Root Cause Failure Analysis of Printed Circuit Board Assemblies

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Wisconsin Chapter

SMTA

Surface Mount Technology Association

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What do you mean 0% first pass yield?

My process is in control , so what happened?

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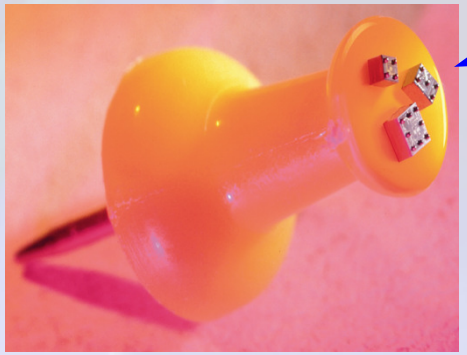
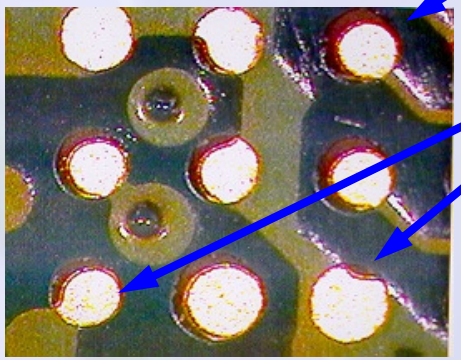
Photo Courtesy of G. Toren

Today's Electronic Designs





- Component Packages Are Getting Smaller
  - 0603 > 0402 > 0201>01005
  - BGA > CSP > WL-CSP > ?
- Assembly Design Density Is Increasing
  - Tighter Component to Component Spacing (Spacing Smaller Than 0.020" Common)
  - Smaller Copper (Pad) Interconnections
- Assembly Process Margins Are Tighter
  - Thermal Balance @ Pad Level Is Critical (Trace/Via Connection Size to Pads)
  - Component Placement Accuracy

(The Thickness Of A Piece of Paper Can Be Difference Between 100% Rework or High Yields)

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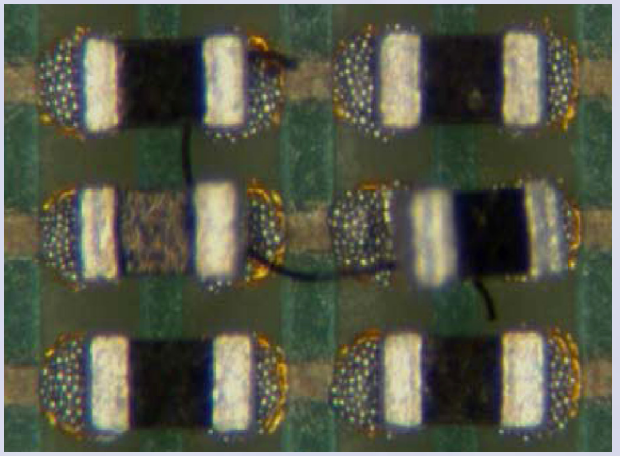
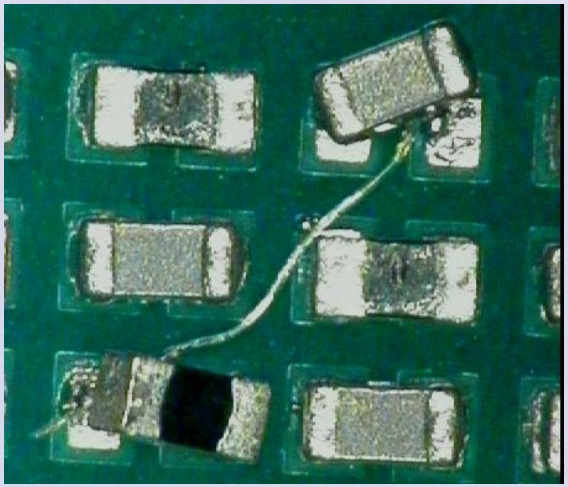
Effects of Mfg Environment

- Elements From Manufacturing Facility May Contribute Defects. These include:
  - Process Equipment Materials
  - ESD Control (Smock/Wrist Strap)
  - Paper Work
  - Component Packaging
  - Facility Environment
  - Clothing
  - Operators (Hair)





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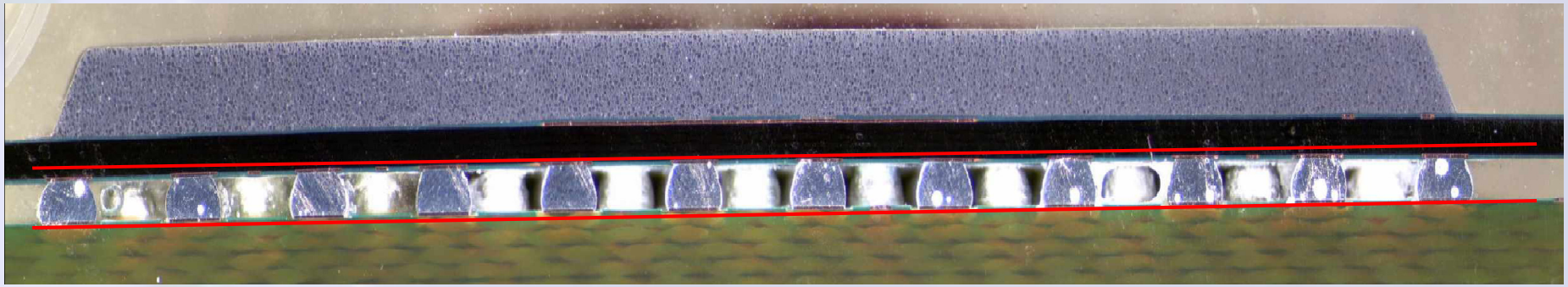
Component Issues - Warpage

- Higher Lead Free Solder Solidification and Process Temperatures, Increases The Amount Of Thermal Expansion Mismatch Of Components Which Can Increase Amount Of Component Warping During Assembly Process

- May Require Redesign Of Package (Material Selection) For Thermal Mass And Expansion Balance.



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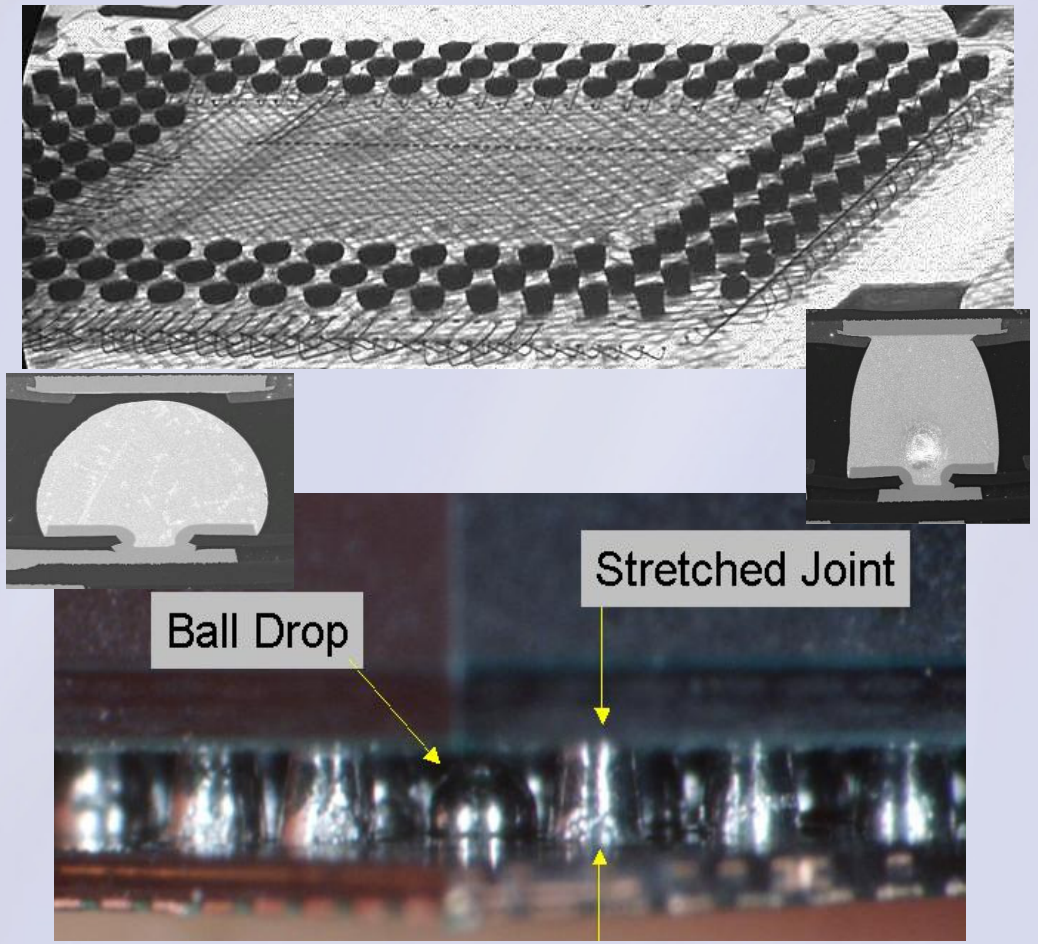
Component/PCB Warpage Impacts

Split Planes/Unused Pad Removal:

- Localize Changes In Thickness/Coplanarity Of PCB
- Potential Opens From Tilted Components (Teeter-Totter Effect)
- Potential Opens From “Dropped” Solder Connection
- Potential Reduced Reliability From Stretched Solder Joints



Some Photos Courtesy of Amkor

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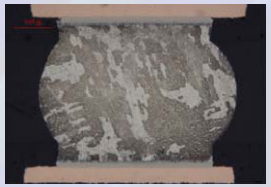
Component Issues - Decreasing Pitch

0.2 mm



0.4 mm

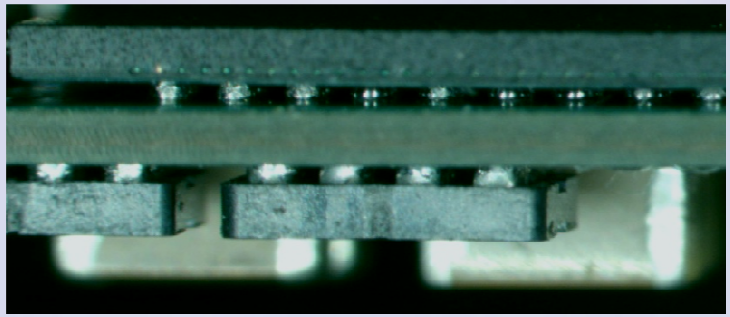
0.8 mm

1.0 mm

1.27 mm

Potential Issues:

- Paste Volume Control
- Component/PCB Flatness
  - Internal Split Plane
  - NFP Removal Impacts
- Component/PCB Warpage



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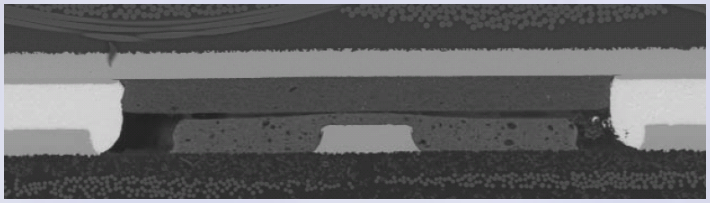
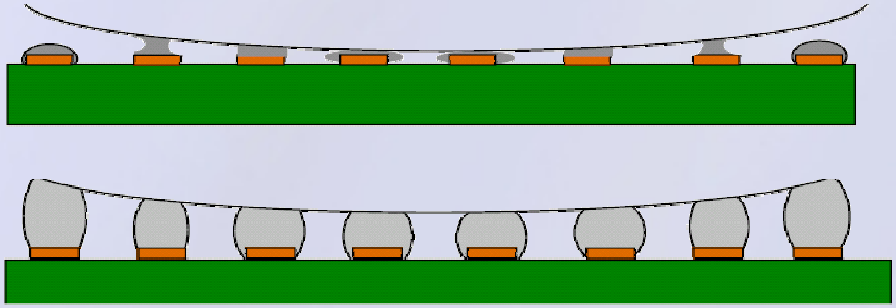
LGA/QFN Package Assembly

- Trace Routing Under Component Create Localized Height Variations
  - Standoff Height Variation



- Leadless Devices Are More Sensitive To PCB/Component Flatness/Warpage
  - Received Condition
  - In-process Condition (During Reflow/Rework Solder Process)



LGA Package

BGA Package

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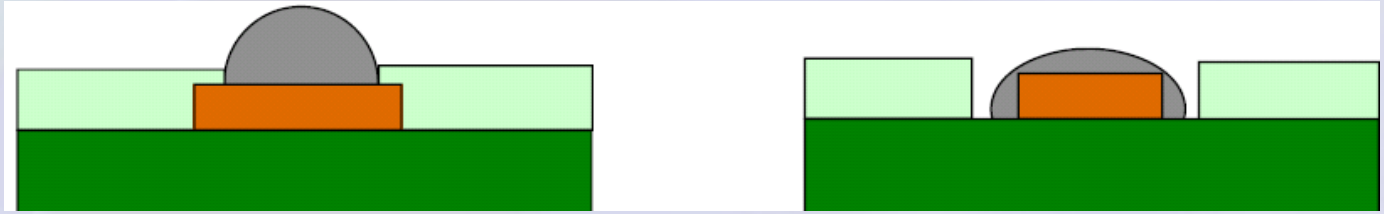
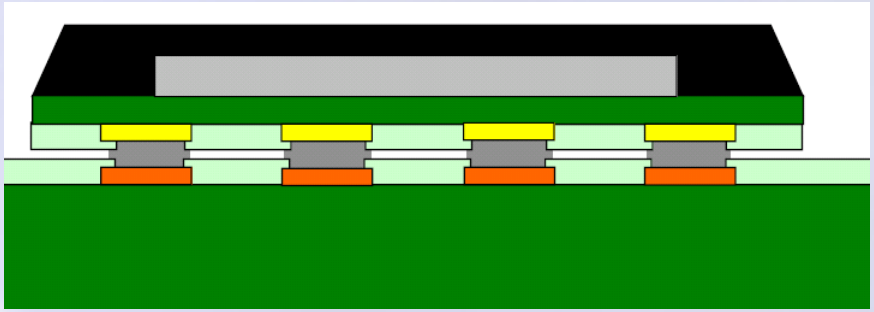
LGA Pad Design



Solder Mask Defined

Non-Solder Mask Defined

- Solder wicking around NSMD pads produce significantly lower molten solder height.
- Solder mask defined pads should be used for LGA and 0.4mm & smaller pitch BGA/CSP packages.



