Agenda

- Introduction
  - Definitions, Defect levels, etc
- Electrical test
  - MDA, ICT, FTP, & FT
- Inspection
  - MVI, SPI, AOI, & AXI
- Other test issues
  - DFT, DFM, Economics
Inspection - Topics

- IPC 610 Electronic Acceptability Standard
- Manual Visual Inspection (MVI)
- Solder Paste Inspection (SPI)
- Automated Optical Inspection (AOI)
- Automated X-ray Inspection (AXI)
IPC-A-610C

Acceptability of Electronic Assemblies

IPC-A-610C illustrates industry-accepted workmanship criteria for electronics assemblies through full-color photographs and illustrations.

The topics include component orientation and soldering criteria for through-hole, SMT and discrete wiring assemblies, etc.

Now available in Chinese, Finnish, French, Portuguese, Spanish and Swedish. Translation work is continuing for other languages

372 pages, released January 2000

Additional information: http://www.ipc.org
IPC-A-610C

Three classes:

Class 1 - General Electronic Products
Typically consumer products, some computer and computer peripherals of consumer type

Class 2 - Dedicated Service Electronic Products
Typically Communication equipment, sophisticated business machines, and instruments

Class 3 - High Performance Electronic Products
Typically Medical life support, Aero-space and military equipment

The contract between the CM and the OEM may say that quality levels should be according to IPC-A-610 Class 2.
12 Surface Mount Assemblies

12.2.2.1 Chip Components - Rectangular or Square End Components - 1, 3 or 5 Side Termination, Side Overhang (A)

Target - Class 1,2,3
- No side overhang.

Acceptable - Class 1,2
- Side overhang (A) is less than or equal to 50% width of component termination area (W) or 50% width of land (P), whichever is less.

Acceptable - Class 3
- Side overhang (A) is less than or equal to 25% width of component termination area (W) or 25% width of land (P), whichever is less.
12 Surface Mount Assemblies

12.2.2.2 Chip Components - Rectangular or Square End Components - 1, 3 or 5 Side Termination, End Overhang (B)

Target - Class 1,2,3
- No end overhang.

Figure 12-16

Defect - Class 1,2,3
- Termination overhangs land.

Figure 12-17
IPC-A-610C

AOI and AXI systems do NOT measure directly to the IPC-A-610C

Some cases it is very clear
  - Missing components
  - Opens
  - Bridging

Some cases is not so clear
  - Insufficient
  - Misalignment
  - Voids
  - Solder balls

In most of those cases the AOI or AXI calls the joints and the Repair Operator makes the call

In some cases AOI and/or AXI does not call IPC-A-610C violations
Inspection - Topics

- IPC 610 Electronic Acceptability Standard
- Manual Visual Inspection (MVI)
- Solder Paste Inspection (SPI)
- Automated Optical Inspection (AOI)
- Automated X-ray Inspection (AXI)
MVI and MXI

- Manual Visual Inspection
- Pros and Cons

- Manual X-ray Inspection
- Pros and Cons
Manual Visual Inspection (MVI)

- Naked eye
- Magnifying glasses
- Microscope
Manual Visual Inspection (MVI)

**Advantages:**
Inexpensive, easy to implement, flexible, finding defects
Manual Visual Inspection (MVI)

How Often Do Different Visual Inspectors Agree?

1 Inspector

Green: % of Agreement

1 Inspector

Blue: % of Disagreement

2 Inspectors

Green: 44%

Blue: 28%

3 Inspectors

Green: 12%

Blues: 6%

4 Inspectors

AT&T study
Hidden Solder Joints

These Solder Joints Can Not Be Inspected Visually
Manual Visual Inspection (MVI)

Advantages:  
- Inexpensive  
- Easy to implement  
- Flexible

Disadvantages:  
- Subjective  
- Inconsistent  
- Hard to inspect small components  
- Typically no process monitoring  
- Can not see hidden joints
Manual X-ray

Can see hidden joints
Can tilt the board in different directions
Manual X-ray

Can see hidden joints
Can tilt the board in different directions

Not always that easy

Can you see the open BGA?
## Manual X-ray Inspection (MXI)

