AXI Voiding Detection on High Power Transistor

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Abstract
High Power Transistors contain materials and structure that pose unique challenges to AXI technologies. The work discusses traditional AXI imaging and processing techniques and their limitations in very heavily shaded, and non-uniformly shaded situations. The work further discusses methods for voiding detection and presents a novel technique developed to overcome challenges presented by Copper Coin Power Transistors. Lastly the work presents considerations for optimal region size and data presentation to support testing to component-level voiding specifications.

Power Transistor Structure
JEDEC TO-270 describes 2 and 4 lead transistor packages with leads that extend from the body side, and a large heat slug underneath. Figure 1 shows an isometric view of a typical TO-270 package [1], Figure 2[2] details the JEDEC specification for the bottom-side of 4-leaded TO-270 devices, and clearly shows the heat slug area. Figure 2 also details typical package, and pad dimensions. Heat slug solder joint quality impacts heat transfer through the slug, voids reduce the available heat transfer area, and so must be minimized, and inspected. Assembly recommendations for High Power Transistors sometimes include soldering of the part to both printed circuit board and a carrier, a metal piece that is attached to the PCB ground plane, forming part of the electrical, and thermal connection[3].

Two common form factors for the carrier are: (1) size similar to the Printed Circuit Assembly (PCA), or (2) size similar to the component sometimes called “copper coin”[4]. Both of these assembly techniques add copper thickness to the x-ray imaging path, and so make image collection more challenging.

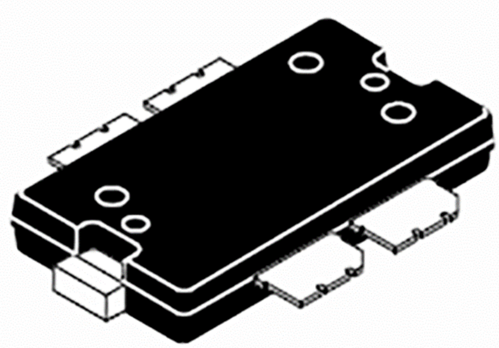
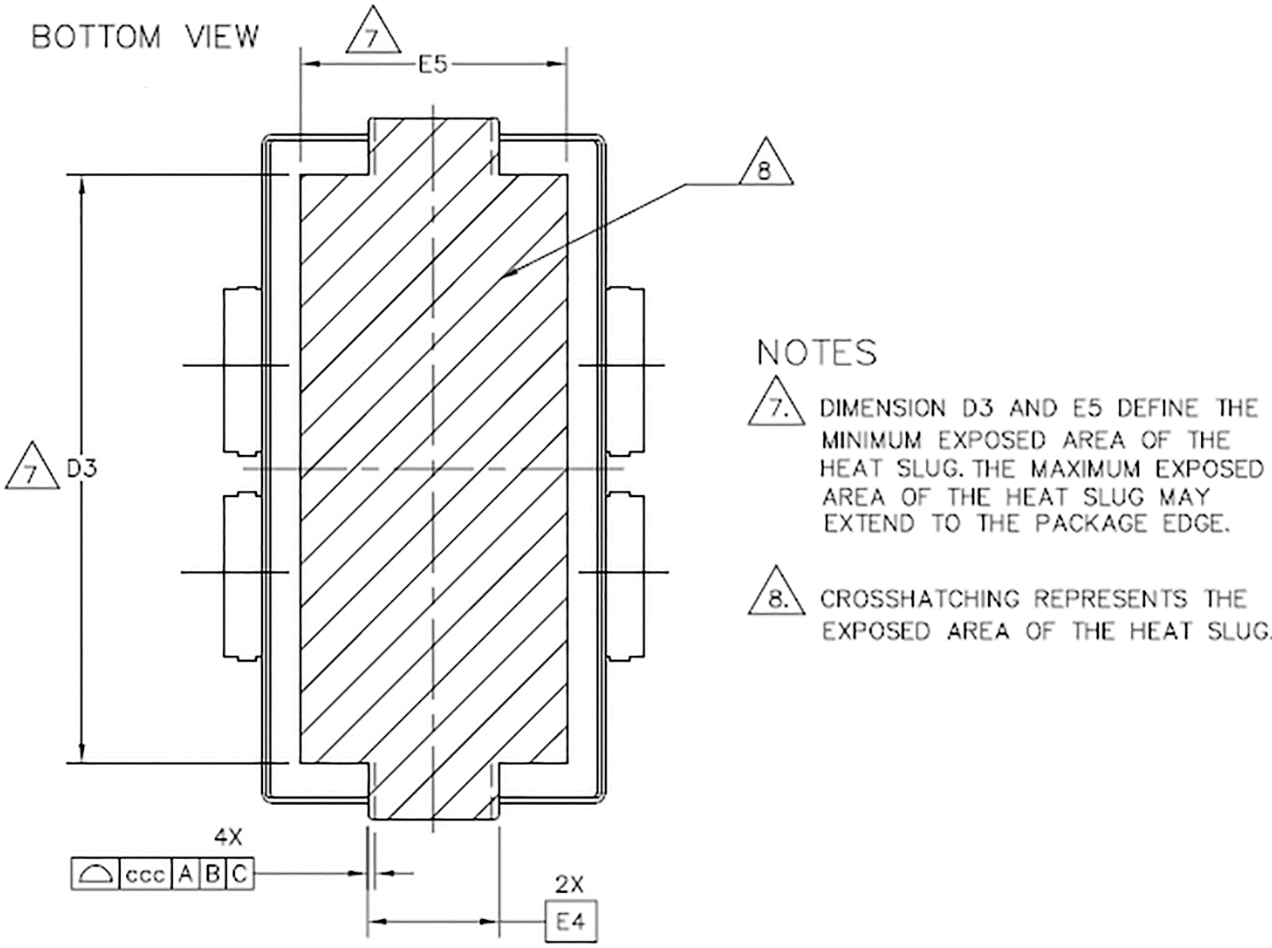


Figure 1 - JEDEC TO-270 Package, Isometric View



VARIATIONS												
	AA				AB				AC			
SYMBOL	MIN	NOM	MAX	NOTE	MIN	NOM	MAX	NOTE	MIN	NOM	MAX	NOTE
D3	7.67	---	---	7	15.34	---	---	7	20.40	---	---	7
E4	1.78 BSC			7	3.45 BSC			7	3.45 BSC			7
E5	4.12	---	---	7	6.88	---	---	7	6.88	---	---	7

Figure 2 - TO-270 Bottom View, JEDEC Standard TO-270C
Crosshatch represents the exposed area of the heat slug.

X-Ray Technologies

X-Ray inspection technologies can be divided into four main categories: 2-D manual, 2-D automatic, 3-D manual, and 3-D automated. Generally it is possible for 3-D systems to provide 2-D images, but not vice versa. Likewise many automated systems have manual modes available. 3-D systems provide an important benefit over 2-D systems in that they can show not only the defect, but also isolate the z-height of the defect. The z-height is especially important for voiding as voids that are near the pad or package are generally considered more dangerous than voids that are in the middle of the solder joint. Automated systems provide automatic image collection, and, more importantly, automatic defect detection. These systems enable near 100% inspection of solder joints, with speed and repeatability much higher than can be achieved by a human operator using a manual system. Images presented in this work were collected on a 3-D automated x-ray inspection system, often referred to as AXI.

Within 3-D AXI there are two main approaches to imaging chain design: utilize area-mode cameras, or, utilize line-scan cameras. Systems that utilize one or more area mode cameras typically collect images while the PCA is stationary. Line scan cameras collect one row of data each time the camera is triggered. These systems must either move the camera during imaging, as is done in desktop scanning, or move the panel during imaging. Historically area-mode systems have proven faster when imaging small regions with unique settings, line scan cameras are faster if a large area (many neighboring components) can be imaged with one set of settings. The system utilized for this work is a production line-scan x-ray imaging system.