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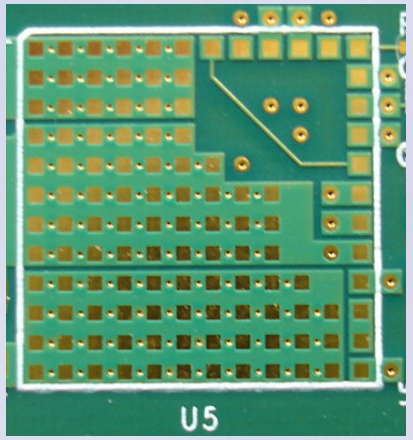
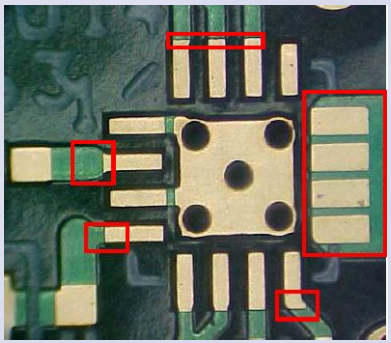
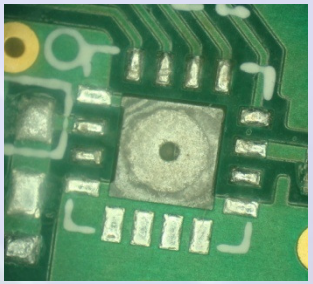
Component Issues - LGA & QFN

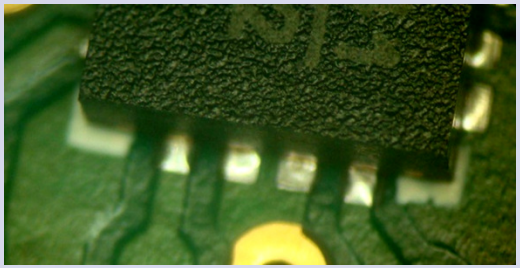
Potential Issues:

- Land Pattern Design
  - Pad Size Uniformity (SMD vs NSMD)
- Paste Volume Control
  - Pad to Pad Volume
  - Pad to Design Defined Volume
- Component/PCB Flatness
  - Internal Split Plane
  - NFP Removal Impacts
- Component/PCB Warpage
- Decrease Component Standoff Height
  - Decreased Reliability









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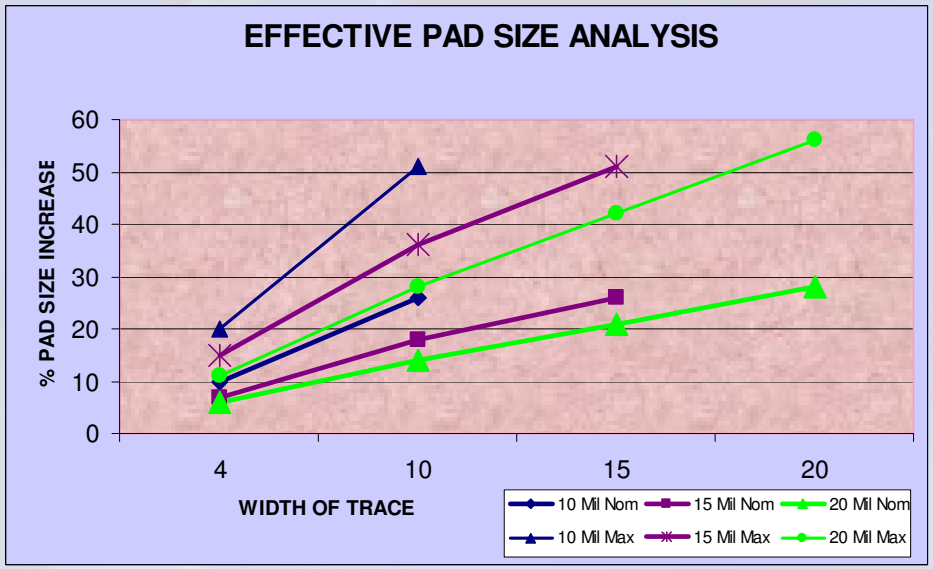
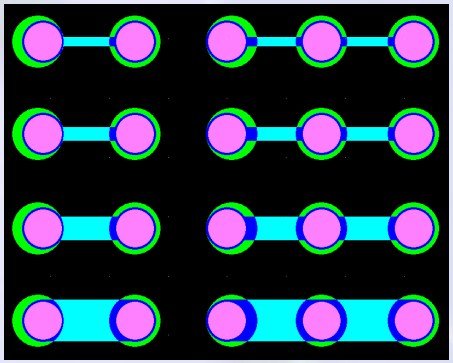
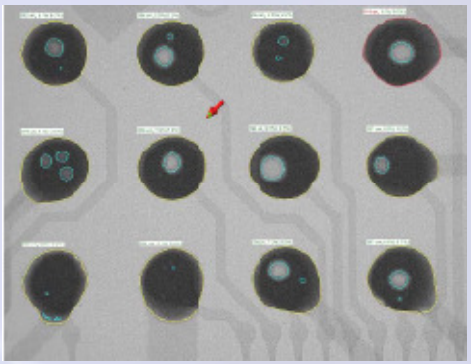
Trace Routing Impacts Solder Joint







Increased Mounting Pad Size Affected By:

- Number Of Trace Connections To Each Pad
- Width Of Trace Connections To Each Pad
- Size of Pad
  - Small Pads Have Less Margin
- Uniformity Of Trace Egress Direction
  - Some Package Types Are More Sensitive Than Others
- Uniformity Of Trace Sizes

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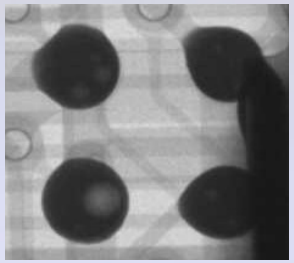
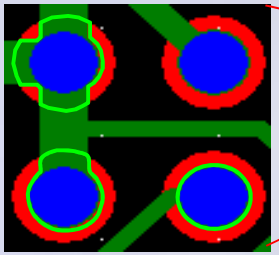
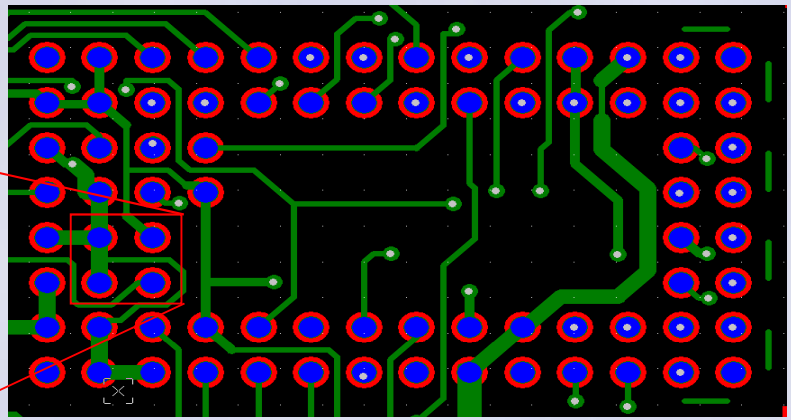
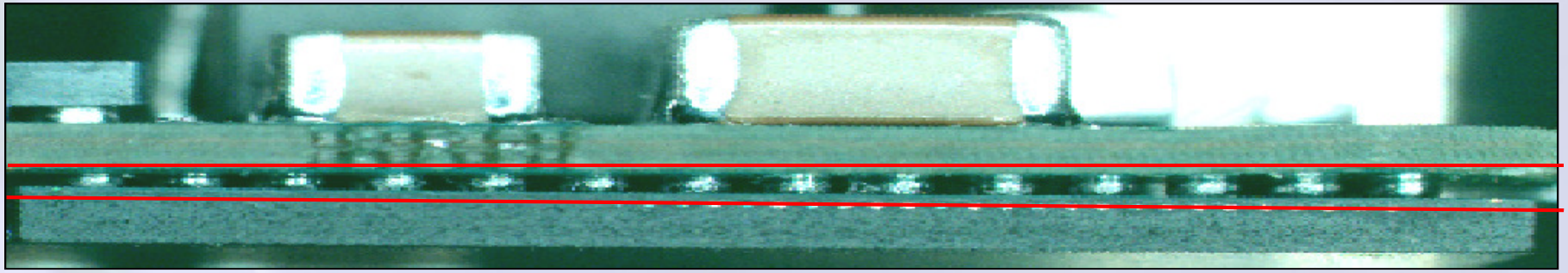
Trace Routing Impacts Solder Joint

- Gradient Of Different Trace Sizes
- Localized Concentrated Large Trace Connections Increase Defect Potential









Concentrations Of Design Variability Can Create:
Solder Bridge, Open Connection, Insufficient Solder, Tilted Components

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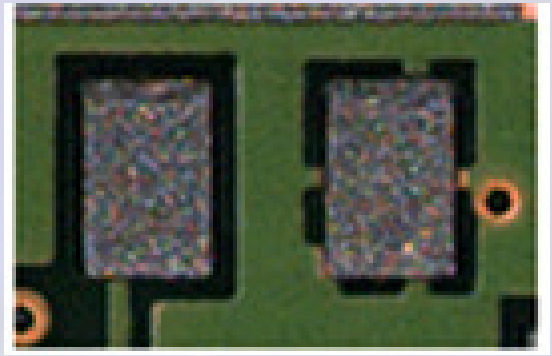
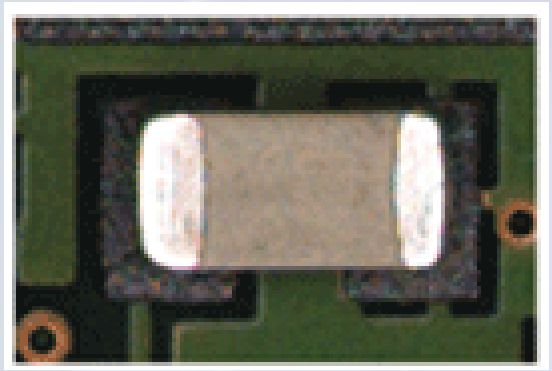
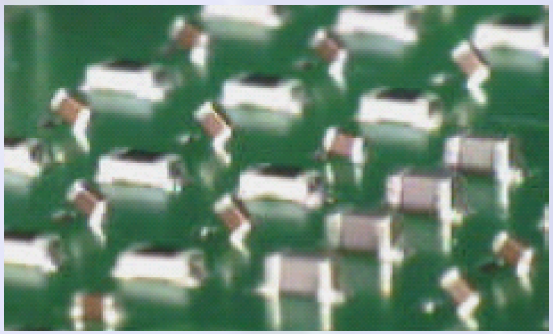
Component Pad - Thermal Imbalance







- Multiple Trace Connections
  - Number Of Trace Connections Per Pad
  - Uniformity Across All Pads On Single Component
- Solder Mask Defined Pad
- Increased Soldering Defects
  - Delayed Reflow Across SMT Components
    - Tombstone Components
    - “Ball in Socket” Area Array Component

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Component Pad - Thermal Imbalance

- Small Passive Component Pad Design
  - Mixed Solder Mask Defined
    - Multiple/Large Trace
    - Exposed Plane
  - Smaller Component Package, The Greater The Impact

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Thick Copper Design

A CTE Mismatch Between Copper And FR-4 Exists

- Copper = 18ppm
- FR-4 = 15-16ppm
- As Copper Gets Thicker, It Has Greater And Greater Influence Over Post Lamination Dimensions Of The Resulting Substrate

Rolled , Annealed Copper Reacts Differently Than ED Copper

- Design Influences On Net Shrinkage Become Far More Significant Standard Scaling Factors (That Compensate Net Shrinkage Effects) Do Not Apply!

More Resin Is Required To “Fill” Etched Out Areas

- “In-plane” CTE Increases With % Resin Content
- “Another Complication To Net Shrinkage Prediction”
- Resin Rich Package = Higher Z-axis CTE = Greater Sensitivity To Thermal Excursions, Assembly In Particular.
- Heavy Copper Substrates Generally Require More Heat Input To Assemble
- Reliability!

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Thick Copper Design

- Heavy Copper, Embedded In Glass Epoxy, Can Result In Nonplanar Conditions On The Surface Of The Substrate
- The Heavier The Copper, The Worse The Effect
- In Multi-layer Applications, Local Areas With “Stacked” Copper, Beside Areas That Are Etched Out, Can Result In Extreme Non-planarities
- PCB Fabrication Industry Typically Refers To This As “Image Transfer”

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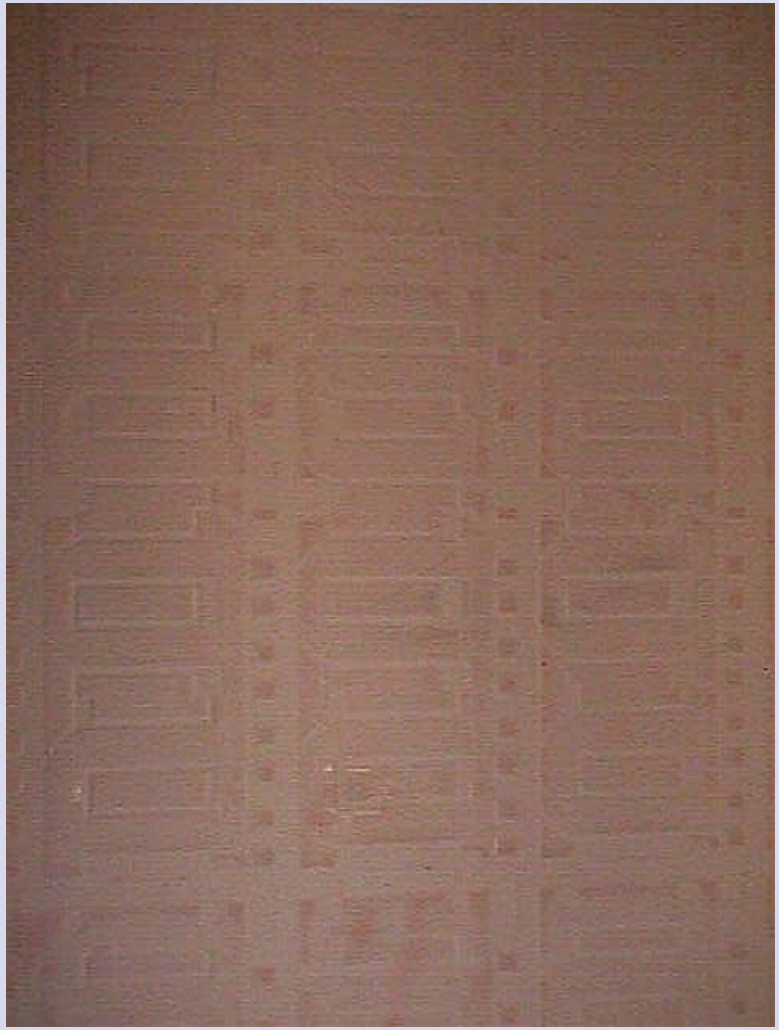
Thick Copper Design

Lack Of Planarity
- Reduces The Effective Resolution Of The Fabrication Process, Limiting Feature Size



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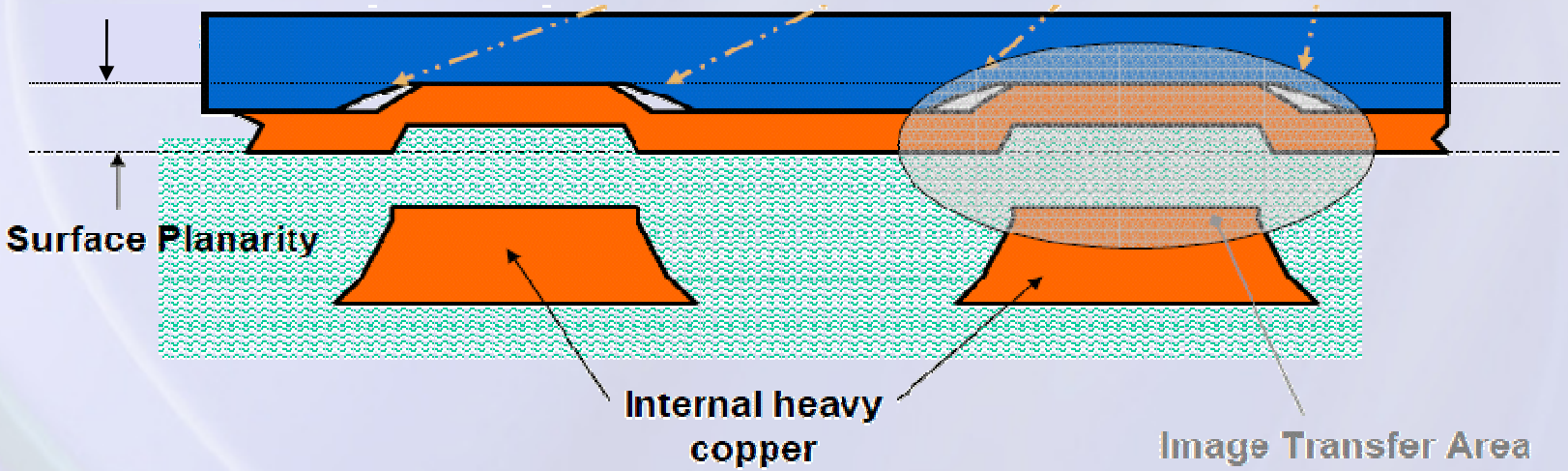
Heavy Copper Lamination

- Imaging Resist Thickness Is 1.3 - 2mils. At Some Point, Image Transfer Interferes With The Imaging Resists Ability To “Conform” To The Lack Of Planarity On The Surface Of The Substrate.

