	15.41	8.8	8.07
Repeatability %		1.75	3.55	5.58	7.77	8.93	5.74	2.39	7.83	8.23	13.79	8.69	8.07
Reproducibility %		1.07	2.3	5.28	0	1.64	1.34	1.22	6.6	3.52	6.88	1.4	0

Gage R&R - CSP

Gage R&R	Package-Location	AXI3 Gage R & R			AXI4 Gage R & R		
		Ball Diameter (mil)			Ball Diameter (mil)		
		Middle	Pad	Package	Middle	Pad	Package
Gage RR %	CSP-U303	5.09	10.88	9.48	9.97	15.39	7.89
Repeatability %		2.22	5.37	8.49	9.09	14.44	7.41
Reproducibility %		4.58	9.46	4.2	4.1	5.31	2.71

Gage R&R – FP Gullwing

Gage R&R	Package-Location	AXI3 Gage R & R		AXI4 Gage R & R
		Thickness (mil)	Fillet Length(mil)	Thickness (mil)
Gage RR %	FP-U20	5.79	11.17	0.98
Repeatability %		5.79	10.98	0.9
Reproducibility %		0	2.09	0.4

Gage R&R - QFN

Gage R&R	Package-Location	AXI3 Gage RR	AXI4 Gage RR
		Fillet Thickness (mil)	Solder Area (mil^2)
Gage RR %	QFN-U506	15.35	16.93
Repeatability %		13.98	16.91
Reproducibility %		6.33	0.75

Gage R&R - RES

Gage R&R	Package-Location	Thickness (mil)	Thickness (mil)
Gage RR %	RES 0201-R1, R2…	12.74	1.94
Repeatability %		12.22	1.72
Reproducibility %		3.3	0.9

Gage R&R – Press Fit

Gage R&R	Package-Location	Grey level	Thickness (mil)
Gage RR %	Press Fit-J288	23.57	1.74
Repeatability %		21.14	1.56
Reproducibility %		10.44	0.76

Gage R&R – SMT Connector

Gage R&R	Package-Location	Fillet Length	Thickness (mil)
Gage RR %	SMT connector J1-J25	14.26	0.94
Repeatability %		14.08	0.92
Reproducibility %		2.24	0.17

3. SMT Connector Testing

In the beginning, the main challenge we faced was real defects missed by AXI due to SMT connector opens. Besides using the AXI machine under normal testing conditions and having good Gage R&R, we focused on comparison studies with AXI algorithm threshold settings.

The DDR3 DIMM SMT Connector was shown in Figure 2. We expected to use the common AXI process to attain zero defects with reasonable false calls. We provided two boards with a total of 21 real defects to fine tune. With an algorithm threshold setting (Maximum Center to Heel Thickness Percentage) set at 105 percent, 6 of 21 defects were missed, with three pins as false calls by AXI3 machine. However with the threshold set at 95 percent, no defect was missed, with 28 pins as false calls. False calls for DIMM happened because of small voids on the pad as shown in Figure 3. At AXI4 machine, no defects were missed, with about 13 false calls using 12 standard images. When using 8 standard images, the number of defects not found was 2, and 1 false call was observed. Figure 4 shows the images of good, bad, and false calls for SMT connectors from AXI4 machine. There is a clear difference between good and bad solder joints; however the false calls are due to the solder shape or slices not being on the same level. With fine tuning under normal testing conditions, the false calls for both AXI machines reduced to PPM < 1500 with zero defects missed for these 25 SMT connectors, shown in Table 3. For the last ten months, our AXI engineers have monitored this ongoing process with the production team.

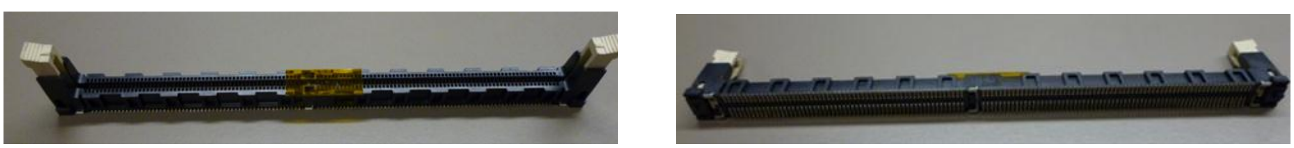


Figure 2. DDR3 DIMM SMT Connector (240 pins with 1mm pitch size)

