0201 Issues and Process Window

Advanced Process Lab

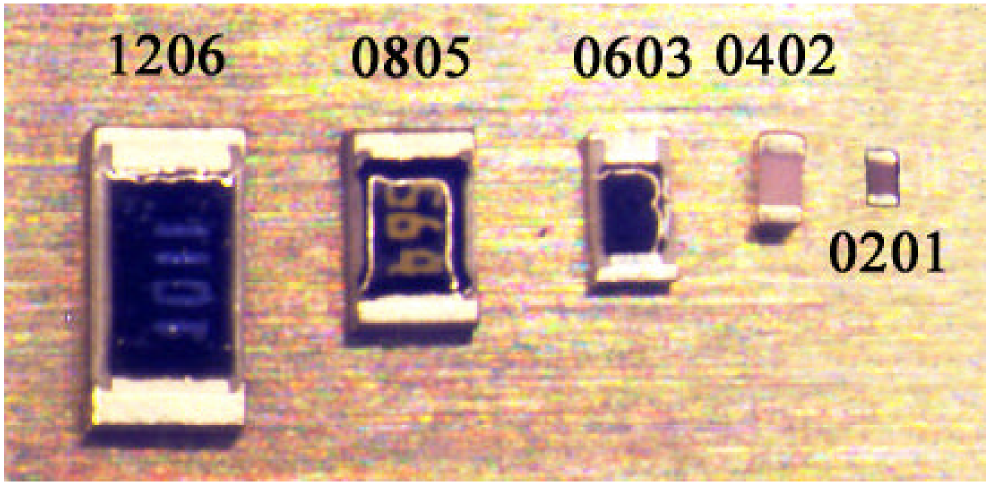
George Westby,
Universal Instruments Corp.

Jim Adriance,
Universal Instruments Corp.

Wilhelm Prinz von Hessen,
Universal Instruments Corp.

Jeff Schake,
DEK Printing Machines, Ltd.

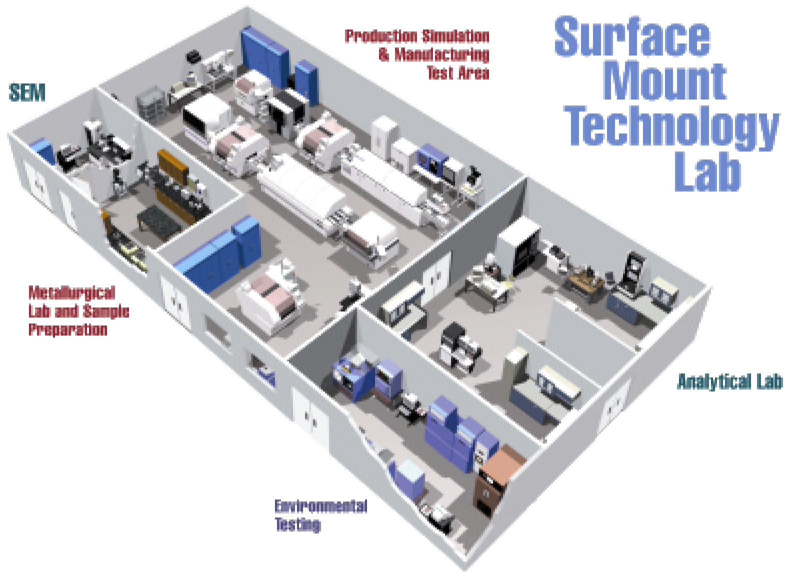
Denis Barbini,
Vitronics Soltec, Inc.



September 2000

By Universal Instruments'
Advanced Process Laboratory

0201 Assembly Development Project



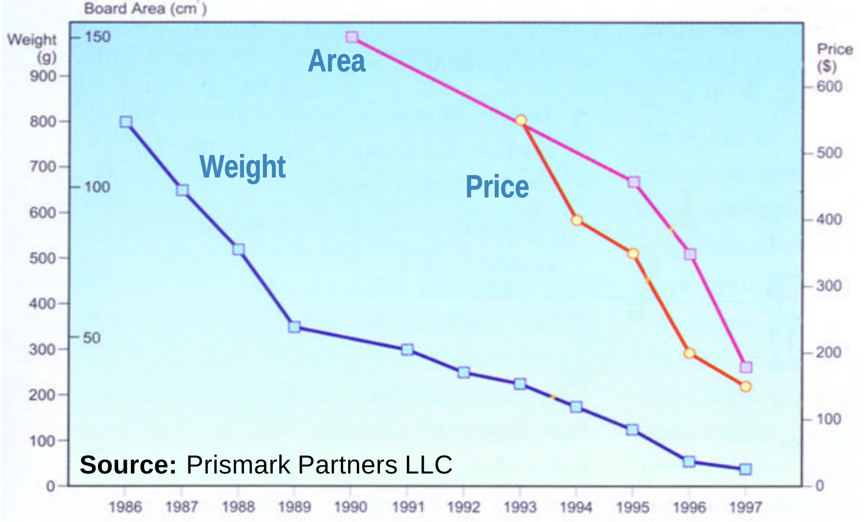
- Conducted in the SMT Laboratory at Universal Instruments by :
  - Universal Instruments
  - DEK Printing Machines
  - Vitronics Soltec
- SMT Laboratory is dedicated to the development of cutting edge assembly technologies
- Driven by need to understand machine and process limitations
- Optimize product yield and product reliability for our customers

Vitronics Soltec
Our reliability is your productivity

September 2000

By Universal Instruments'
Advanced Process Laboratory

0201 Market Drivers

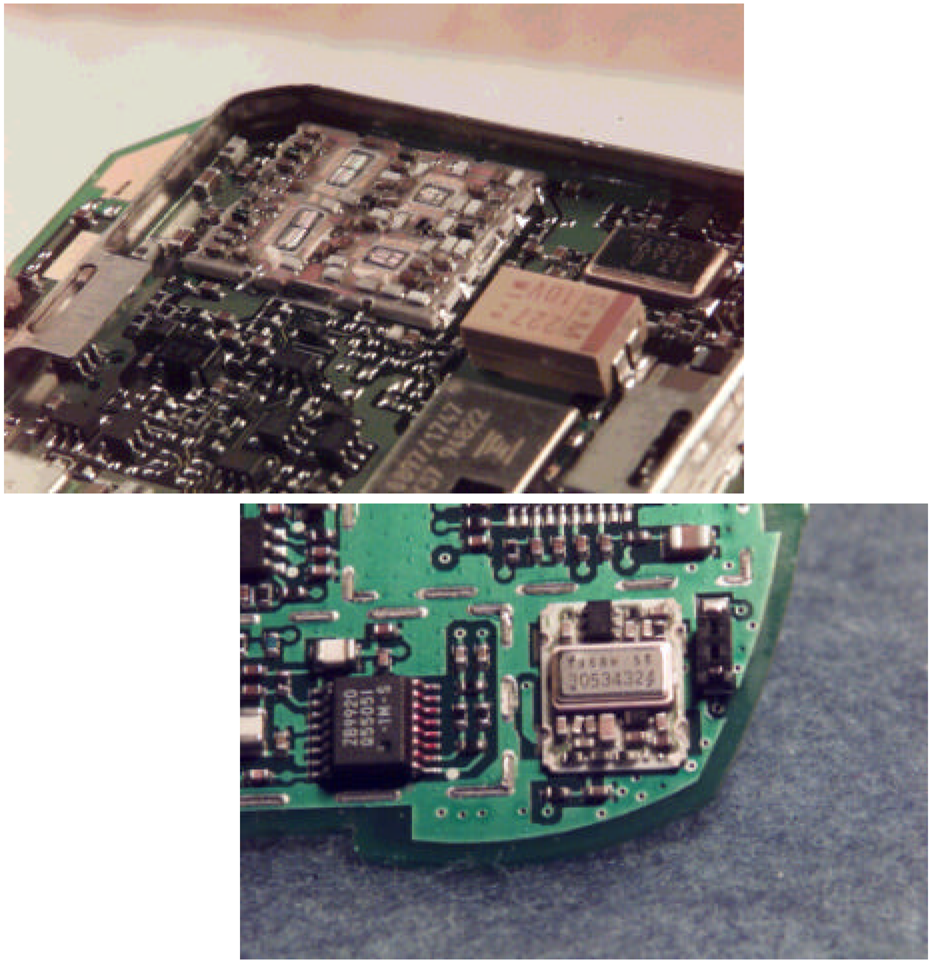


Mobile Phone Evolution

Source: Prismark Partners LLC

- Continued miniaturization of cell phones, pagers, PDA's and microwave devices have driven passive component sizes down from 0805,0603,0402 to 0201
- Shift to multi-chip modules with integrated functions (e.g. Bluetooth, Global Positioning Systems [GPS])
- Higher performance in smaller packages.

Applications



- Smaller passives result in smaller lighter products
- Use of functional modules in cell phone and other similar applications reduce 2nd level assembly complexity
- Modules allow for specialization in electrical and functional design improving performance of product