<table>
<thead>
<tr>
<th>Advantages:</th>
<th>Disadvantages:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Inexpensive</td>
<td>Slow</td>
</tr>
<tr>
<td>Can see hidden joints</td>
<td>Typically no process monitoring</td>
</tr>
<tr>
<td>Good for failure analysis and</td>
<td>Can not be in-line</td>
</tr>
<tr>
<td>diagnostic help</td>
<td></td>
</tr>
</tbody>
</table>

Last revised: September, 2003
What is Driving Automated Inspection?

- Continuing miniaturization
- Higher volumes
- Increasing complexity
- Decreasing quality
Inspection - Topics

- IPC 610 Electronic Acceptability Standard
- Manual Visual Inspection (MVI)
- Solder Paste Inspection (SPI)
- Automated Optical Inspection (AOI)
- Automated X-ray Inspection (AXI)
SPI (Solder Paste Inspection)

- Introduction
- 2D
- 3D
- Laser Triangulation
- Potential defects and possible causes
- Pros and Cons
Where should test inspection be deployed?

For process control with shorter feedback loop.

For higher defect coverage.

Defects introduced & Defects removed

Defects introduced

Defects introduced & Defects removed

Many Defects introduced

or Selective Wave

Also defects introduced to side 1

Also defects introduced to SMT side 1&2
Main reasons for Solder Paste Inspection

- Many solder joint defects are caused by paste printing
  - For 0201s and CCGAs, paste volume and registration very important
- Defects are prevented at the most cost-effective stage
- Components are becoming more and more difficult and expensive to rework
- Repair costs are minimal since the board is unpopulated
- Can be used real time as a process control and process indicator tool
Printing Equipment

Printers have vision too

• Vision alignment is used for precise stencil to board registration, X-Y and Theta also....

• 2D Paste Inspection Systems available on most machines. Adds to cycle time and is limited.

• This part will focus on dedicated Paste Inspection Machines
Important features of SPI

- **High Speed Paste Inspection**
  - Enable the system to scan all deposits for volume, at line speeds

- **Repeatability**
  - GR&R of less than 10%

- **Board Warpage Compensation**
  - Ability to handle large warp in double sided SMT boards
Technology SPI 2D

- Camera
- Light
Lighting Head & Camera 3D

Camera

Z-Axis

Camera Lens

2nd Laser or light

Light Ring Illumination for Fiducial Inspection

Laser Line Generators or light
Lighting Head & Camera 3D

Camera
Laser or light

Light Ring Illumination for Fiducial Inspection

Z-Axis
Camera Lens

2nd Laser or light
Camera

Camera
Laser Line Generators or light
Laser Beam Head

Laser Beam Head diagram showing:
- Laser
- Sheet of light
- PCB
- Camera
- 2nd Laser
- 2nd Sheet of light not shown
- Paste deposit
- Beams from two lasers
Laser Triangulation

H = D * tan(α)

Deflection of laser beam (D), is directly proportional to the height of the solder paste
Scanning with 2 Lasers

Scan Direction

Laser A

Laser B

3D Height Data

View with Laser 'A'

View with Laser 'B'

No data 'shadow'
Combining Images from 2 Lasers

Scan Direction

Laser A

Laser B

3D Height Data for all points

Removed all 'shadowing'

Combined Laser View
Z-Axis Compensation

1. Height Measurement on rigid PCB
2. Warped PCB throws off results

Typically the laser and camera move
## Paste to Pad Offset / Misaligned Print

<table>
<thead>
<tr>
<th>SPI Measurement</th>
<th>Possible Cause</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paste to Pad Offset</td>
<td>Mis-aligned stencil</td>
<td>Adjust screen printer</td>
</tr>
<tr>
<td></td>
<td>Bad stencil or boards</td>
<td>Measure stencil and boards</td>
</tr>
</tbody>
</table>

