NON-DESTRUCTIVE TECHNIQUES FOR IDENTIFYING DEFECT IN BGA JOINTS: TDR, 2DX, AND CROSS-SECTION/SEM COMPARISON

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ABSTRACT
The industry needs Non-Destructive Techniques to identify BGA opens and cracks. Currently X-ray and Time Domain Reflectometry (TDR) are most widely used.

In this paper we report the results of our comparison of the following techniques: TDR, Automatic X-ray inspection (AXI), Transmission X-ray (2DX), Cross-section/SEM and Dye & Pry. The first three are Non-Destructive; the Cross-section/SEM and Dye & Pry are destructive techniques.

We looked for a correlation among the various techniques in finding opens and cracks in BGA joints. Our experiment included:

1. Testing thirty pins on a particular BGA from ten different boards using TDR, AXI, and 2DX.

2. Further examining eight of those boards with Cross-section/SEM, and the remaining two boards with Dye & Pry.

These studies helped us to gain a good understanding of TDR, AXI, 2DX, Cross-section/SEM and Dye & Pry techniques. With 1,200 experimental data points, we found the following correlation figures**:** 15.1%, 21.9%, 23.8% for TDR versus SEM, 2DX and Dye & Pry; 51.3%, 51.9% for 2DX versus SEM and Dye & Pry respectively. TDR has the capability to identify BGA opens and larger cracks while 2DX can easily detect opens and much smaller sized BGA cracks.

Further, we will discuss the methods for effective identification of cracks in BGA joints using 2DX. The limitation of TDR, AXI, 2DX, Cross-section/SEM, and Dye & Pry techniques will also be addressed.

Key words: TDR, AXI, 2DX, Cross-section/SEM, Non-Destructive techniques, and comparison.

INTRODUCTION
More BGA and area array devices are appearing on PCBAs as product/functional complexity increases. Furthermore, to achieve good signal integrity, more I/Os are packed in smaller areas within the available real estate. Therefore engineers need Non-Destructive Techniques to identify BGA defects when ICT or FT calls for a faulty device[1-2]. Identifying BGA cracks is not an easy task with the available tools including 2DX. Automatic X-ray inspection (AXI) systems are used for identifying BGA opens in electronics manufacturing; however it is challenging for AXI Laminography to detect BGA defect size less than 4 mils. Time Domain Reflectometry (TDR) has capability to identify BGA full crack (opens) using impedance measurement data. The 2DX has been widely used to identify BGA defect because of its clear image. Engineers often use Cross-section/SEM or Dye & Pry to identify defective BGA pin, however the boards are destroyed during these tests. Thus we studied the Non-Destructive techniques to look for a correlation with the Cross-section/SEM and Dye & Pry.

AXI has more than 90% coverage for PCBA, and is an effective tool for collecting real time data for SMT process improvement[3-4]. Engineers usually use 2DX to verify critical defective BGA pins found with the AXI. Both AXI and 2DX are Non-Destructive techniques, and so is TDR. Thus we chose to use TDR, AXI and 2DX for this study. The objective was to find the correlations between the different testing methods:
a. TDR, SEM, and Dye & Pry;
b. 2DX, SEM and Dye & Pry;
c. TDR and 2DX.

We used the above five techniques and collected 1,200 experimental data points. The experimental methods are described in the methodology section, and data are analyzed in the results and discussions section.

In the conclusion section we summarize our findings that 2DX is the more effective Non-Destructive technique for identifying BGA joint defects. There is a good correlation between 2DX and SEM. Setting the right testing conditions is the key for optimizing the benefit of the 2DX technology. Lastly we discuss the best ways to use TDR, 2DX and SEM in order to improve the efficiency of the testing process and also the limitations of each of the three techniques.

METHODOLOGY

Equipments used for our work were a LeCroy WE100H mainframe with ST-20 TDR module, an Agilent Laminography 5DX, a Dage XD7500 transmissive X-ray, and a JEOL Scanning Electron Microscope. These are TDR, AXI, 2DX and SEM, respectively. The BGA DMN-8802 Dual Encoder processor has defects based on ICT and FT testing, and was selected as the object of our experiments. The BGA is on a board which is Set-Top Box bundled with user-controlled broadcast, frame enhancement and network access. The BGA X-ray image is shown in Figure 1. The fab, which has six layers has 388 pins with pitch size of 0.75 mm. Thirty BGA pins were selected for the experiment including A24 and C26. Solder joint problems have been reported previously for A24 and C26 using SEM and Dye & Pry. The pins are listed in Figure 2.