- This Lack Of Planarity Also Reduces The Effective Resolution Of The System, Limiting Feature



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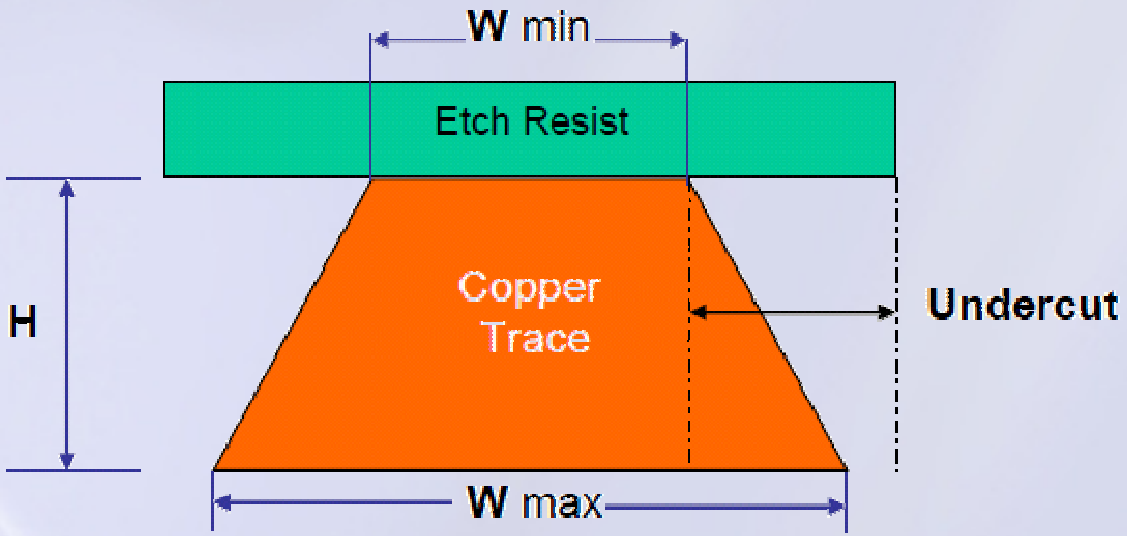
Copper Etch Process

- H = Height of Copper Trace
- Etch Factor = 2H / (W max - W min)
- Etch Factor Should Be Larger Than 1.0



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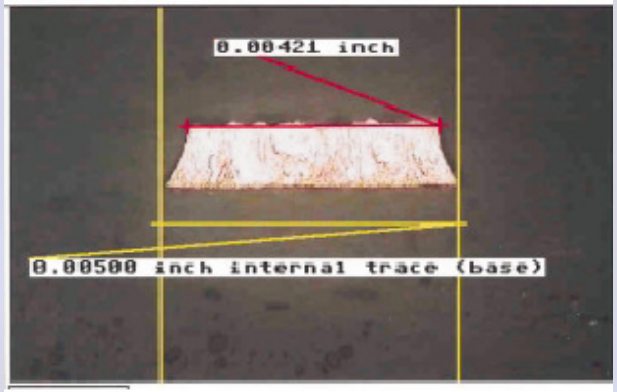
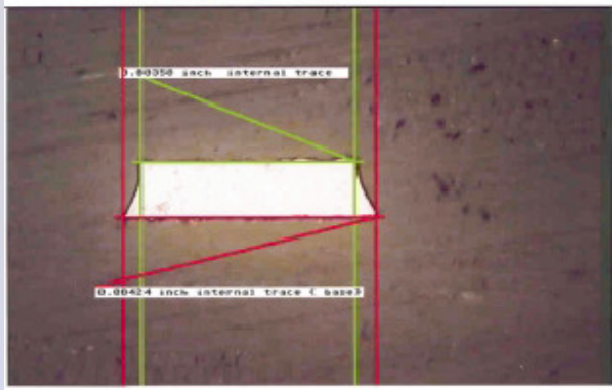
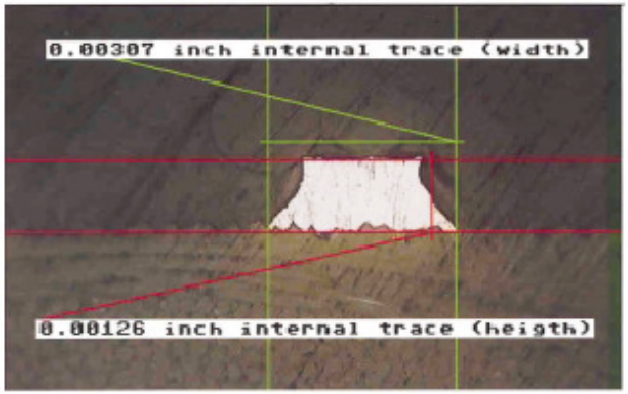
Etched Trace Design Considerations



0.005” Trace 1 oz copper



0.004” Trace 1 oz copper



0.003” Trace 1 oz copper

- Thinner Copper Produces More Precise Geometries on Lines Less Than 0.005” in Width
- Actual Conductor Shape is Close to a Trapazoid
- Copper Thickness is Slightly Reduced After PCB Processing

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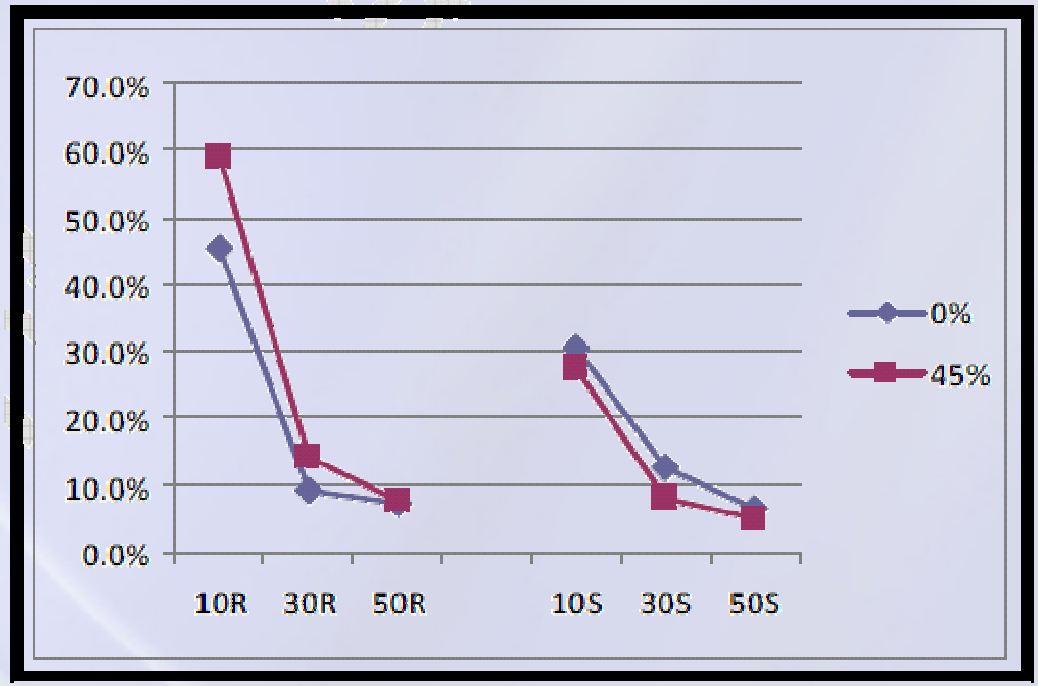
Pad Size Reduction

Current Procedures For Applying Uniform Etch Compensation Values Across All Surface Features Are Inadequate.

Below Illustrate A Near Exponential Reduction In Pad Size As The Pad Gets Smaller, For Both Round And Square Pads In Either Orientation.



Percentage Reduction by Pad Size

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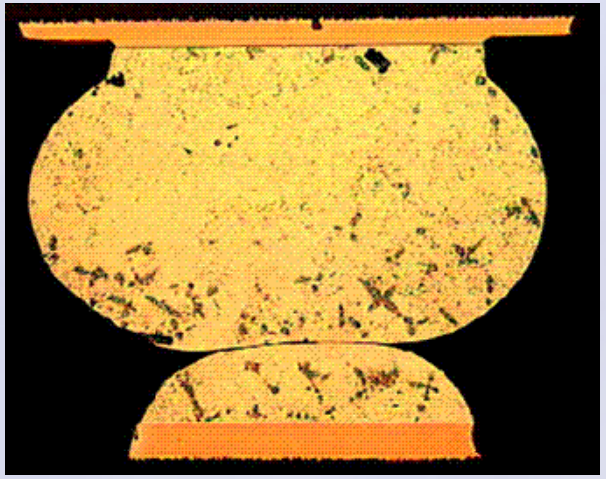
Warpage & Thermal Profile Issues

May Require Change In Production Process

- Tooling To Bridge Warpage Gap.
  (Increased Solder Paste Volume Application, etc. Reflow Pallets For Board Support)
- Reflow Profile To Bridge Component Warpage Gap.
  (Decreased Thermal Change Rate And Delta T Vertically In Component Package – Reduce Surface To Cooler Location Temperature Delta - TCE Induced Warpage)
- Reflow Profile To Bridge PCB Warpage Gap.
  (Decreased Thermal Change Rate And Delta T Vertically In PCB – Reduce Surface To Cooler Location Temperature Delta - TCE Induced Warpage)



Large ΔT across Board

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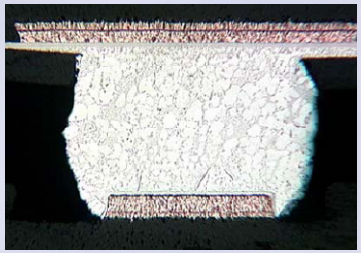
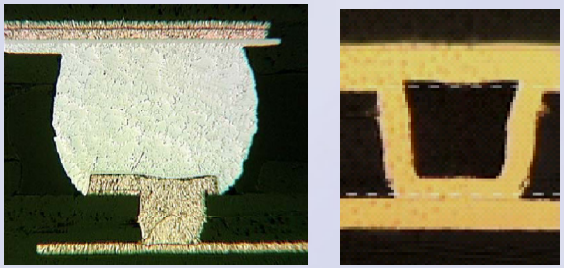
Micro-Via in Pad

- Voids in Solder Joints
  - Unfilled Via in Pad
- Provide Flat Pad With Filled/Plated Closed Via
- Solder Joint Formation
  - Thermal Connection
    - Plane Connection
    - Multiple Connections
    - Stacked Via
  - Solder Volume
    - Via Location - Edge



No Via

Unfilled Via's



Plated Closed & Filled Via

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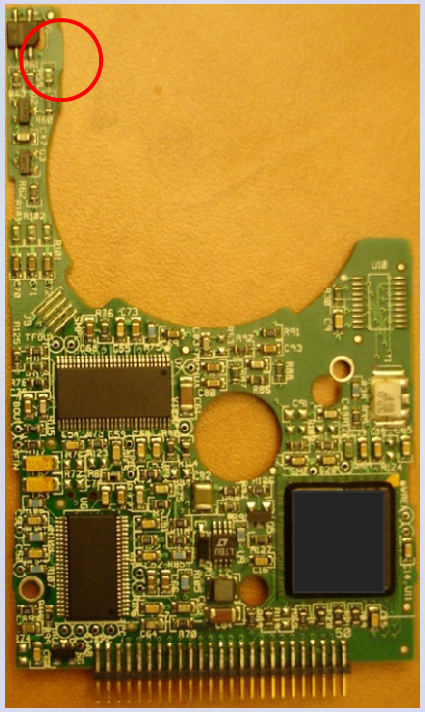
PCB Tolerances

Artwork Feature Positional Tolerances Increase

- Inner/Outer Layer Shrinkage (Technology / Material Dependant)
- Some Materials Do Not Shrink Uniformly
- PCB Size – TCE Impact On Dimensional Measurements
- Fabrication & Depanelization Material Movement / PCB Fabrication Tolerances Artwork Registration
  - As Fabricated
  - Pre-routing of Array
  - After Depanelization



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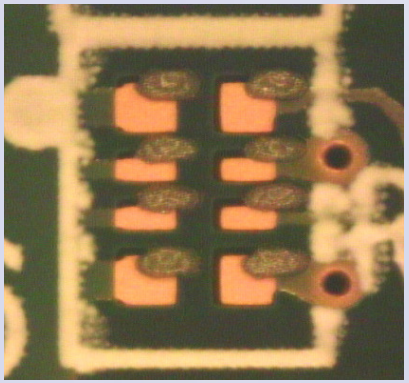
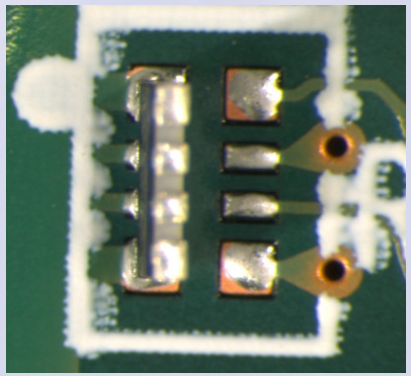
Stencil Tolerances

Artwork Feature Positional Tolerances Increase

- Fabrication Tolerances Artwork Registration
  - Etched Feature Position
  - Etched Feature Size
  - Etched Feature Quality
  - Etched Feature Directional Etch
- Stencil Print Directional Compensation Orientation





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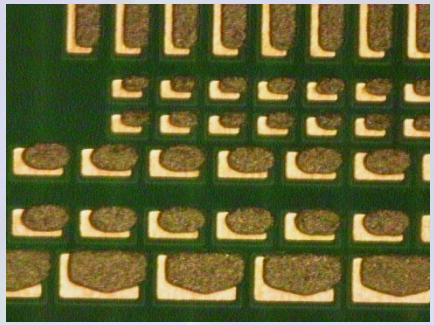
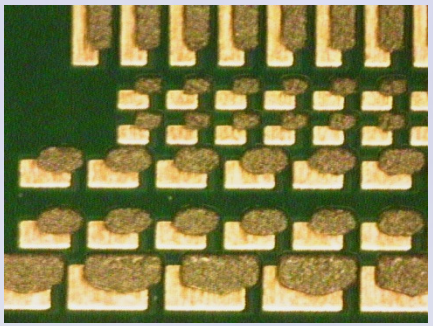
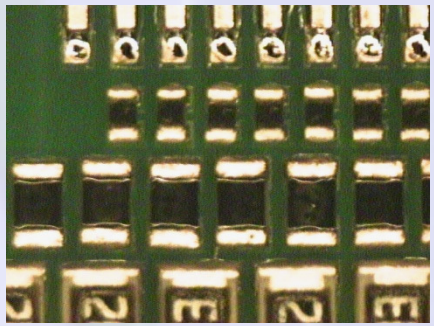
Stencil To PCB Alignment