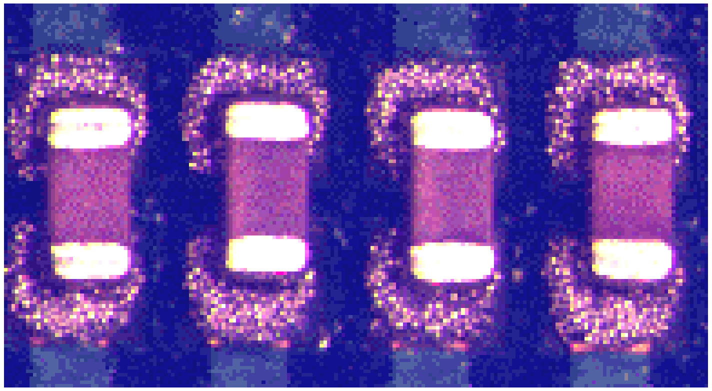
0201 ASSEMBLY RESEARCH

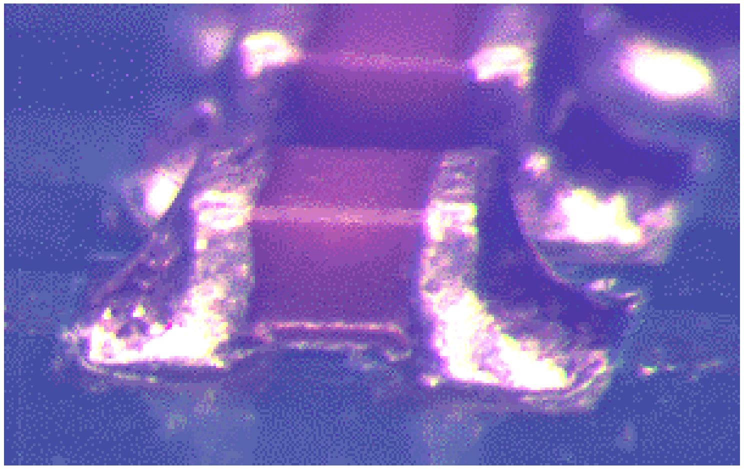
September 2000

By Universal Instruments'
Advanced Process Laboratory

Process Variables

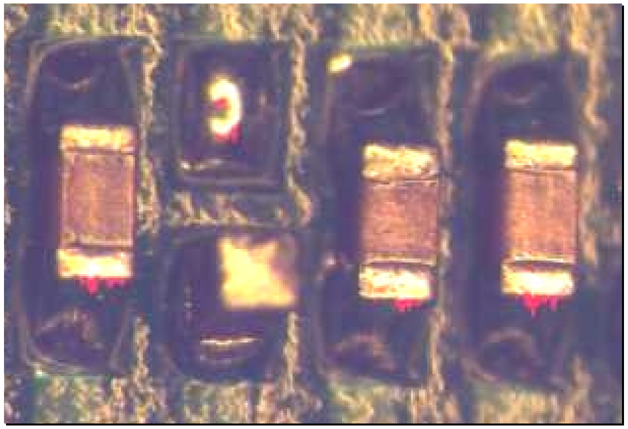
- **Attachment Pad Design**
  - Spacing Between Pads, Pad Width, Pad Length
- **Solder Paste**
  - Powder Size, No-Clean/ Water Soluble, Vendor, Alloy
- **Stencil Design**
  - Stencil Thickness, Aperture Size & Shape
- **Printing**
  - Accuracy, Parameters
- **Component Placement**
  - Accuracy, Placement Pressure
- **Reflow**
  - Oven Profile, Atmosphere



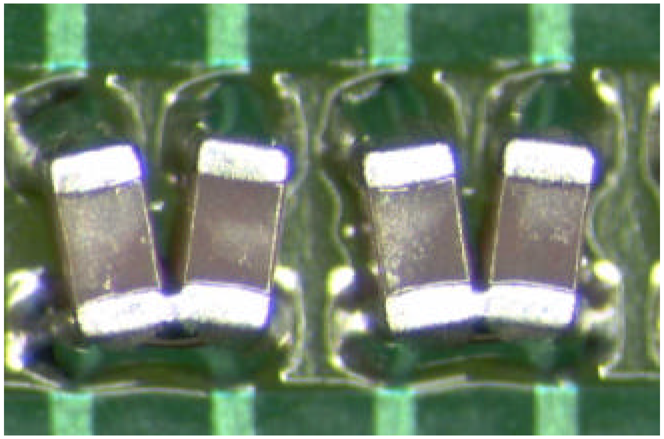


0201 Failures

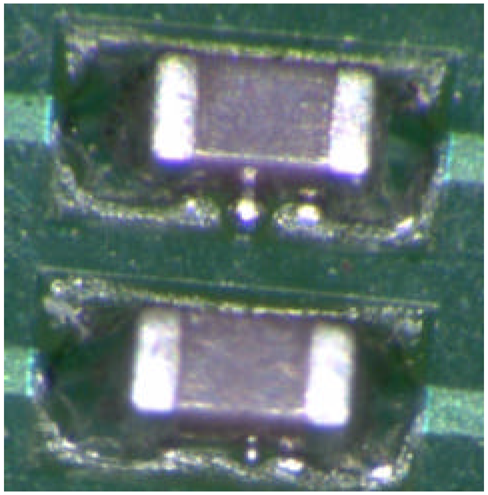
Open Solder Joints (“Tombstones”)



Solder Bridging

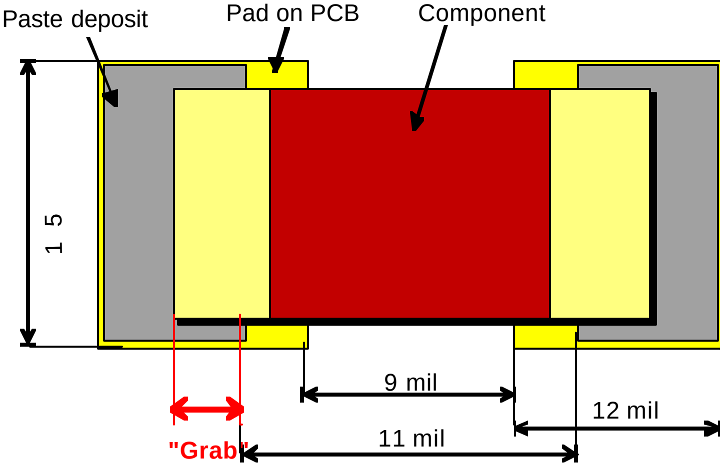


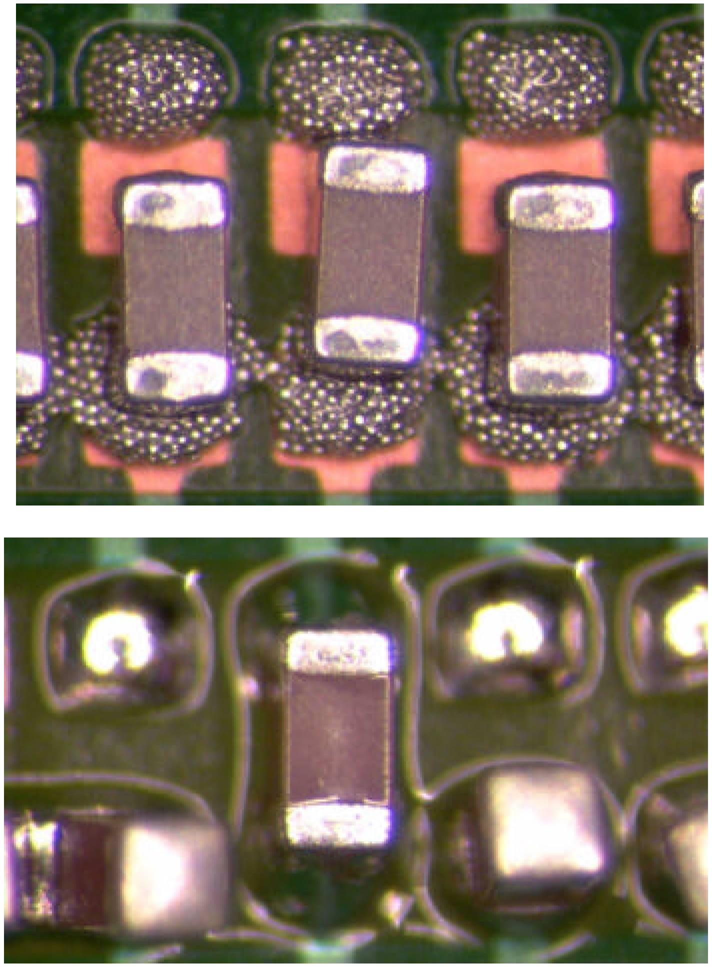
Solder Balls



Tombstones

- **No Overlap Between Paste Deposit & Component Causes Tombstoning**
- **Influenced By:**
  - Pad & Stencil Design
  - Placement & Printing Accuracy
  - Reflow





Vitronics Soltec
Our reliability is your productivity

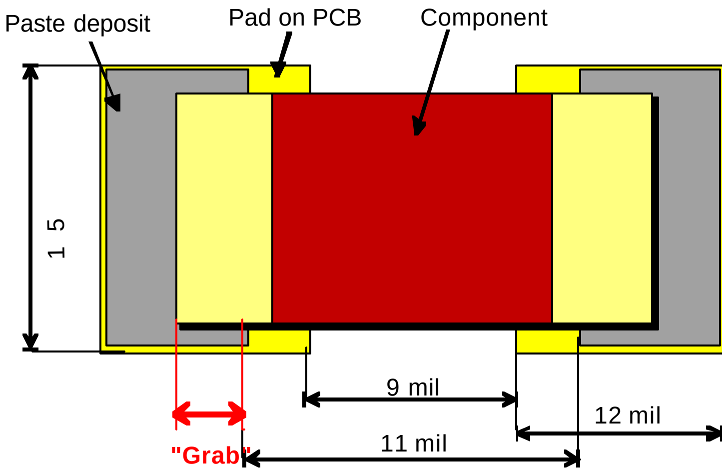
DEK

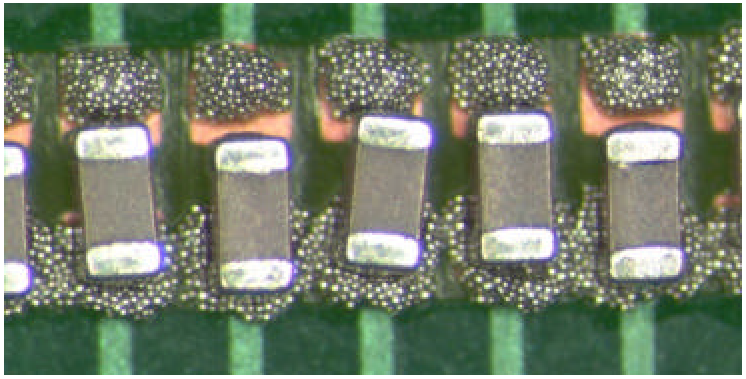
Universal

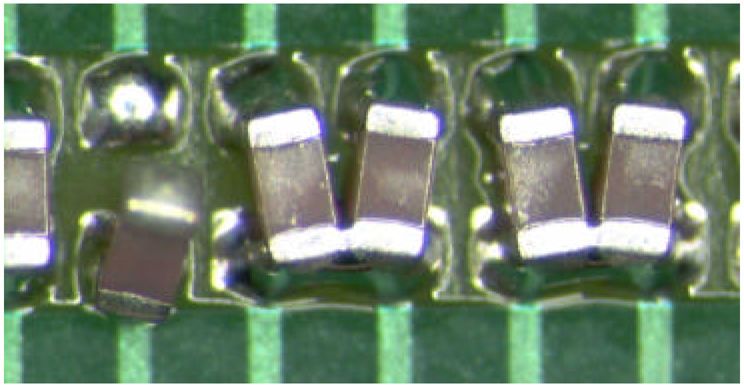
By Universal Instruments'
Advanced Process Laboratory

Solder Bridges

- **Occurs From Touching Solder Paste Deposits After Printing & Placement**
- **Influenced By:**
  - Pad Spacing
  - Printing & Placement Accuracy
  - Placement Pressure