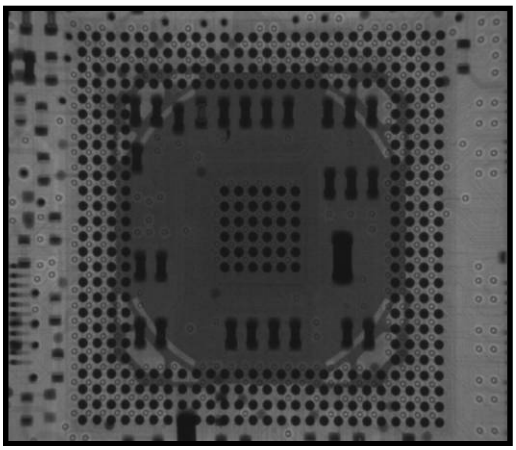

Figure 1 BGA DMN-8802 Dual Encoder Processor

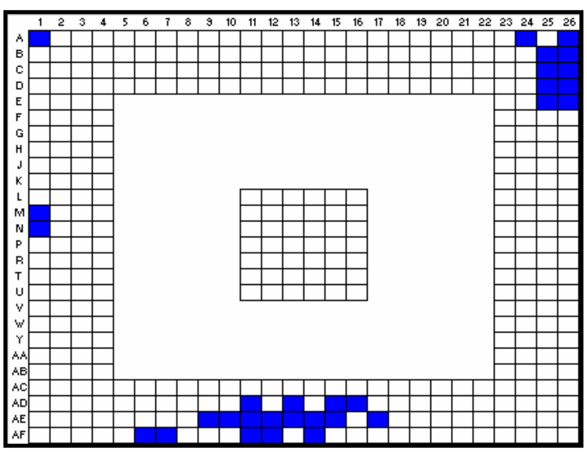

Figure 2 BGA Pins Selected for the Study

1. TDR

TDR is a measure of the reflections on an applied step pulse from the device under test (DUT), and is a powerful tool for analyzing the change in Impedance through a device, thus helping analyze poor connections, mismatched traces and other circuit discontinuities in transmission systems. TDR measures the reflections that result from a signal traveling through a transmission environment of some kind — a circuit board trace, a cable, a connector and so on. The TDR instrument sends a pulse through the medium and compares the reflections from the “unknown” transmission environment to those produced by standard impedance. Figure 3 shows TDR results for a complex line (trace) with ideal, wide, and narrow trace, where $Z_0 = 50\Omega$ is ideal; Z_1 is lower ($< 50\Omega$) because the trace is wide; and Z_2 is high ($> 50\Omega$) because trace is narrow. Test starting point must be one end of PCB trace. Sometimes the PCB trace is too long or the starting point is not available for probing, so in these cases the users cut off the PCB traces in order to get new starting point.

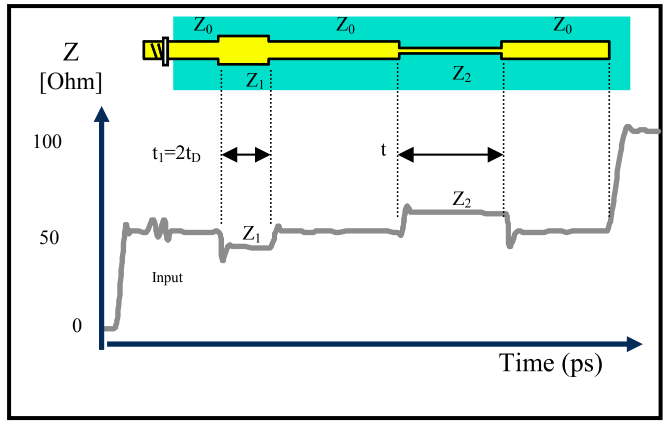

Figure 3 TDR Impedance of a Complex Line (Trace)

The LeCroy ST-20 RMS has 20 GHz Bandwidth, 700µV noise, 2.92 mm K-connector, and integrated 18 ps TDR step generator. The resolution is half step rise time (9 ps) which is 1.25 mm on PCB. The resolution means the minimum distance among two impedance mismatch points. If the two impedance mismatch points are so close that the distance between them is smaller than the TDR resolution, TDR will take it as one impedance mismatch point. If the trace is totally broken, even if the gap is lower than 1.25mm, TDR can detect it.

The Gauge Repeatability and Reproducibility (Gage R&R) experiments were done with 10 coupons used for measuring Impedance. Three operators measured the coupons, and each tested three times. The Gage R&R is 12.32% with 20% of tolerance.

The TDR test procedure is listed below:

1. Find a test point which is connected to the I/O we need to measure; this test point must be easy to contact with the probe and also needs to be close to the ground point. The distance between the test point and the ground point cannot be longer than the distance between two tips of the probe (0-10mm).
2. Measure the length of the trace between the test point and the solder ball of the BGA using any tool available.
3. Adjust the TDR equipment, then turn to the TDR test mode and choose the Impedance -Time mode.
4. Connect the probes to the test point and ground point on a golden board.

5. Wait until the Impedance-Time curve becomes stable, and then press the STOP button.
6. Adjust the cursor to the point where the distance value display is the same as the measured value that we got in Step 2.
7. Save the curve and the data.
8. Repeat step 4 to step 6 using a test board at the same location.
9. Compare both curves to identify if there is a crack or open on the solder ball.

All pins' graphics of DUT are recorded and compared to corresponding pins on a golden board.

2. AXI

These ten boards were automatically tested with Agilent 5DX after the TDR test. The 5DX pin number (1-388) was converted to a standard pin number (A1 - AF26). The defective pins were recorded. We included the 5DX data, and just wanted to find out what size of BGA open can be detected with the AXI technique.

3. 2DX

The Dage XD7500VR machine was used for the study after TDR and AXI testing. The X-ray absorbency of a particular material depends on its atomic number and density. Figure 4 shows how the transmission X-ray image is generated from a BGA ball and pads. It is an image showing grey level variations (detector bandwidth is 65,000 grey levels). The darker areas correspond to a higher X-ray absorption that is due to thicker material and/or material that absorbs the X-rays to greater extent. For instance metals absorb X-rays much more than organic material for the same thickness. In Figure 4, ray number 4 is absorbed more than ray number 2. The void and crack are lighter on the images as less X-rays have been absorbed. We might not be able to detect the crack if the difference in absorption between rays is very small. Figure 5 shows two different configurations for the X-ray inspection. Trying to detect cracks from X-ray direction A is very difficult because there is a large amount of material absorbing the X-rays and hiding the crack. Identifying the crack from direction B is much easier and the crack size can be measured. However looking at the board at 90 degrees is impractical as there are many obstacles in the X-ray path. Dage XD7500 has an oblique angle viewing capability of up to 70 degrees. It uses open transmissive X-ray tube technology and has sub-micron (0.950µm) feature recognition.

The Dage machine settings were as following: tilt (oblique) angle 55 to 68 degrees and rotation of the X-ray detector 0 to 360 degrees around the examined joint. This is not trivial, but it is very easily accomplished using the Dage X-ray equipment. The oblique and rotation angles of the X-ray detector are key factors for identifying small cracks[5]. The images were collected for all 30 pins of the 10 boards, and measurements were done for some joints with cracks. It is noted that 2DX measurement data for cracks (below 4 mils) is just for reference as the most accurate measurement is accomplished using top view.

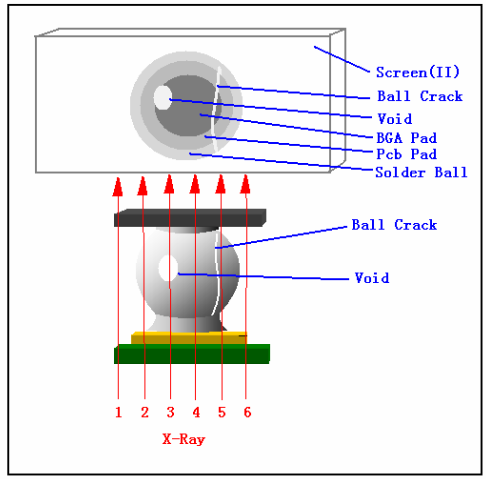

Figure 4 How Transmission X-ray Image Is Generated?