Acceptability Criteria

The voiding acceptability requirements used for this work have been derived from IPC-A-610D[5] and IPC-7095A[6] and are as listed in Table 2.

Table 2 – Voiding Acceptability Requirements

Rule 1	The maximum accepted cumulated surface of voids is 25% of the entire solderable area and compliancy to rules 2 and 3.
Rule 2	Voiding must be preferably spread; this means that the maximum surface allowed in one internal unique location (void) is 10% of the total solderable area (equivalent to 40% of 25% rule 1).
Rule 3	Voiding must be preferably spread; this means that the maximum voiding surface allowed for side open voiding is 5% of the total solderable area (equivalent to 20% of 25% rule 1).

Challenges Posed to AXI

The challenges posed by the power transistors fall into three main categories. First, the part has very heavy shading due to the copper 'carrier' and the heat slug within the part. Second, the area of the heat slug is much larger (388 mm x 788 mm) than typical pads, and larger than maximum available region size for the AXI system. Generally the AXI system will split regions of this size into multiple regions, in this case splitting is not OK because some of the voiding specifications must be measured on a per-pad, not a per-region basis. The third challenge that AXI faces is classification of the voiding, specifically identification of voids, and conversion of voiding measurements to calls. In this case the logic required to implement the rules specified in Table 2 was missing from the classification engine.

New AXI Techniques

Automated AXI systems are designed to provide "just enough" image quality for classification, this enables 100% test coverage in an in-line setting. There is a trade-off between image quality and image time. Offline systems can use more time without impacting production throughput, in-line systems must manage the inspection time versus image quality trade-off more carefully. For this work the imaging settings, and reconstruction technique were both modified. The new imaging settings provided an increase of x-ray flux during imaging. The new reconstruction settings utilize non-linear combination methods to optimize the dynamic range within the projections ahead of projection combination, this techniques is referred to as Dynamic Range Optimization or (DRO). These two changes, applied together, enabled optimization of image quality for voiding detection in the heavily shaded regions of the part. Figure 3 shows x-ray images of the heat-slug before and after these changes.

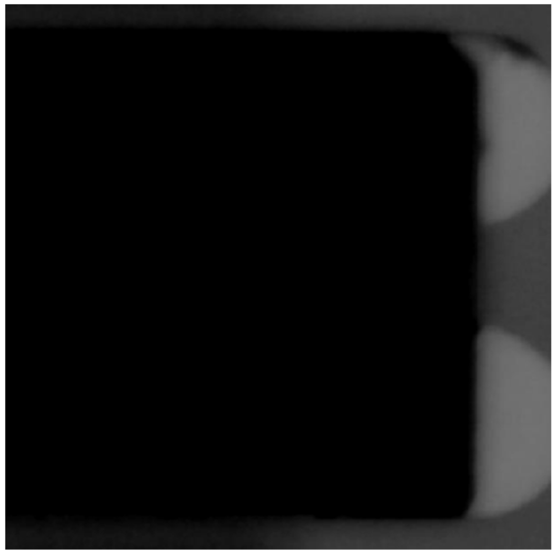


Figure 3a: Original x-ray image quality

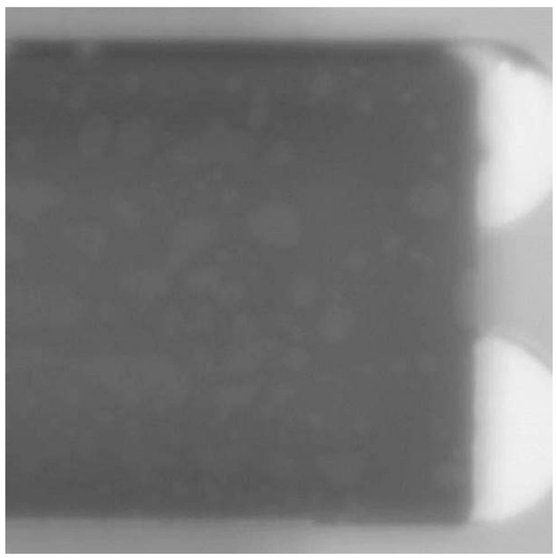


Figure 3b: Image Quality with DRO Applied

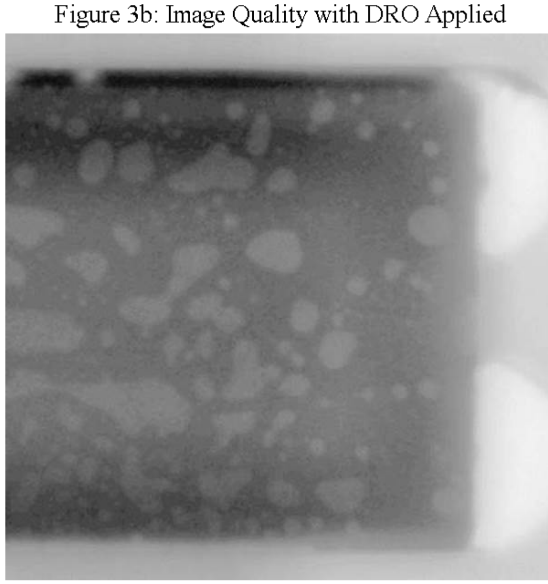


Figure 3c: DRO Image, optimized for viewing

The second challenge, large region size, is generally a limitation of software architecture and memory, rather than a limitation of camera hardware. The maximum image size is not a function of the camera area, or length, rather a function of the software architecture, and memory available to process the projection images. In this case the pad size for the heat slug pushed beyond existing region size limits. An additional complication came from the DRO technique itself: the dynamic range optimization is a function of image contents, so with three small regions (as seen in Figure 4a) the average gray level within the divided pad varies from image to image. The solution for this challenge, presented in Figure 4b, was to support a larger reconstruction region so that the entire pad would be reconstructed with the same DRO settings. This change also enables pad-level voiding analysis, and so supports Rule 1.