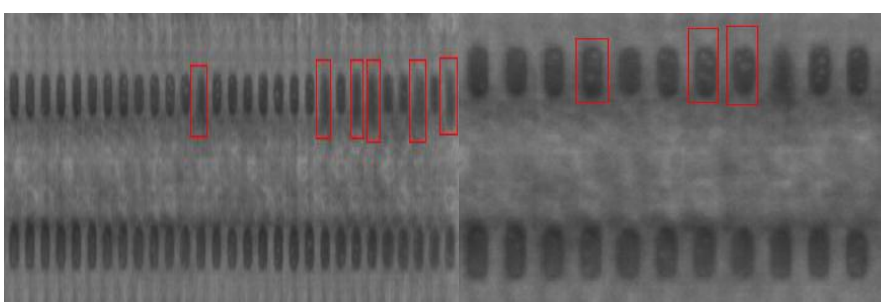


Figure 3. AXI3 Images (Real Call) **False Call Image**

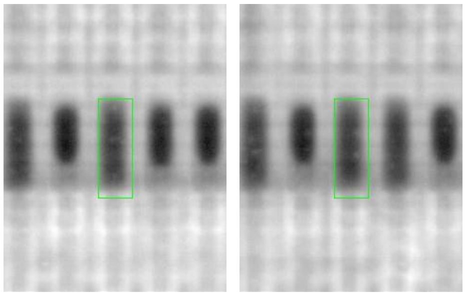
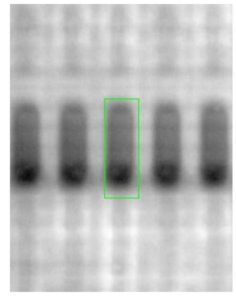


Figure 4. AXI4 Images (Real Call)



False Call Image

Table 3 – DIMM Inspection Capability for AXI3, and AXI4

Item	Total Pins Tested	Real Defects #	Defect Escaped %	False Call FPMO
AXI3	5760	21	0	1446
AXI4	5760	21	0	1446

4. QFN (BTC) Inspection

There are several types of QFN (BTC) components on the boards. Per the customer's request, voids above 25 percent on the pad including thermal pad were not allowed. At the beginning, besides the process issues with voids, there was room for improvement in AXI measurements regarding reliability and accuracy. We have performed several types of X-ray comparisons with the project. Because we use 2DX as a reference for AXI detection, the accuracy of the 2DX measurement is very important. First, we did comparisons using 2DX machines on the manufacturing floor and in the failure analysis (FA) lab. The results showed no significant difference between 2DX measurement data from different sites. However, there was a difference between 2DX and cross-section testing with vertical and horizontal sections, and generally the void percent from cross-section was slightly larger than 2DX at the beginning (Figure 5). Therefore we adjusted contrast and some parameters, including calibrating the 2DX machine with its standard samples to gain more accurate results for 2DX. Since cross-section is a destructive method, we opted to have reduced samples sent to the failure analysis (FA) lab.

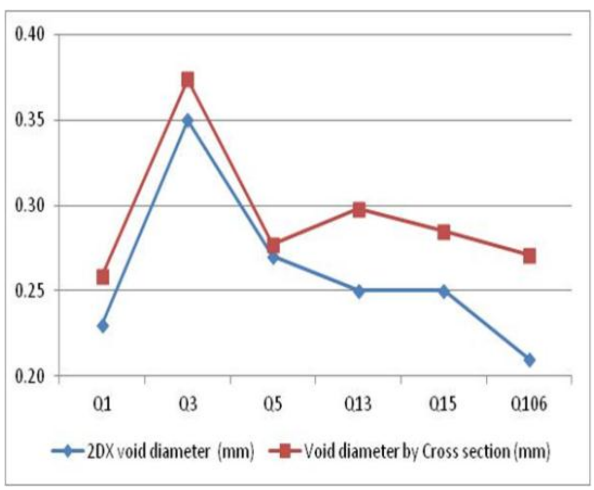
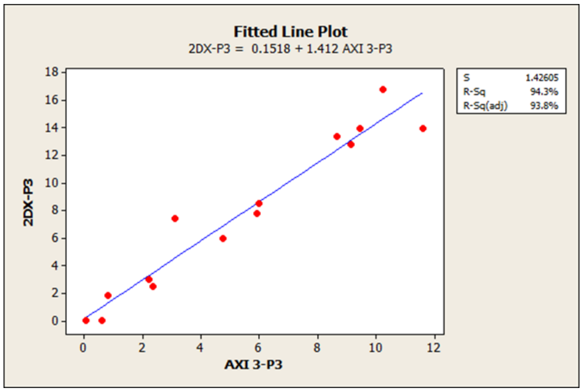
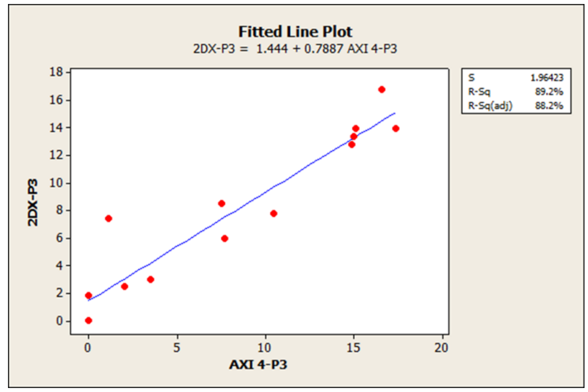