- **2D**
  - Offset defect
  - Potential area defect

- **3D**
  - Potential volume defect
  - Potential height defect
Bridge

<table>
<thead>
<tr>
<th>SPI Measurement</th>
<th>Possible Cause</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge</td>
<td>Excess paste</td>
<td>Collect 3D data</td>
</tr>
<tr>
<td></td>
<td>Damaged apertures</td>
<td>Inspect stencil</td>
</tr>
</tbody>
</table>

- **2D**
  - Offset good
  - Potential area defect if bridge area is large

- **3D**
  - Volume defect
  - Potential height defect
## Smear

<table>
<thead>
<tr>
<th>SPI Measurement</th>
<th>Possible Cause</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smear</td>
<td>Poor handling</td>
<td>Clean stencil</td>
</tr>
<tr>
<td></td>
<td>Paste on back on stencil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Snap-off height too high</td>
<td></td>
</tr>
</tbody>
</table>

- **2D**
  - Offset good
  - Potential area defect if smear area is large

- **3D**
  - Potential volume defect
  - Height defect
Small Area / Large Area

<table>
<thead>
<tr>
<th>SPI Measurement</th>
<th>Possible Cause</th>
<th>Action</th>
</tr>
</thead>
</table>
| Small Area      | Dried paste on stencil aperture  
                | Paste volume on printer too low  
                | Squeegee speed too fast         | Clean stencil  
                | Add fresh paste  
                | Adjust printer |
| Large Area      | Poor aperture gasketing due to excessive squeegee pressure  
                | Debris on board  
                | Damaged aperture               | Adjust printer  
                | Clean stencil and board  
                | Inspect stencil |

2D
- Offset good  
- Area defect

3D
- Volume defect  
- Potential height defect
Volume High or Low / Height High or Low

<table>
<thead>
<tr>
<th>SPI Measurement</th>
<th>Possible Cause</th>
<th>Action</th>
</tr>
</thead>
</table>
| Volume High / Height High| Contamination at board/stencil interface  
Warped stencil          | Clean stencil and board              
Inspect stencil          |
| Volume Low / Height Low  | Polymer blades scoop out paste  
Squeegee speed too fast  | Adjust printer              |

- **2D**
  - Offset good
  - Area good

- **3D**
  - Volume defect
  - Height defect
### Slump / Large Height Variation

<table>
<thead>
<tr>
<th>SPI Measurement</th>
<th>Possible Cause</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump</td>
<td>Squeegee speed too fast</td>
<td>Adjust printer</td>
</tr>
<tr>
<td></td>
<td>Paste temperature to high</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paste has absorbed moisture</td>
<td></td>
</tr>
<tr>
<td>Large Height Variation</td>
<td>Warped stencil</td>
<td>Inspect stencil</td>
</tr>
<tr>
<td></td>
<td>Separation control speed too fast</td>
<td>Adjust printer</td>
</tr>
<tr>
<td></td>
<td>Squeegee speed too fast</td>
<td></td>
</tr>
</tbody>
</table>

- **2D**
  - Offset good
  - Potential area defect

- **3D**
  - Volume defect
  - Height defect
Defect Identification

- Both 2D and 3D provide valuable process information.
- Some overlap exists between 2D defect calls and 3D defect calls.
- Only 3D inspection provides volume measurements.

- We know from case studies and publications that the solder paste volume information is a good predictor of finished board quality.

<table>
<thead>
<tr>
<th>2D/3D</th>
<th>3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paste to pad offset/Misaligned print</td>
<td>Bridge</td>
</tr>
<tr>
<td>Small area/Large area</td>
<td>Slump/Large height variation</td>
</tr>
<tr>
<td>Smear</td>
<td>Volume high or low/Height high or low</td>
</tr>
</tbody>
</table>

ITC Board Test Tutorial Part 1, Last revised: September, 2003
Advantages

- Both 2D and 3D SPI provide value
  - Process control
  - Finding defects (potential defects)
- 3D inspection provides the added value of volume information, which is important producing robust joints
- Catching defects early, pre-placement saves money, easy repair
Disadvantages