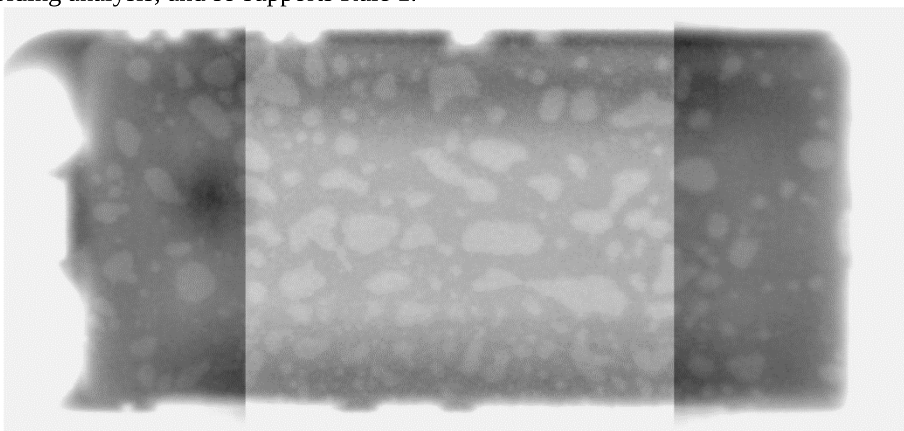


Figure 4a: Heat Slug X-Ray Images, 3 Regions

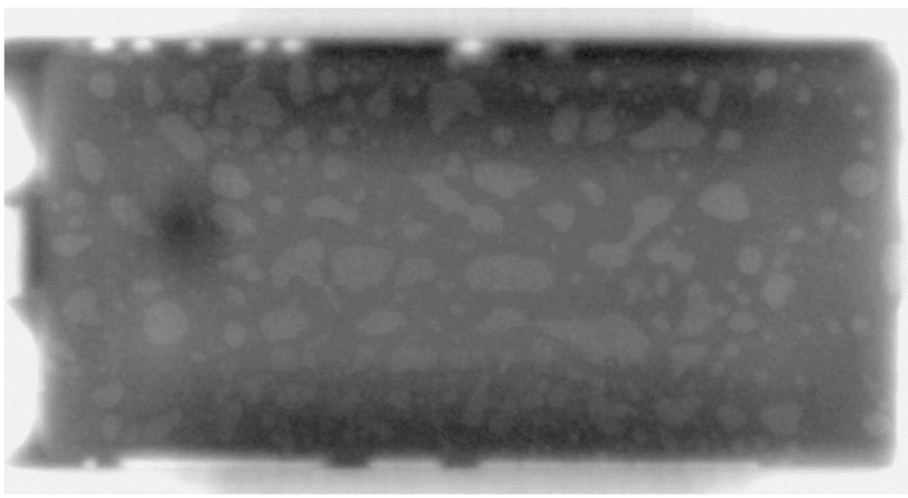


Figure 4b: Heat Slug X-Ray Image, 1 Region

The third challenge for AXI is to support differing customer requirements via a flexible classification engine. In this case the classifier capabilities included the ability to measure largest void for a pad, and the ability to measure total voiding area for a pad. This work included modification of classification software to implement Rule 3 (measurements near edge of part and tighter requirements near the edge of a part.) These changes provided better overall voiding sensitivity. Figure 5c shows voiding classification alongside the before and after DRO images for another power transistor part.

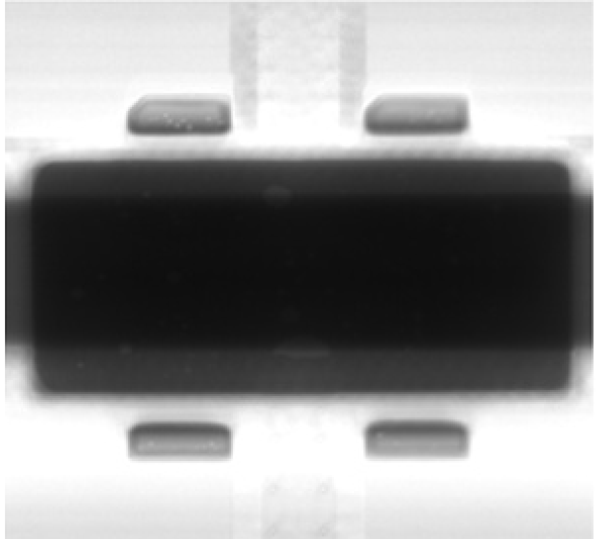


Figure 5a: Original X-Ray Image

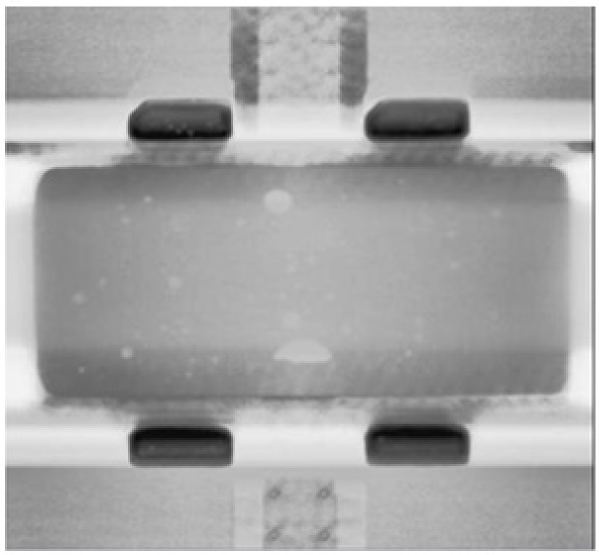


Figure 5b: X-Ray Image, Optimized with DRO

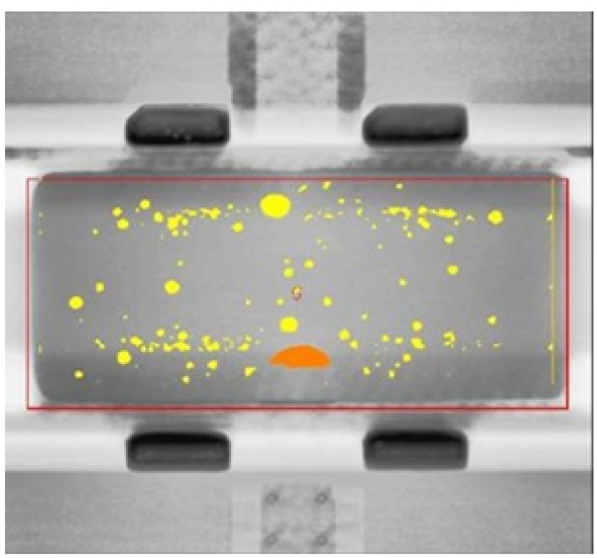


Figure 5c: X-Ray Image, Defect Detected by Automated Classifier

Summary/ Conclusions

Power transistors present new challenges for AXI systems including new voiding detection requirements, heavier shading levels, and larger than usual solder pad sizes in the heat slug pads. Initial results showed that inspection results were not sufficient. The work was able to identify and overcome three main challenges for inspection of the parts, and implement a workable solution. It should be noted that changes were limited to the realm of applications and software, no hardware changes were necessary to inspect the power transistor voiding successfully with AXI.

References

[1] RF_ISO_TO_270WB_4.gif. Retrieved December 10, 2015 from http://cache.nxp.com/files/graphic/product_freescale/

[2] JEDEC Solid State Technology Association (July 2008). "2 & 4 Lead Surface Mount Power Package" (PDF). p. 8-12. Retrieved 2015-12-10.

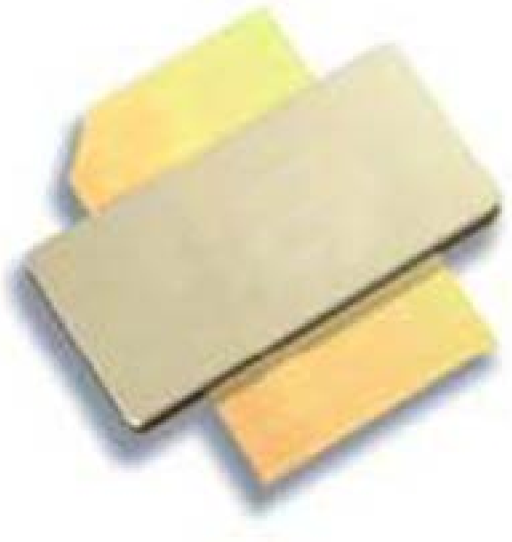
[3] "Solder Reflow Attach Method for High Power RF Devices in Air Cavity Packages". Page 1. Retrieved December 10, 2015 from http://www.nxp.com/files/rf_if/doc/app_note/AN1908.pdf.

[4] "Solder Reflow Attach Method for High Power RF Devices in Air Cavity Packages". Page 1. Retrieved December 10, 2015 from http://www.nxp.com/files/rf_if/doc/app_note/AN1908.pdf.

[5] IPC Association Connecting Electronics Industries (January 2000). "IPC-A-610D".

[6] IPC Association Connecting Electronics Industries (January 2000). "IPC 7095A".