Figure 5. Voids Diameter Comparison of 2DX and Cross-section

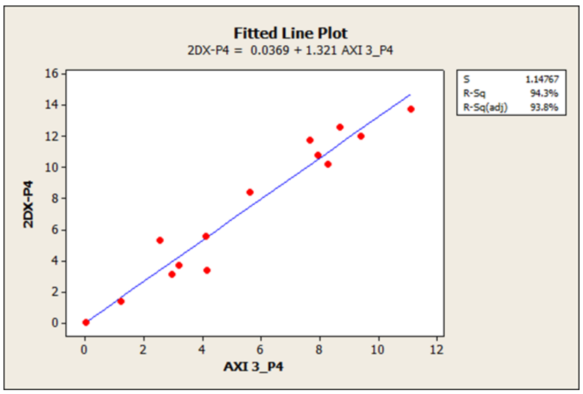
We have studied comparisons with 2DX and AXI machines for QFN components. We started from Q-Mosfet Thermal pins #3, #4, and #5 which void greater than 15 percent. Figure 6 listed results of 2DX versus AXI3 machine and AXI4 machine for Q-Mosfet pin # 3, #4, and #5, respectively. The correlation data are analyzed with a SPC software tool in Table 3. For pins #3 and #4, the correlations for AXI3-AXI4, AXI3-2DX, and AXI4-2DX were strong due to Pearson correlation coefficients greater than 0.9^2. However pin #5 had less strong correlation between 2DX and both AXI machines. In Figure 6, one Fitted Line Plot equation in each graphic show how the AXI machine data needed to be adjusted to be close to 2DX. In Table 3, the slope was the parameter of the reference points for AXI programming adjustment.