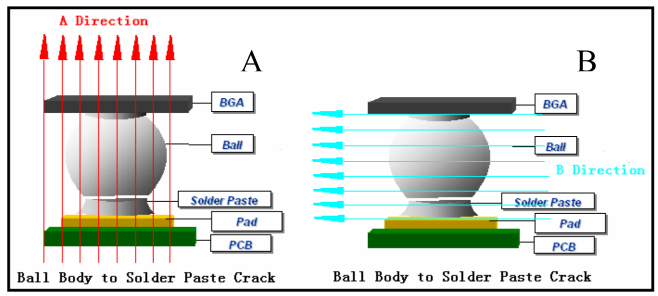

Figure 5 2DX Imaging of BGA Crack

4. Cross-section/SEM

After completing TDR, AXI and 2DX, eight boards were sent for Cross-section/SEM. We chose the best fitting mounting cup, uniformly applied resin, and grinded very carefully at the location of interest which was previously precisely aligned. The cross section has the following limitation that is explained in Figure 6. The solid red line is a micro-crack in the X-Y plane. The rectangular boxes (red, yellow and green colors) are Cross-section locations. We will not detect the crack if the cuts are made in the red locations. The crack will appear as a dot on the SEM image if the cuts are made in the yellow locations. The green color box indicates the "PERFECT" cross section location. However no one knows in advance where this "perfect" cross section location is. Therefore the grinding needs to be done extremely carefully using different grinding grade from 200µm to 22µm. The cross sectioned sample was imaged using a JEOL 5900 SEM machine.

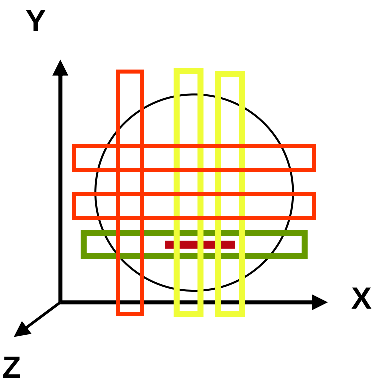

Figure 6 Limitation of Cross-section/SEM Technique (The BGA pad is on the X-Y plane)

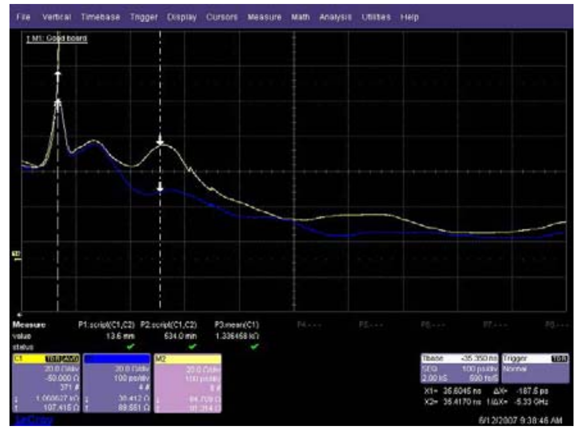

Figure 7 TDR Shows Open Defect (pin A1 board 17385)

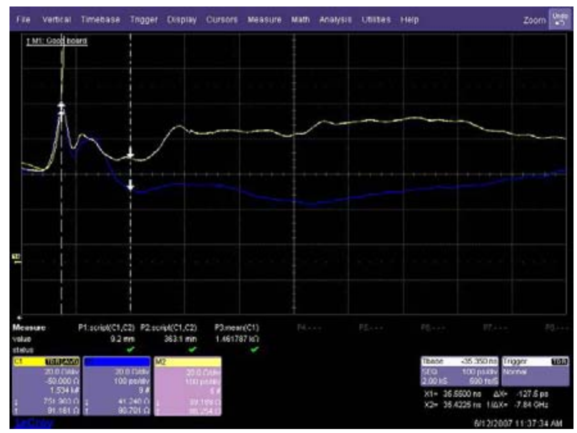

Figure 8 TDR Shows Open Defect (pin A26 board 17385)

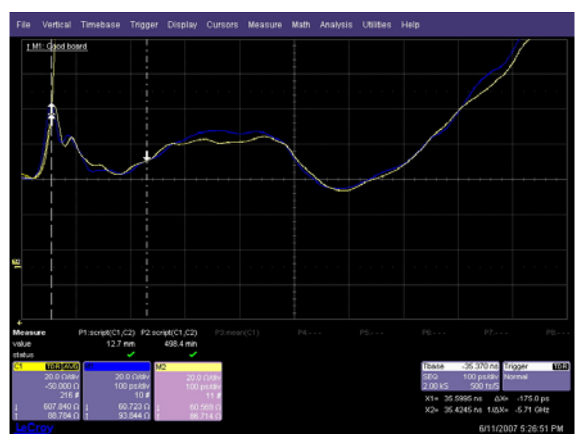

Figure 9 TDR Shows Good Joint (pin C26 board 17385)

5. DYE & PRY

After completing TDR, AXI and 2DX, two boards were used for Dye & Pry testing. The dye used in the test was a Dykem product. The dye sample was inspected using a high magnification microscope (>25X) to identify dye penetration and failure mode presented.

RESULTS AND DISCUSSIONS

Totally we acquired 1,200 data points using the different test methods. The comparisons and discussions of the Non-Destructive techniques (TDR, AXI, 2DX) and the Destructive ones (Cross-section/SEM, Dye & Pry) is presented below.

1. TDR

Figure 7 is TDR measurement graph for pin A1 of board (S/N 17385), where M1 is the reference data from a golden board, the impedance is 38.4 Ω; the impedance for M2 is 64.7 Ω, which is the test pin A1. Based on the TDR data, it is easy to tell the pin has an open defect. The pin A1 is missing ball, all TDR, AXI, 2DX and SEM called it as defect. Figure 8 shows pin A26 on the same board (M1 = 41.2 Ω, and M2 = 59.2 Ω). It shows open defect as well. This pin was found defective by 2DX and SEM also. Figure 9 is the TDR graph for pin C26 on the same board (M1 = 60.7 Ω, M2 = 60.6 Ω). The difference between them is about 0.1 Ω. So it is not identified as defective ball by TDR. Actually the BGA ball has about 1.5 mil cracks. Table 1 lists the results for this board: column 1 is the pin # location; column 2 is the length of the trace between the test point and the solder ball of the BGA; the impedance columns have TDR measurement data for reference point and DUT (device under test) data; and the last column is comments for pass or fail per the difference of impedance of reference and test data (Delta Impedance).