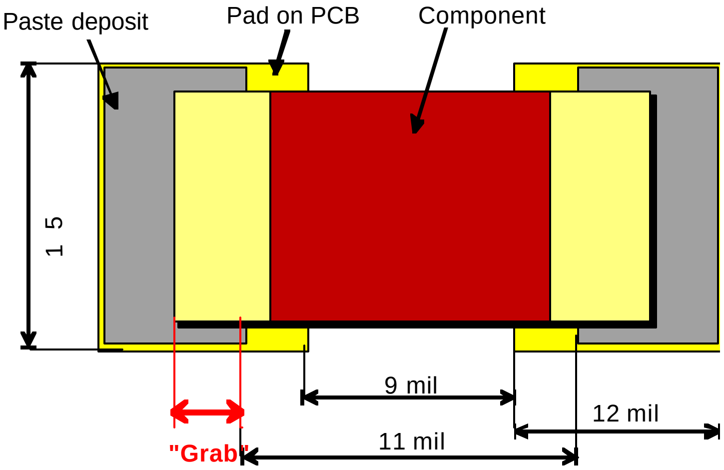


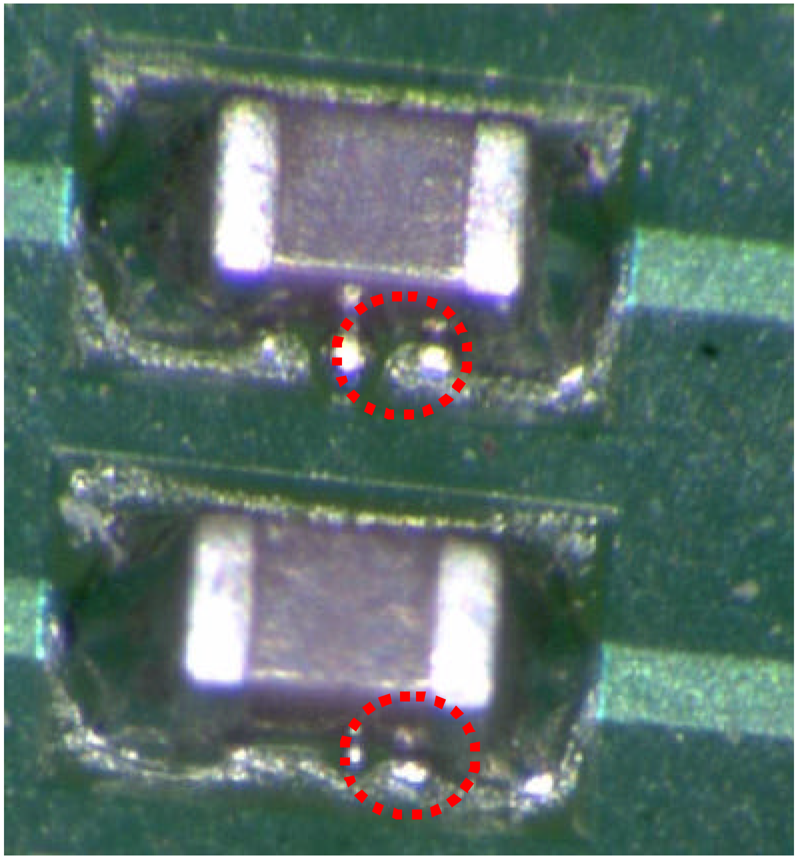




Solder Balling

- **Formed From Alloy Separation During Reflow Under Component**
- **Influenced By:**
  - Pad & Stencil Design
  - Placement & Printing Accuracy





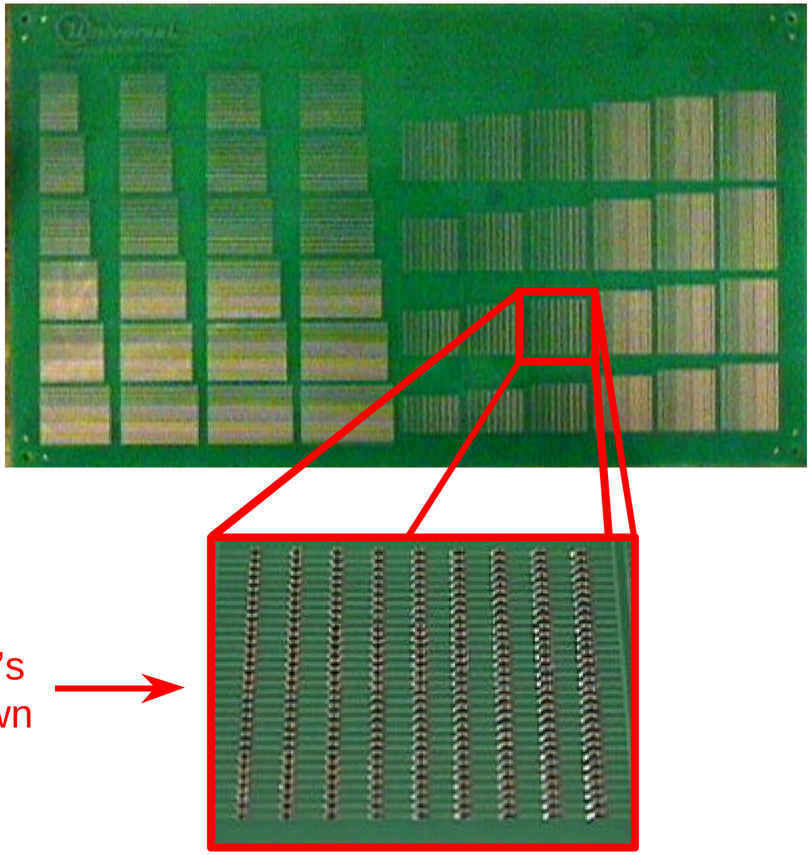
PAD SIZE OPTIMIZATION

September 2000

By Universal Instruments'
Advanced Process Laboratory

Test Vehicle 1

- **Parameters Tested**
  - Pad Design
  - Flux Type / Reflow Atmosphere
- **PCB**
  - FR4, 62 mil Thick, 7.5” x 12.5”
  - Cu/OSP Pads
  - 2 Component Orientations
  - 6480, 0201 Components
  - 6480, 0402 Components



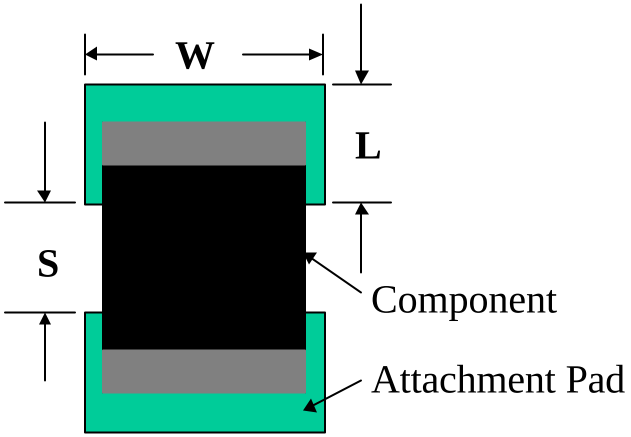
0201’s Shown

Design of Experiments TV-1

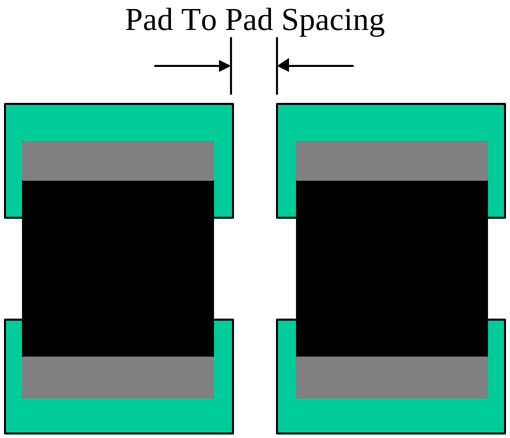
- **Experiment #1: Filter Testing**
  - 4 Process Builds: No-Clean & Water Soluble Paste Reflowed In Nitrogen & Air
  - 311,040 Components Assembled For Experiment #1
  - 5 Stencil Designs Per Attachment Pad Design, Optimum Selected
- **Experiment #2:**
  - 3 Process Builds: Water Soluble Paste Reflow In Nitrogen Dropped (Low Usage)
  - 1,116,000 Components Assembled For Experiment #2
  - 1 Stencil Design Per Attachment Pad Design

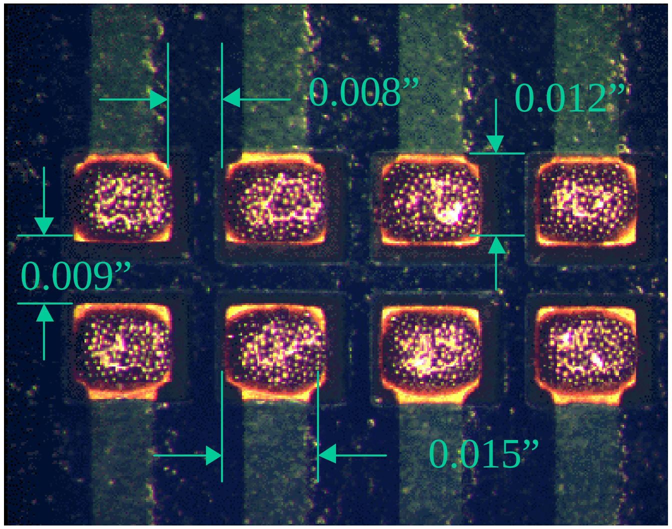
Pad Design Parameters

- **27 Different Attachment Pad Designs**
  - W = 0.012”, 0.015”, 0.018”
  - L = 0.008”, 0.012”, 0.016”
  - S = 0.009”, 0.012”, 0.015”



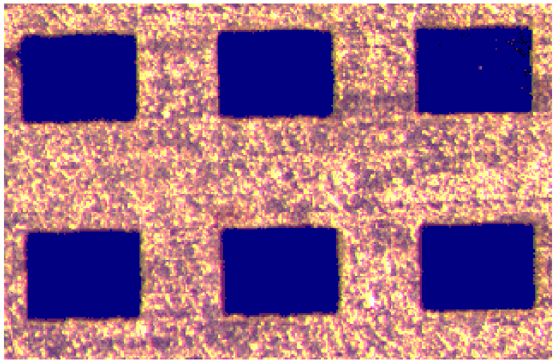
- **4 Different Pad To Pad Spacing**
  - 0.008”, 0.012”, 0.016”, 0.020”