AXI Voiding Detection on Power Transistor



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Agenda

- Power Transistor Acceptability Criteria
- Challenges for AXI
  – Heat Sink Shading – Not enough flux
  – Pad Size
  – Voiding Identification
- New Techniques for Inspection
  – Improved Signal in Images
  – Non-Linear Reconstruction Techniques (DRO)
  – Larger Regions of Interest, to Support Classification of Large Pad in One Piece
  – Updated Flood Fill Voiding Algorithm
- Results

Acceptability Criteria – Voiding Specific

Requirements derived from IPC-A-610D and IPC-7095A for BGAs

Acceptable class 1, 2, 3: 25% or less voiding of the "pad" X-ray image area.

Rule 1: The maximum accepted cumulated surface of voids is **25%** of the entire solderable area and compliancy to rules 2, 3.

Rule 2: Voiding must be preferably spread; this means that the maximum surface allowed in one internal unique location (void) is **10%** of the total solderable area (equivalent to 40% of 25% rule 1).

Rule 3: Voiding must be preferably spread; this means that the maximum voiding surface allowed for side open voiding is **5%** of the total solderable area (equivalent to 20% of 25% rule 1).

Acceptability Criteria – Voiding Specific

Criteria	Package A	Package B
Dimensions	20 mm x 9.6 mm	15.2 mm x 6.8 mm
Soldering surface area (mm^2)	192 mm^2	103 mm^2
Rule 1: Max cumulated surface of voids (<25%)	47	25
Rule 2: Max surface of 1 unique closed void (<10%)	19	10
Rule 3: Max cumulated surface side open voids (<5%)	9	5

Acceptability Criteria – Voiding Specific

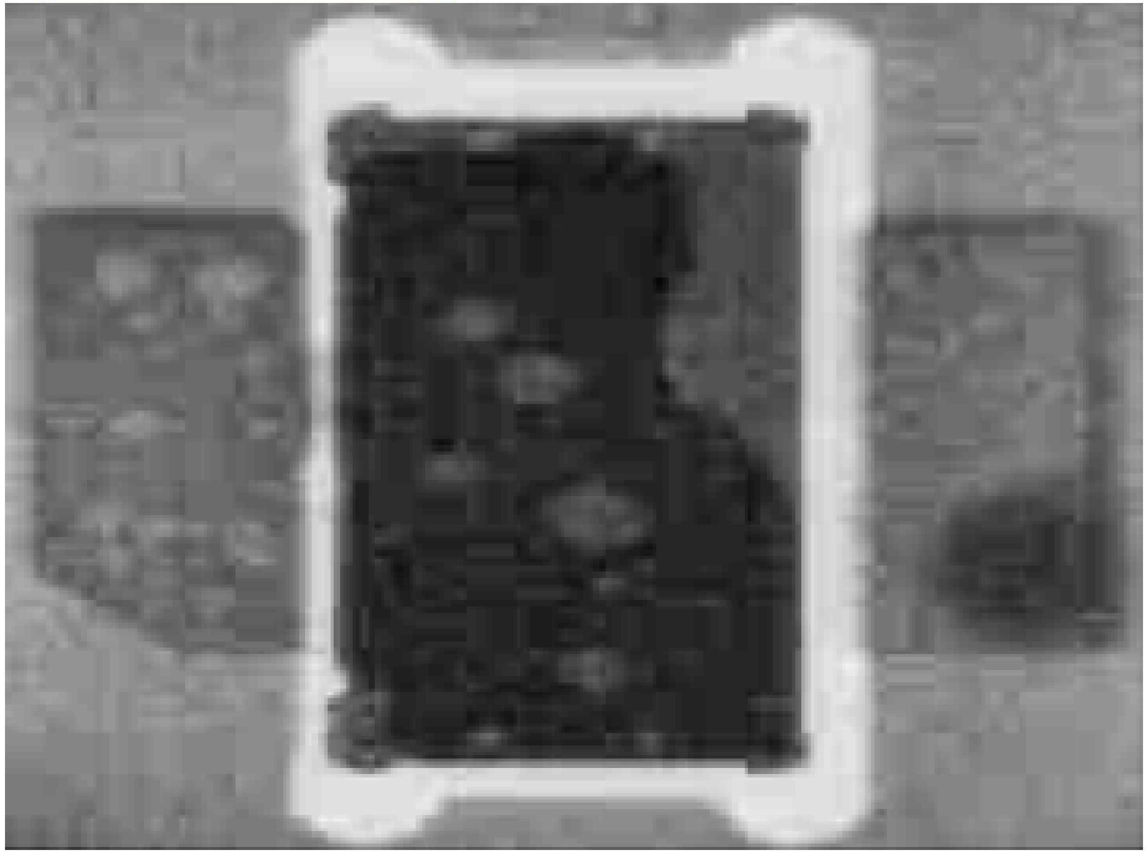
Item	Sample Combinations on Package Type A											
	A	B	C	D	E	F	G	H	I	J	K	L
Void diameter 1 mm	10	10	10	10	10	10	10	10	10	10	10	10
Void diameter 3.2 mm		1					1	1		1		
Void diameter 4.8 mm		1	2		1	1	1		1		1	
Void diameter 5mm or shape >10%												1
Corner triangle 2.4x5				1	1			1	1			
Corner triangle >= 3.2x6.7 (1 third)	1			1		1				1		
Small side 0.9 mm width void				1					1		1	
Large side 0.9 mm width void												
Total voiding per example (mm^2)	19	34	44	33	41	46	43	31	41	36	44	26
Cumulated side open voids (mm^2)	11	0	0	25	15	20	9	15	15	29	18	0
Rule 1: cumulated void surface 25%	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Rule 2: biggest internal void 10% max	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	NOK
Rule 3: cumulated side open voids 5% max	NOK	OK	OK	NOK	NOK	NOK	OK	NOK	NOK	NOK	NOK	OK
OK Passed / NOK Failed	NOK	OK	OK	NOK	NOK	NOK	OK	OK	OK	NOK	NOK	NOK

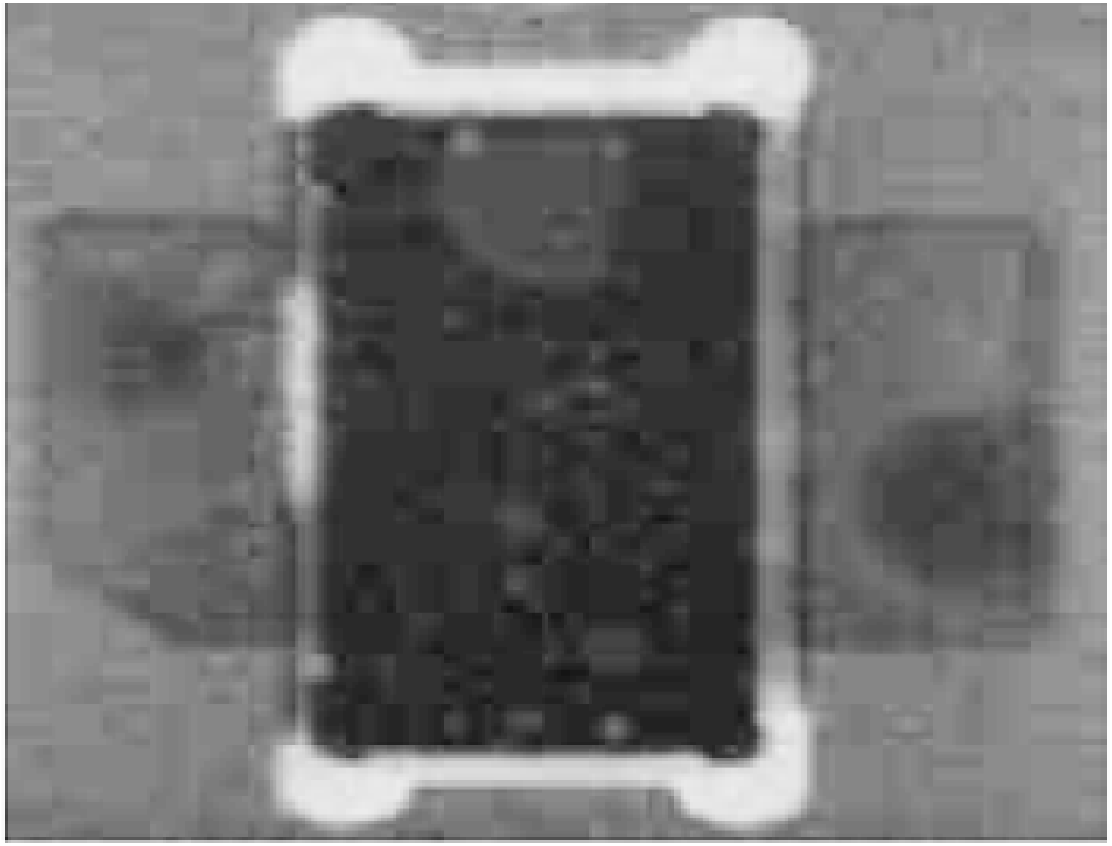
For cases B, C, & G the minimum distance between the biggest shapes must be larger than 3 mm.