Table 2 lists TDR test results for 300 pins of the 10 boards, and a total of 18 defects are found based on TDR measurement data.

Table 1 TDR Test Measurement Data for Board 17385

BGA Pin # Location	Distance (mm)	Impedance (Ω)		TDR comment
		Good board	DUT board	
A1	9.6	38.412	64.709	Solder joint is not good.
A24	7.2	58.883	59.803	Good
A26	5.5	41.248	59.189	Solder joint is not good.
AD11	76.1	31.511	31.665	Good
AD13	83	29.901	30.361	Good
AD15	97.1	22.234	22.234	Good
AD16	85	22.311	22.464	Good
AE9	11	64.786	64.863	Good
AE10	11	64.863	66.473	Good
AE11	87.9	34.118	35.191	Good
AE12	76.1	32.585	33.658	Good
AE13	85	32.891	32.278	Good
AE14	11.8	62.946	63.099	Good
AE15	83	26.374	27.218	Good
AE17	61.1	32.201	34.348	Good
AF6	6.7	70.92	72.99	Good
AF7	6.7	73.527	73.22	Good
AF11	76.1	32.968	33.198	Good
AF12	88.1	33.811	34.501	Good
AF14	11	65.553	62.869	Good
B25	21.3	49.069	50.986	Good
B26	9.1	59.036	60.646	Good
C25	2.9	71.533	70	Good
C26	12.7	60.723	60.569	Good
D25	2.9	76.133	76.977	Good
D26	3.3	65.169	66.933	Good
E25	5	82.957	84.49	Good
E26	4.5	74.907	76.977	Good
M1	19.1	61.413	64.019	Good
N1	17.1	70.153	70.766	Good

2. AXI

Five defective pins were detected using AXI. Three of them (light green color in Table 2) were found with TDR. Two defective pins were detected with 5DX, but were not found using TDR. However all these five defective pins were found with 2DX, SEM or Dye & Pry as indicated with dark blue color in Table 3. AXI has capabilities to detect BGA

3. 2DX

Figure 10 is a 2DX image of pin A26 on board 17385 where a 40 µm crack is found at the BGA side; the defect is found by TDR and SEM as well. Figure 11 is for pin C26 and shows correlation with SEM data showing a crack of about 30 µm on the BGA chip side. Figure 12-13 are for pins A26 and B25 on board 13907. 2DX has correlation with TDR and SEM at pin A26 where both BGA chip and PCB sides are defective (crack size is 40-140µm). But only 2DX and SEM found a defect at B25 — crack at FR4 side of the BGA ball.

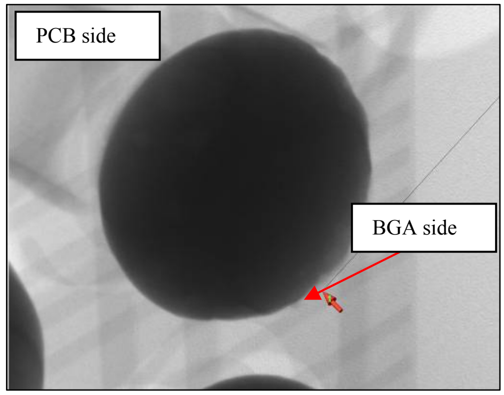

Figure 10 2DX Image (pin A26, board 17385)

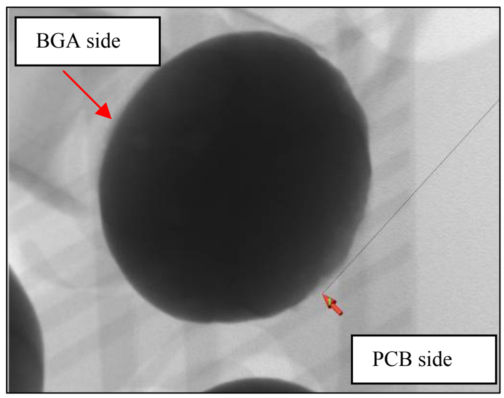

Figure 11 2DX Image (pin C26, board 17385)

The 2DX data points for the 300 pins of interest are listed on Table 3. A total of 70 pins were identified as defective solder joint balls. The different colors mean the following: yellow — one machine found the defect, blue — both 2DX and SEM/Dye & Pry found defect, dark blue — AXI, 2DX and SEM/Dye & Pry called the defect. 78.6% of the 2DX defective calls show correlation with SEM/Dye & Pry — 41 pins for SEM; and 14 pins for Dye & Pry. This was a very good correlation and was expected based on previous studies.

Table 2 TDR Test Results for Ten Boards.

BGA Pin #	17415	17385	17291	17159	16596	13907	13537	13526	11617	11201
A1	Good	Bad	Good	Good	Good	Good	Good	Good	Good	Good
A24	Good	Good	Good	Good	Good	Good	Good	Bad	Good	Good
A26	Bad	Bad	Bad	Bad	Good	Bad	Bad	Good	Bad	Good
AD11	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AD13	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AD15	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AD16	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AE9	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AE10	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AE11	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AE12	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AE13	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AE14	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AE15	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AE17	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AF6	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AF7	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AF11	Good	Good	Good	Good	Bad	Good	Good	Good	Good	Good
AF12	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
AF14	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
B25	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
B26	Good	Good	Good	Bad	Good	Good	Good	Good	Bad	Good
C25	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
C26	Good	Good	Good	Bad	Good	Good	Good	Good	Good	Good
D25	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
D26	Good	Good	Good	Bad	Good	Good	Good	Good	Good	Good
E25	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
E26	Good	Good	Bad	Good	Good	Good	Good	Good	Good	Good
M1	Good	Good	Good	Good	Good	Bad	Good	Good	Good	Good
N1	Good	Good	Good	Good	Good	Bad	Good	Good	Bad	Good

TDR and AXI called defective pin   TDR called defective pin.