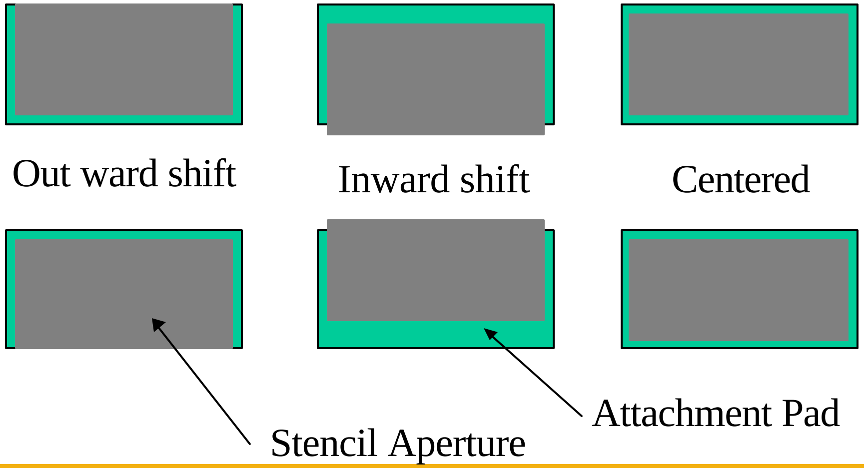


Stencil Design

- **5.0 mil Thick Laser Cut Stencil**
  - 6.0 mil Too Thick For Paste Sufficient Release
  - 4.0 mil Too Thin For Many SMT Devices

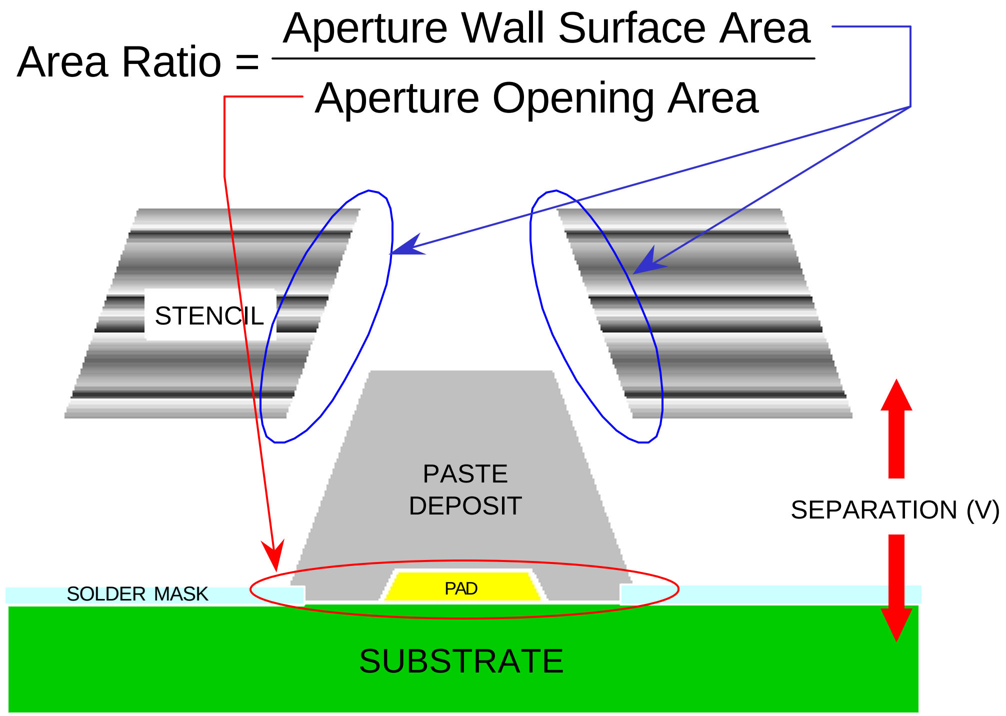


- **3 Different Stencil Aperture Positions Possible**
  - Outward Paste Shift
  - Inward Paste Shift
  - Centered Paste



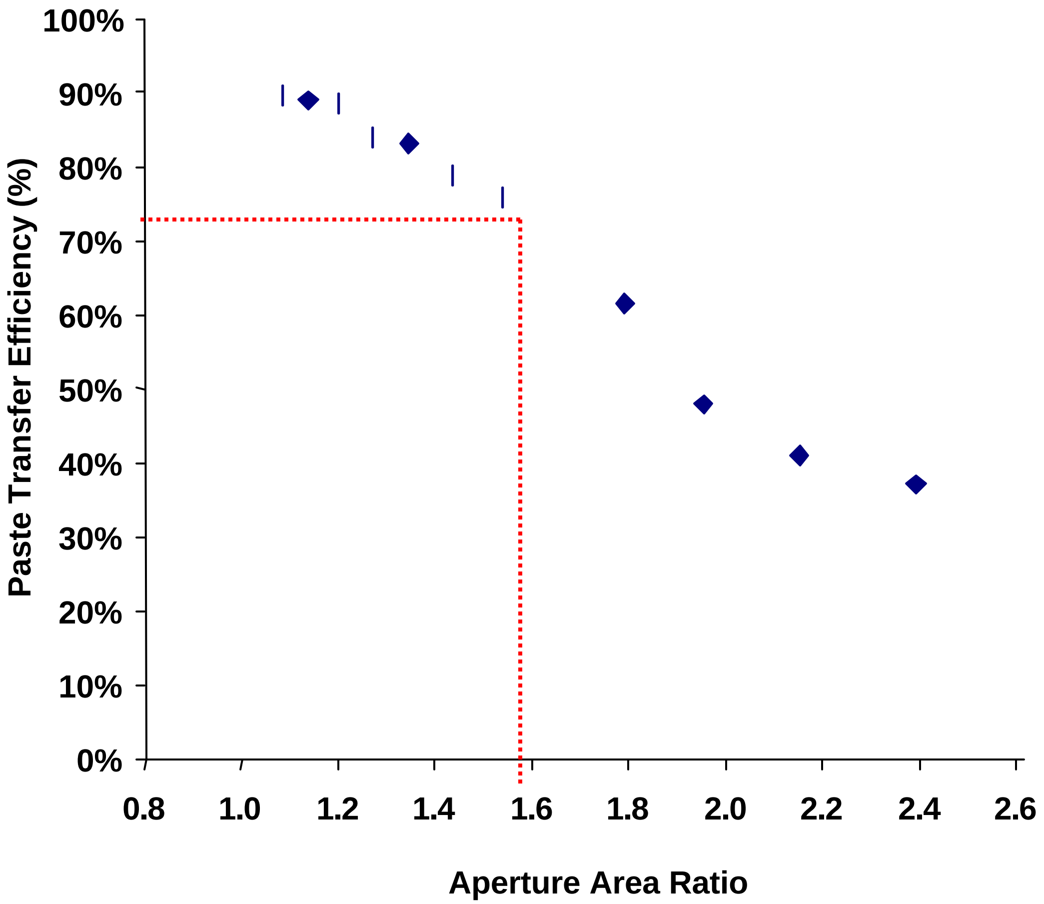
Stencil Apertures

- **11 x 15 mil Rectangular Apertures**
- **5 mil Thick Laser Cut Foil**
- **Selected Based On Filter Testing (Experiment 1)**
- **Area Ratio = 1.576**



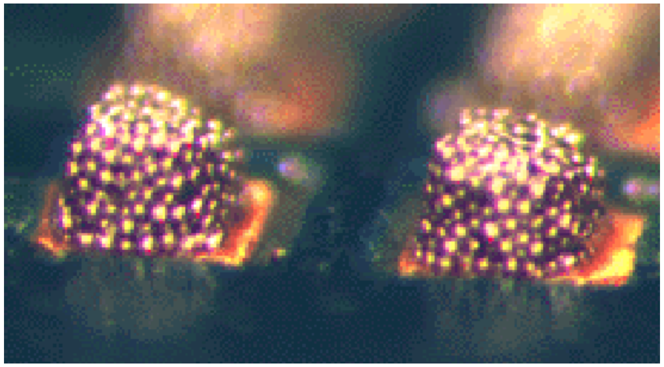
$$\text{Area Ratio} = \frac{\text{Aperture Wall Surface Area}}{\text{Aperture Opening Area}}$$

Paste Transfer Efficiency



Stencil Printing

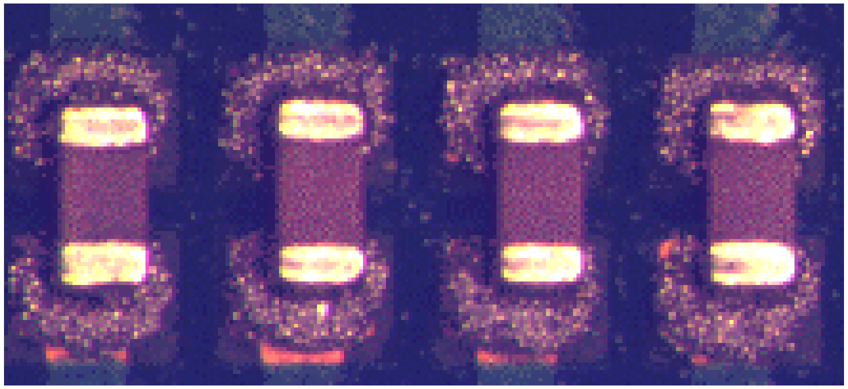
- **Solder Paste**
  - One No-Clean & One Water Soluble Paste Were Tested
  - 90% Metal
  - Type IV powder size
  - Sn63/Pb37 Alloy

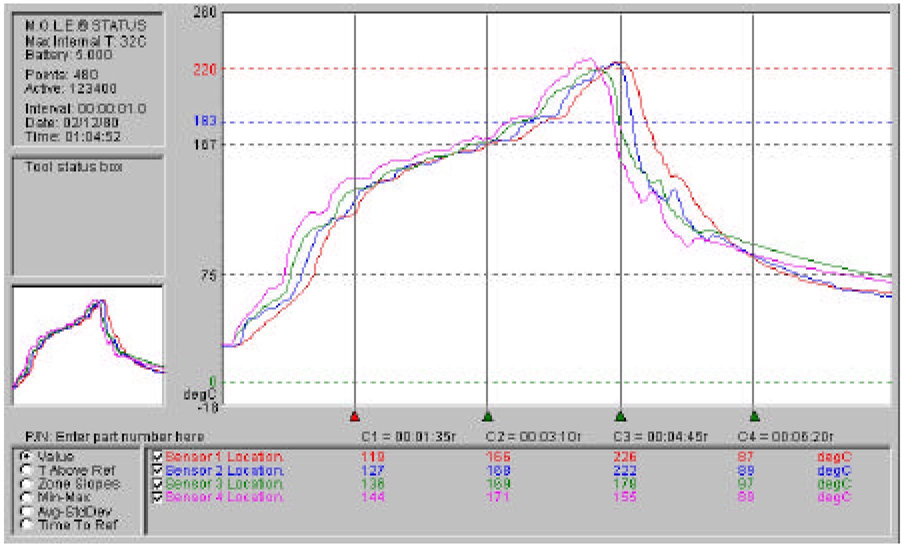


- **Printing Parameters**
  - DEK 265GSX Printer
  - Print Speed 1.0”/sec.
  - Metal Squeegee Blades, Squeegee Angle 60°
  - Squeegee Pressure 2.3 lb/inch
  - Print Gap 0 (On Contact)
  - Separation Speed 0.02”/sec.

