Automated X-Ray techniques, Image quality, and the effect on defect detection.

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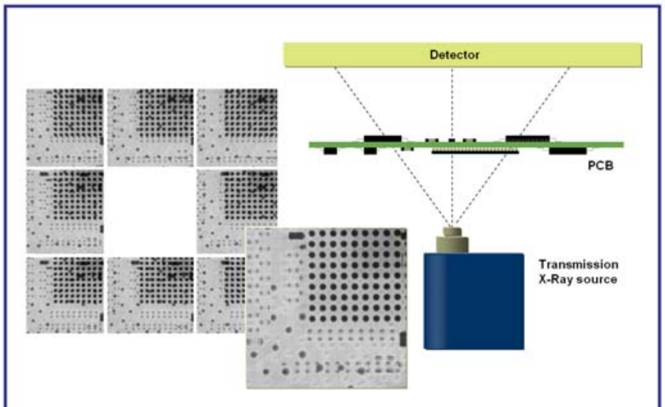
There are many X-Ray imaging techniques available in today's market place. Some which are suitable to the automated production environment and many that are not, Manual X-Ray Inspection for example. The purpose of this document is to discuss the attributes of the varied automated X-Ray imaging techniques, and detail what is important to provide reliable (low false call), high quality, fault detection.

X-Ray imaging techniques for real-time production.

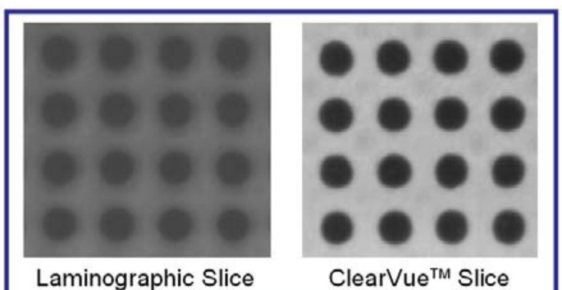
The most common automated 3D X-Ray systems use a Laminographic technique through a mechanical rotating movement that averages obscured parts outside of an X-Ray focal plane. This averages component and defect features with the background of the board or obscured components. Averaging is good where it can remove most of an obscuration (components in the same xy position on top and bottom side of a PCBA), but has limitations where the dynamic range and features in an image can be masked by the same averaging techniques used.

The other automated techniques available include TraX™ High Speed Transmission X-Ray (preferred for components without obstructions) and ClearVue™ (The 4th generation 3D X-Ray technique developed by Teradyne). Both Techniques as shown in Figure 1, take only static X-Ray images at all times without averaging. The ClearVue technique re-constructs the image using the high and low points (maximum value) in a series of images to re-construct a slice providing a greater dynamic range. The maximum value method allows all details on the part being inspected to be retained, and not averaged with other features of the board. As High Speed Transmission X-Ray is not a reconstructive technique it does not loose dynamic range. Examples of feature recognition, using averaging and ClearVue's max value techniques are shown in figure 2:



Teradyne's ClearVue technique divides the detector area into 9 regions, creating the Off-Axis images required for 3D reconstruction. High quality images are obtained without X-Ray source, detector or board movement.

Figure 1



Center slice of 31mil balls from a Motorola PBGA

Figure 2.

Simply the greater dynamic range in the final image allows for improved inspection, and thus lowers false fails. As you can see in figure 2, the ClearVue reconstruction technique provides a greater dynamic range in the image allowing for easier algorithms and threshold settings for accurate defect detection. With the static imaging techniques employed in the construction of images on systems like Teradyne's XStation images of at least twice the resolution of averaging systems are achieved at the same FOV. How this is achieved?

Dynamic range is important in an image, but so is resolution. To obtain high image resolution two techniques are commonly used, first using magnification, secondly using a high resolution detector. Magnification, as the name describes, moves the part to be inspected close to the X-Ray source, and the detector a distance equaling the magnification required from the inspection plane. This has a number of limitations; the X-Ray source or spot size needs to be as small as possible, the small spot size limits the power output from the X-Ray source, and the final Field Of View (FOV) size is small. To gain the required resolution, which is dependant of X-Ray source and geometries used, FOV's are normally below 400 mils. For production line rates the small FOV and low power limits throughput. In all cases this technique provides a below line rate throughput which is unacceptable for production test and inspection. The magnification technique is used commonly in failure analysis, MXI and quality sampling applications.