Table 3 2DX, SEM and Dye & Pry test results for ten boards

Board #	17415		17385		17291		17159		16596		13907		13537		13526		11617		11201	
Pin #	2DX	SEM	2DX	SEM	2DX	DYE & PRY	2DX	DYE & PRY	2DX	SEM	2DX	SEM	2DX	SEM	2DX	SEM	2DX	SEM	2DX	SEM
A1	good	good	Bad	Open	crack	good	crack	Bad	good	Bad	crack	good	good	Bad	Void	good	crack	Bad	good	Good
A24	good	good	good	good	crack	good	crack	Bad	crack	Bad	crack	Bad	crack	Bad	Bad	Bad	good	Bad	good	Good
A26	Bad	Bad	crack	Bad	open	Bad	crack	Bad	good	Good	crack	good	good	Bad	Good	good	crack	Bad	crack	Good
AD11	good	good	good	good	good	good	good	good	good	Good	good	good	good	Good	Good	good	good	Good	good	Good
AD13	good	good	good	good	good	good	good	good	good	Good	good	good	good	Good	Good	good	good	Good	good	Good
AD15	good	good	good	good	good	good	good	good	good	Good	good	good	good	Good	Good	good	good	Good	good	Good
AD16	good	good	good	good	good	good	good	good	good	Good	good	good	good	Good	Good	good	good	Good	good	Good
AE9	good	good	good	good	good	good	good	good	good	Good	good	good	good	Good	Good	good	good	Good	good	Good
AE10	good	good	good	good	good	good	good	good	good	Good	good	good	good	Good	Good	good	good	Good	good	Good
AE11	good	good	good	good	good	good	good	good	good	Bad	good	good	good	Good	Good	good	good	Good	good	Good
AE12	good	good	good	good	crack	good	good	good	good	Good	good	good	good	Good	Good	good	good	Good	good	Good
AE13	good	good	good	good	good	good	good	good	good	Good	good	good	good	Good	Good	good	good	Good	good	Good
AE14	good	good	good	good	good	good	good	good	good	Good	good	Bad	good	Good	Good	good	good	Good	good	Good
AE15	good	good	good	good	good	good	good	good	good	Good	good	good	good	Good	Good	good	good	Good	good	Good
AE17	good	good	good	good	good	good	good	good	good	Good	good	good	good	Good	Good	good	good	Good	good	Good
AF6	good	good	good	good	good	good	good	good	good	Good	good	Bad	good	Good	Good	good	good	Good	good	Good
AF7	good	good	good	good	good	good	good	good	good	Good	good	good	good	Good	Good	good	good	Good	good	Good
AF11	good	good	good	good	good	good	crack	Bad	crack	Bad	crack	Bad	good	Bad	Good	good	crack	Bad	good	Good
AF12	good	good	good	good	good	good	crack	Bad	good	Good	crack	Bad	good	Bad	Good	good	crack	Bad	good	Good
AF14	good	good	good	good	crack	good	good	Bad	good	Good	good	Bad	good	Good	Good	good	good	Bad	good	Good
B25	Bad	Bad	good	Bad	crack	Bad	good	Bad	good	Bad	good	Bad	good	Bad	Crack	good	crack	Bad	good	Good
B26	Bad	Bad	Bad	Bad	crack	good	crack	Bad	good	Bad	crack	Bad	good	Bad	Good	good	crack	Bad	good	Good
C25	crack	Bad	good	Bad	crack	Bad	crack	Bad	good	Good	crack	good	crack	Bad	crack	good	good	Bad	good	Good
C26	Bad	Bad	crack	Bad	crack	good	crack	Bad	crack	Bad	crack	Bad	good	Bad	Good	good	crack	Bad	crack	Bad
D25	good	good	good	good	crack	good	good	Bad	crack	Bad	good	good	good	Good	Good	good	good	Bad	good	Good
D26	crack	Bad	void	Bad	good	Bad	crack	Bad	crack	Bad	crack	Bad	good	Bad	Good	good	good	Bad	good	Good
E25	good	Bad	good	good	good	good	good	Bad	good	Good	good	good	good	Good	Good	good	good	Bad	good	Good
E26	crack	Bad	crack	Bad	good	good	good	Bad	crack	Bad	good	Bad	good	Bad	Good	good	good	Bad	good	Good
M1	good	good	good	good	good	good	crack	Bad	good	Good	crack	Bad	good	Bad	Crack	good	crack	Bad	crack	Bad
N1	good	good	crack	Bad	good	good	crack	Bad	good	Bad	crack	Bad	good	Good	Good	good	good	Bad	good	Good

AXI, 2DX, SEM / Dye & Pry test data confirm the pin as defective solder

2DX, SEM / Dye & Pry test data confirm the pin as defective solder

Only one tester data shows the pin as defective s

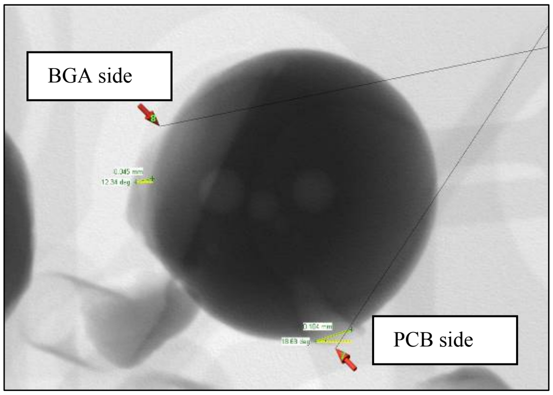

Figure 12 2DX Image (pin A26, board 13907)

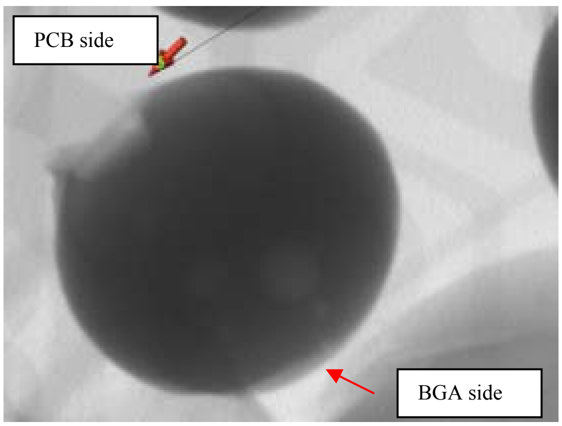

Figure 13 2DX Image (pin B25, board 13907)

4. Cross-section/SEM

We have 240 Cross-section/SEM data points. Figures 14 -15 are SEM images for pin A1 and B25 of board 17385 and 13907 respectively. Both 2DX and SEM found a defect for those two locations. Figures 16A and 16B are SEM images at the different locations for pin A26 on board 13907. Ball diameter is 788µm at Figure 16A and 826µm at Figure 16B. There are about 38µm difference for ball diameter between these two cross sections, and about 44µm difference for the void diameter between the SEM images. Both images show clear cracking at the BGA chip level, and only Figure 16B shows defect at the ball edge. SEM indicates 72 pins total with defects and 41 pins have correlation with 2DX. The detail of SEM and 2DX results is listed in Table 3, and 51.3% data points have defect agreement between SEM and 2DX.