Placement and Reflow

- **Component Placement**
  - Universal 4796R HSP
  - Two Global Fiducials Used For PCB Alignment
- **Reflow**
  - Forced Convection Oven
  - 8 Heating & 1 Cooling Zones
  - Assembly Performed In Both Air & Nitrogen Atmospheres
  - Oxygen Levels For Nitrogen Reflow Less Than 50 PPM





M.O.L.E.® STATUS
Max Internal T: 32C
Battery: 5.000
Points: 480
Active: 123400
Interval: 00:00:01.0
Date: 02/12/80
Time: 01:04:52

Tool status box

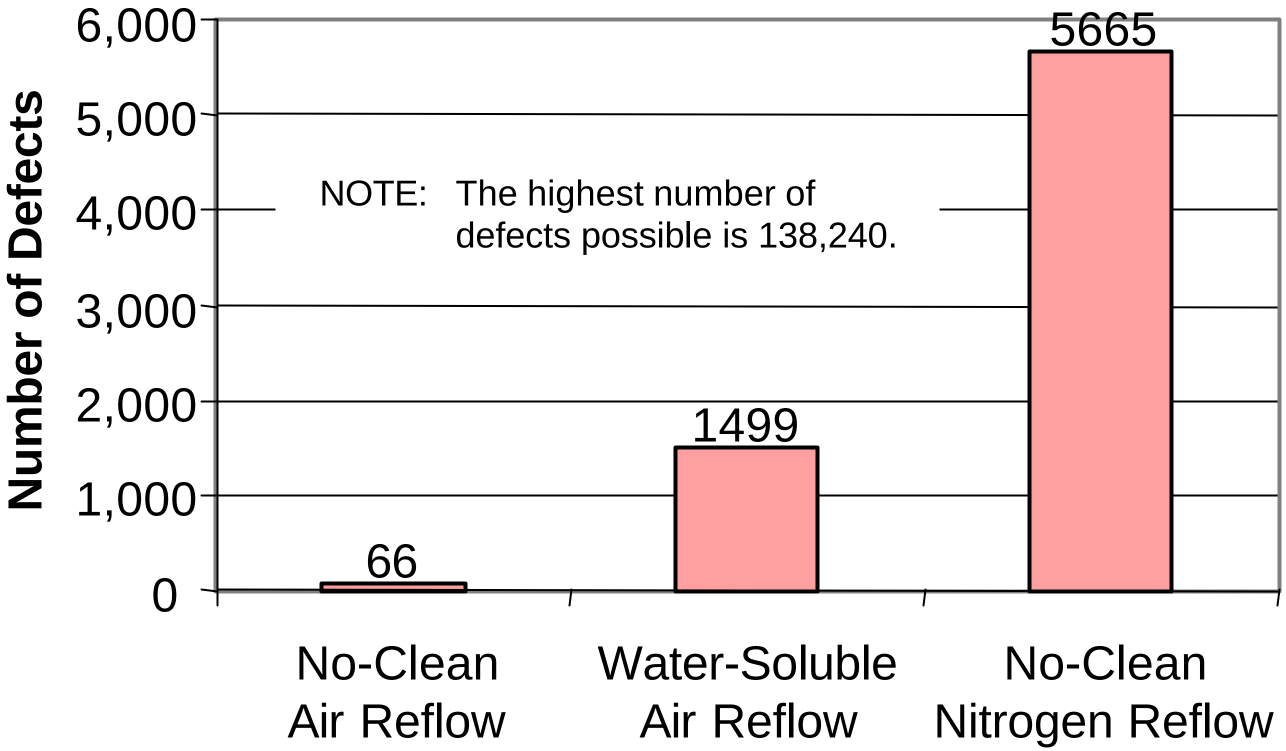
P/N: Enter part number here

● Value
○ T Above Ref
○ Zone Slopes
○ Min-Max
○ Avg-StdDev
○ Time To Ref

	C1 = 00:01:35r	C2 = 00:03:10r	C3 = 00:04:45r	C4 = 00:06:20r	
☑ Sensor 1 Location	119	166	226	87	degC
☑ Sensor 2 Location	127	168	222	89	degC
☑ Sensor 3 Location	138	169	179	97	degC
☑ Sensor 4 Location	144	171	155	88	degC

Reflow Atmosphere / Paste Type

- **Defects By Assembly Process For Test Vehicle 1**
- **Data Shown For "Optimum" Pad Design**



NOTE: The highest number of defects possible is 138,240.

Technical Paper Details

- **Results Published at APEX 2000**
- **Paper Available For Viewing/Downloading at www.uic.com**

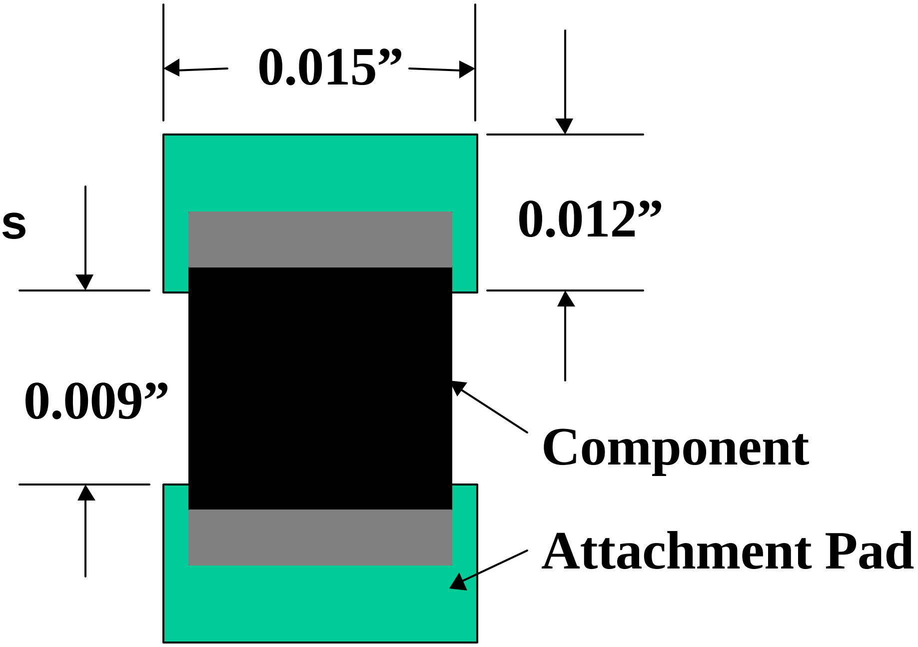
Process Parameters Optimization for Mass Reflow of 0201 Components (pdf format)

Jim Adriance, Process Research Engineer, Surface Mount Technology Laboratory, Universal Instruments, Jeff Schake, Process Research Engineer, DEK

The research summarized in this article will help to address some of the issues associated with solder paste mass reflow assembly of 02\01 components. Attachment pad design, stencil design, component to component spacing, component orientation, flux type, and solder paste reflow atmosphere were the major variables researched during the project. The two major responses from the experimentation were assembly yield and assembly quality. Assembly yield defects, such as tombstones (open solder joints), solder bridges, and solder balls (beads) were used to determine the assembly yield. Solder joint shape, solder appearance, and solder volume (unacceptable low, acceptable or unacceptable high) responses were used to determine the quality of the assembly process.

Test Vehicle 1 Experimental Conclusions

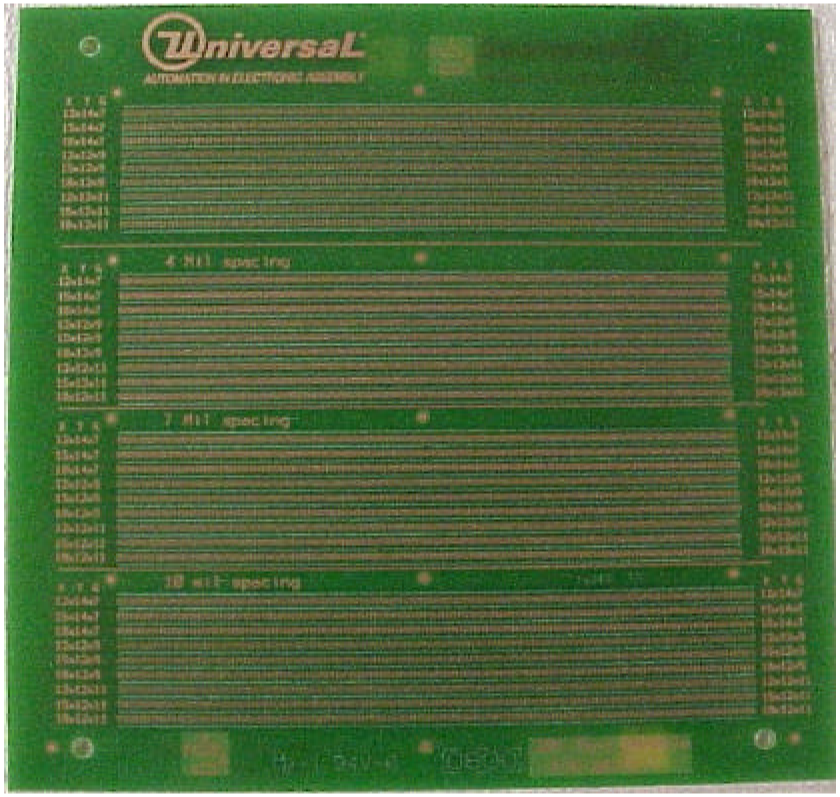
- Optimum Pad/Stencil Design Determined
- No-Clean Paste Reflowed in Air Produced Fewest Assembly Defects
- 8-mil Component To Component Spacing Produced Good Yields
- Solder Balling Lower When Paste Under Component Is Reduced
- Component Orientation In Reflow Affected Yield For NN & WA Only, NOT NA!