- Defect introduced after paste will not be caught
- A balance between repairing “potential defects” and letting them pass
- Limited value if not enough attention to process information is used.
Inspection - Topics

- IPC 610 Electronic Acceptability Standard
- Manual Visual Inspection (MVI)
- Solder Paste Inspection (SPI)
- Automated Optical Inspection (AOI)
- Automated X-ray Inspection (AXI)
AOI (Automated Optical Inspection)

- Laser
  - Technology
  - Pros and cons

- Camera
  - Camera
  - Lighting source
  - Color - Monochrome
  - Algorithm
  - Warp compensation

- Pre-reflow - Post-reflow
- Pros and Cons
Laser

Component Position Test

Sensors

Laser Source
Laser

Solder Joint Test

Laser Source

Sensors
Laser

**Advantages:**
- High Accuracy

**Disadvantages:**
- Limited Polarity
- Limited Curvature
- Speed
Top Camera Only

CCD Camera, typical area CCD not line scanner

Visible Light Source

Limited J-lead
Top Camera Only

Possibility for several Camera

CCD Camera, typical area CCD not line scanner

Visible Light Source

Limited J-lead
Angled Cameras

Focus point, warpage problem
“Penta” Optical Head

CCD Cameras

Visible Light Source

Focus point, warpage problem
**Advantages:**
- “Everything Visible”

**Disadvantages:**
- No Hidden Joints
- Limited J-lead

---

**Advantages:**
- “Everything Visible”

**Disadvantages:**
- No Hidden Joints
- Calibration

---

*Camera*

---

**Single Camera**

**Multiple Camera**
Typical Illumination Systems

Fluorescent Ring Lighting

LED Ring Lighting

LED lighting

Flash tube lighting
## Lighting Sources

<table>
<thead>
<tr>
<th>Visible Light Source:</th>
<th>Disadvantages:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Halogen light</td>
<td>• Lifetime &amp; calibration</td>
</tr>
<tr>
<td>• LED</td>
<td>• Intensity</td>
</tr>
<tr>
<td>• High frequency fluorescent</td>
<td>• Lifetime &amp; calibration</td>
</tr>
<tr>
<td>• Flashes</td>
<td>• Lifetime</td>
</tr>
</tbody>
</table>
Lighting Technologies

Technologies:
- Diffuse light
- Directed light
- 3D Lighting

Disadvantages:
- No curvature information
- Different specula reflections
- Possible speed impact
Color and Monochrome Systems

Can either be color camera or color lighting

Why is color used?
- Used to get solder fault coverage in 2D systems
- Provide choices for optimizing contrast between item of interest and background
- Angled, colored lighting substitutes for angled cameras
- Read laser marks

Pros and Cons of color
- May induce unwanted “noise” into images
  - Color is sometimes a non-controlled process variable on PC assemblies.
    - Manufacturers usually don’t spec or care about color of packages or boards
- Added processing may impact throughput
- Some solutions have trouble with lead-free solder inspection
3 Major Algorithm Types

**Correlation**

**Programming:** no programming, uses images from camera as search template.

**Advantages:** zero programming

**Disadvantages:** sensitive to background, high false calls, multiple boards to program

**Feature Extraction**

**Programming:** Manually input device dimensions or edit from similar device

**Advantages:** robust algorithms with low false fails. Good on joints

**Disadvantages:** more complex programs, sensitive to component changes

**Geometric Pattern Matching (GPM)**

**Programming:** Draw (or link to) models based on device shape

**Advantages:** Simple intuitive programming, scales and rotates with device

**Disadvantages:** can not model joints, grayscale only
Warp Correction

Angled Cameras and Lighting Systems Require Warp Correction

- To achieve low false flag and escape rates, warp correction is a must
- Board warp causes the image to move within inspection windows
- Warp correction system digitally or mechanically compensates for it during inspection
AOI Pre-reflow - Post-reflow

**Pre-reflow**
- Catching fewer defects
+ Efficient for process control

**Post-reflow**
+ Catching more defects
- Not as efficient for process control
AOI

Advantages:
- High throughput
- Good defect coverage
- Relative low cost
- No fixtures