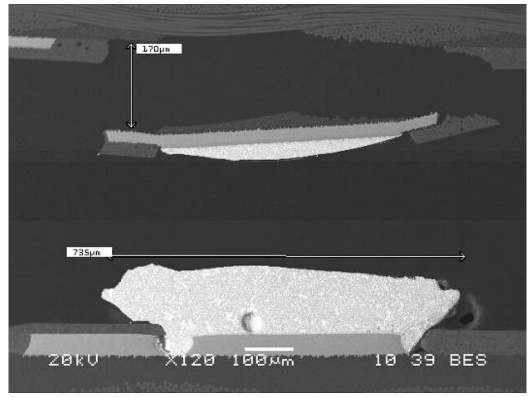

Figure 14 SEM Image (pin A1, board 17385)

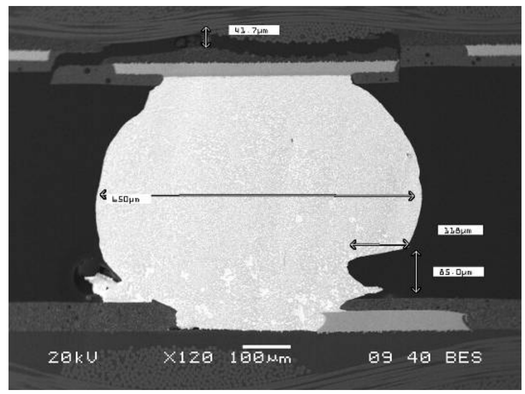

Figure 15 SEM Image (pin B25, board 13907)

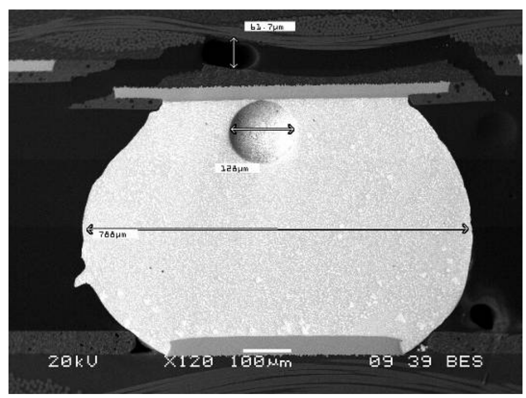

Figure 16A SEM Image (pin A26, board 13907)

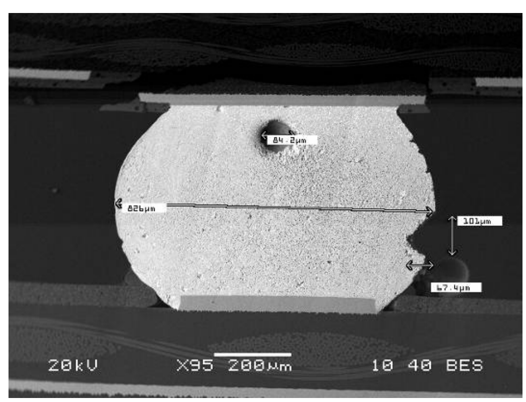

Figure 16B SEM Image (pin A26, board 13907)

5. DYE and PRY

We used two boards for Dye & Pry study, in which 60 data points were collected. Figures 17A (BGA side) and 17B (PCB side) show Dye & Pry images for pin A26 on board 17159 revealing defect. Twenty pins were identified as defected and are listed in Table 3. Fourteen of 20 (70%) Dye & Pry data shows good correlation with 2DX.

Figure 17A Dye & Pry Image BGA Side (pin A26, board 17159)

Figure 17B Dye & Pry Image PCB Side (pin A26, board 17159)

6. COMPARISON

Table 4 lists TDR data (Delta Impedance ΔΩ) for ten boards where ΔΩ is the difference between Impedance of Test pin on the experiment board and Impedance of Reference pin on the golden board. TDR engineers determined the pin as defective or not based on the ΔΩ. TDR detected 18 pins as defective solder joint, of which 3 pins (dark green fill color) have correlation with AXI, 2DX, and SEM, 12 pins (light green fill color) show correlation with 2DX and SEM/Dye & Pry, 2 pins (blue fill color) agree only with 2DX. Seventeen of the 18 defective pins from TDR have good correlation with 2DX; only one pin does not show correlation with both 2DX and SEM. The Delta Impedance is -6.98 Ω, and shown short inside the IC or the trace. However 2DX and Dye & Pry did not find any short issue for the particular BGA ball location.

The impedance of TDR for the first 5 pins of 10 boards is shown in Figure 18. If the impedance is bigger than 7 ohm, the pin is very likely defective. Figure 19 shows delta impedance of TDR for 300 data points. ΔΩ between -7 Ω to +7 Ω indicates mostly good solder joints. The largest delta impedance is 45Ω due to a defect located on the BGA ball side. All TDR, 2DX, and SEM identified the ball as defective (Figures 20-22).