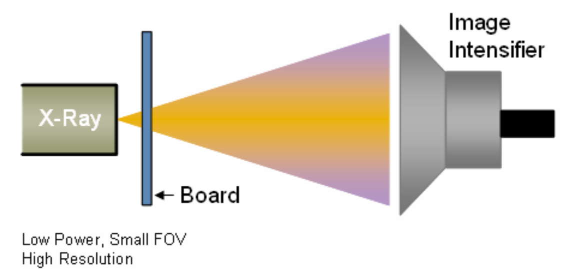


Figure 3: Example High Resolution, Small FOV Imaging Configuration.

Alternatively to magnification a different imaging geometry and high resolution digital detector can be used. This X-Ray imaging technique allows the X-Ray source to be run at high power, while retaining the needed resolution at a large FOV.

The detectors in figure 4 range to over 2" FOV with resolution retained at ~20 lp/mm. This is accurate enough to detect 0201's, fine pitch components and all commonly used area array packages. An example of such a system is Teradyne's XStation which employs the techniques in figure 4 to provide resolution between 20 and 40 lp/mm, complete image dynamic range and still provide throughput rates of 6 sq in/S.

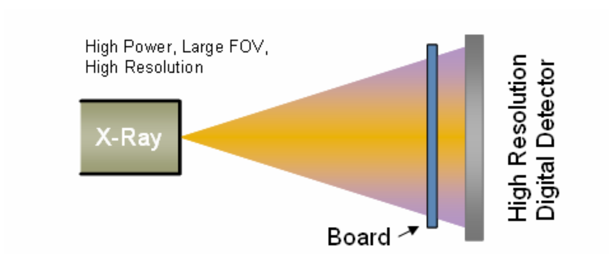
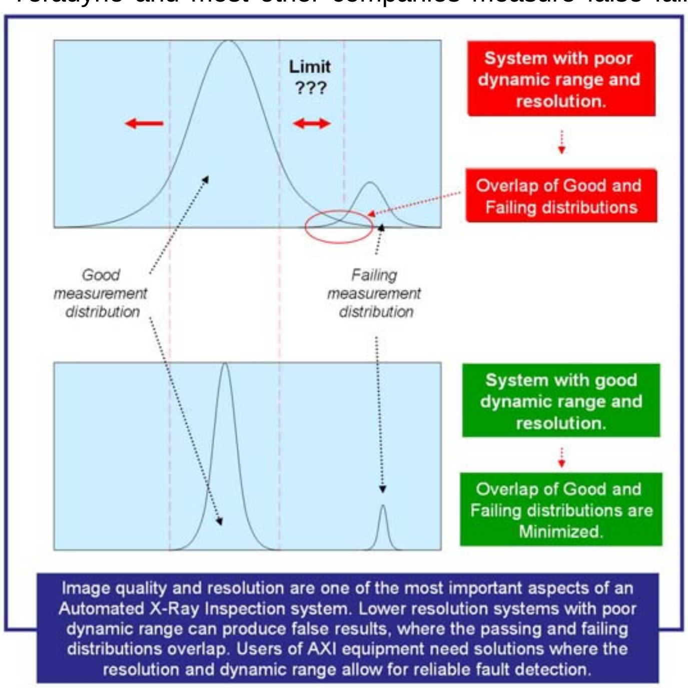


Figure 4: Example High Resolution, Large FOV, Imaging Configuration's used by Teradyne.

X-Ray Imaging Capabilities, how they effect defect detection and false fails.

Teradyne and most other companies measure false fail rates in ppmJ (parts per million Joints) by the detailing the number of incorrectly identified failing solder joints (false fails) per 1,000,000 joints inspected. Today's 3D automated X-Ray solutions such as Laminography which use averaging techniques provide false fail rates between 1000 and 10,000 ppmJ. Systems with good dynamic range, such as TraX and ClearVue based systems, are commonly running products in the order of 50-500 ppmJ false fail rates.



Better dynamic range and resolution in an image allow for better margining and thresholds. This in-turn allows for greater fault detection, accurate diagnostics, and low false fails. Figure 5 describes an example of a solder measurement on X-Ray Technologies with good (all features retained as imaged) vs. poor dynamic range.

For example, if you look at the heal thickness of a QFP with low resolution and poor dynamic range imaging you can commonly end up in the position where the measurements for good and bad parts could overlap. This causes escapes to the field and false fails, driving WIP and expense with increased repair operators. Choosing a solution with high resolution and good dynamic range allows for increased separation between good and bad parts, overall a more reliable process.