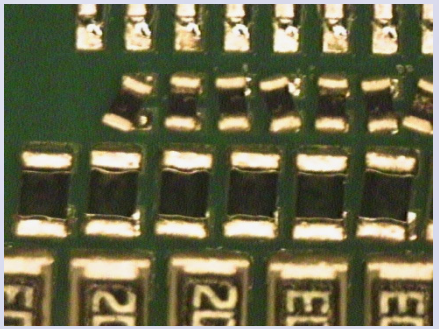


- Smaller Components Decrease Total PCB & Assembly Process Tolerance
- Minor Misalignment Can Impact Process Yields





3 mil



6 mil

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Offset Paste - Normal Placement

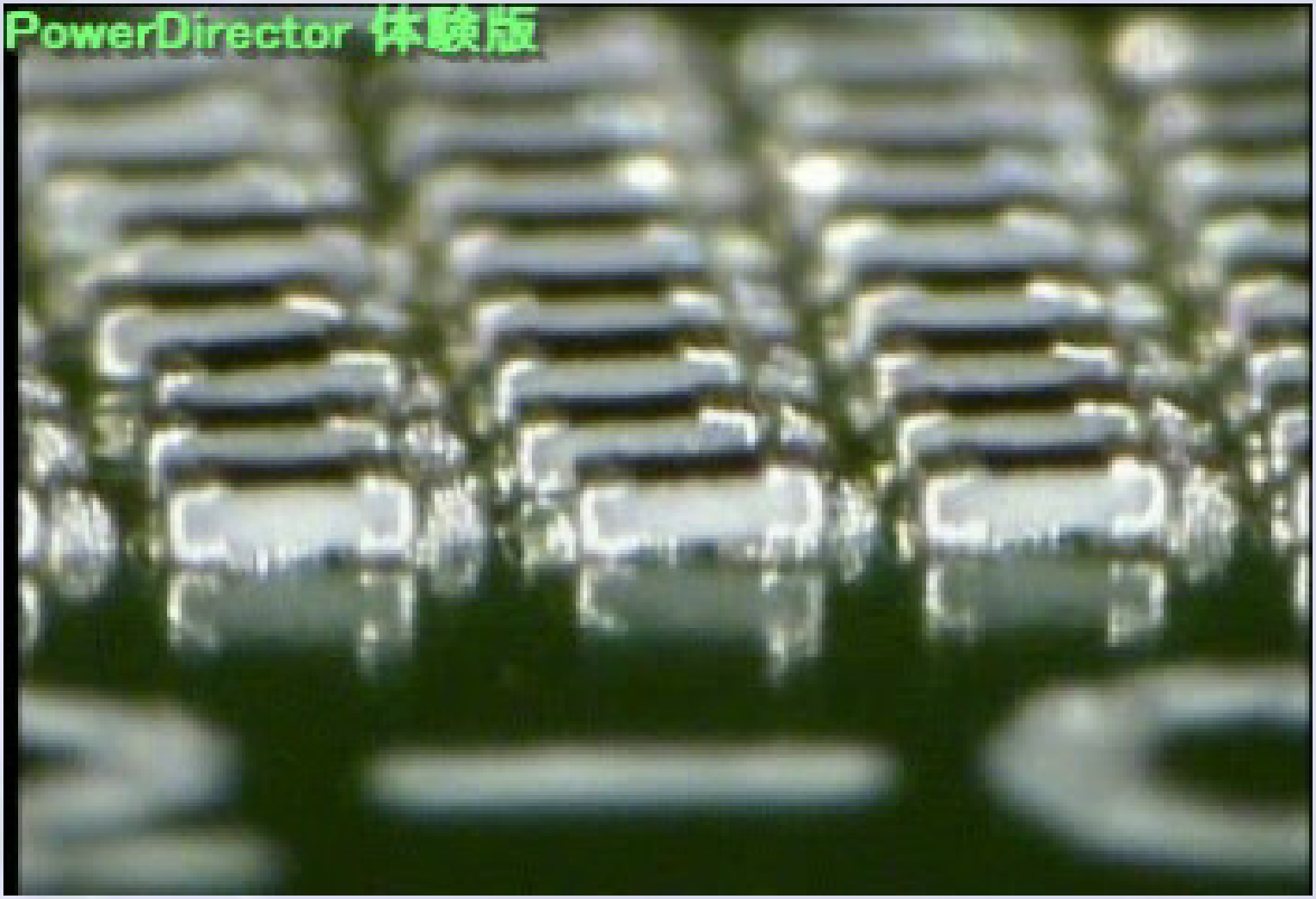

Photo Courtesy of Juki Automation

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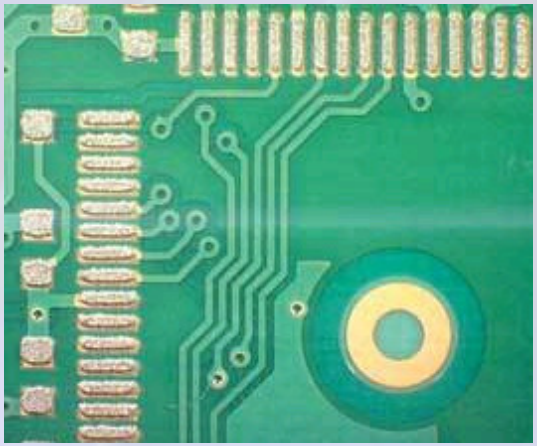
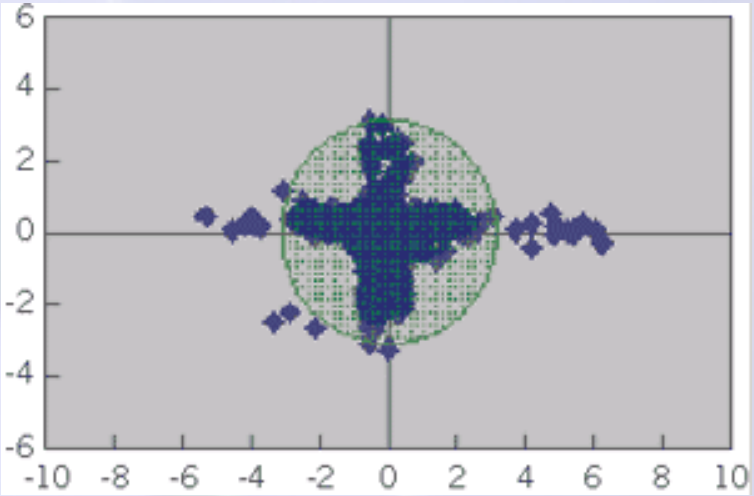
Match Tooling Design To Parts

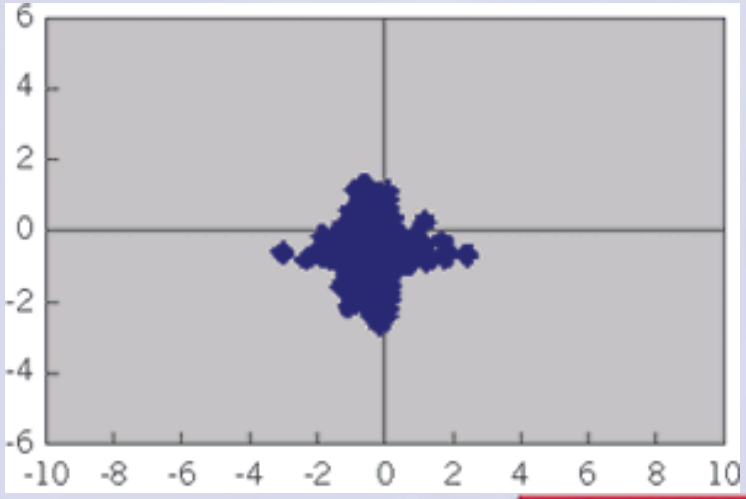


- Normal Manufacturing Process Variability May Exceed Allowable Assembly Process Tolerance For High Yield, Reliable Assembly
- Matched Tooling (Stencils) To Materials (PCB) May Be Required

PCB to Stencil Pad Positional Deviation Measurements No Adjustments



PCB to Stencil Pad Positional Deviation Measurements With Scaling Adjustments



"Using Stencil: Design to Reduce SMT Defects", SMT, April 2006

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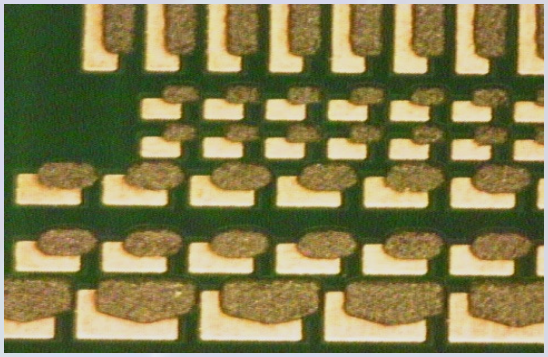
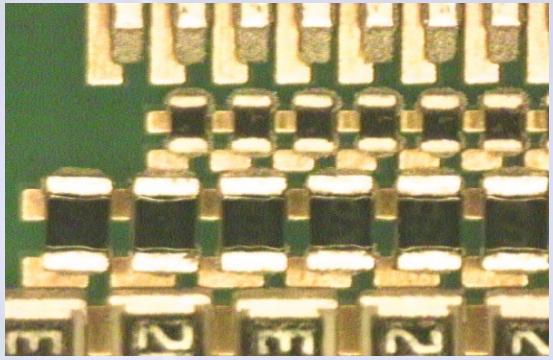
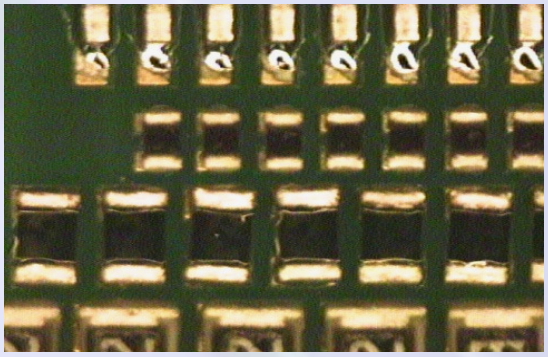
Match Placement To Paste







- Slight Offset Of Solder Paste And Component Placement May Improve Soldering Yields
  - Paste and Placement Must Have Same Offset
  - Tombstone Passives
  - BGA Voiding

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Matched Offset – Paste & Part

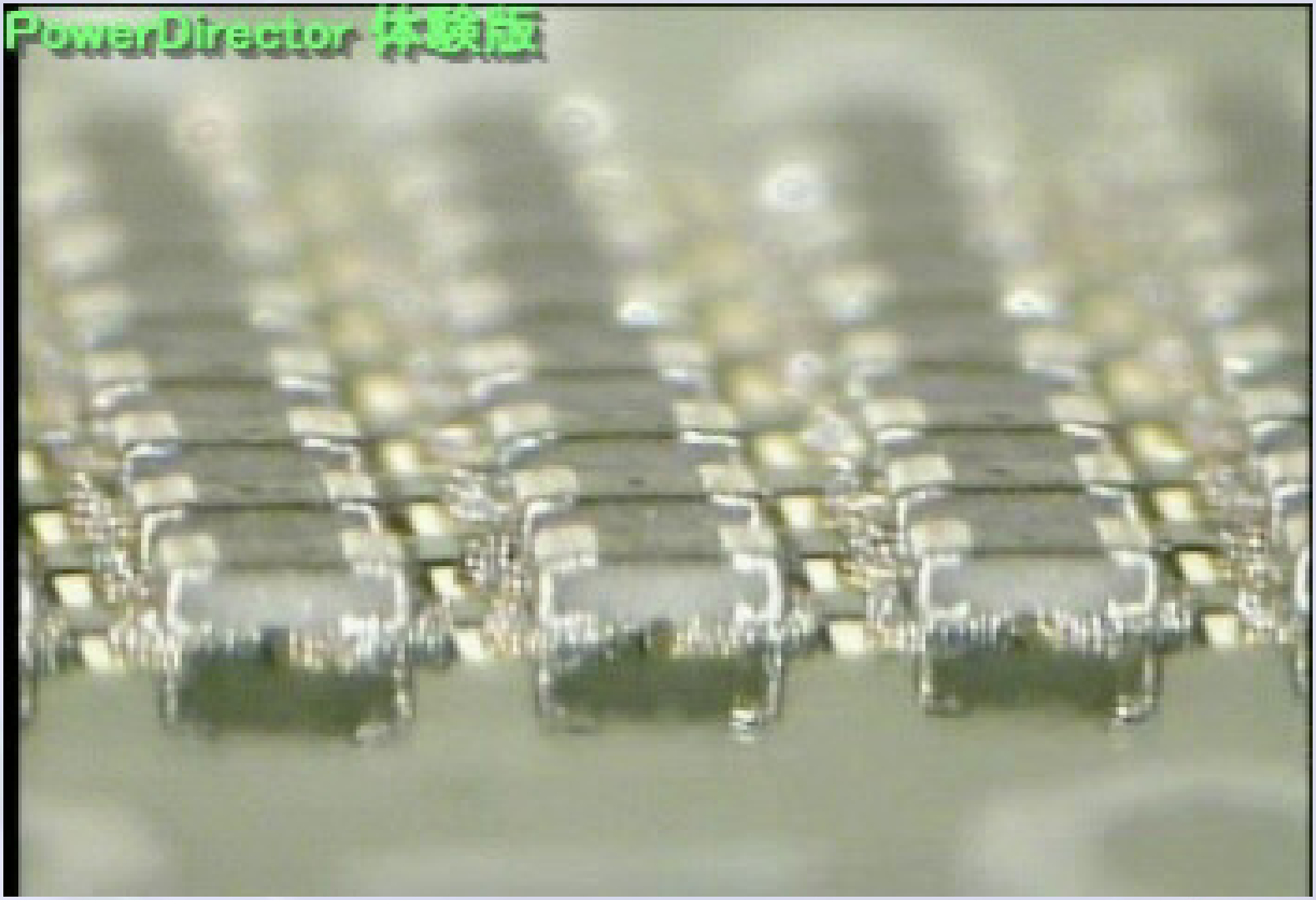

Photo Courtesy of Juki Automation

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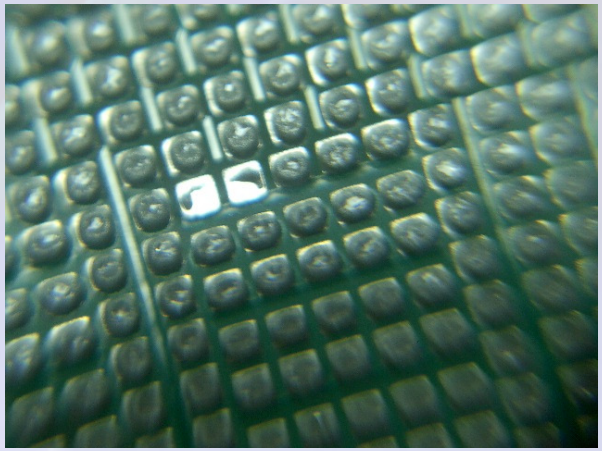
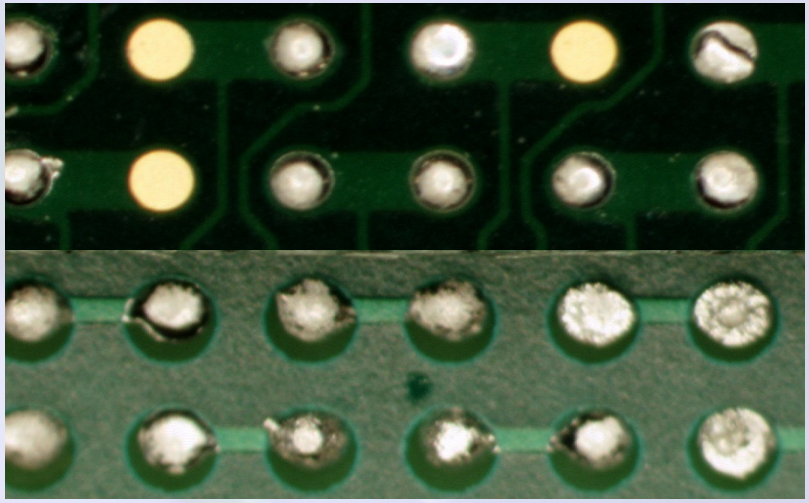
Solder Paste Printing Volume