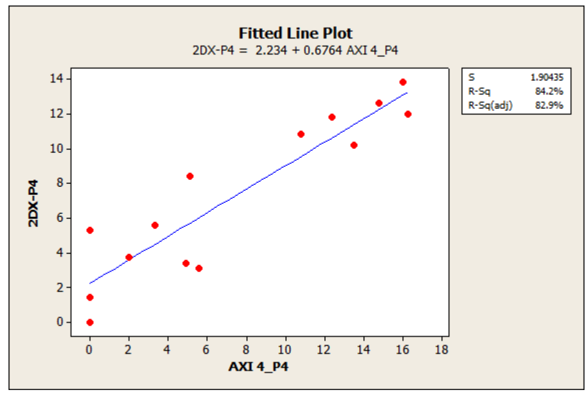
Pin #3, 2DX versus AXI3



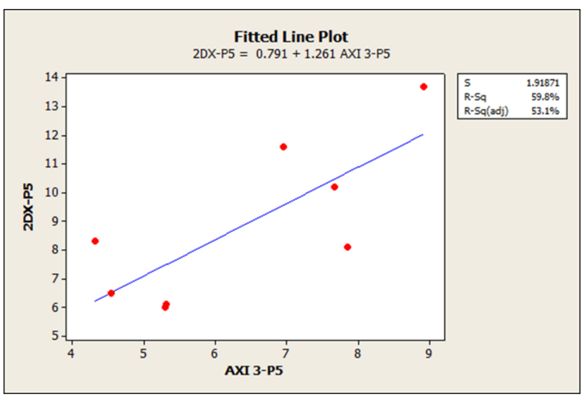
Pin #3, 2DX versus AXI4



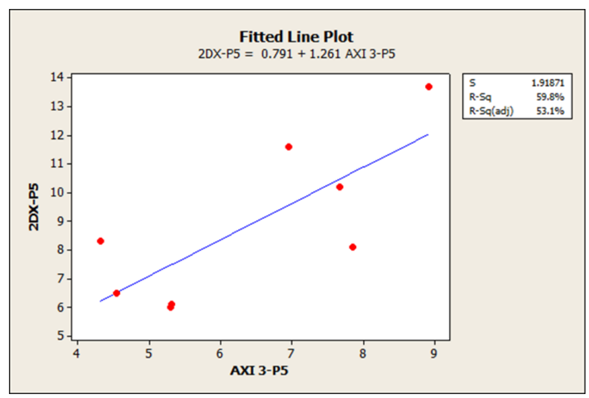
Pin #4, 2DX versus AXI3



Pin #4, 2DX versus AXI4



Pin #5, 2DX versus AXI3

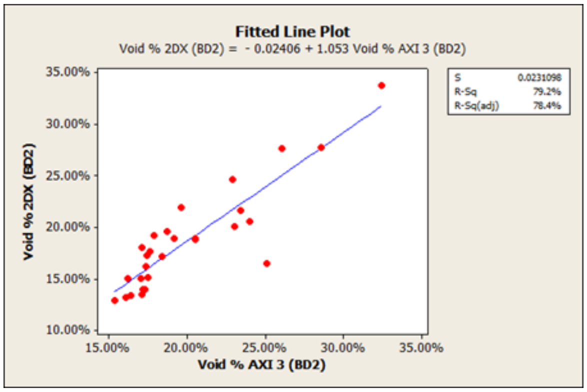


Pin #5, 2DX versus AXI4

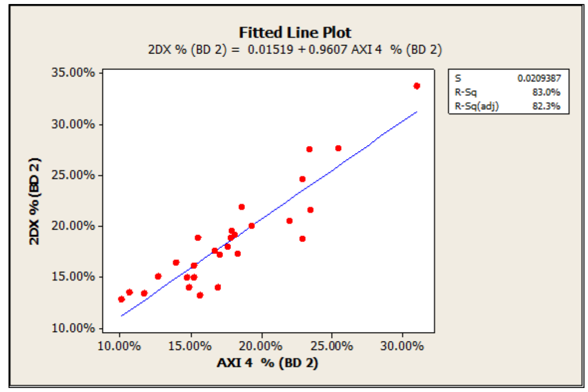
Figure 6. Correlations of 2DX and AXI3, and AXI4 with QFN-Mosfet Thermal Pads (#3, #4, #5)

Table 3 – Correlation of 2DX and AXI3 machine, and AXI4 machine Before AXI Program Improvement

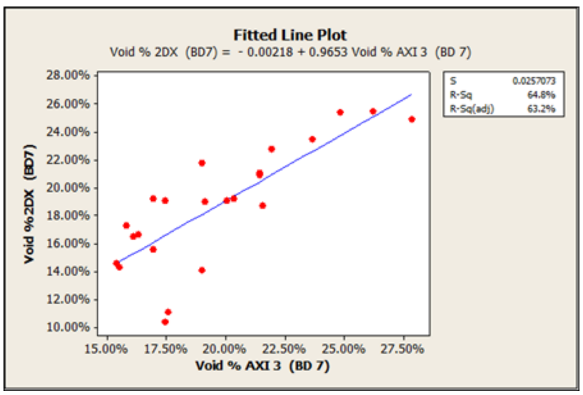
Q-Mosfet	Machines	Correlation (Before Improvement)		Fitted Line Plot (Before Improvement)	
Pin #		Pearson Coefficient	P-Value	Slope	Y-Intercept
3	AXI 3 - 2DX	0.971	0.000	1.412	0.1518
4	AXI 3 - 2DX	0.971	0.000	1.321	0.0369
5	AXI 3 - 2DX	0.773	0.024	1.261	0.791
3	AXI 4 - 2DX	0.944	0.000	0.7887	1.444
4	AXI 4 - 2DX	0.918	0.000	0.6764	2.234
5	AXI 4 - 2DX	0.767	0.026	0.6254	2.387