ACCURACY

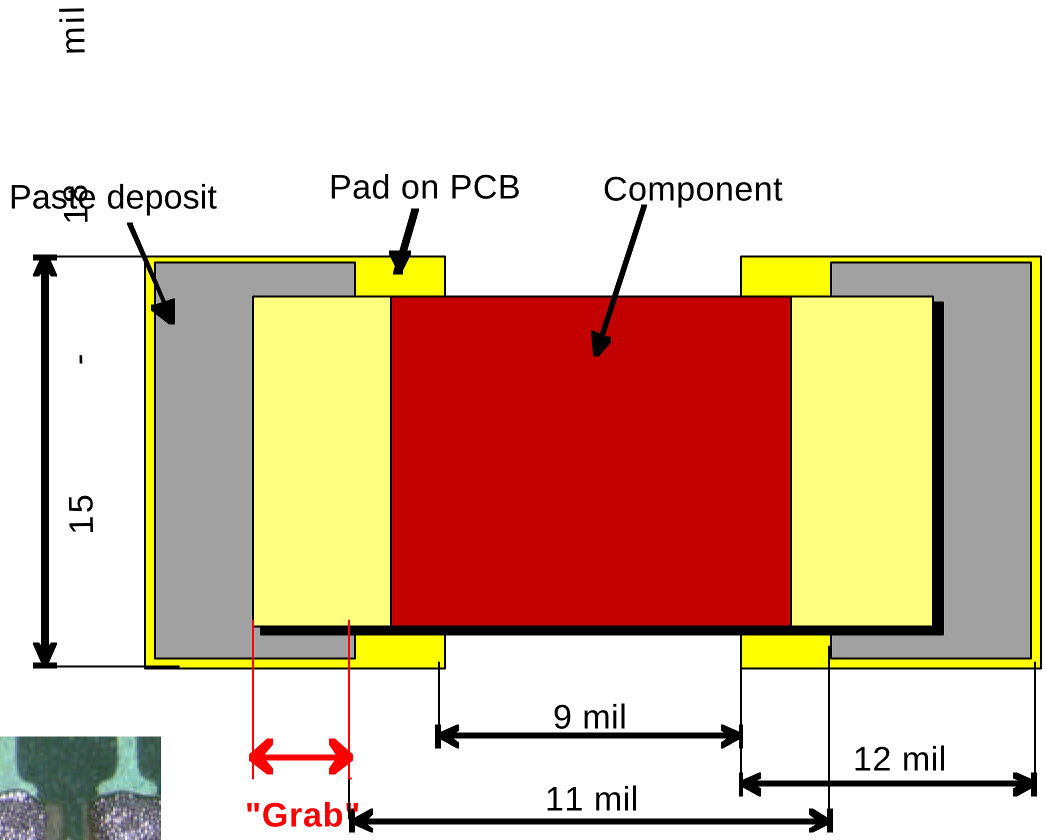
Test Vehicle 2

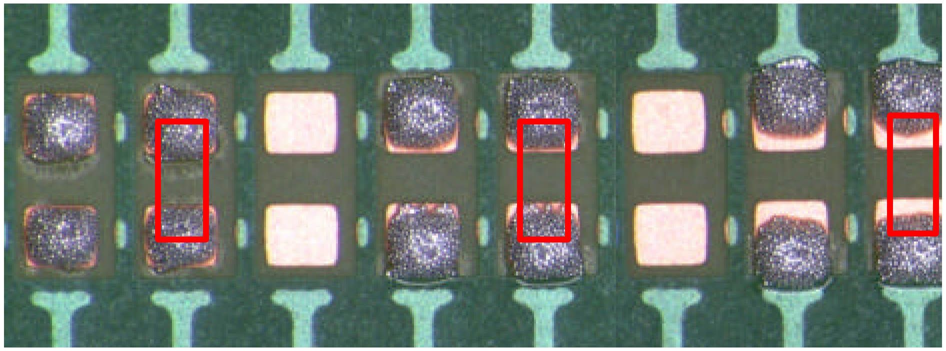
- **Evaluate**
  - Required Print/Placement Accuracy
  - Aperture Separation
  - O_2 PPM Concentration
  - Reflow Orientation
  - Pb-Free vs. Sn/Pb
- **PCB**
  - FR4, 62 mil Thick, 5.5”x5.5”
  - Cu/OSP Pads
  - 360, 0201’s (12x15x9 mil Pads)
- **Equipment**
  - DEK 265 GSX Printer
  - GSMxs Placement Machine (0.5 mil/pixel camera)
  - Vitronics XPM 1030 N Reflow Oven



Materials

- **Solder**
  - No-Clean Paste
  - Type III Powder Size
  - Sn63/Pb37 (90.25% Metal)
  - Sn95.5/Ag4/Cu0.5 (89.3% Metal)





6 mil grab

4 mil grab

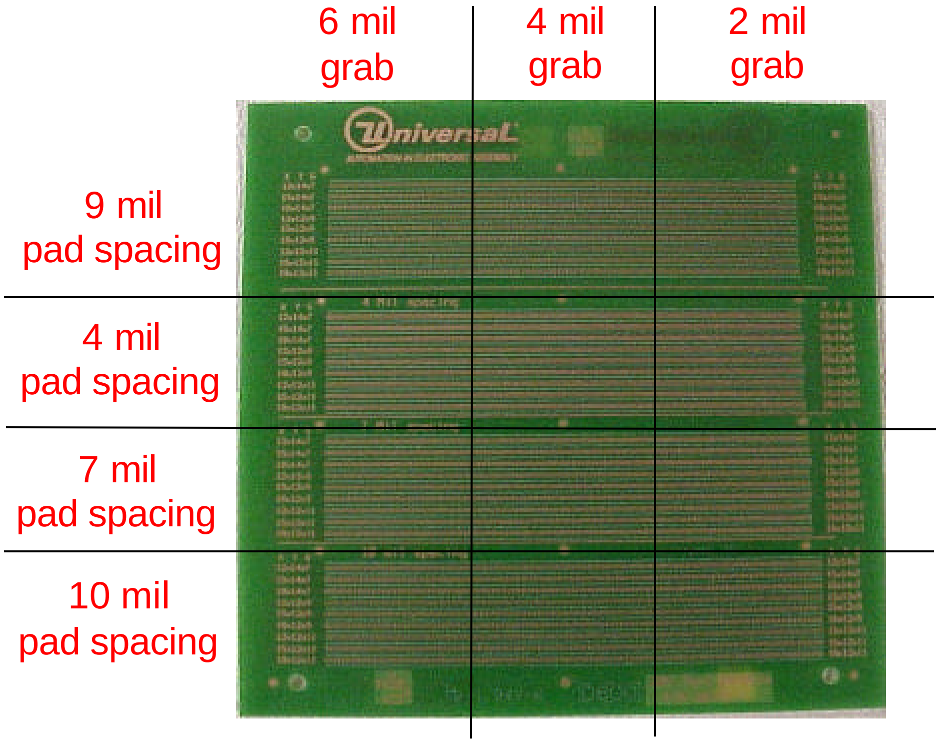
2 mil grab

- **Stencil**
  - Laser Cut Foil
  - 5 mil Thick
  - 11 x 15 mil Apertures
  - 3 Levels Of Deposit Separation

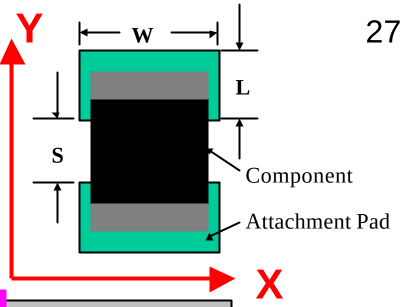
Vitronics Soltec
Our reliability is your productivity
DEK
Universal

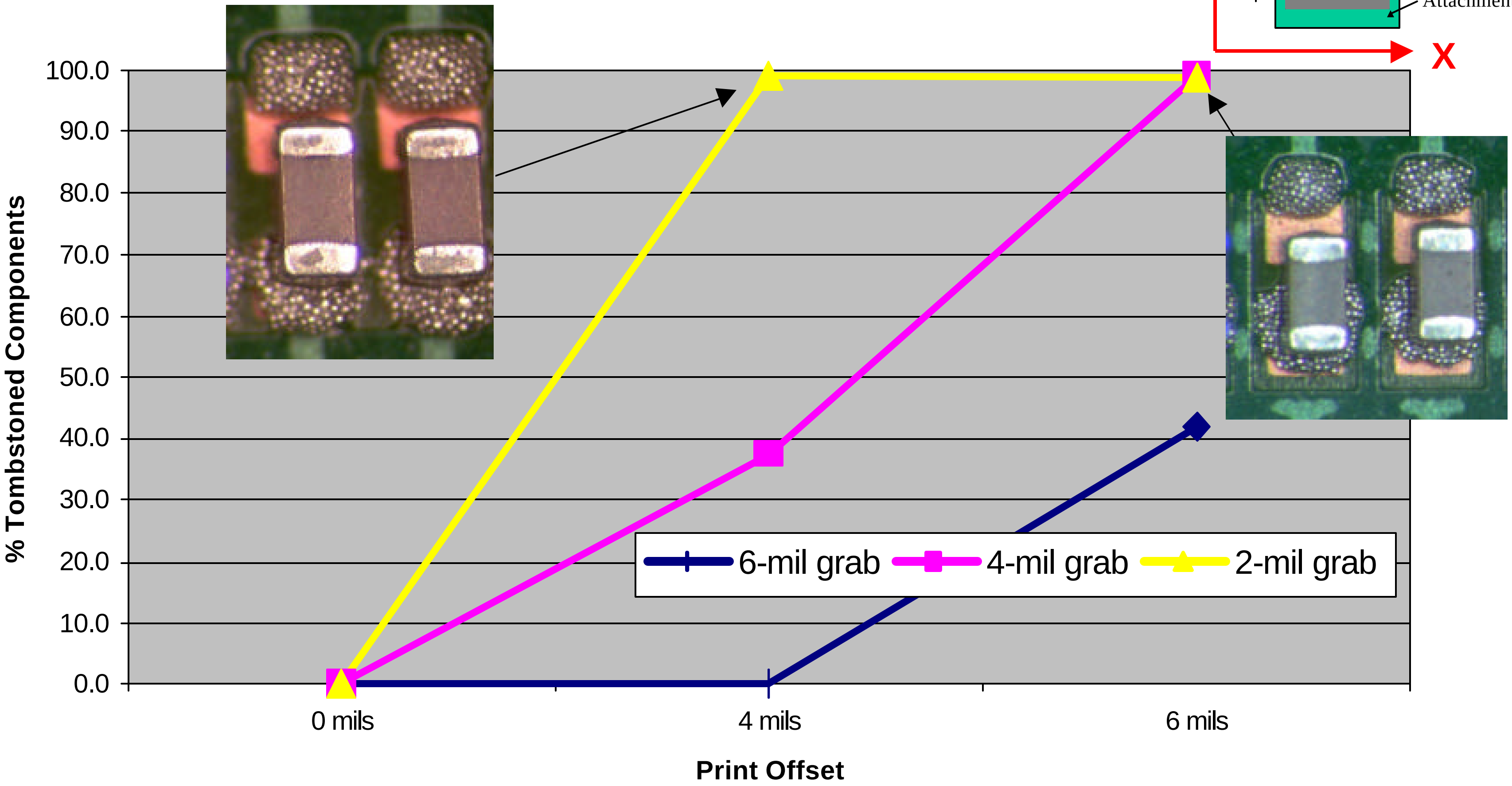
Design of Experiments TV-2

- **0, 4, and 6 mil Print / Placement Offsets Tested**
- **2 Boards Per Offset, 60 Components Per Design Combination**
- **Identify Defect Sensitivity In Worst Case Scenario Conditions**
  - Component Reflow Orientation
  - Tightest Pad Spacing
  - N_2 Reflow
- **Track Defect Trends**