Air Bubble In Solder Paste Bead



Open/Unwetted LGA Connection

- Leadless Device Usage Increase (DFN, QFN, LCC LGA) & Ultra-fine Pitch Components Impacts:
- Tighter Tolerance On Solder Paste Volume – Thinner Stencil
- Increased Uniformity Of Paste Volume Across Component (Pad to Pad)
- Paste Volume/Pad Trace Egress Direction Impact
  - Some Package Types Are More Sensitive Than Others

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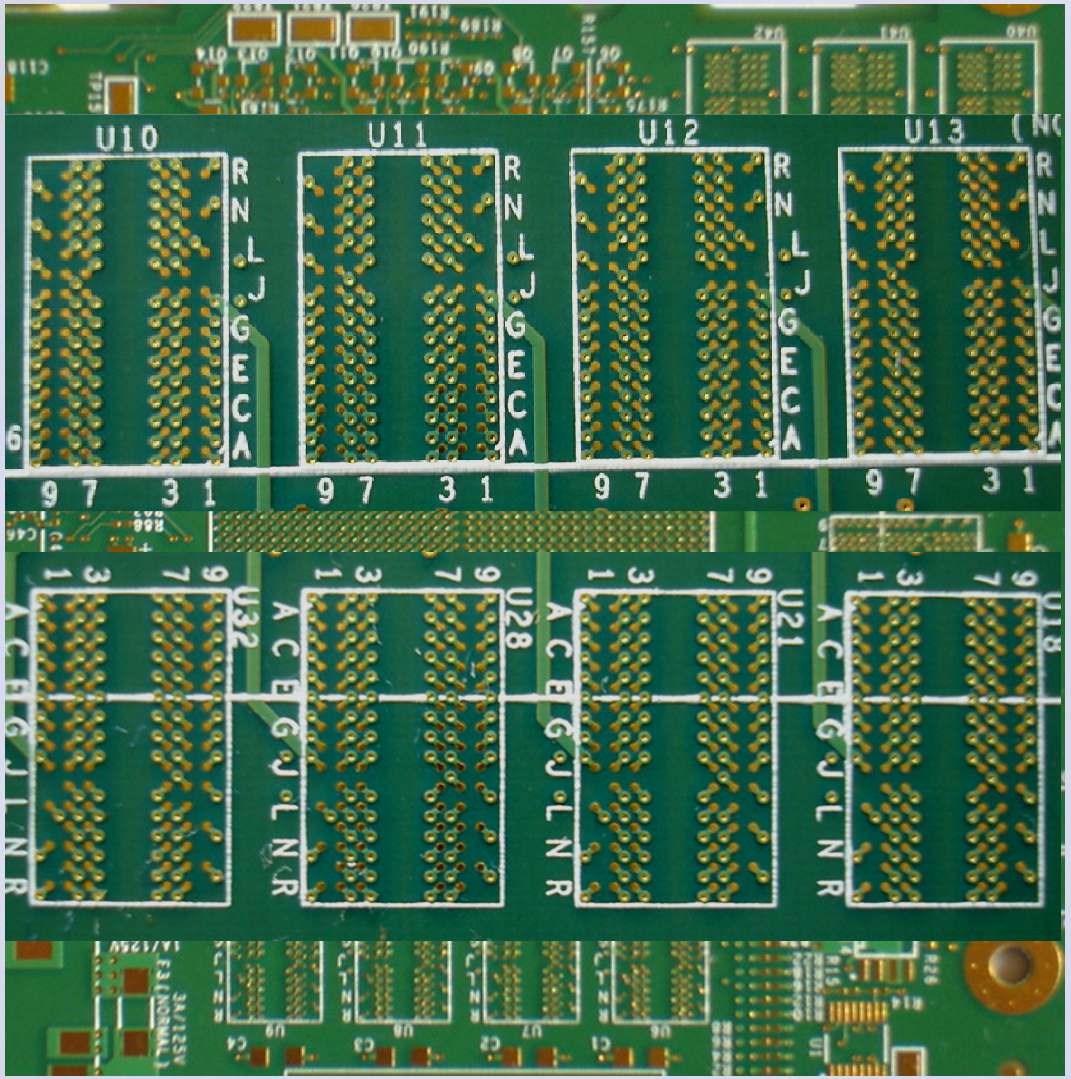
Silk Screen Design

Low Component Stand-off Height

- Tilted Component
- Open Joints (standoff from PCB)
- Misalignment

Component Types

- Leadless
  - QFN, DFN, Passives, etc.
- Fine Pitch Area Array
  - BGA, WL-CSP, CSP, etc.



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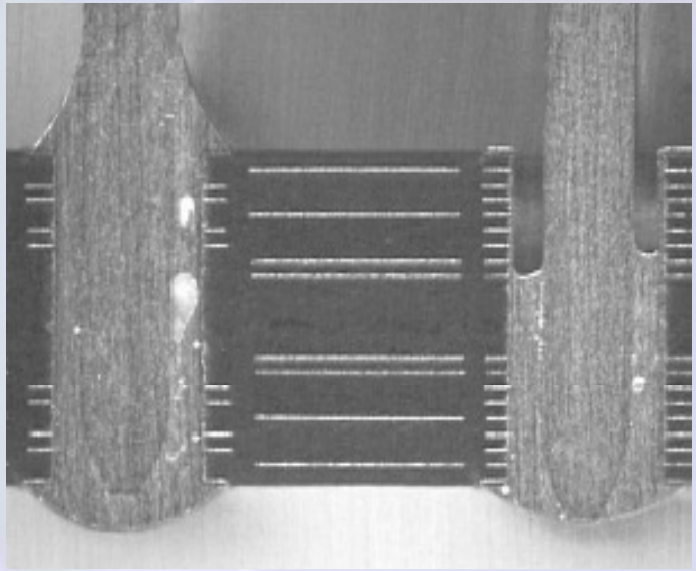
Internal PCB Impacts



Number Of Layer Connections to Plated Through Hole

- Increased Number Of Layer Connections Increases Thermal Mass Of Plated Through Hole
- Increased Number Of Plane Layer Connections Greatly Increases Thermal Mass Of Plated Through Hole
- Increase Thermal Pad Isolation To Improve Solder Flow To Topside

Issues Include:

- PTH Hole Fill

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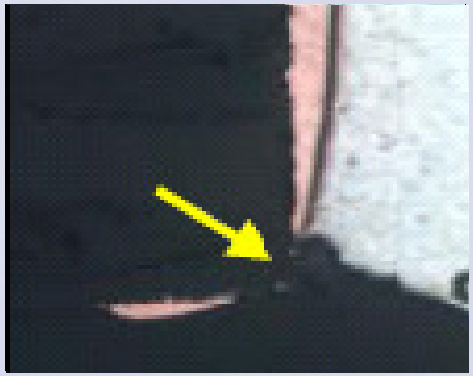
What To Do?

- Increase Solder Temperature?

250°C

Lead Free Solder Issue

Higher Solder Temperatures Or Increased Solder Dwell Times Create Problems With Pads On Solder Side



* Dr. S. Zweiger, Solectron GMBH, Productronica Green Day, November 2005

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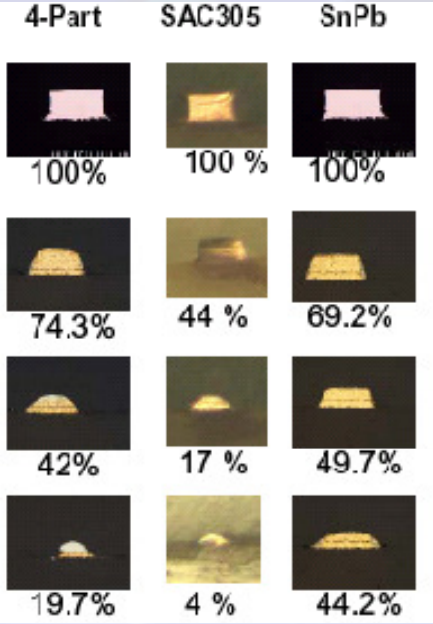
Wave Solder & Rework Issues

Limit Effects Of Copper Dissolution



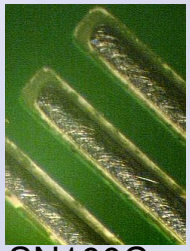
0.005” Trace Dissolution in 30 Seconds

- Use Lower Dissolution Rate Solder Alloy
  - Modified SAC Alloy
    (Sb, Ni, Zn, Ge, In, Etc)
  - Non-SAC Alloy
    (Sn/Cu/Ni, Etc)


Original

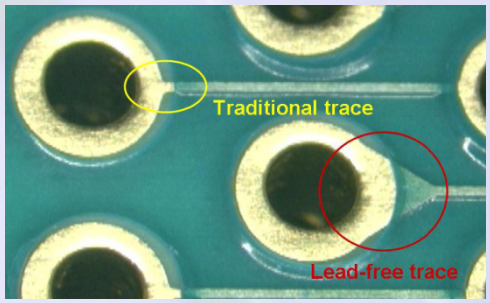

SnPb


SAC 305


SN100C

After wave soldering, 265°C solder temperature, 12 seconds contact time

- Pad Trace Connection
  - Tear Drop
  - Snow Man Connection
  - Wide Trace
  - Greater Than 0.010”



- PCB Photo Courtesy of Cookson – Alpha Metals
- Byle, Jean & Lee, “Copper Dissolution Rate in Pb-Free Soldering Fountain Systems”, SMTA-I 2006

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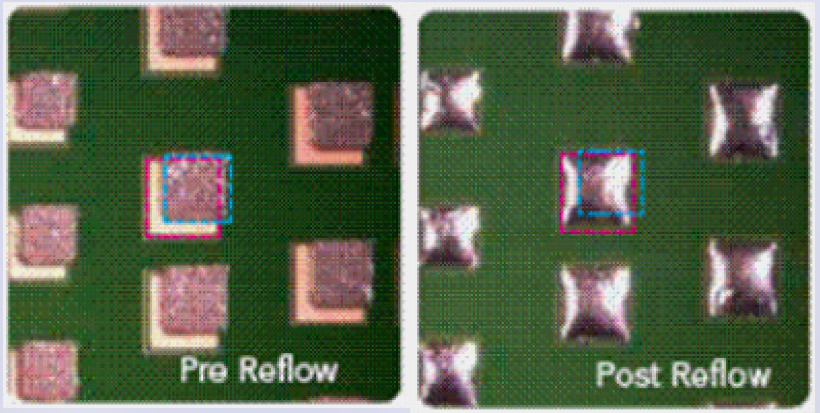
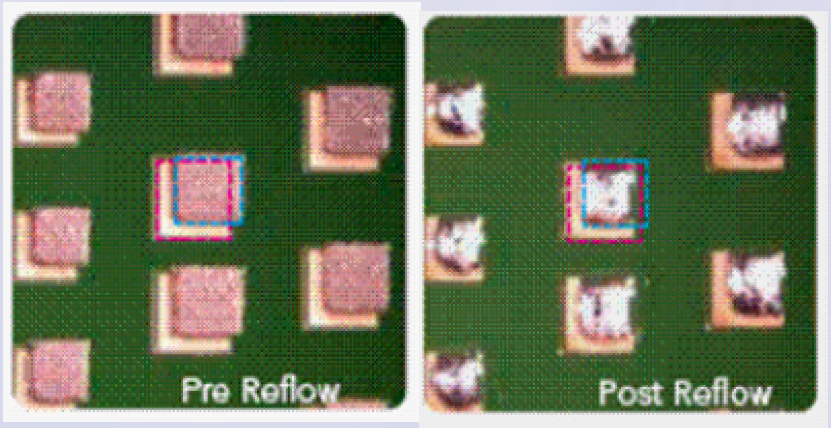
Lead Free Solder Spread

- Stencil Alignment Tolerance of Solder Paste To SMT Pad May Be Critical For Achieving Good Manufacturing Yields
  (Dependant Upon PCB Surface Finish)
- Example – OSP Finish



Tin-Lead Paste



Lead Free Paste

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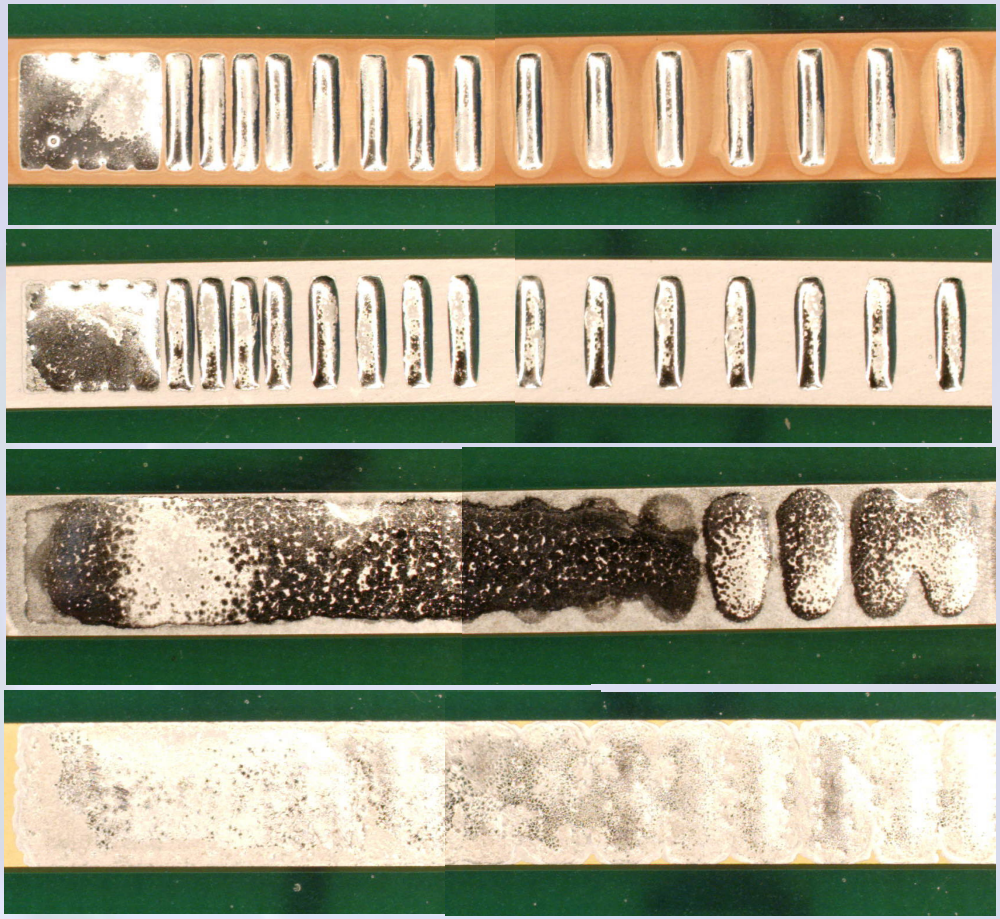
PCB Finish Vs Solder Spread



– OSP

– Immersion Silver

– Immersion Tin

– ENIG

Amount Of Lead Free Solder Wicking Is Dependant Upon Finish

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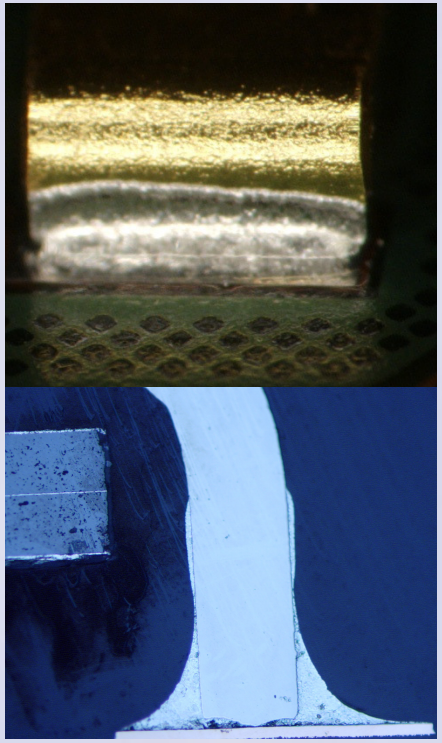
Tin-Lead Vs Lead Free Wicking

Depending Upon The Pairing Of PCB Surface Finish And Component Lead Finish, The Amount Of Solder Wicking / Spread Can Induce or Reduce Solder Defect Formation.