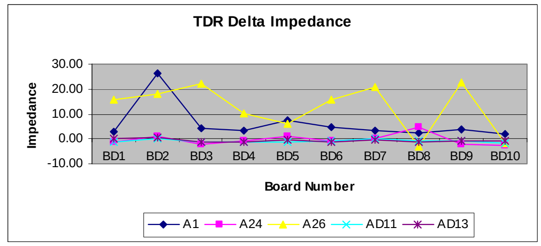

Figure 18 Delta Impedance of TDR for Five Pins of Ten Boards

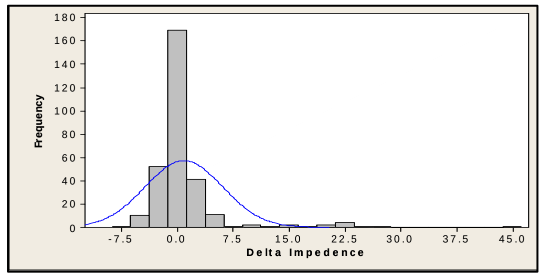

Figure 19 Delta Impedance of TDR for 300 Data Points

Table 5 TDR vs. 2DX or SEM or Dye & Pry Comparison

Description	Number of Defective Pins	Correlation
TDR - SEM Agree	11	15.1%
TDR - SEM Disagree	62	84.9%
TDR - 2DX Agree	16	21.9%
TDR - 2DX Disagree	57	78.1%
TDR - Dye & Pry Agree	5	23.8%
TDR - Dye & Pry Disagree	16	76.2%
2DX - SEM Agree	41	51.3%
2DX - SEM Disagree	39	48.8%
2DX - Dye & Pry Agree	14	51.9%
2DX - Dye & Pry Disagree	13	48.1%

Table 6 Detection Correlation Comparisons.

Description	TDR	2DX	SEM	Dye & Pry
# of Defective Pin Call	18	70	72	20
2DX - SEM or Dye & Pry	17			
TDR - SEM or Dye & Pry		55		
TDR - 2DX			41	14
Correlation %	94.4%	78.6%	56.9%	70.0%

Table 5 lists comparisons of TDR versus 2DX, SEM, Dye & Pry; 2DX versus SEM, Dye & Pry based on the experimental data. The TDR has 15% - 24% agreement with 2DX, SEM and Dye & Pry, taking into account all defective pins found. The 2DX has high correlation (51-52%) with SEM and Dye & Pry. TDR, 2DX, SEM and Dye & Pry found the following number of defects: 18, 70, 72, and 20 respectively (Table 6). Note that TDR and 2DX data is for ten boards, SEM for eight boards, and Dye & Pry for two boards.

Table 4 TDR Variable Data (Delta Impedance ΔΩ) for Ten Boards

Pin #\Board #	17415	17385	17291	17159	16596	13907	13537	13526	11617	11201
A1	2.85	26.30	4.22	3.53	7.28	4.60	3.53	2.45	3.83	2.07
A24	-1.30	0.92	-1.99	-0.84	0.84	-1.00	0.15	4.75	-2.22	-2.45
A26	15.87	17.94	22.01	10.20	5.88	15.72	21.01	-3.22	22.46	-1.76
AD11	-1.15	0.15	-1.15	-1.38	-1.07	-0.92	-0.08	-0.61	-0.77	-1.54
AD13	0.31	0.46	-1.23	-1.38	-0.38	-1.07	-0.31	-1.23	-0.84	-0.61
AD15	-0.77	0.00	-0.46	-1.00	0.00	-0.46	0.08	-0.08	-0.08	-0.77
AD16	-0.54	0.15	-0.08	0.23	-0.08	0.38	-0.38	0.00	0.23	0.61
AE9	-4.22	0.08	-2.53	-1.15	1.76	-3.30	-2.07	-2.38	-2.22	-4.22
AE10	-2.68	1.61	-0.08	-0.69	4.29	-2.22	0.54	0.08	-0.54	-1.76
AE11	1.23	1.07	1.30	1.46	3.30	0.54	2.15	1.38	1.07	0.84
AE12	-0.77	1.07	0.08	-0.31	1.61	-0.15	0.00	-0.23	-0.08	-0.28
AE13	0.23	-0.61	0.00	-1.46	-0.54	-0.46	-0.54	-0.46	-1.53	-1.00
AE14	-3.45	0.15	-1.61	-0.23	1.84	-2.61	-0.23	-1.84	-1.61	-3.45
AE15	1.15	0.84	0.61	0.00	-0.46	1.00	0.15	0.15	-0.61	-0.54
AE17	1.53	2.15	0.31	1.92	2.99	1.15	1.53	1.53	1.23	0.38
AF6	-0.23	2.07	1.07	0.15	-0.61	-2.76	1.00	-0.61	0.23	-0.31
AF7	-2.68	-0.31	-3.99	-2.45	-3.37	-4.60	-1.46	-2.38	-3.14	-2.91
AF11	-0.92	0.23	-0.92	-1.92	44.62	-1.23	0.38	-0.69	-0.69	-0.69
AF12	0.54	0.69	0.54	-6.21	-0.46	0.00	0.23	-0.38	0.08	-0.61
AF14	-2.76	-2.68	-2.38	-2.91	0.38	2.07	4.29	-2.61	2.76	0.77
B25	0.46	1.92	0.38	1.60	4.98	1.07	2.15	-1.23	1.07	-0.92
B26	-0.61	1.61	-0.77	19.17	-0.31	-0.46	1.53	-0.31	22.00	-1.38
C25	-1.84	-1.53	-2.30	-0.08	0.15	-0.84	0.00	-0.61	1.00	-0.54
C26	-3.68	-0.15	-1.76	23.08	0.69	-0.08	0.31	-0.92	-1.00	-1.84
D25	-0.08	0.84	0.08	-0.38	0.61	1.61	0.23	-0.38	0.08	0.84
D26	-0.84	1.76	-1.38	12.96	2.91	3.68	3.80	0.23	-0.08	0.84
E25	1.46	1.53	1.00	1.61	-1.30	-2.84	1.46	-0.31	-3.91	1.00
E26	-0.45	2.07	-6.98	-1.15	-0.54	0.38	1.76	0.08	0.08	-0.31
M1	-3.07	2.61	1.99	-0.77	4.14	2.07	-1.00	0.54	0.54	-1.23
N1	-5.90	0.61	-4.22	-5.60	6.21	8.89	-1.99	-1.99	24.46	-5.21

All four machines agree
TDR - 2DX - SEM or Dye & Pry agree
TDR - 2DX agree
TDR only