Tombstones Versus Print Offset (Y-Shift) and Grab (Sn/Pb Solder)





Vitronics Soltec
Our reliability is your productivity

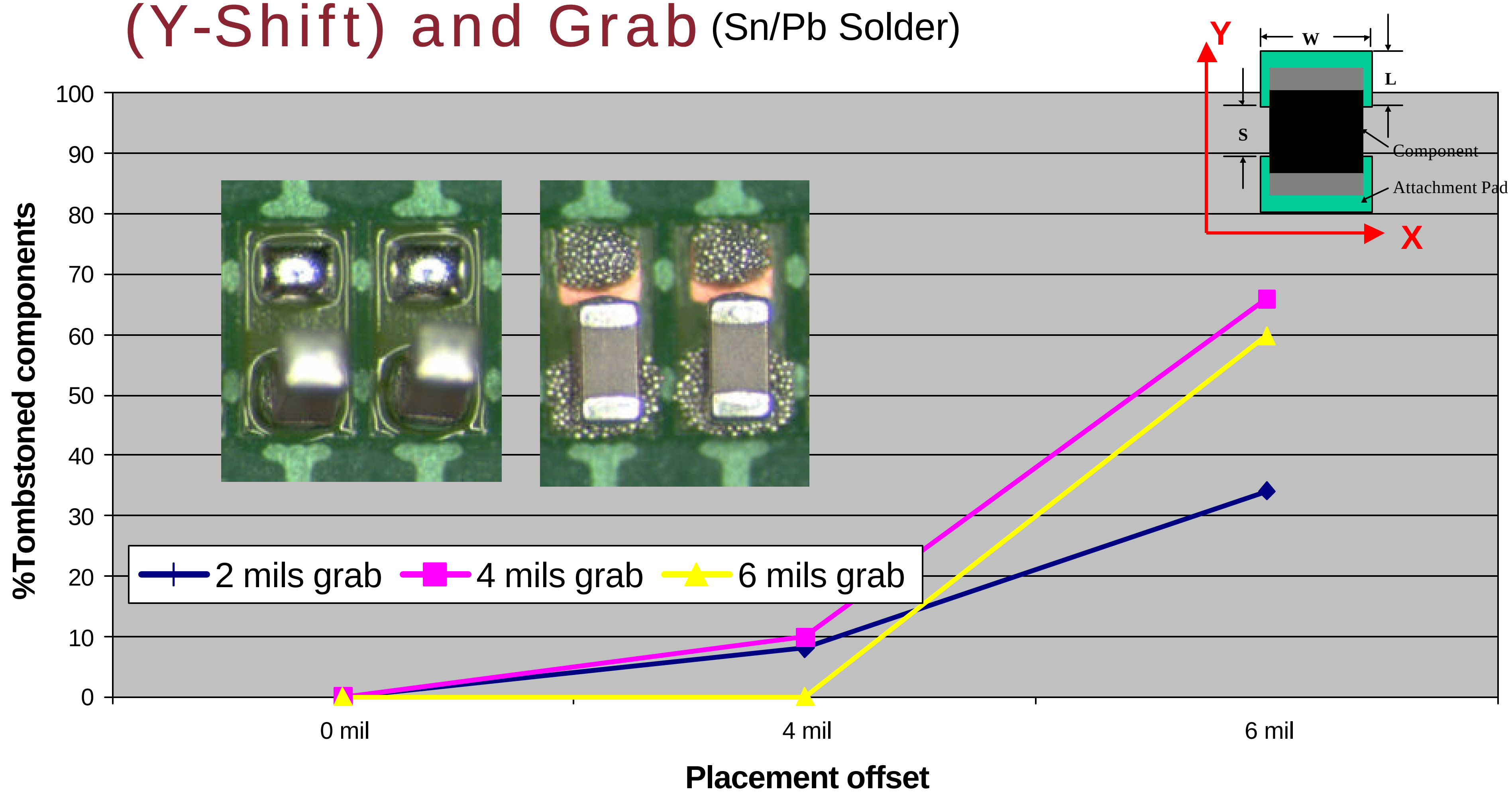
DEK

Universal

September 2000

By Universal Instruments'
Advanced Process Laboratory

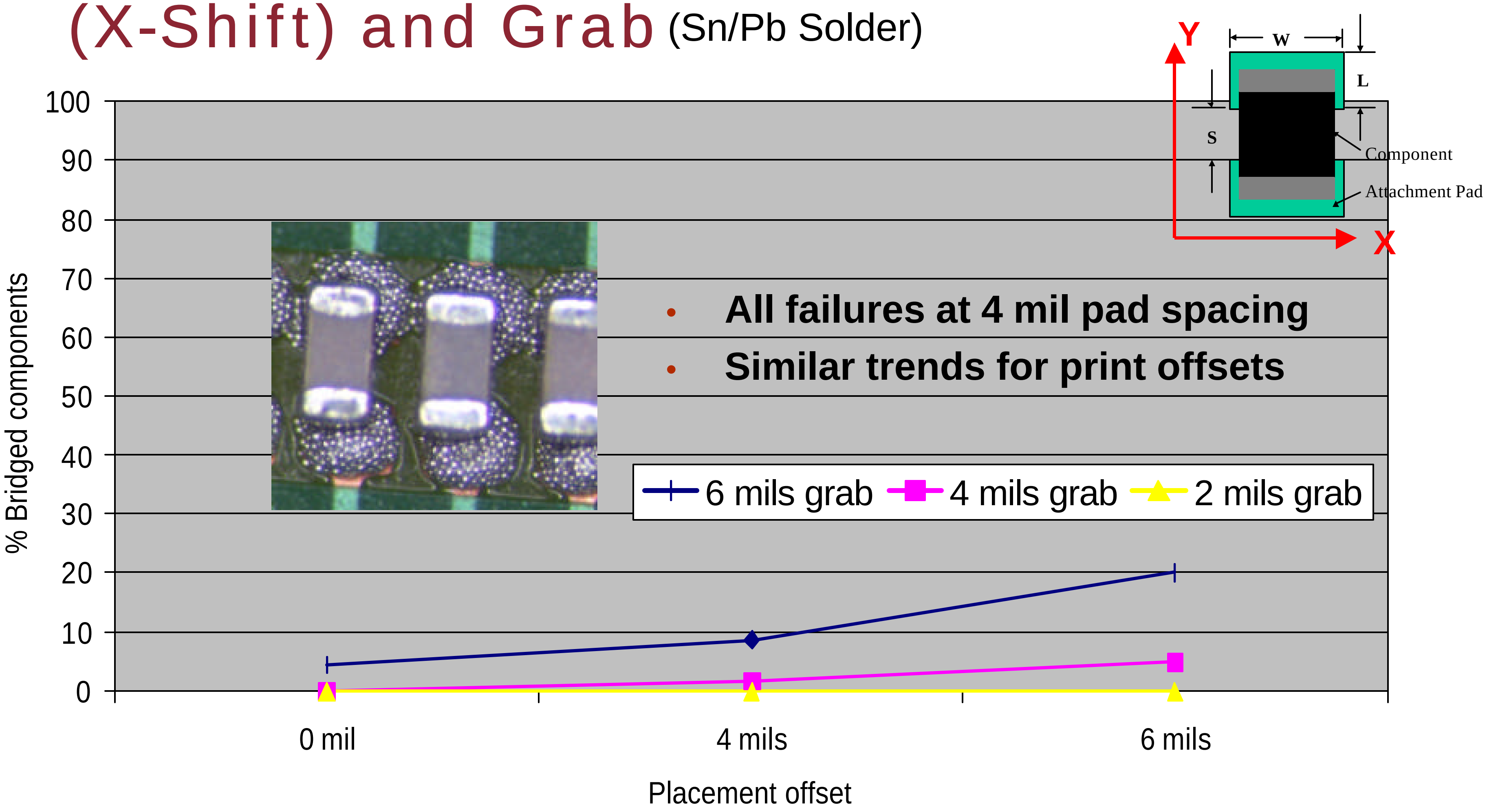
Tombstoning Versus Placement Offset (Y-Shift) and Grab (Sn/Pb Solder)



