# X-Ray Inspection Benefits & Applications

*By Doug McClure, MarCom Manager, FocalSpot, Inc.*

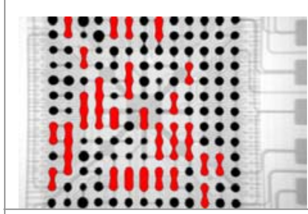
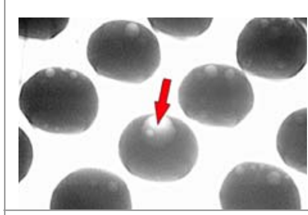
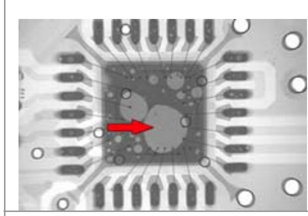
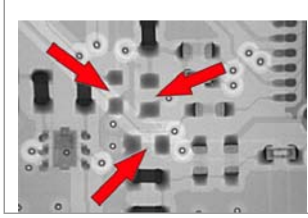
## *Benefits of X-Ray Inspection*

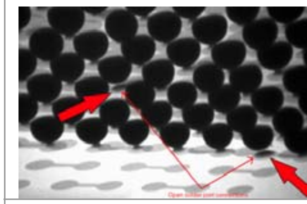
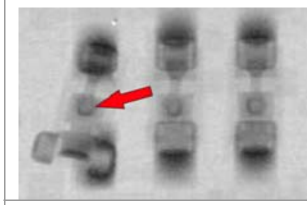
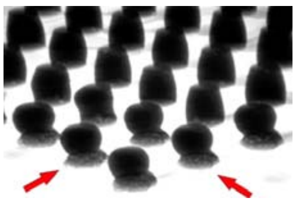
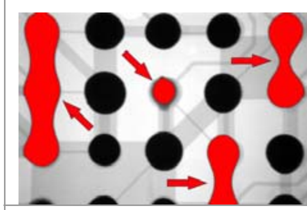
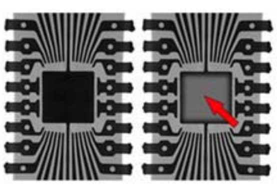
The benefits of x-ray inspection are broad in scope due to the ability of x-rays to see through packages, including: encapsulation, heat sinks and metallic shielding to reveal obscured connections and identify potential quality issues non-destructively. X-ray inspection is particularly beneficial to applications that involve advanced packaging technologies such as: BGA, CSP, FC, WLP, POP, SIP, QFN; as these type of components all lack quality assessment access by alternative inspection methodologies (i.e., Vision 2D/3D, AOI, Laser, ICT etc.).

X-ray inspection has become an irreplaceable tool for design evaluation, process improvement, quality assessment and rework verification. While, x-ray image processing, fault detection and failure analysis tools provide the ability to quantify and fine-tune manufacturing processes, improve quality and yield, reduce scrap and decrease warranty returns. In short, having x-ray inspection capability can positively affect the entire lifecycle of a product. For these reasons, more and more OEMs are making x-ray inspection a process requirement and a prerequisite for CM and rework service vendors, by favoring or mandating in-house x-ray inspection capability.

## *X-Ray Inspection Detectable Faults*

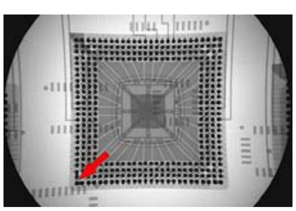
Solder joint defects are caused by a variety of unique thermal and mechanical conditions that occur during the manufacturing process. Below is a list of typical manufacturing defects showing x-ray image examples, fault definitions and possible fault cause:

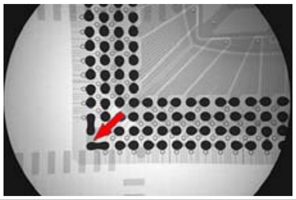
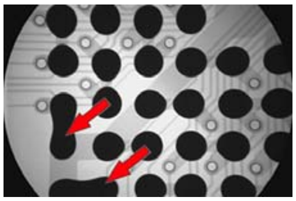
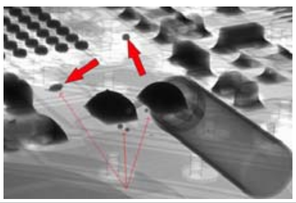
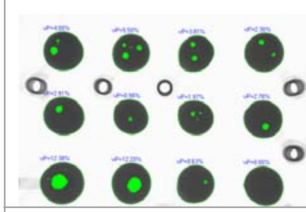
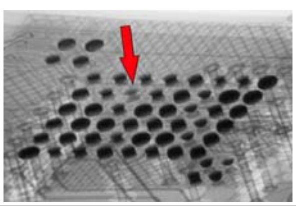
| Defect Example | Fault Definition/Cause |
|---|---|
|  | ***Shorts or Bridging:*** An electrical connection of solder across conductors or lands that should not be joined. |
| | ***Cause:*** Excess or uneven solder paste deposition, damaged solder mask or conformal layer, solder splash, movement during reflow aka "disturbed joint" and over heating during reflow / rework. |
|  | ***Voiding:*** An open area void of solder located inside or on the surface of a solder joint. |
| | ***Cause:*** Trapped gas or contaminants inside a solder joint while cooling, aka "outgassing." If gas escapes during the solder process this can cause air bubbles, pin holes or blow holes. |
|  | ***Delamination:*** Separated layers within a device structure; an open area void of adhesive located under the die of a component. |
| | ***Cause:*** Stress, impact, contaminants or excessive heat during the manufacturing process. |
|  | ***Missing:*** Missing part or missing connection point (i.e., solder ball) |
| | ***Cause:*** Usually occurs during the part handling process (pick-&-place) or by poor quality control in reference components delivered on tape-&-reel, or caused by a chip shooter mechanics malfunction (turret head, table and feeder carriage) miss-feed or dropped part. |