Acceptability Criteria – Voiding Specific

Item	Sample Combinations on Package Type B											
	A	B	C	D	E	F	G	H	I	J	K	L
Void diameter 1 mm	10	10	10	10	10	10	10	10	10	10	10	10
Void diameter 3.2 mm		1					1	1		1		
Void diameter >3mm or shape >10%												1
Corner triangle 1.7x3.8				1	1			1	1			
Corner triangle 2.25x5.1	1			1		1				1		
Small side 0.7 mm width void				1					1		1	
Large side 0.3 mm width void					1	1	1	1		1	1	
Total voiding per example (mm^2)	14	16	8	22	16	18	21	24	16	26	17	18
Cumulated side open voids (mm^2)	6	0	0	14	8	10	5	8	8	10	9	0
Rule 1: cumulated void surface 25%	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Rule 2: biggest internal void 10% max	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	NOK
Rule 3: cumulated side open voids 5% max	NOK	OK	OK	NOK	NOK	NOK	OK	NOK	NOK	NOK	NOK	OK
OK Passed / NOK Failed	NOK	OK	OK	NOK	NOK	NOK	OK	OK	OK	NOK	NOK	NOK
For cases B, C, & G the minimum distance between the biggest shapes must be larger than 3 mm.												

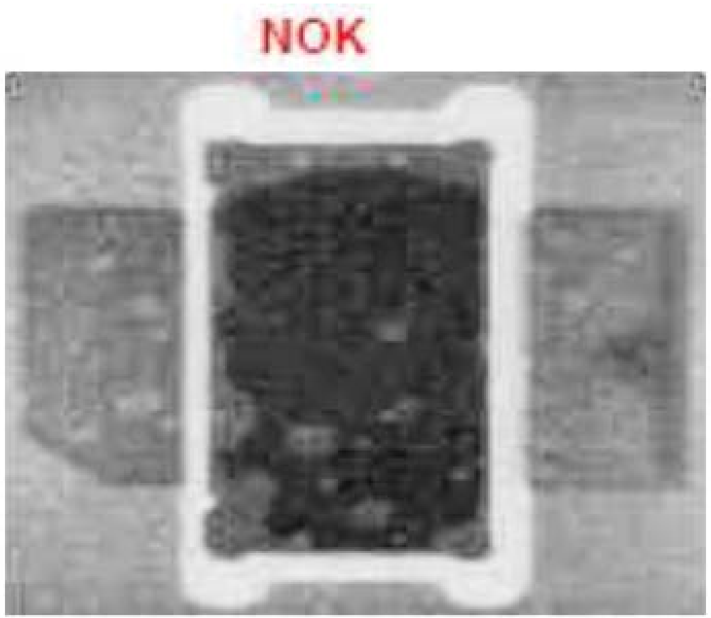
Acceptability Criteria – Voiding Specific





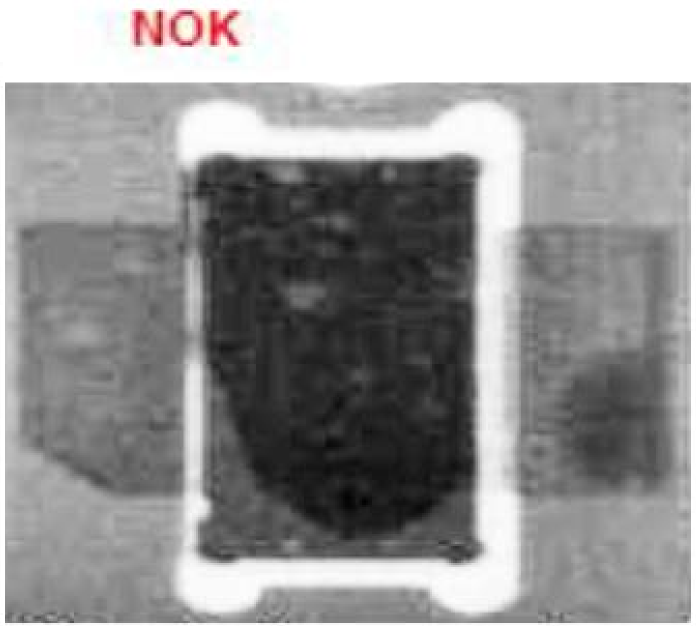
Examples of “open” and “closed” voids

Acceptability Criteria – Voiding Specific



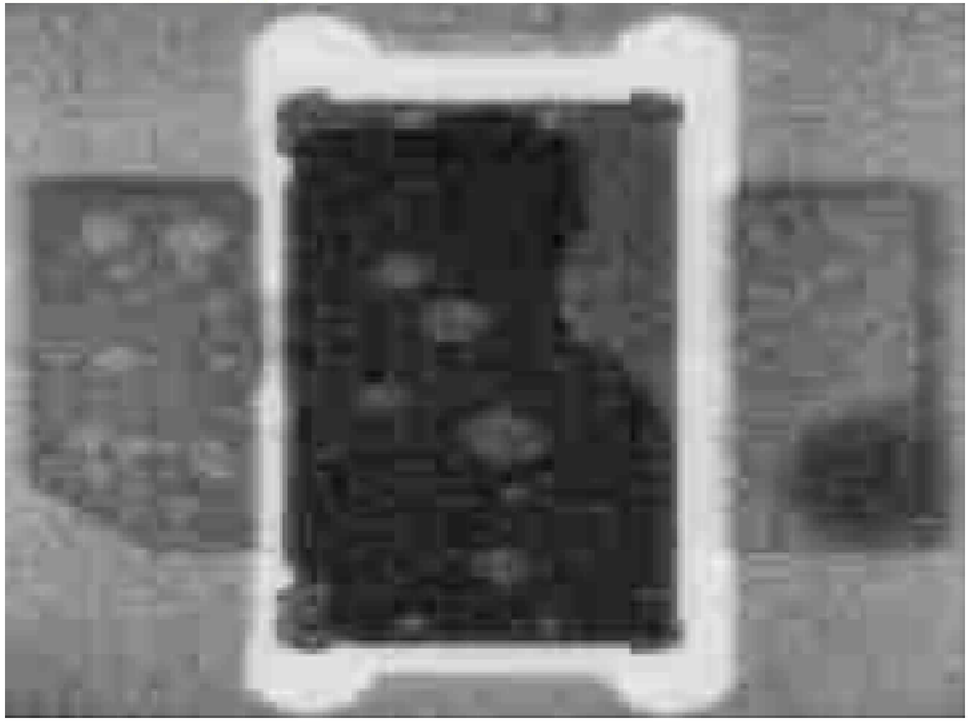
This part has a band of less than 0,9 mm on a small side & a remaining void on a unique corner around 9 mm^2, total > 18 mm^2. Rule 3 is violated.