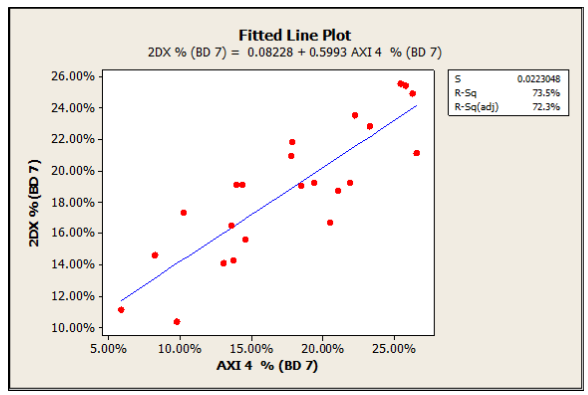
Board #2, 2DX versus AXI3



Board #2, 2DX versus AXI4

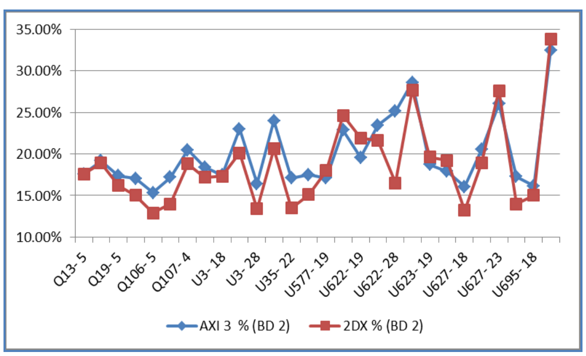


Board #7, 2DX versus AXI3

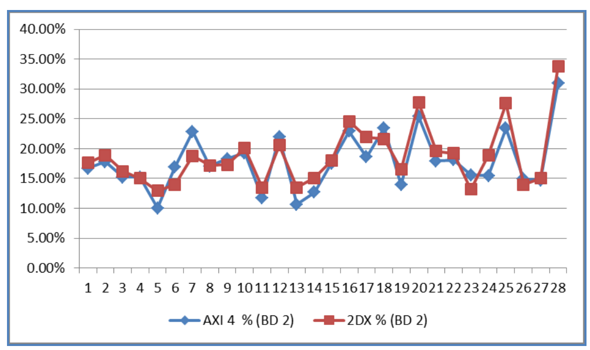


Board #7, 2DX versus AXI4

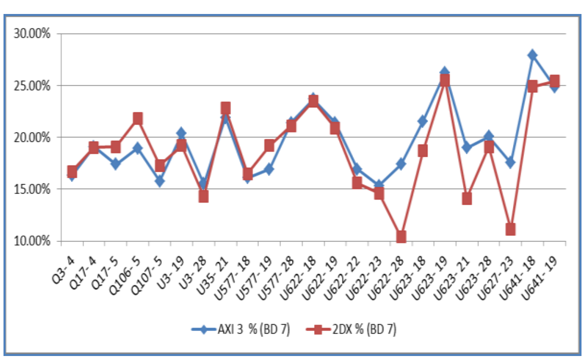
Figure 7. Correlations of 2DX and AXI3, and AXI4 with QFN-Mosfet Thermal Pads (#3, #4, #5)



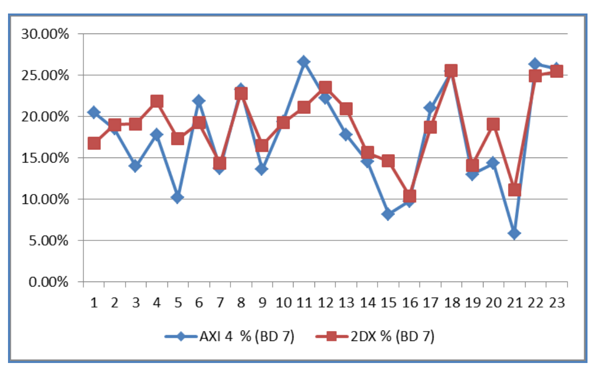
Board #2, 2DX versus AXI3



Board #2, 2DX versus AXI4



Board #7, 2DX versus AXI3



Board #7, 2DX versus AXI4

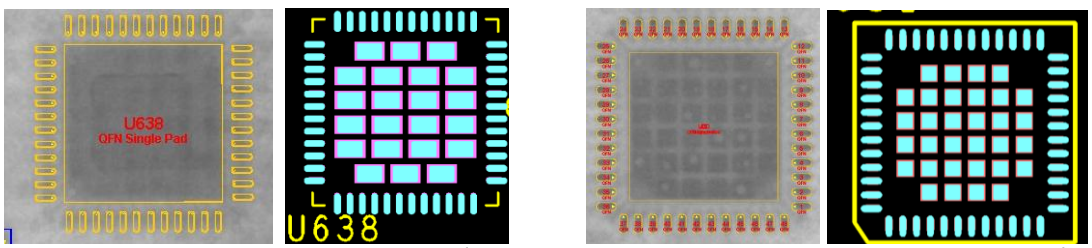
Figure 8. Measurement Data of 2DX and AXI3, and AXI4 for QFN Thermal Pads with Void > 10%

We provided these data and analysis results to the AXI machine vendors, and worked with them. After one week, the correlation results improved significantly. Figure 7 lists correlation results of 2DX versus AXI3 machine and AXI4 machine, respectively from two boards for all QFN components with voids. Figure 8 lists differences between 2DX and AXI machines, and the difference for voiding data was decreased and closer to 2DX. Table 4 lists the correlation after AXI programming improvement for two boards' results with QFN thermal pins which had void greater than 15 percent.

Table 4 – Correlation of 2DX and AXI3 machine, and AXI4 machine After AXI Program Improvement

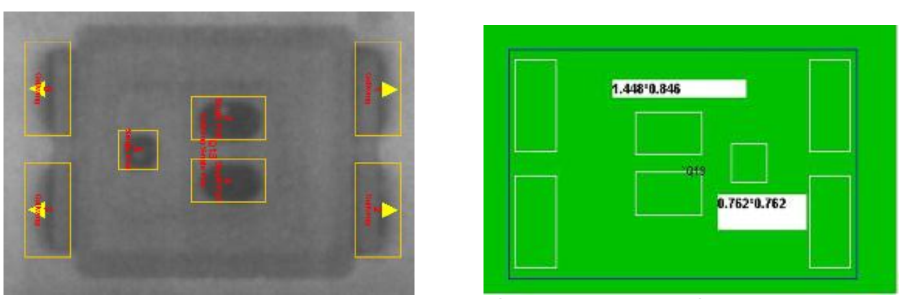
Machines	Correlation (After Improvement)		Fitted Line Plot (After Improvement)	
	Pearson Coefficient	P-Value	Slope	Y-Intercept
AXI3 - 2DX	0.890	0.000	1.053	-0.02406
AXI3 - 2DX	0.805	0.000	0.9653	-0.00218
AXI4 - 2DX	0.911	0.000	0.9607	0.01519
AXI4 - 2DX	0.858	0.000	0.5993	0.08228