Disadvantages:
- "Hidden joints" (BGA, RF-shields)
- Can have high false calls
- Not the highest defect coverage
Inspection - Topics

- IPC 610 Electronic Acceptability Standard
- Manual Visual Inspection (MVI)
- Solder Paste Inspection (SPI)
- Automated Optical Inspection (AOI)

Automated X-ray Inspection (AXI)
AXI (Automated X-ray Inspection)

- Introduction
- Automated and Manual
  - High end Manual X-ray
  - Pros and Cons
- 2D AXI - Transmission
  - Technology
  - Pros and Cons
- 3D AXI - Cross sectional
  - Laminography - Technology
  - Tomosynthesis - Technology
  - Pros and cons
- Combo - Pros and Cons
- Lead-free and x-ray
General X-Ray Overview

BGAs Under Direct Transmission 2D X-ray

X-ray beam

Attenuation

X-ray sensitive material

Light created x-ray attenuation
Types of AXI

Automatic

- Transmission AXI “2D”
- Cross-section AXI “3D”
  - Laminography
  - Digital Tomosynthesis
- Combo AXI (2D and 3D)

Manual

- Transmission MXI “2D”
High End Manual 2D X-Ray Systems Continue to Increase Capability

- Continued product segmentation between very low cost/limited capability systems and higher cost/higher capability systems.

- For higher end products there is increased use of multiple axis manipulation for better inspection capability and in some cases the ability to “capture” images at different angles to provide a “pseudo” 3D image.

- Increased use of software to automated” defect calls - especially for BGA/area array packages

- These systems do NOT use laminography or Tomosynthesis and are not suitable where in-line or automated handling are required.
Manual 2D Transmission x-ray

Advantages:
- No Programming
- System will not shut down line if failure occurs
- Lower support costs than automated systems
- Easy to use

Disadvantages:
- Marginal accuracy
- False call potential increases
- Operator oriented (fulltime)
- Slower than automated systems
- Operator must manually move DUT to area of interest
- Can’t be used for highly populated double sided boards
Defect coverage AXI

This is a conceptual diagram!
2D - Transmission AXI

The entire solder volume is inspected by transmission AXI.
2D - Transmission AXI

Finds defects that 3D AXI cannot typically detect

- 2D AXI finds “out-of-slice” defects
What About AXI Test Access?

Physical Layout of Double-sided Board

2D X-ray Image of Double-sided Board

PCB

J-lead

Resistor

Non or Partially Testable Joints
2D - Transmission AXI

2D AXI Provides Good Test Access on Double Sided Boards

<table>
<thead>
<tr>
<th>COMPLEXITY</th>
<th>BOARD SIZE [IN]</th>
<th>TOTAL # COMP.</th>
<th>TOTAL # JOINTS</th>
<th>% ACCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>12x2.7</td>
<td>454</td>
<td>2036</td>
<td>79%</td>
</tr>
<tr>
<td>Medium</td>
<td>14x7</td>
<td>1,071</td>
<td>7112</td>
<td>55%</td>
</tr>
<tr>
<td>High</td>
<td>13 x 16.5</td>
<td>1,710</td>
<td>11,115</td>
<td>72%</td>
</tr>
<tr>
<td>High</td>
<td>14.5 x 16</td>
<td>2375</td>
<td>13,904</td>
<td>73%</td>
</tr>
<tr>
<td>High</td>
<td>13.5 x 17</td>
<td>2918</td>
<td>24,758</td>
<td>79%</td>
</tr>
</tbody>
</table>

Your “mileage” may vary
2D - Transmission AXI

Advantages:
- High Throughput
- Accurate
- Reliable calls (if programmed properly)
- No operator Intervention required for inspection

Disadvantages:
- Must have qualified programmer
- Limited applicability on double sided boards
- Learning curve to program system
- Several Algorithms to learn and understand
2D vs 3D X-Ray Inspection