This part has 3 corner triangle voids, total area 18 mm^2 Rule 3 is violated

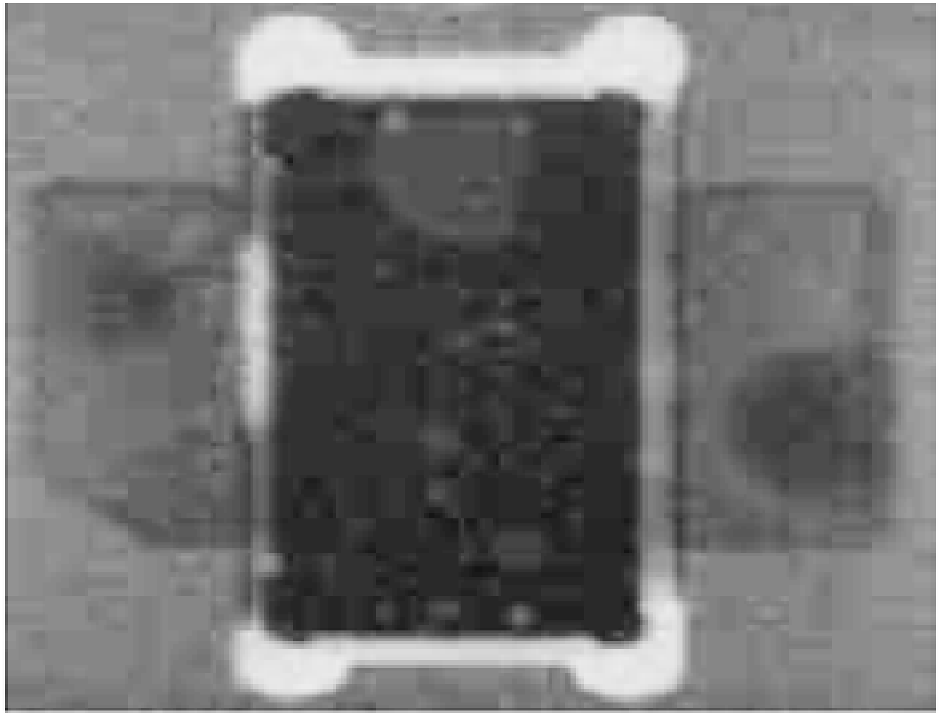


This part has 2 corner triangles total area 30 mm^2. Rule 2 is violated.

Acceptability Criteria – Voiding Specific



Picture 5: view with "open" voids

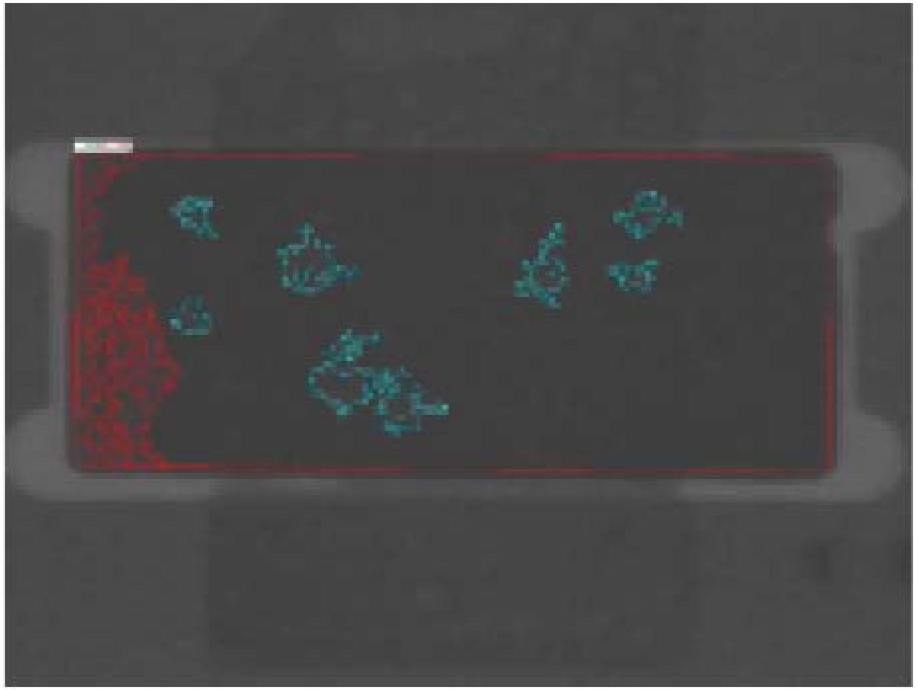


Picture 6: view with "closed" voids

On Picture 5 we can see 1 corner triangle of 4.8 mm x 10 mm (24 mm^2).
Based on rule 2 we cannot accept the part in picture 5.
On picture 6 we can see 1 shape larger than 4.8 mm diameter void, lower than 5-mm diameter, & there are a few other voids, so acceptable.

Acceptability Criteria – Voiding Specific

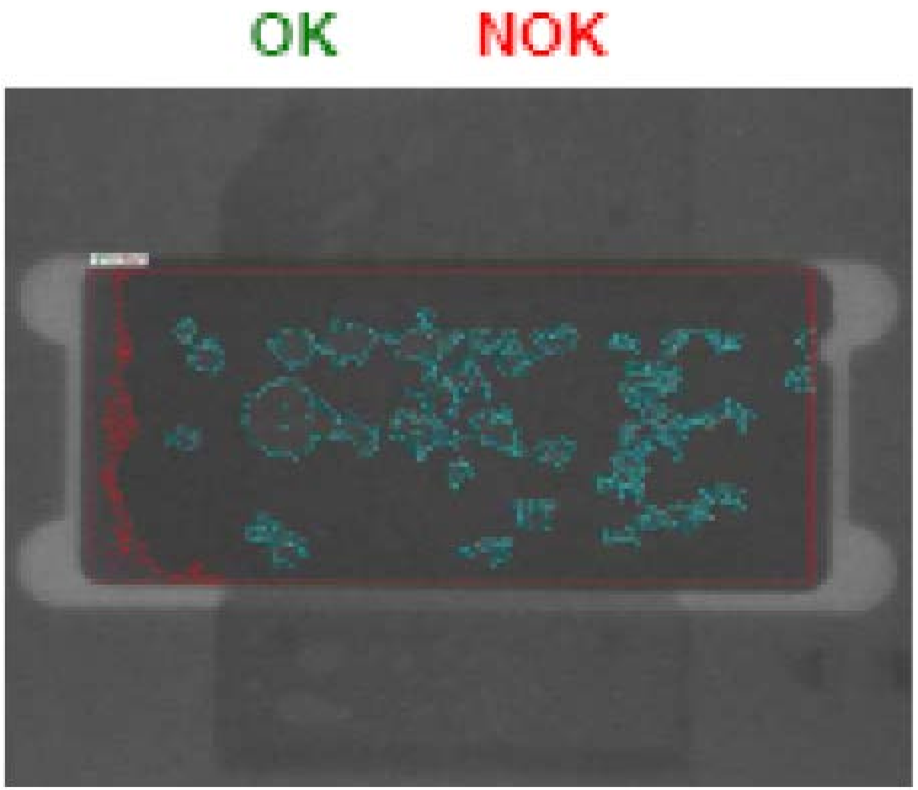
NOK



Picture 7 : view open voids

The total voiding area is only around 10%, but the side open is a bit higher than 6%, so (by rule 3) it is NOK.