For different types of QFN (BTC), our AXI program Algorithm settings are different for thermal pads. We use one area or single pad for the QFNs due to their size and number of single pads. The one area is used when thermal solder pads have small size and small space between solder pads; single pad is used when thermal solder pads have big size and large space between solder pads. Figure 9 shows examples for AXI program settings as the one area, the small PCB pad for the thermal pad of QFN are 1 X 0.6 mm^2, 0.5 x 0.5mm^2 respectively. Figure 10 shows the QFN for AXI program with single pad.

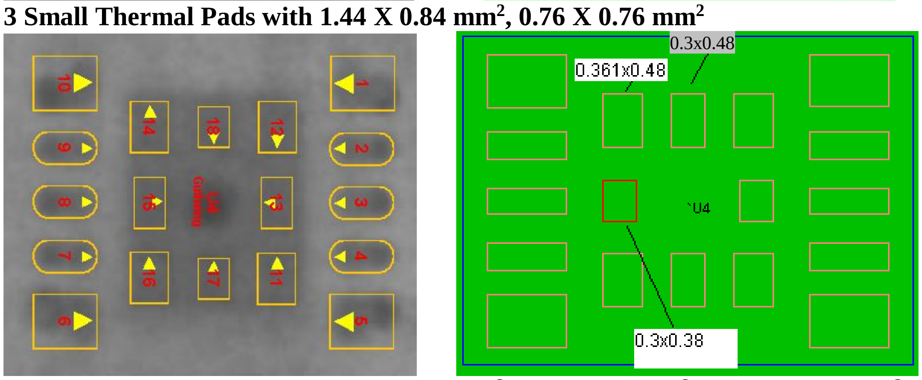


22 Small Thermal Pads with 1 X 0.6 mm^2 **32 Small Thermal Pads with 0.5 X 0.5 mm^2**

Figure 9. AXI program with One Area for these QFN Thermal Pads



3 Small Thermal Pads with 1.44 X 0.84 mm^2, 0.76 X 0.76 mm^2



22 Small Thermal Pads with 0.3 X 0.38 mm^2, 0.3 X 0.48 mm^2, 0.36 1X 0.48 mm^2

Figure 10. AXI program with Single Pad for these QFN Thermal Pads

Improvement

With accurate, real-time AXI data feedback to the SMT line, our process engineers worked with the AXI team to improve production with the DIMM connectors and QFN components[3]. The main process actions for DIMM were: reflow fixtures and support pallets, top and bottom reflow profile, solder paste type and volume, double check SPI data, and eliminate material transfer handling, etc. to reduce open, short, and insufficient defects.

Figure 11 is an example of a DIMM component open soldering issue. First, we reviewed the SPI data for defects and found none. Next, per the vendor's recommendation, we changed the press to two DIMM connectors at once instead of the three DIMM connectors required in the customer's PCB layout, also taking into consideration the unit per hour rate. We discovered that the press machine was malfunctioning. The machine pressure head was misaligned during pressing, so some points did not have enough force to push the connectors down to touch the PCB, causing some pins to not adequately make contact with the PCB pad. Once discovered, this situation was corrected. Figure 12 shows DIMM component defect per million opportunities (DPMO) for the last seven months. We are still monitoring the SMT process.