Under 2D Inspection

Under 3D Inspection

Top

Bottom
3D Cross-Section AXI

Laminography

- Mechanical Image Integration

Rotating X-ray Beam

Focal plane

Rotating Detector

• Z-Axis Mapping required

ITC Board Test Tutorial Part 1, Last revised: September, 2003
3D Cross-Section AXI Laminography

Majority of solder joints 3-4 mils

BGA, CCGA solder joints 15-70 mils

Focal depth of each slice 3-4 mils

Only solder joints and PCB thickness to scale
X-Ray Measurements

Gullwing pin → IC → Solder

Calibration Data

Image Processor

X-ray image with 5 gullwing pins
## 3D Cross Section AXI Technology

<table>
<thead>
<tr>
<th>Cross-section Height Definition</th>
<th><strong>Digital Tomosynthesis</strong></th>
<th>Laminography</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Digitally computed</td>
<td>Electro-mechanically initialized via laser surface map</td>
</tr>
<tr>
<td>Image Acquisition</td>
<td>Independent off-axis transmission images</td>
<td>Synchronous mechanical rotation and movement of x-ray beam, detector and Z table</td>
</tr>
<tr>
<td>Cross-section Formation</td>
<td>Software focal plane shift</td>
<td></td>
</tr>
</tbody>
</table>
3D Cross-Section AXI

Tomosynthesis
• Digital Image Synthesis

• No Z-Axis Mapping required
• Computational intensive
Principle of Digital Tomosynthesis

- Individual transmission images are acquired
- Later digitally synthesized to produce x-section views or “slices”
- Image acquisition and image synthesis are independent stages

![Diagram of digital tomosynthesis setup.
- Steerable X-Ray Source
- Inspection Plane
- Large Area Detector]
AXI Test Access

Physical Layout of Double-sided Board

Transmission (2D) X-ray Image of Double-sided Board

PCB

QFP

Resistor

Non or Partially Testable Joints
Digital Tomosynthesis - Slices

A Method for separating and analyzing data on opposite sides of a PCBA

Off-Axis Transmission Images

Multiple off-axis Transmission X-ray images are used to separate the top and bottom board side. Thereby, separating overlapping or obscured solder connections

3D X-ray provides the capability to generate separate views of top and bottom side joints
Digital Tomosynthesis is a Computational Technique

\[ Z = \frac{X}{\tan} \]

Objects at different elevations move by different horizontal distances.
Digital Tomosynthesis

Inspection Plane

Image E

Image A

Large Area Detector
Tomosynthesis

- Multiple Cross-sections per Acquisition: ‘infinite slicing’
Digital Tomosynthesis and Combo

- De-coupling capacitors are increasingly placed directly below other interconnections to deliver controlled impedance and higher frequencies
- Tomosynthesis can completely remove ‘shading effects’ from the opposite of the board
3D Cross-Section AXI

Advantages:
- Accurate
- Reliable calls (if programmed properly)
- No operator Intervention required for inspection
- Multiple Slices on any solder joint

Disadvantages:
- Must have qualified programmer
- Longer learning curve to program system
- Several Algorithms to learn and understand
Combo AXI

A combination of 2D transmission and 3D cross-section automatic x-ray
Advantages:
- Apply transmission and cross-section where they are best suited
- Can remove shading effects to delivery high quality x-ray images

Disadvantages:
- Longer Programming Times
- Slower Inspection Speed in 3D mode
Lead-Free Solder -- X-ray Images

Tin/Lead Joint

Tin/Silver/Copper Joint

Tin/Silver/Copper paste

Tin/Lead coated Lead

Implication:

AXI has no problem imaging different materials
Where should test inspection be deployed?

For process control with shorter feedback loop.

For higher defect coverage.

Defects introduced

Defects introduced & Defects removed

Defects introduced

Defects introduced & Defects removed

Many Defects introduced

or Selective Wave

Paste → P&P → Reflow → Paste → P&P → Reflow → Hand-load → Wave
Inspection - Topics

- IPC 610 Electronic Acceptability Standard
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- Solder Paste Inspection (SPI)
- Automated Optical Inspection (AOI)
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