| | |
|---|---|
|  | ***Open:*** A missing (or cold) solder connection between conductors or lands that should be electrically joined. |
| | ***Cause:*** Insufficient heating during reflow or rework phase, poor thermal stability of the PCB and/or component, faulty solder paste deposition, disturbed joint, contamination, missing connection point such as a missing solder ball. |
|  | ***Misaligned (lifted or tombstone):*** Placement error, component orientation is other than intended. Misalignment can result in low joint strength and poor electrical connection, or defects such as bridges, opens, etc. |
| | ***Cause:*** Usually occurs during the part handling process, placement error, uneven solder deposition or disturbed joint. |
|  | ***Poor Coplanarity (open or misaligned):*** A solder joint or series of solder joints on a component is out of alignment or fails to make contact with the land. Also, contact points in an area array that do not make contact or are inconsistent with the intended geometric plane (ball to solder and matching land). |
| | ***Cause**:* Insufficient/uneven heating during the reflow phase causing incomplete reflow and uneven settling of the component-to-pad, poor thermal stability of the PCB and/or component, uneven solder paste deposition, disturbed joint or contamination. |
|  | ***Size/Shape (Unacceptable variations):*** Unacceptable size and shape variations in solder volume. |
| | ***Cause:*** Uneven or excess/insufficient solder deposition, damaged mask, insufficient heating during reflow phase, poor thermal stability of the PCB and/or component, disturbed joint, contamination. |
|  | ***Identification of Counterfeit "Gray Market" Components*** |
| | Although not a fault, counterfeit device screening has recently presented itself as a necessary measure to protect manufacturers from unknowingly incorporating fraudulent components in their assemblies. The image (left) shows missing die found in a counterfeit component. |

## *Manual X-Ray Inspection Application Strategy*

By using the x-ray inspection system as a microscope (real-time manual inspection); fast accurate quality assessment can be achieved using the following x-ray inspection techniques.

| Technique Example | Inspection Technique |
|---|---|
|  | ***Low Magnification (0 -10X), Large Field-of-View (FOV)***<br><br>A fast method of detecting gross defects. By using low magnification, an operator is able to quickly scan large inspection areas in search of fault indications. This technique is useful for detecting gross anomalies such as: bridging (shorts), Excess and Insufficient solder, misaligned and tombstoned components, unacceptable size and shape variations in solder joints, etc.<br><br>*NOTE: Best practice for a first pass inspection to get the job done quickly and efficiently.* |

| | |
|---|---|
|  | ***Medium Magnification (10 -75X), Medium Field-of-View (FOV)***<br><br>A moderately fast method of detecting gross defects that reveals more detail and information than low magnification, but offers faster visual scanning than high magnification. |
|  | ***High Magnification (100 -1000X), Small Field-of-View (FOV)***<br><br>This technique is the slowest method but provides the greatest detail for characterizing subtle defects. The high magnification technique is generally employed by operators after seeing something suspicious during a scan at lower magnification.<br><br>*NOTE: The best balance of throughput and magnification depends upon the application and the experience level of an operator.* |
|  | ***Low X-Ray Energy***<br><br>Using low x-ray power provides quick detection of bridges, poor reflow indicators (shape) and registration of the solder-to-pad characteristics. The image (left) shows solder balls and solder splash. Low energy x-ray also reveals trace paths, pads and other low density characteristics about the sample. |
|  | ***High X-Ray Energy***<br><br>At higher x-ray energy x-rays pass through traces and pads as well as the most of the solder to reveal hidden voids and internal component features such as wire bonds and die attachments. The green areas (image left) identify voids and measurements of the void volume for each solder joint. |
|  | ***Oblique View***<br><br>Moving, rotating and tilting a sample under real-time x-ray can reveal shape, size and *location* of solder connections and faults. This is especially important for double-sided boards, where top and bottom side components may obscure clear viewing of object details. |

## *System Application Suitability*

X-ray inspection systems vary broadly by designs and capabilities, yet all have similar fundamental components which make them x-ray systems. Therefore, to answer the question of system to application suitability requires basic x-ray technology explanations, provided below.