Acceptability Criteria – Voiding Specific



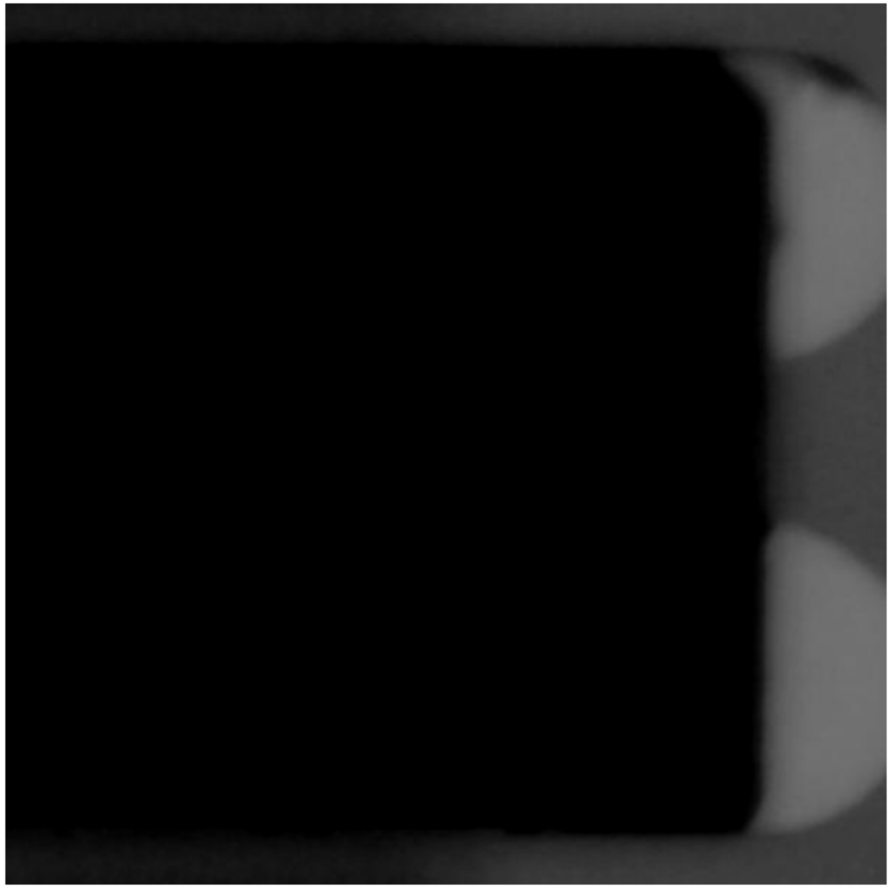
Picture 8 : view open voids

On picture 8 the total voiding area is around 20% so OK for rule 1

The side open is around 5-6%, so at the limit for acceptance for rule 3 and NOK.

AXI Challenge 1: Shading

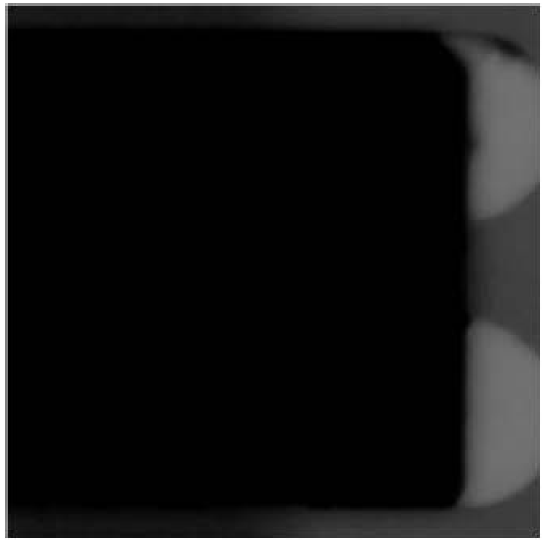
- 3-D Automated X-Ray Inspection systems are designed to provide "just enough" image quality for classification.
- There is a trade-off between image quality and image time. Offline systems can use more time without impacting production throughput, in-line systems must manage the inspection time vs. image quality trade-off more carefully.
- Default settings for the production line x-ray imaging system are not sufficient for the power transistors in question.



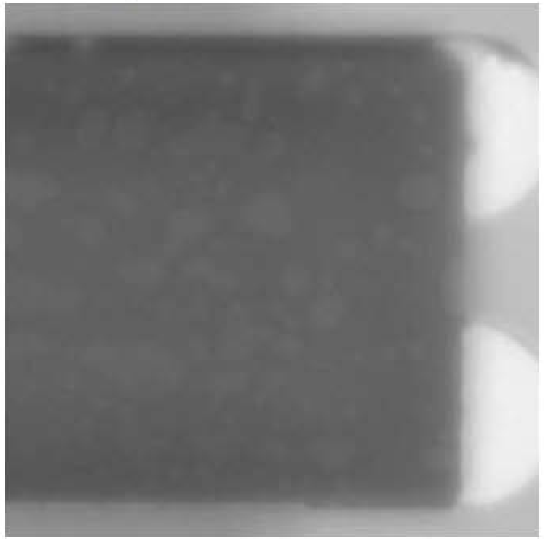
Challenge 1 Solution :
DRO – Dynamic Range Optimization

- Dynamic Range Optimization is a new technique to produce x-ray image
- Capture 2-D projection image multiple times on same angle to increase signal-to-noise ratio(SNR), and available power.
- Similar to adjusting exposure time for every x-ray angle, but better suited for line-scan implementation.
- Image normalization is applied to even out the dynamic range (power) from each angle before reconstruction (image averaging).
- This helps even out the contribution from every angle, even if some angles are much more shaded than others.