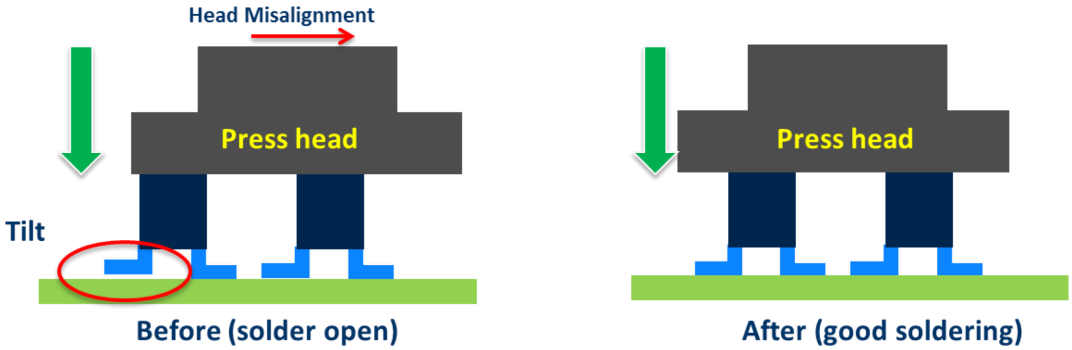


Figure 11. Before and After Improvement for DIMM Connector Process

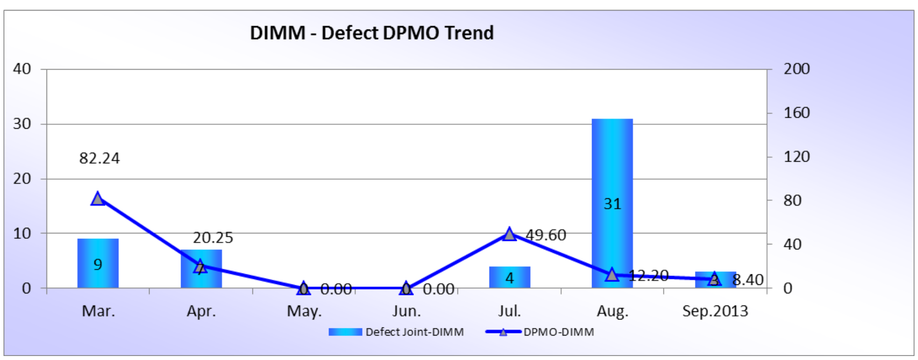


Figure 12. DPMO of DIMM SMT Connector (March – September, 2013)

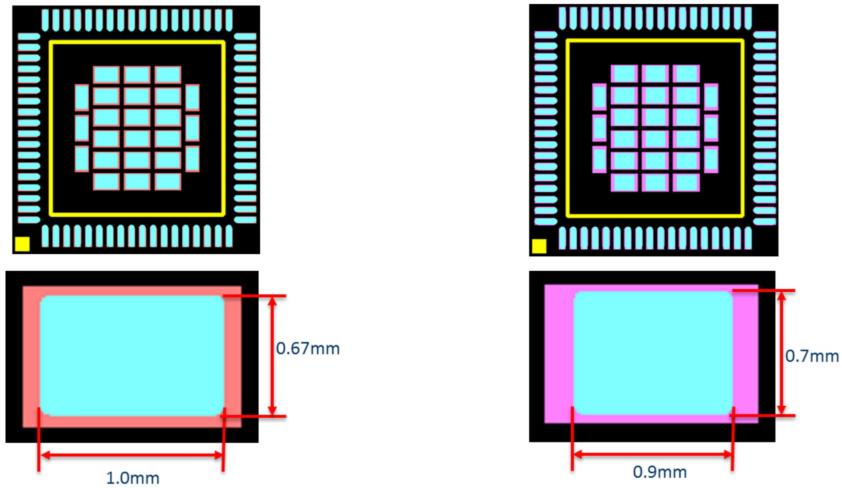


Figure 13. Before (left) and after (right) Stencil Design Improvement for DIMM Connector

With accurate, real-time AXI data feedback to the SMT line, we have been seeing large improvements in the process. The main process actions for reducing QFN voids are: stencil design, reflow profile, solder paste type and volume, double check SPI data, AXI program Algorithm setting. Figure 13 is an example for the QFN (BTC) stencil design for which there is no void greater than 25 percent. With such PCB processes in place, there is significant improvement in void reduction over the last seven months. The void defects per million opportunities (DPMO) for QFN and Q-Mosfet are shown in Figures 14, and 15 respectively.

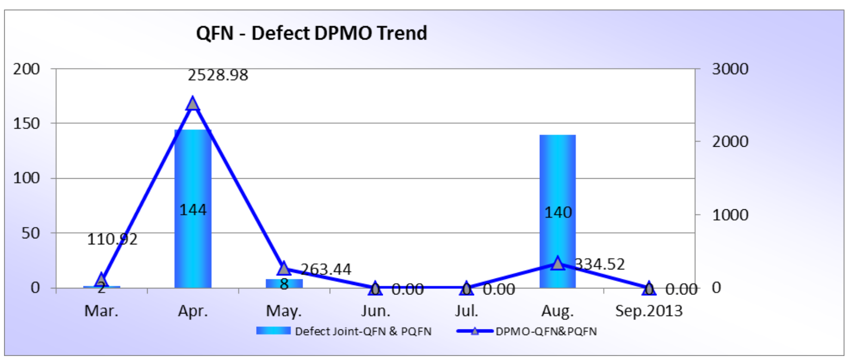


Figure 14. DPMO of QFN (March – September, 2013)