Tin-Lead

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Defects Caused By Improper Thermal Balance

Wave Solder Process
Thermal Shock
Damage

- Increase thermal pad isolation
- Balance number connections for component per each plated through hole
- Uniformity of trace size connection to component plated through hole

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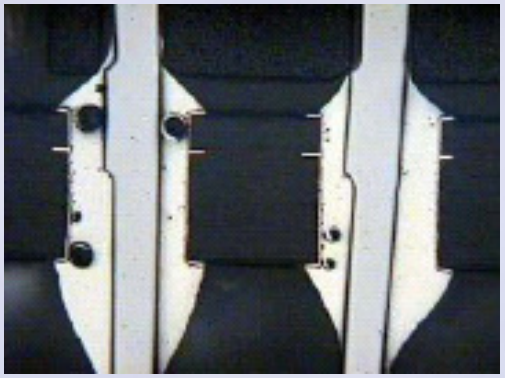
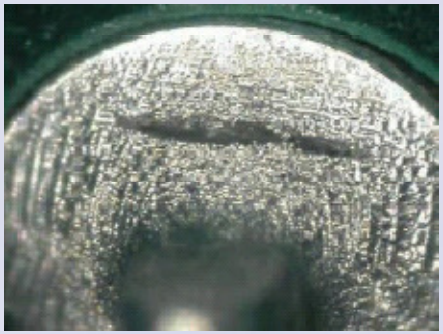
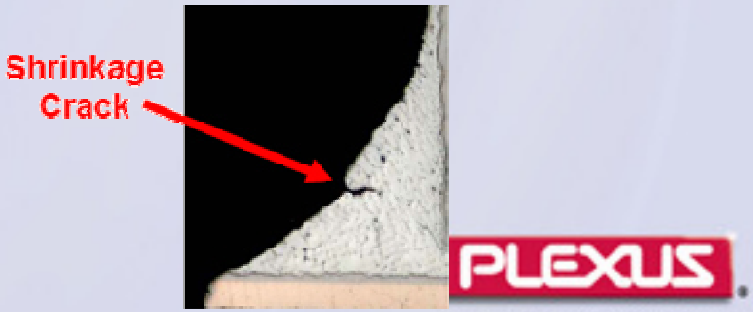
Lead To Hole Clearance

- **Lead Free Soldering**
  - Lead Clearance Minimum May Increase
  - Increasing Board Thickness May Further Increase Lead To Hole Clearance (Aspect Ratio)
  - Larger Holes Create Less Voids
- **Smaller Lead To Hole Clearance Decreases Shrinkage Holes / Hot Tear Joints**







IPC-A-610D, Fig. 5.67

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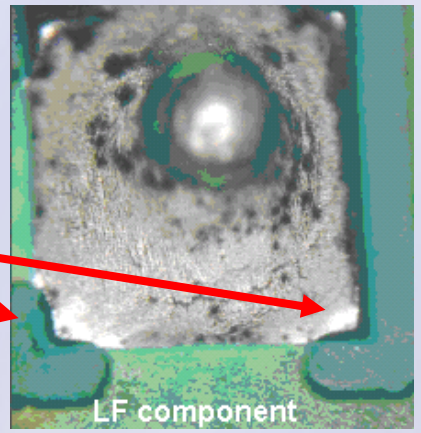
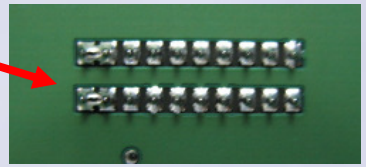
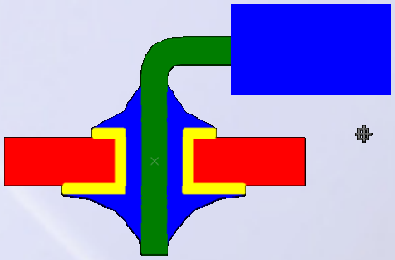
Through Hole Pad Design

- Square Pads Should Not Be Used On Solder Side
  - Increased Pad Lifting*
  - Increased Solder Defect – Bridge/Flag/Web





- Decrease Component / Top Side Pad Size**
  - Reduced Fillet Lifting



* Dr. S. Zweiger, Solectron GMBH, Productronica Green Day, November 2005

** K Puttlitz, K Stalter, "Handbook of Lead-Free Solder Technology For Microelectronic Assembly", pp 628, Fig 48

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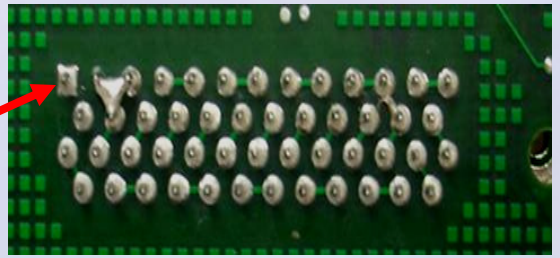
Through Hole Pad Design

- All Pads Should Be Same Shape
  - Oval or Round
  - Pin 1 square pad should not be used on solder side



  - In some situation legend ink in between pads can help to minimize solder bridges

- High Density Components (< 2mm Pitch)
  - Pads Should Be Oval In Shape
  - Staggered Pad Designs Should Be Used To Enhance Solder Joint Formation On Exit Side Of Component

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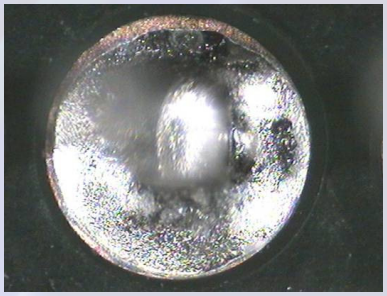
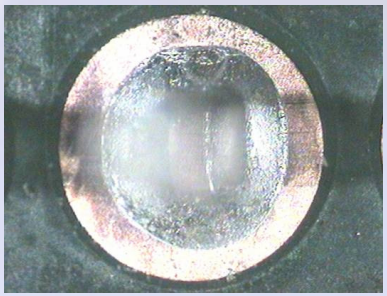
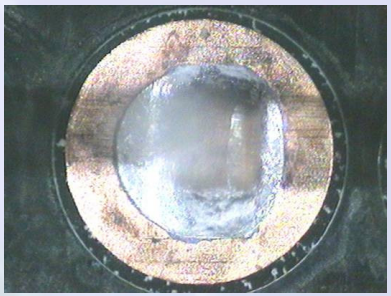
Effect of Board Thickness On Topside Fillet Formation



0.062”



0.100”



0.150”

Board Thickness

- Board thickness increase thermal mass of plated through-hole
- Increase thermal pad isolation to improve solder flow to the top side
- Increase lead hole clearance (aspect ratio) to improve solder flow to top side

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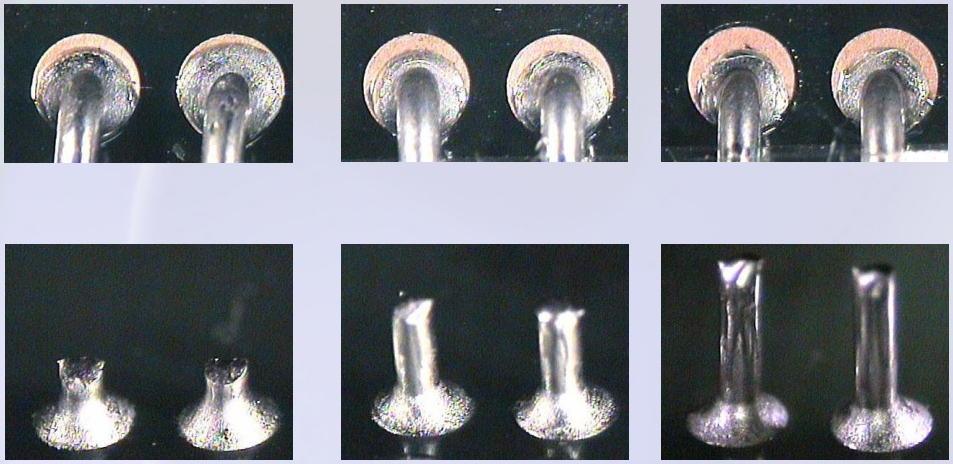
Effect of Lead Length on Topside Fillet Formation

1.0mm Φ hole, 0.45mm Φ lead



Lead Length: 0.040”/1mm

Lead Length: 0.080”/2mm

Lead Length: 0.120”/3mm

- Lead Length protrusion too long on solder side:
  - Only a small quantity of solder retained in soldering area, solder flow downwards along component lead
- Lead Length protrusion too short on solder side:
  - Only a small quantity of solder can transferred, and the heat transfer maybe insufficient

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Solder Mask Selection

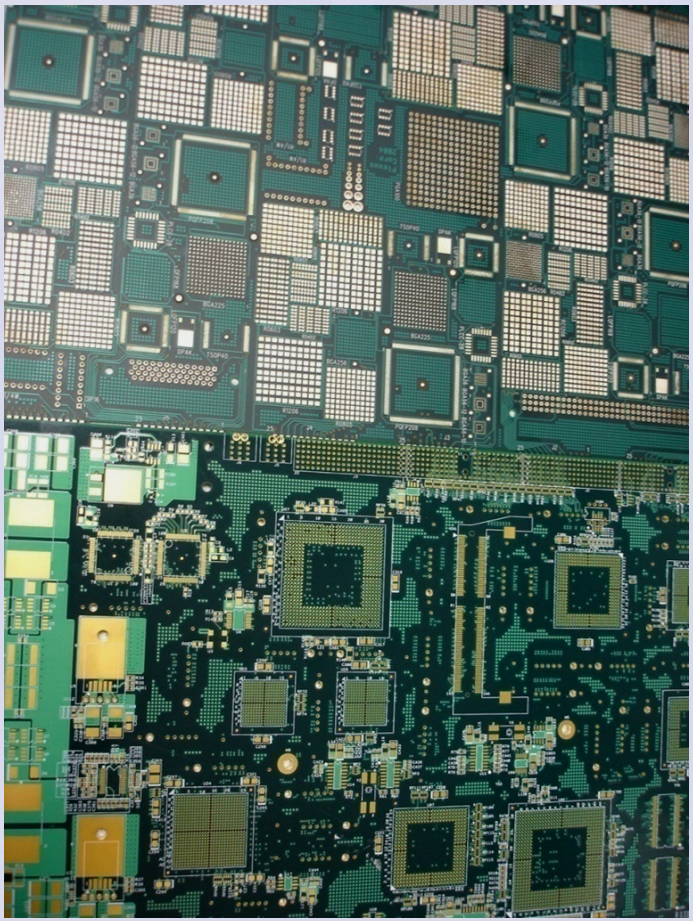
Matte Finish Solder Mask Has Increase Surface Energy To Hold Flux To The Board (More Flux For Solder Joint Formation)

Dull/Low Reflection Appearance

Glossy Finish Solder Mask Has Low Surface Energy to Flux To The Board (Less Flux For Solder Joint Formation – Solder Balls, Icicles, Flags, etc.)

Highly Reflective Appearance

Preferred



Not Preferred

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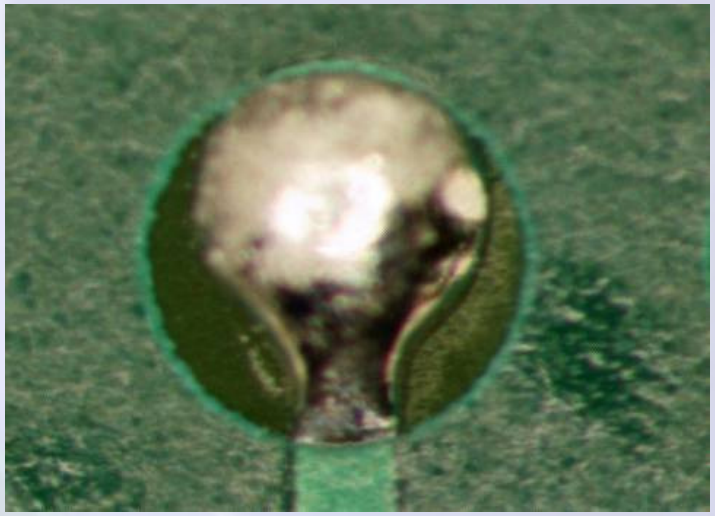
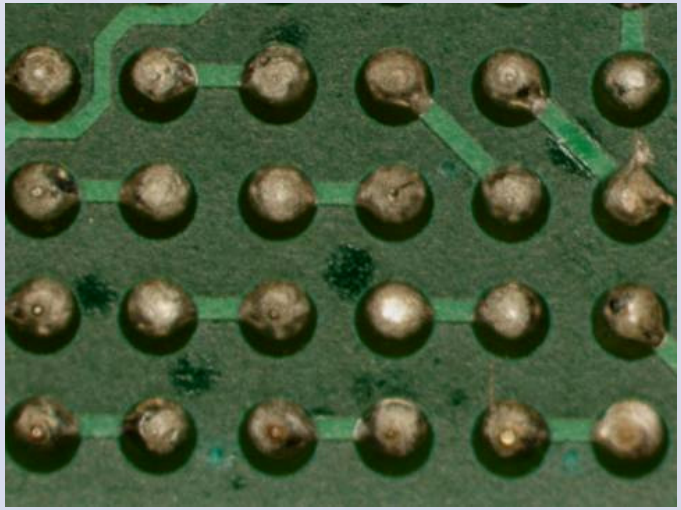
Cleaning

"Remember it is not the cleanliness of the entire board that causes the electrical failure but the amount of residue between two pads on a critical circuit the define the cleanliness of the assembly."