### Sample Handling

Sample handling with respect to board size is a fairly obvious question, but none the less, it is an important consideration. *Machine loadable board size:* Does the board fit into the sample holder of the machine?

*NOTE: This is generally the first question asked when qualifying a system for a range of PCB inspection applications.*

### Sample Manipulation (Oblique Viewing)

This refers to the ability of a sample (PCB) to be rotated within the x-ray imaging path to display oblique (off-axis) viewing of the inspection area. The purpose of oblique viewing is to reveal the shape, size and *location* of faults within solder connections. This is especially important for double-sided boards, where top and bottom side components may obscure clear viewing of object details.

*NOTE: A rotation angle from 0 to 40 degrees is ideal for this application. Manual or mechanical board manipulation will influence machine cost and operator convenience but makes little difference to the effectiveness of the inspection.*

### Magnification vs. Field-of-View (FOV)

Magnification and field-of-view have opposing correlations. Ultimately the goal should be to obtain a good balance between sufficient magnification (inspection detail) and sufficient FOV (inspection view area) to view as much of the inspection area to minimize the time required for a complete board inspection.

*NOTE: When using high magnification, the field-of-view becomes smaller thereby reducing the speed at which a board can be completely inspected. Therefore, throughput and magnification have opposing objectives and the best balance of each depends upon the application and operator experience.*

### X-Ray Source (Resolution)

For all x-ray inspection systems spot size, spot circularity and applied power are components of x-ray source resolution. The most commonly used specification is spot size.

*NOTE: Because spot size varies in relation to the applied electron beam power; a nanofocus x-ray source may be restricted to relatively low power operation, else the spot size will grow to microfocus size as the power is increased to penetrate materials of relative density and/or thickness. Also Note: Essentially all systems are nearly equal in resolution below 40X magnification regardless of spot size due to what is known in x-ray physics as the "unsharpness effect."*

### X-Ray Source (Power)

X-ray source power is measured in kV. By adjusting the flow of current the number of emitted x-ray photons can be controlled to provide the required degree of material penetration. Low energy reveals traces and solder connection shape, while higher energy is used to reveal hidden internal characteristics such as voids.

*NOTE: The typical kV range of real-time x-ray inspection systems is between 50kV to 130kV. X-Ray tube power selection depends upon the materials being inspected. Printed circuit boards and most SMT components require between 50kV to 90kV to adequately inspect the entire board. Whereas, heavily shielded components, castings and mechanical assemblies may require 90kV to 130kV or more depending upon the materials and density of the parts.*

### Image Processors

For all x-ray systems, the image processor and software have a direct impact on speed, accuracy and repeatable analysis results. Typical software packages include basic image quality enhancement tools such as: image averaging and visual improvement filters. By way of this collective "image processing," visual detail is improved thereby making it easier for an operator to quickly evaluate overall quality and identify subtle anomalies. Other software tools such as data collection, measurement and analysis reporting tools provide interactive diagnostics that further isolate, quantify and document faults for corrective action.

*NOTE: It should be noted that most users only use the minimal tools needed to get the job done and some advanced visualization features (i.e., 3D rendering) are time consuming and not particularly useful for quality assurance inspection.*

## *Conclusion*
## *Manual X-Ray Inspection Strategy Best Practices*

A good x-ray inspection strategy should employ a balance of (low magnification) to view as much of the inspection area at one time to quickly identify gross faults; and (high magnification) to provide adequate inspection detail for in-depth failure analysis. The best balance of each depends upon the application and operator experience.

## X-Ray System Application Suitability

***FIRST:*** *D*oes the system fit your application (i.e., sample handling, tube power, etc.)? For the most part this question is application specific, with the stipulation that system selection should clearly identify actual requirements and system use. In most cases, the actual use model is something like this: “Get the job done, quickly, easily and efficiently, while using the minimal tools necessary accomplish this task. **Summary:** Buy what you need and what you will actually use.

***SECOND*****:** Does the system fit your budget? Beyond the initial purchase price of a complete system, budget should include the long-term cost of ownership, including: service, support and warranty; as well as operational simplicity from the perspective of ongoing maintenance, as well as ease-of-use and minimal training requirements. **Summary:** Value (ROI) is a function total cost and performance over time.

# *About FocalSpot*

FocalSpot, Inc. is a provider of affordable high-quality BGA/SMT inspection and rework solutions to the electronics manufacturing industry worldwide.

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