X-Ray imaging techniques such as TraX and ClearVue provide good dynamic range and resolution and allow for an inspection program to take full advantage of the separation. Simply, the quality of data you can provide to a measurement system affects the quality of the final results.

Quality.

Delivered quality on Complex, High Reliability products such as Telecoms, Datacoms, Automotive, Military, Aerospace, laptops, Servers etc has always been a key requirement, and X-Ray commonly deployed. Current Technologies have varying capabilities as shown in figure 6.

	Opens					Shorts		Missing		Reliability			Parts			Placement				Connectors		Normal Production Sample (ppmJ)		
	Leaded Devices	Area Array / BGA	Power Leaded Devices	Power Area Array / BGA	Ceramic BGA	Shorts Leaded Devices	Shorts Area Array	Missing component	Bypass Caps	Low solder	Void	Solder balls	Bad component	Wrong component	Programming	Rotated 90°	Bypass caps	Skewed (misplace)	Billboard	Barrel Fill	Press Fit	Throughput Capable	False Call Rates	Total Detection Capability
Xstation MX - TraX	98	90	98	90	90	98	98	90	90	90	90	90	0	25	0	25	90	90	90	75	95	Yes	50-200	76.3
Xstation MX - ClearVue	98	90	98	90	90	90	90	90	90	90	90	90	0	25	0	25	90	90	90	95	75	Yes	50-500	75.5
Laminography	90	90	90	90	90	80	90	90	90	90	70	90	0	25	0	25	90	90	90	95	75	No	1000-10000	73.3
AOI Post Reflow	80	0	80	0	0	98	0	98	98	50	0	90	0	50	0	80	98	90	90	25	75	Yes	500-3000	52.5
AOI Post Place	0	0	0	0	0	0	0	98	98	0	0	0	0	50	0	80	98	0	0	0	0	Yes	1000-4000	20.2
AOI Post Paste	20	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0	0	0	0	0	0	Yes	50	4.76
ICT	95	95	25	25	95	98	98	98	10	0	0	0	95	95	100	90	0	0	0	0	90	Yes	N/A	52.8

Figure 6[1]

All three automated X-Ray techniques have very high process fault coverage as shown in figure 6. They are complementary to the techniques deployed in a full In-Circuit Test (Shown as a reference) regarding part coverage, and capable of detecting all process defects. The techniques significantly differ in their production capabilities when we look at other capabilities that are important to electronic manufacturers, detailed in figure 7.

	Board Process	Throughput Capibl	Imaging		False Call Rates
	Single/ Double Sided	Normal Production Sample	Resolution at 1" FOV	Dynamic Range (Good = all original features retained)	Normal Production Sample
Xstation MX - TraX	Single	Yes	20 lp/mm	Good	50-200ppmJ
Xstation MX - ClearVue	Double	Yes	15 lp/mm	Good	50-500ppmJ
Laminography	Double	No	> 5 lp/mm	Poor	3000-10000ppmJ

Figure 7

From the over all functionality and capabilities provided by the three automated techniques TraX High Speed Transmission and ClearVue X-Ray techniques are the clear winners. ClearVue and TraX provide the best image quality, dynamic range, provides high fault coverage at low false fail rates, while still providing high throughput.

Laminography provides good double sided board coverage but with many limitations around the dynamic range of imaging, throughput and high false call rates.

[1] Fault classes detected by technology: Values in Average Percent Coverage.

Finally, with the trend to area array packaging (BGA), the loss of electrical access and the diminishing value of Automated Optical Inspection (AOI), Automated X-Ray Inspection will be a key part of all high quality manufacturing processes.

Paul Groome is responsible for Teradyne's Automated X-Ray Inspection group in California.

Educated at St Albans College in England, Mr. Groome's experience encompasses 26 years in the test and inspection industry with knowledge spanning Functional Test, Logic Simulators, ASIC Design, In-Circuit Test, PCB Design and X-Ray Inspection.

At Teradyne Mr. Groome has had the following experience: Sales Manager for UK and Ireland, Product Manager for Teradyne's In-Circuit products and Business Unit Manager for MXI and AXI products. Mr. Groome has also worked in the telecommunications and military industries and developed the Modular Scan Techniques (MoST) used in many military ASIC's.

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