Terry Munson, President/Senior Technical Consultant, Foresite
Ask the Experts, Circuitnet.com, 7 Jan. 2008

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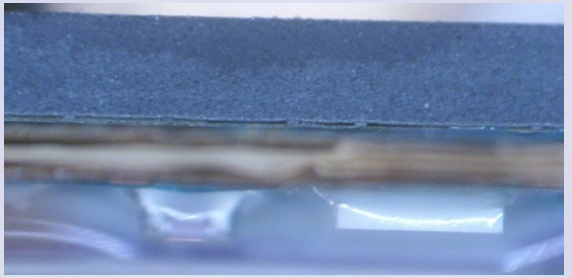
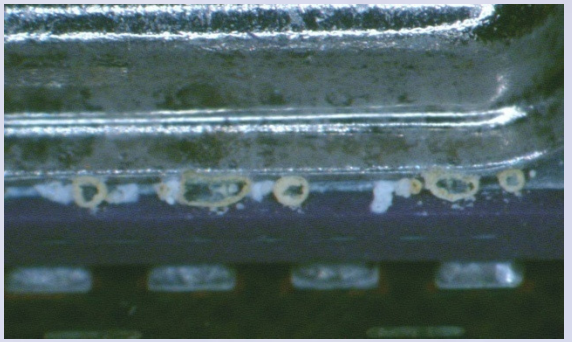
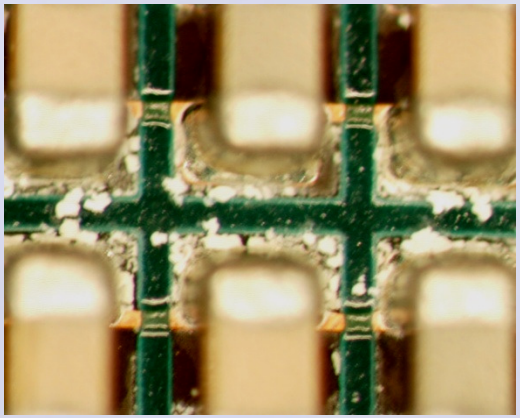
Cleaning Chemistry Compatibility

- Cleaning Chemistries Must Work With Tight Component Spacing
  - Component To Component Spacing
  - Component Stand-off Height
- Compatible With Greater Diversity Of Materials
  - PCB's
    - Substrate Materials
    - Solder Mask
    - Silk Screen Ink
    - Pad Finish
  - Component Materials
    - Package
    - Seals
    - Marking Inks
  - Solder







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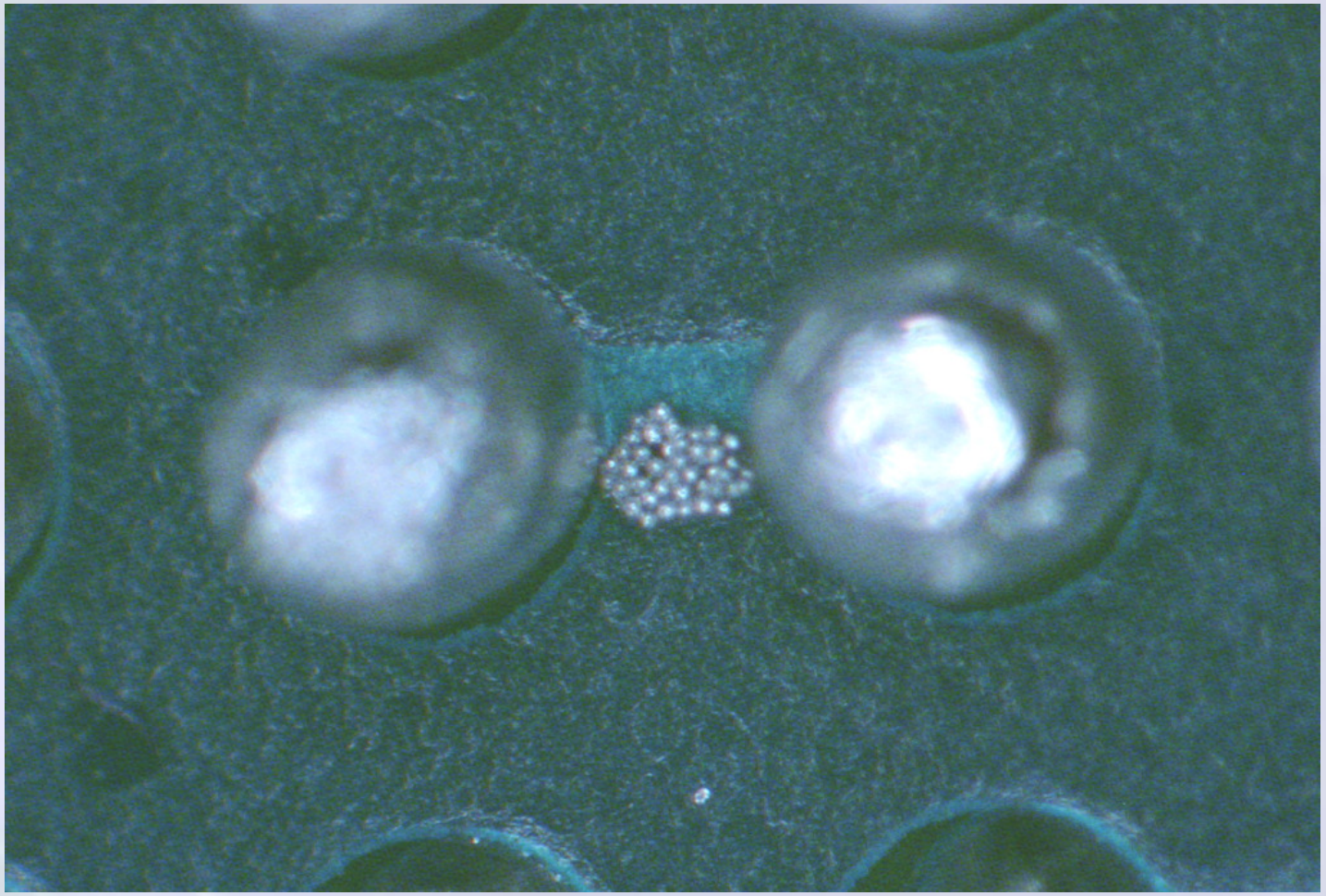
Careful – Clean May Not Be Reliable

Solder Paste Bridge Between Pads on BGA After Reflow and Cleaning



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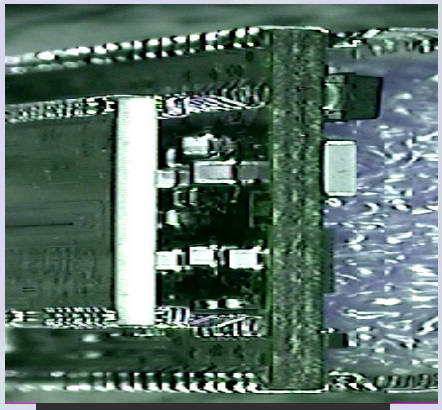
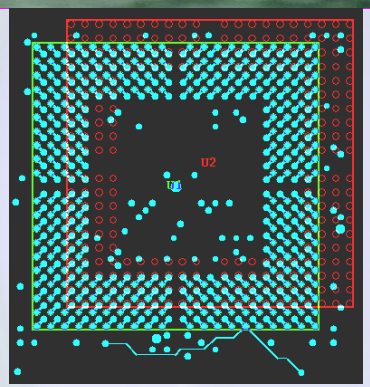
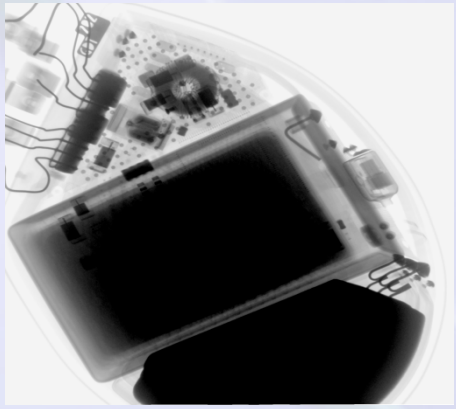
Inspectability - AOI, AXI, HVI







- Accessibility to Solder Joints –AOI, HVI, AXI
  - Component Spacing – Line of Sight
  - Solder Fillet Length
- Masking of Solder Joints
  - Solder Connections Under Component Body
  - Insufficient Separation Between Solder Joints
    - Stacked Component Vertical Separation
    - PCB Thickness
  - Material Density; X-ray Permeability
  - Side to Side Shadowing
- Insufficient Background Contrast
  - Component Package to PCB
  - Solder Joint to PCB

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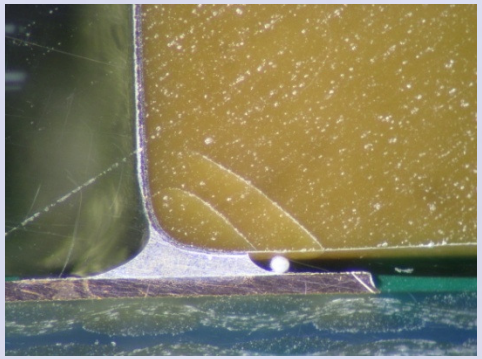
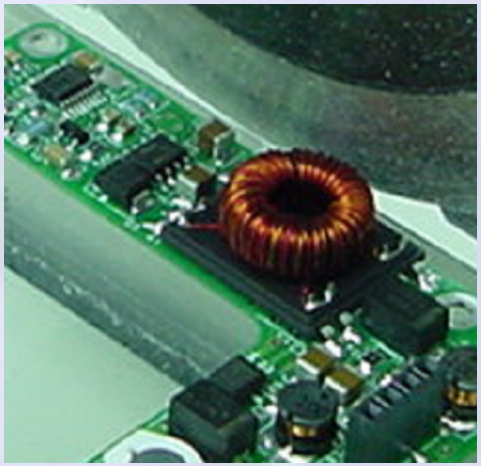
Cracked Cap Issue

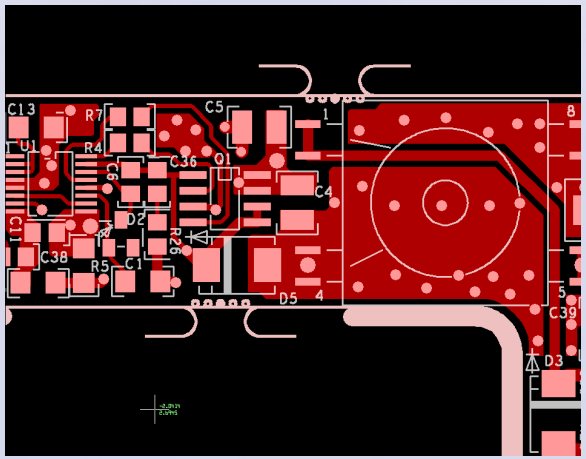
Field Return Issue

- Capacitor Functional Failure
  - Cracked Component



- What is root cause?





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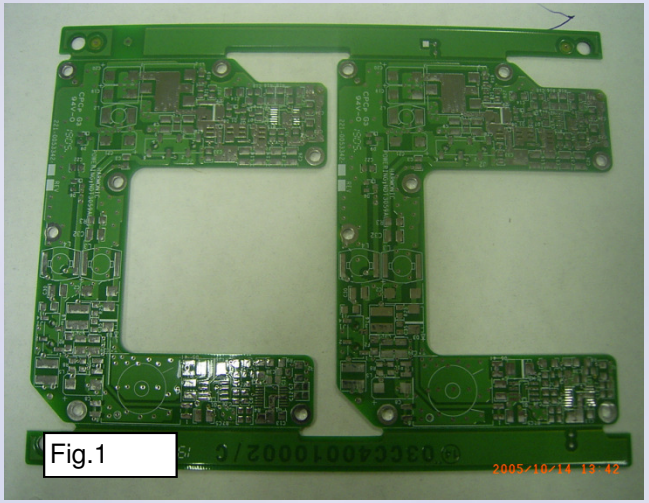
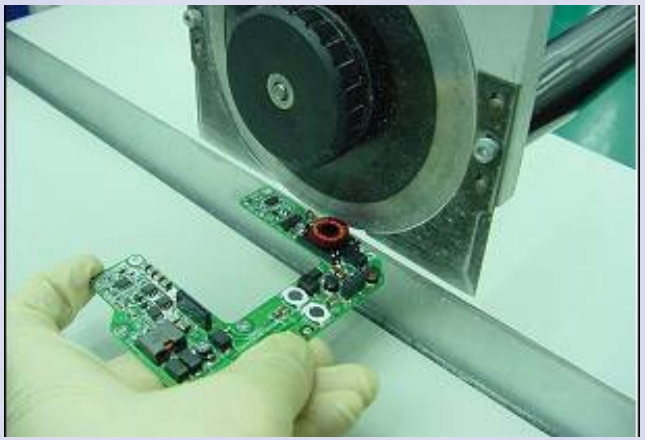
Cracked Cap Issue

- PCA Is Assembled In Panelized Form
- PCA Is Depanelized Using A V-Score Slicing System



- No Indication Of Issue At ICT & Functional Test



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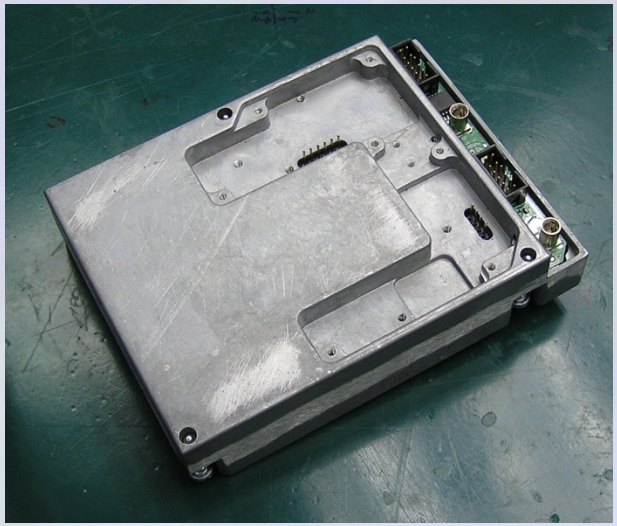
Cracked Cap Issue



- Functional Test Required Mounting Assembly In RF Test Unit Fixture
- Fixture Did Not Have PCA Eject Mechanism In Fixture – Bending Of PCA To Extract From Test Fixture Cracked Capacitor.