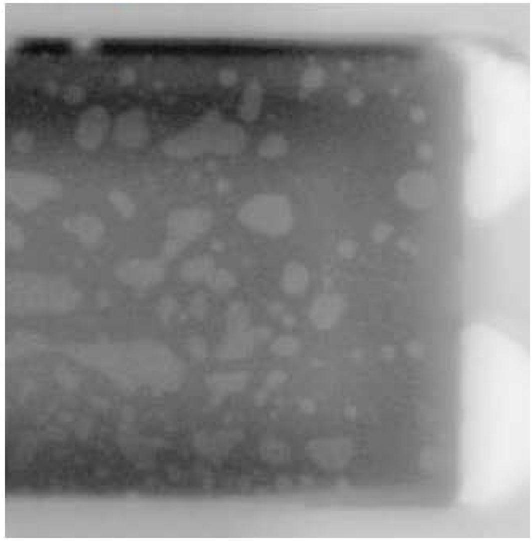
AXI Challenge 1: Shading



Before DRO

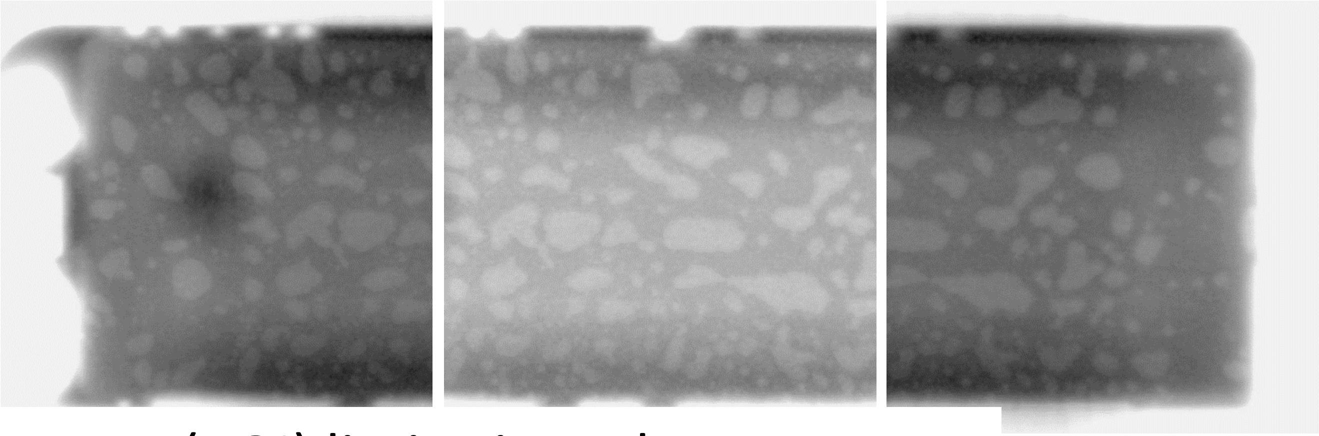


After DRO



Further enhance

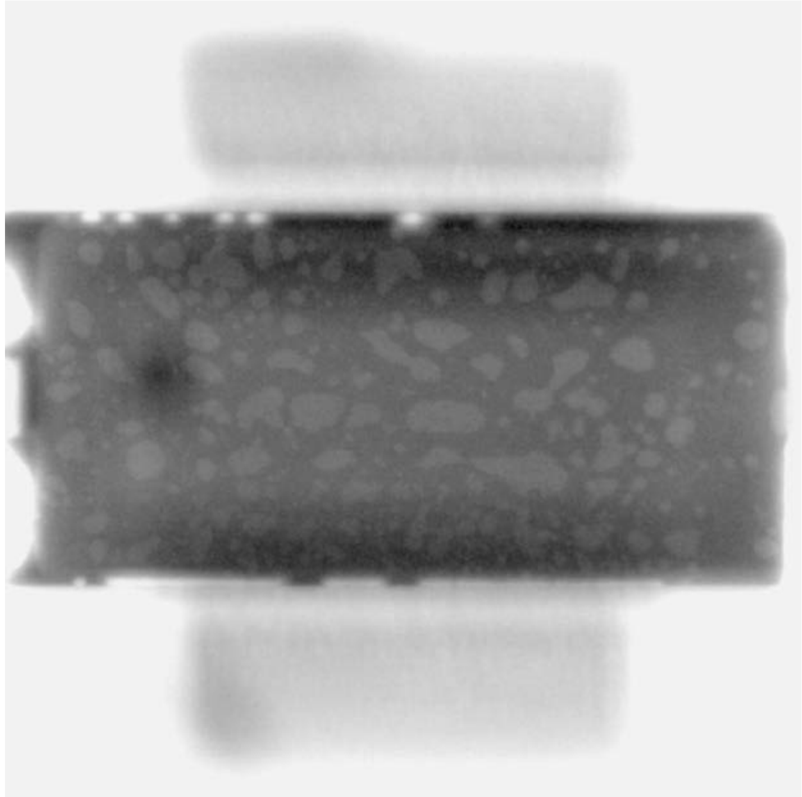
AXI Challenge 2: Pad Size



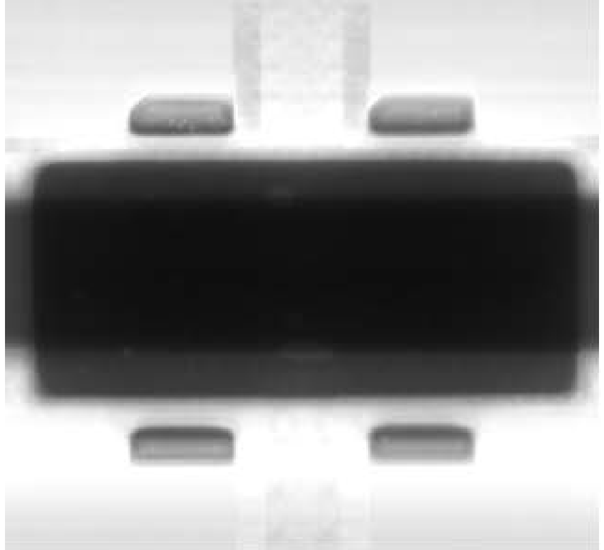
- AXI systems generally have Region of Interest (ROI) limitations that are defined by hardware, software, or both.
- Historically pads that are larger than the maximum ROI are re-defined within the recipe as multiple larger pads, and, analyzed separately.
- The acceptability criteria as discussed at the start of this presentation are not well suited to pads that are split to many pieces because criteria are pad based (need to sum voids across pads) and because criteria are geographic (different rules for different areas on the pads.)
- DRO works on each pad region independently, this creates gray level changes between regions within the large pad.

AXI Solution 2: Support Larger Pads

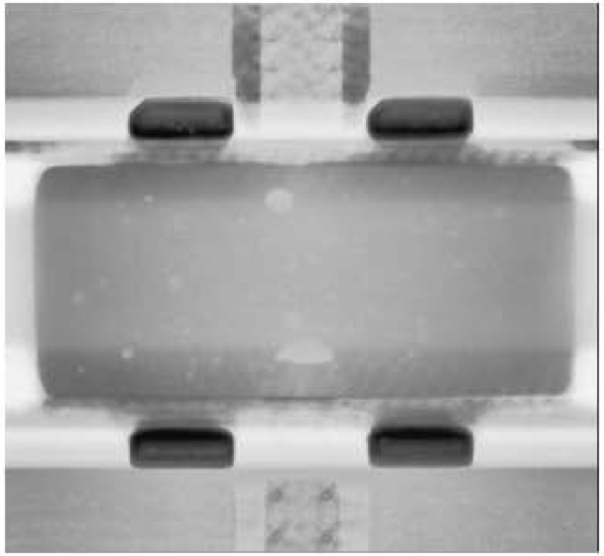
- Region to region gray level differences are eliminated.
- Acceptance criteria are more easily applied.
- Single image easier for humans to interpret.



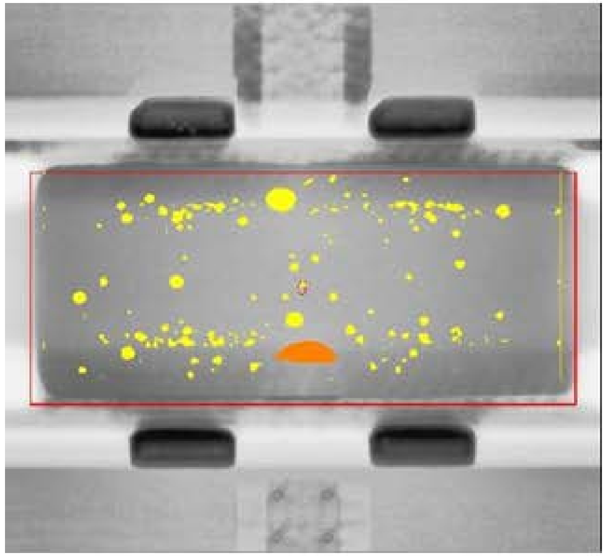
Summary



Before DRO



After DRO



After Classification

AXI Challenge 3: Voiding Classification

Initial Capabilities

- Ability to measure largest void for a pad
- Ability to measure total voiding area for a pad.
- Both of these as long as the pad is in one region.

New Requirements

- Rule 3: measurements near edge of part, tighter requirements.
- Added new threshold to check Rule 3 pass / fail.
- Void detection at the edge of the component. Added “masked voiding” to help identify voids at the edge of the component.
- Better Voiding Sensitivity

AXI Challenge 3: Solutions

- Modified AXI Flood Fill Method to achieve better voiding detection.

Summary

- Initial image quality, and classification results, were not sufficient to separate good power transistors from bad.
- The work helped to understand requirements, implement creative solutions, and provide classification results that meet customer requirements.
- AXI technology was extended, and improved, in order to address the unique requirements of power transistor inspection.

THANK YOU!