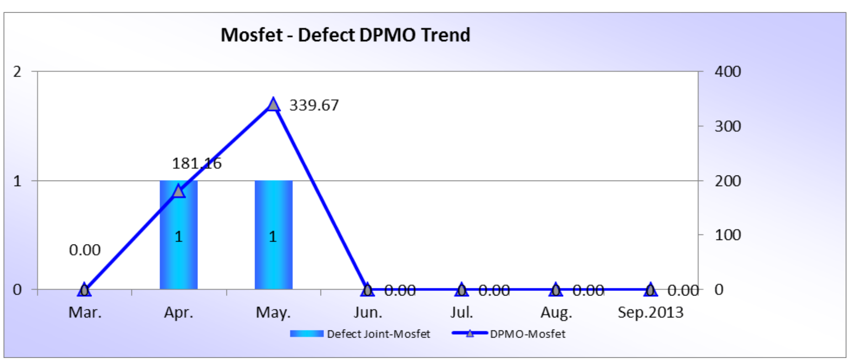


Figure 15. DPMO of Q-Mosfet (March – September 2013)

Conclusions

The following are conclusions which can be drawn from this work:

- Make sure AXI machines are under normal testing conditions, especially for NPI. For accurate calibrations, the AXI machine needs to have its own void standard board.
- AXI Gage R&R is important; however accurate AXI testing data is more important for process improvement.
- Focus on AXI balance of defects missed percentage and false calls PPM.

- Use non-destructive methods to identify process issues, and reduce cross-section samples by first comparing results of the other test methods.
- The AXI system is not only a test machine - it is process improvement tool. Using real-time data measurement feedback is the key to the process[4]. By using AXI as a SMT process improvement tool, we have reaped many benefits. Figures 16-18 list the yield of DIMM connector, QFN, and Q-Mosfet for this project for the last seven months.
- Working with vendors can generate better performance in the AXI field. Each X-ray machine has its own strengths and weaknesses. 2DX is an X-ray microscope which is useful as an AXI reference for certain critical components and borderline defective pins.

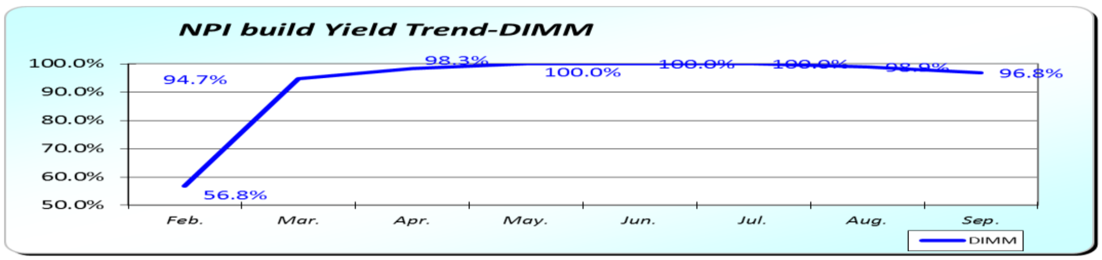


Figure16. Yield of DIMM SMT Connector (March – September 2013)

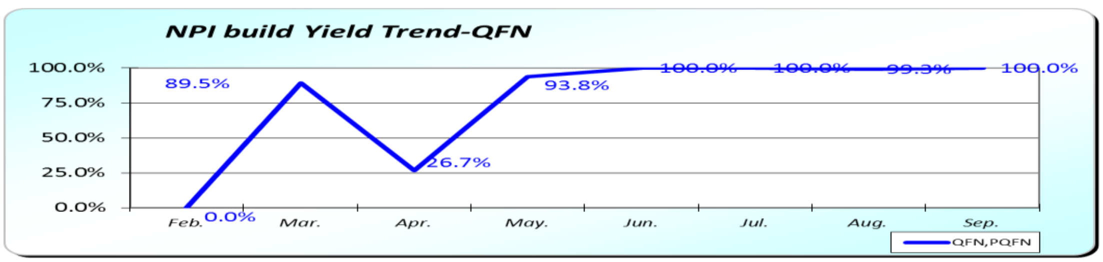


Figure 17. Yield of QFN (March – September 2013)

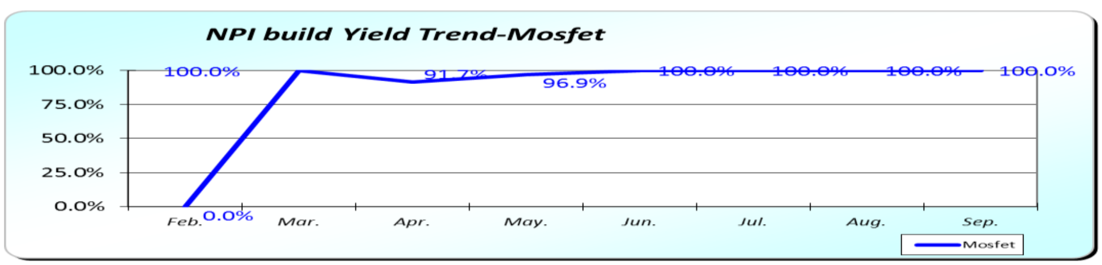


Figure 18. Yield of Q-Mosfet (March – September 2013)

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