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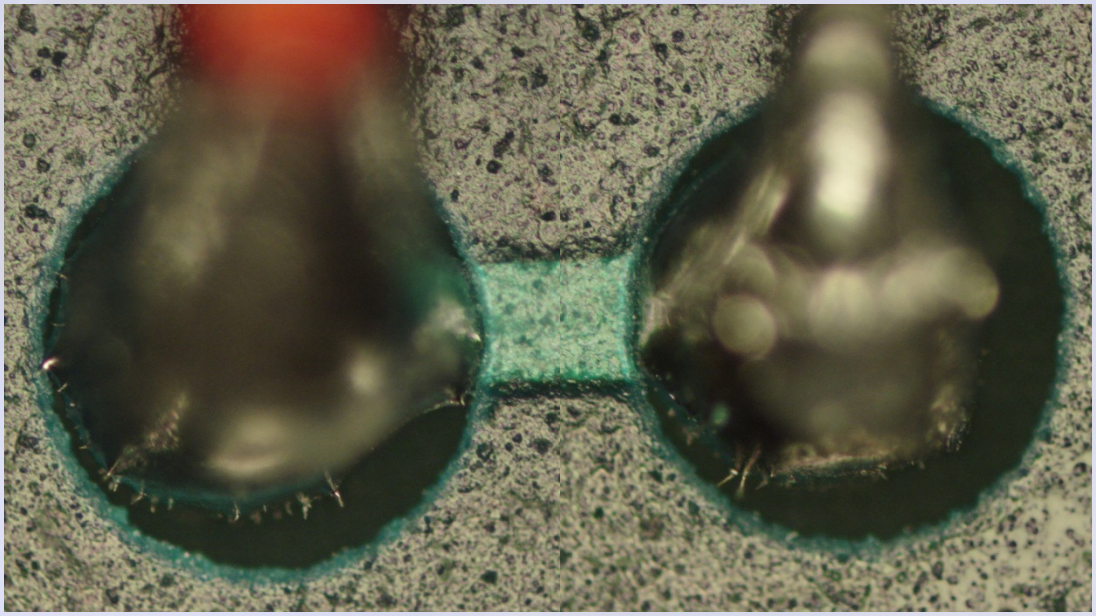
Source Of Contamination



What is Source of Whiskers in Solder Joints at PCB Interface Surface?

1. **Solder Paste**
2. **Stencil Printer**
3. **Reflow**
4. **PCB Finish**
5. **Thermal Aging**

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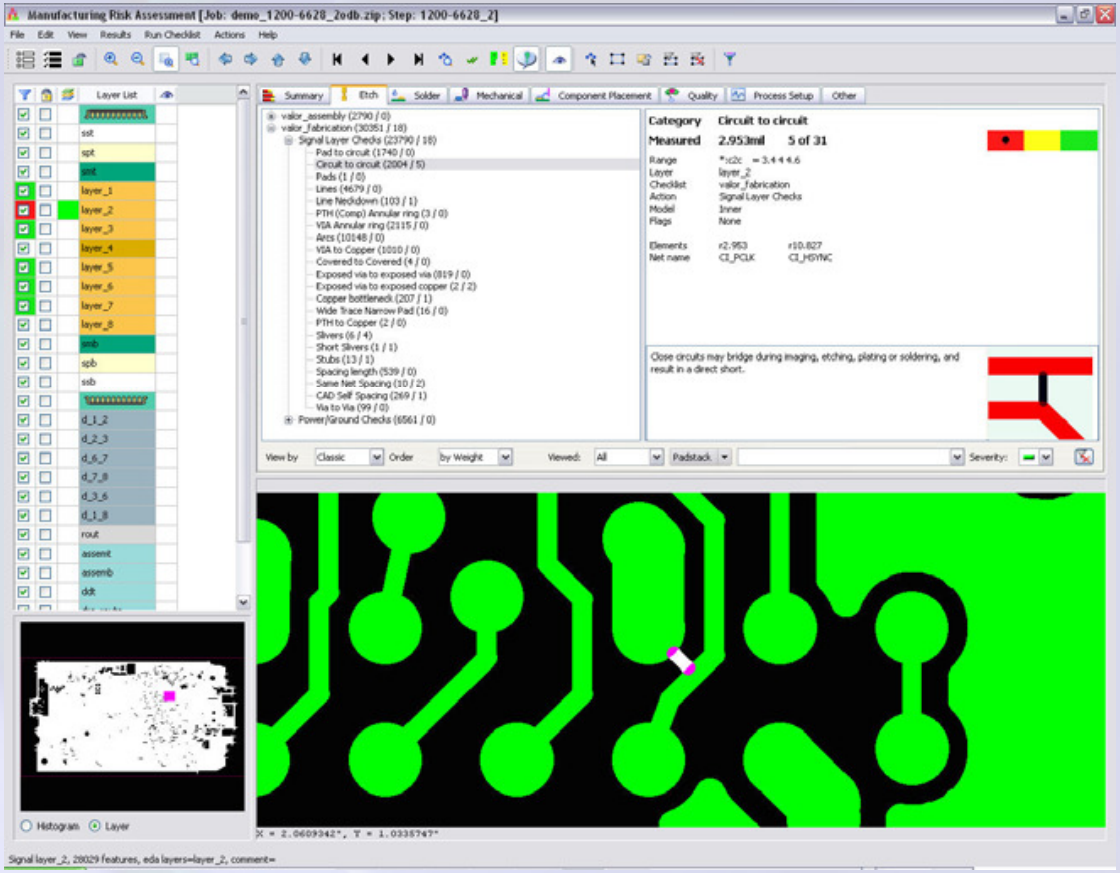
DFX Analysis Software



- Minimize the number of revision spins to bring a new design to production release
- Lower the cost to manufacture
- Improve the reliability of a design
- Reduce the amount of time spent on supplier “call-backs”
- Work with all major PCB layout tools

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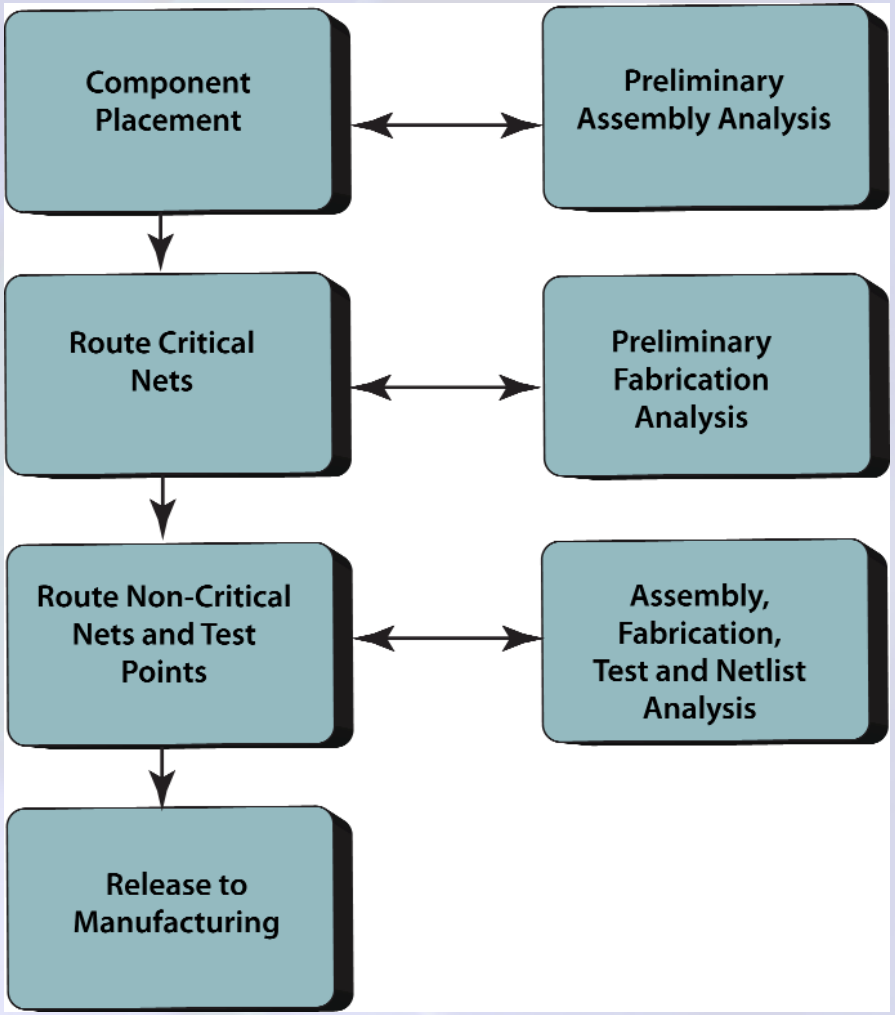
DFX Software Flexibility



- Concurrent DFX Resolves Issues At The Lowest Possible Cost
- Software Flexibility Should Allow For Multiple Points Of Access Into The Design Process

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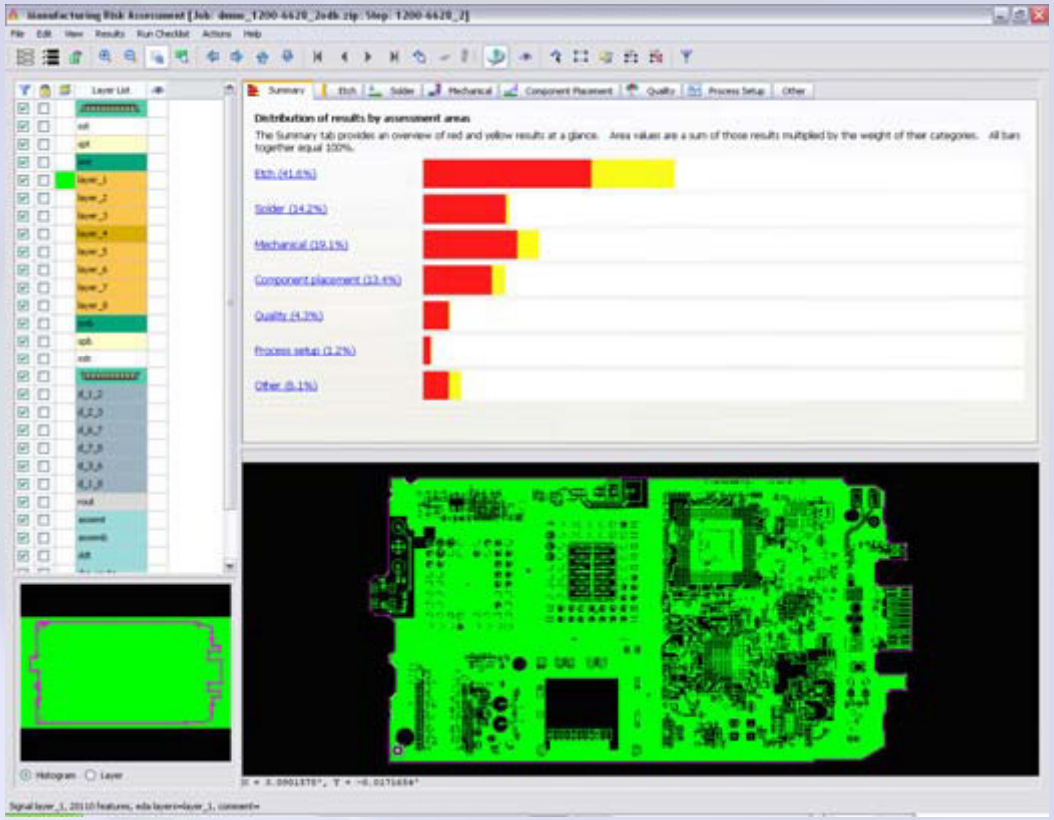
DFX Analysis Results



- Analysis Results Should Be Easy To Review And Intuitive To Any Reviewer
- Issues Presented With Severity Level Ranking

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DFX PCA-PCB Software Systems

- Mentor -Valor Computerized Systems
  (Enterprise 3000, Trilogy 5000)
- Mentor – Router Solutions
  (BOM Explorer, CAMCAD)
- Siemens UGS - Technomatix
  (Assembly Expert)
- Aegis Software
  (CircuitCAM – Fusion)
- SMS
  (Linecontrol)
- Zuken
  (CR-5000 Board Modeler)
- Downstream Technologies
  (CAM350)
- ADIVA
  (DRC – Design Analysis)
- Graphicode
  (GC-CAM, GC-Place, GC-ICT)
- Wise Software
  (Gerbtool)
- Lavenir
  (Viewmate)

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DFX PCA Test Software Systems

- Mentor -Valor Computerized Systems
  (Enterprise 3000, Trilogy 5000)
- Mentor – Router Solutions
  (CAMCAD)
- Siemens UGS - Technomatix
  (Test Expert)
- Teradyne
  (D2B Alchemist, D2B Strategist)
- Digitaltest
  (C-Link)
- Agilent
  (Access Consultant)
- Aster Technology
  (Testway)

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DFX Mechanical Software Systems

Analysis Software

- Boothroyd and Dewhurst
  (DFMA)
- Geometric Ltd.
  (DFMPro)
- Galorath
  (SEER)

Design Software

- PTC
  (Pro/Engineer)
- Autodesk
  (AutoCAD)
- Dessault
  (Solidworks , Catia, Delmia)
- Siemens
  (NX - SDRC)

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Data Format Flexibility

- Fabrication & Electrical Design Information
  - Board Fabrication Data - Gerber (274D, 274X), Drill Files (Excellon), etc.
  - CAM Tools - ODB++, GenCAD, GenCAM, FATF, etc.
  - CAD Tools - Cadence, Mentor, Zuken, Altium, etc.
  - Net Lists - IPC-D-356
- Assembly Information
  - BOM/AVL/Component Placement - ASCII, Excel, Word, etc.
  - Drawings - DXF, HPGL, Gerber, PDF, Postscript, HTML, etc.
- Mechanical Designs
  - Design Data –STEP, IGES, DXF/DWG, VRML, etc.

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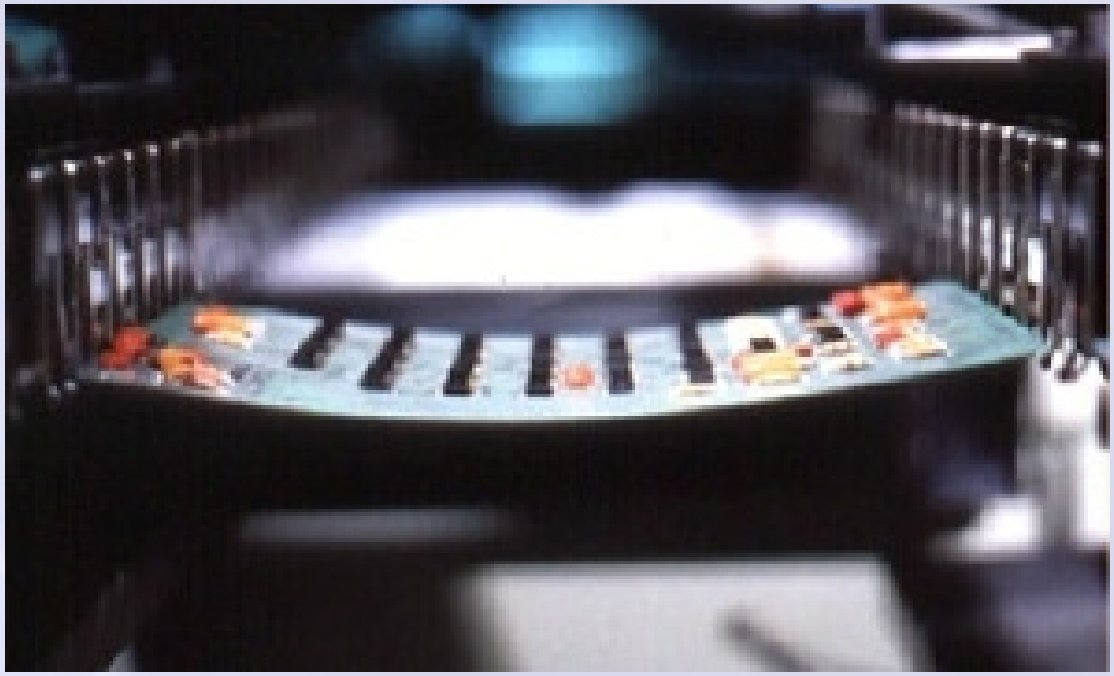
Closing Thought

"We can't solve problems by using the same kind of thinking we used when we created them."

Albert Einstein



Don't Forget About Reflow Process Induced Warpage/Coplanarity Issues.

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Thank You!

Questions

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