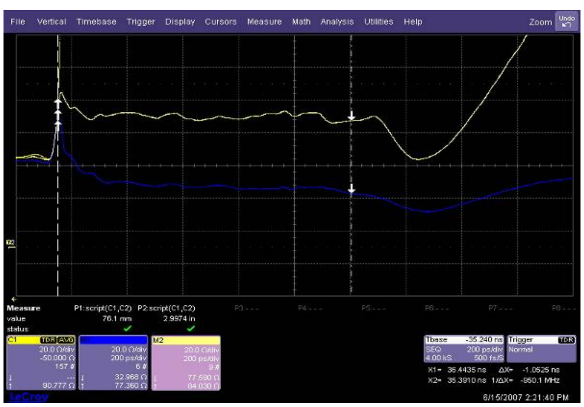

Figure 20 TDR Image (pin AF11, board 16596)

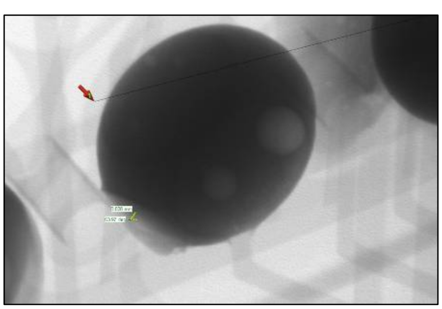

Figure 21 2DX Image (pin AF11, board 16596)

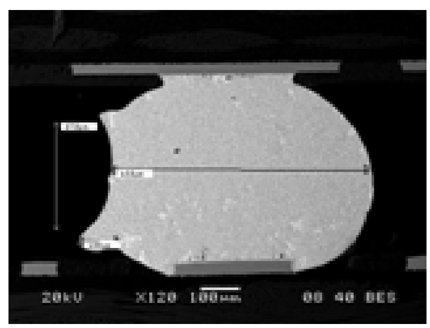

Figure 22 SEM Image (pin AF11, board 16596)

For example, total defects found from TRD are 18 pins: where 17 of 18 have agreement with 2DX and SEM/Dye & Pry. Therefore TDR correlation with other testers is 94.4% in Table 6 based on 18 pins found defective by TDR.

TDR found less defective balls than 2DX and SEM because of its resolution. The current TDR has limitation finding small crack defects (Figures 23) due to its resolution. 2DX and SEM show obvious defect (Figure 24 -25) on the same ball.

The correlation percentage of 2DX, SEM, and Dye & Pry with other testers is 78.6%, 56.9%, 70.0% respectively as shown in Table 6. Overall conclusion is that 2DX is a more effective tool for identifying BGA defects.

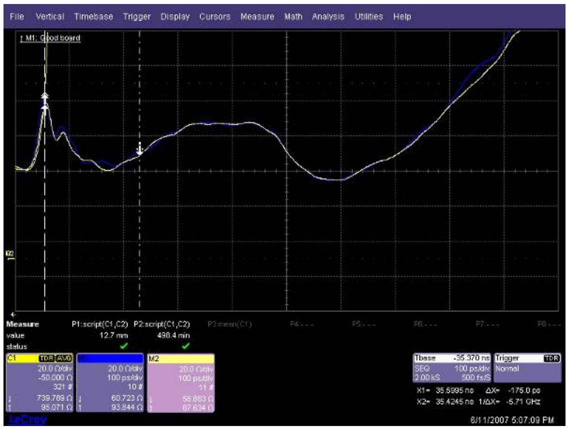

Figure 23 TDR Image (pin C26, board 11201)

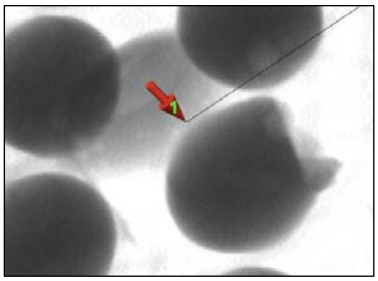

Figure 24 2DX Image (pin C26, board 11201)

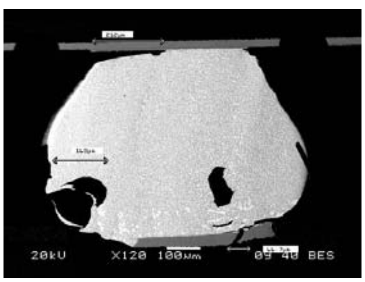

Figure 25 SEM Image (pin C26, board 11201)

CONCLUSIONS

1 There is good correlation between 2DX and SEM / Dye & Pry. Agreement for 55 defective pins is found for 2DX and SEM / Dye &Pry data.

2 The defect agreement is 51% for 80 pins which are called as defect by 2DX and/or SEM. These results are based on eight SEM boards' data (including cracks in FR4 material found by Cross-section/SEM).

3 There are eighteen defective pins found with TDR. TDR has the capability to identify large-sized BGA defects like open (whole crack), or crack size above 50µm. TDR test results also show good correlation with other testers. However it is a challenge for the TDR technique to detect all BGA defects especially small cracks because of its 1.25mm resolution.

4 The defect agreement is 52% for 27 pins which are called as defect by 2DX and/or DYE & PRY based on two boards.

5 2DX is an effective tool to detect BGA defects including opens and cracks down to 30µm. Because FR4 material is very transparent to X-rays, cracks in FR4 are not easily found by 2DX.

6 It is challenging for AXI to detect BGA open or crack defects that are smaller than 100µm in size

REFERENCES

[1] Zhen (Jane) Feng, Evstatin Krastev, Hector Rene Marin Hernandez and Murad Kurwa "Defects in BGA and Fine Pitch Gullwing Identified with Transmission X-ray," SMTA proceeding, Toronto, Canada. April, 2007

[2] John C. McNulty "Understanding Failure Analysis in Electronic Components" Presentation for Flextronics Engineering Forum, November, 2007

[3] Zhen (Jane) Feng, Jacob Djaja and Ronald Rocha, "Automated X-ray Inspection: SMT process Improvement Tool," SMTA proceeding, Chicago, September 2002.

4] Zhen (Jane) Feng, Eduardo Toledo, Jonathan Jian and Murad Kurwa, "Reducing BGA Defects with AXI Inspection," Circuits Assembly, July 2005

[5] Zhen (Jane) Feng, Jayapaul Basani, Murad Kurwa, David Bernard and Evstatin Krastev "Modern 2D X-Ray Tackles Common BGA Defects Facilitating Process and Yield Improvement," to be published in 2008

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