September 2000

By Universal Instruments’
Advanced Process Laboratory

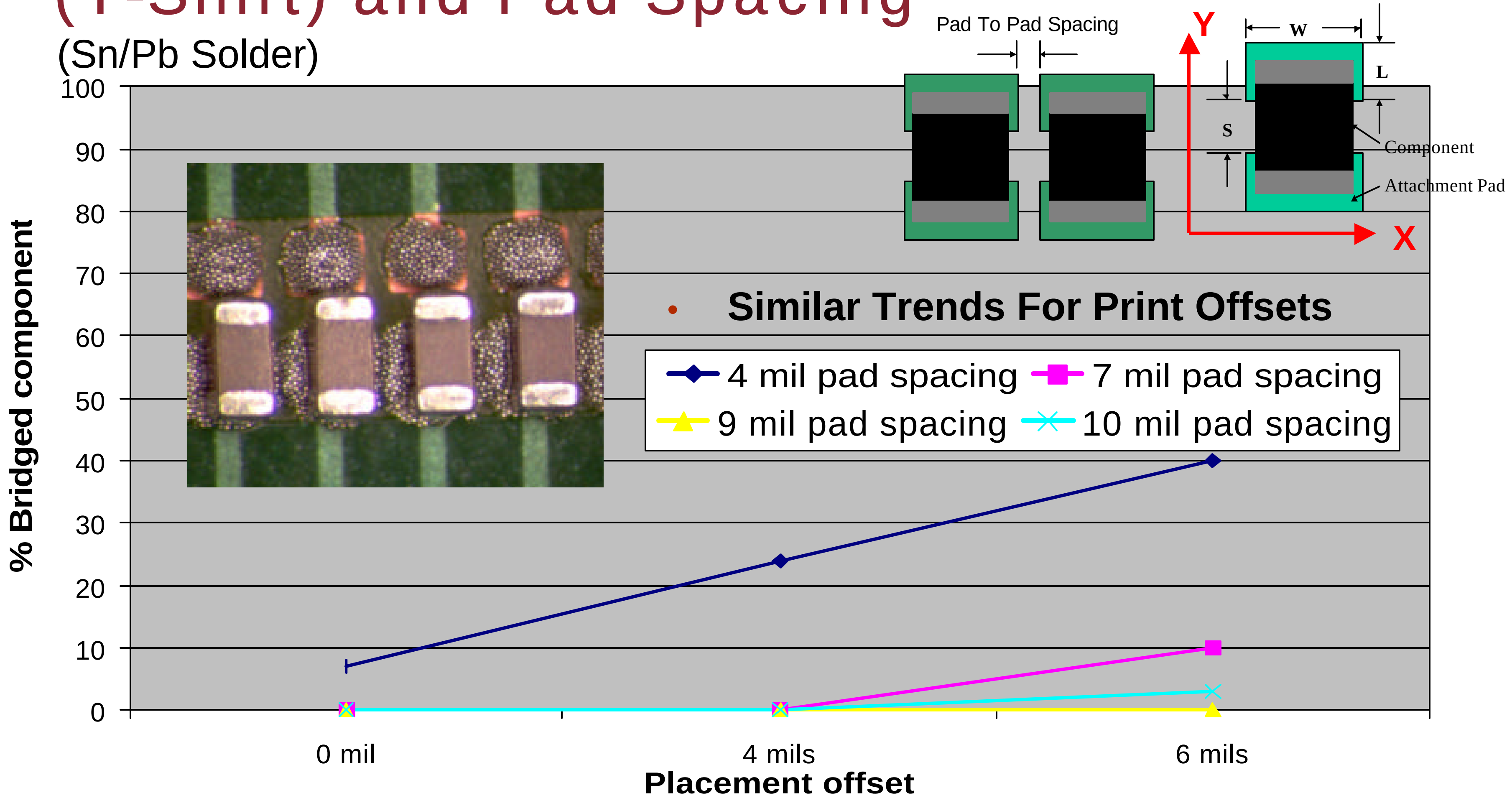
Bridging Versus Placement Offset (X-Shift) and Grab (Sn/Pb Solder)



- **All failures at 4 mil pad spacing**
- **Similar trends for print offsets**

Bridging Versus Placement Offset (Y-Shift) and Pad Spacing

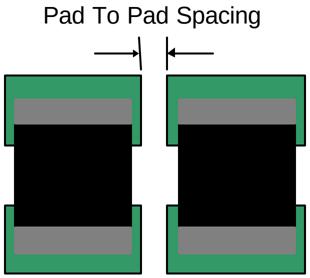
(Sn/Pb Solder)



- **Similar Trends For Print Offsets**

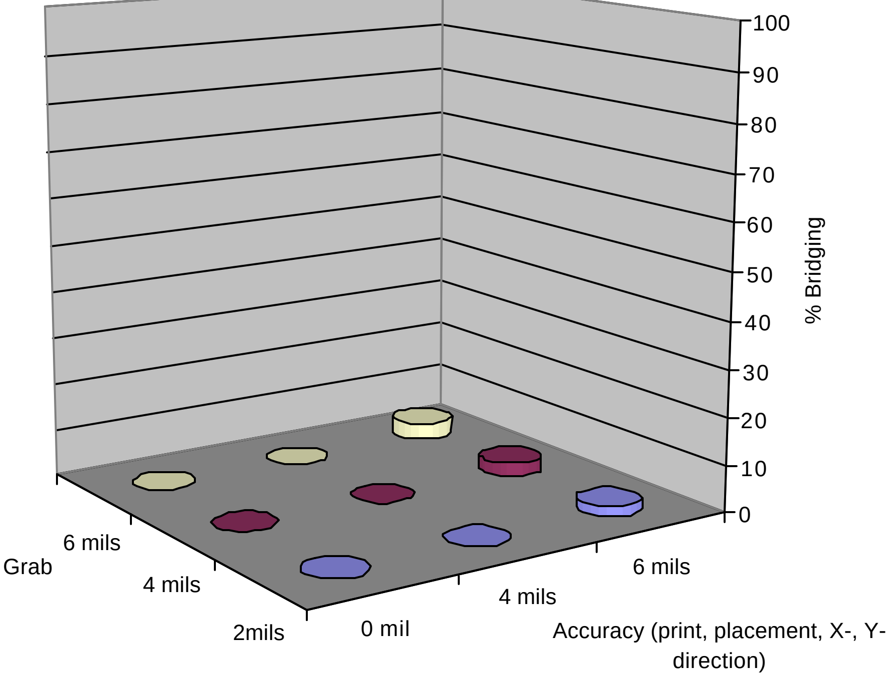
Bridging Versus Pad Spacing

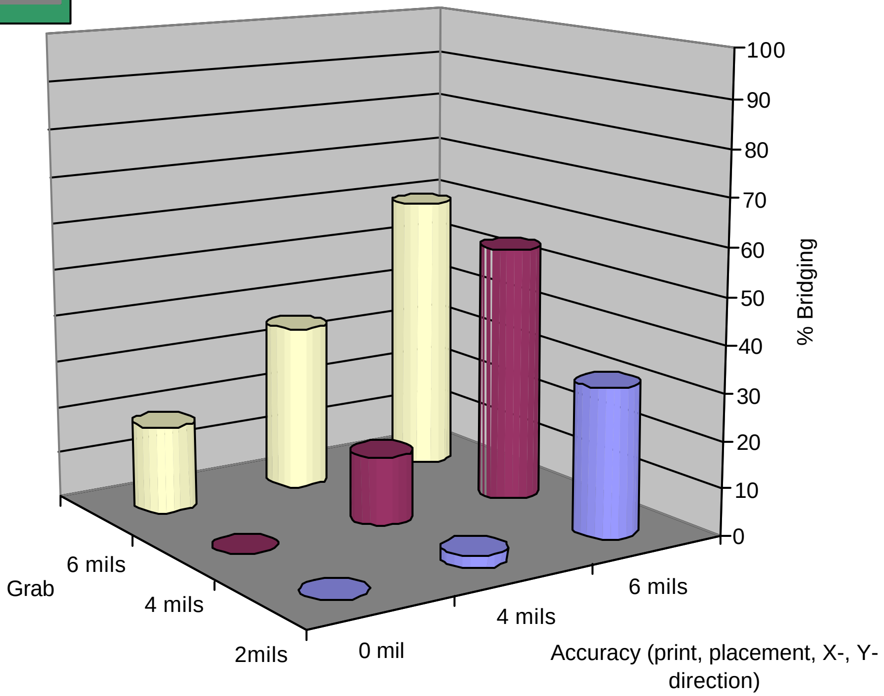
(Sn/Pb Solder)



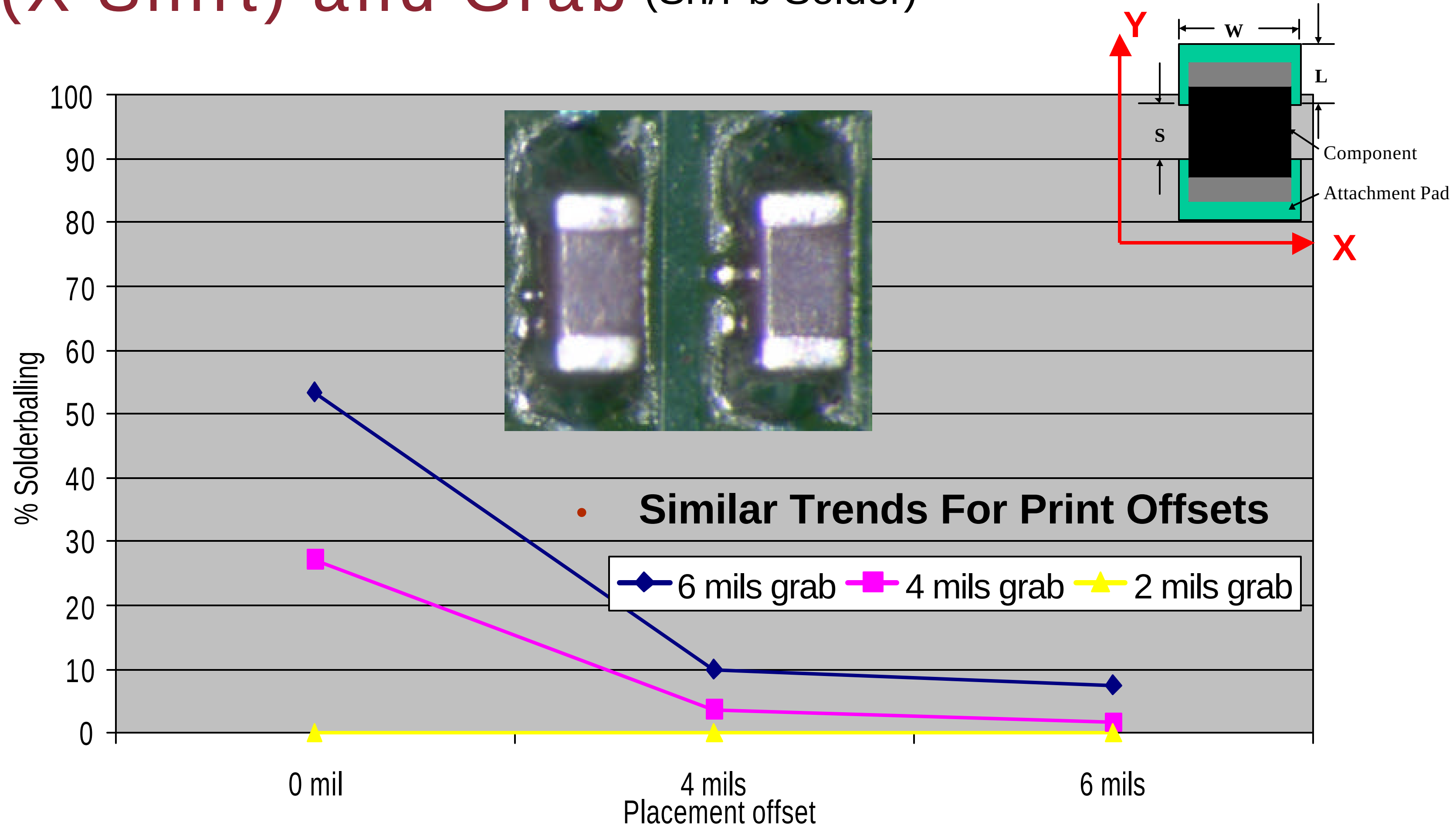
7 mil pad spacing

4 mil pad spacing



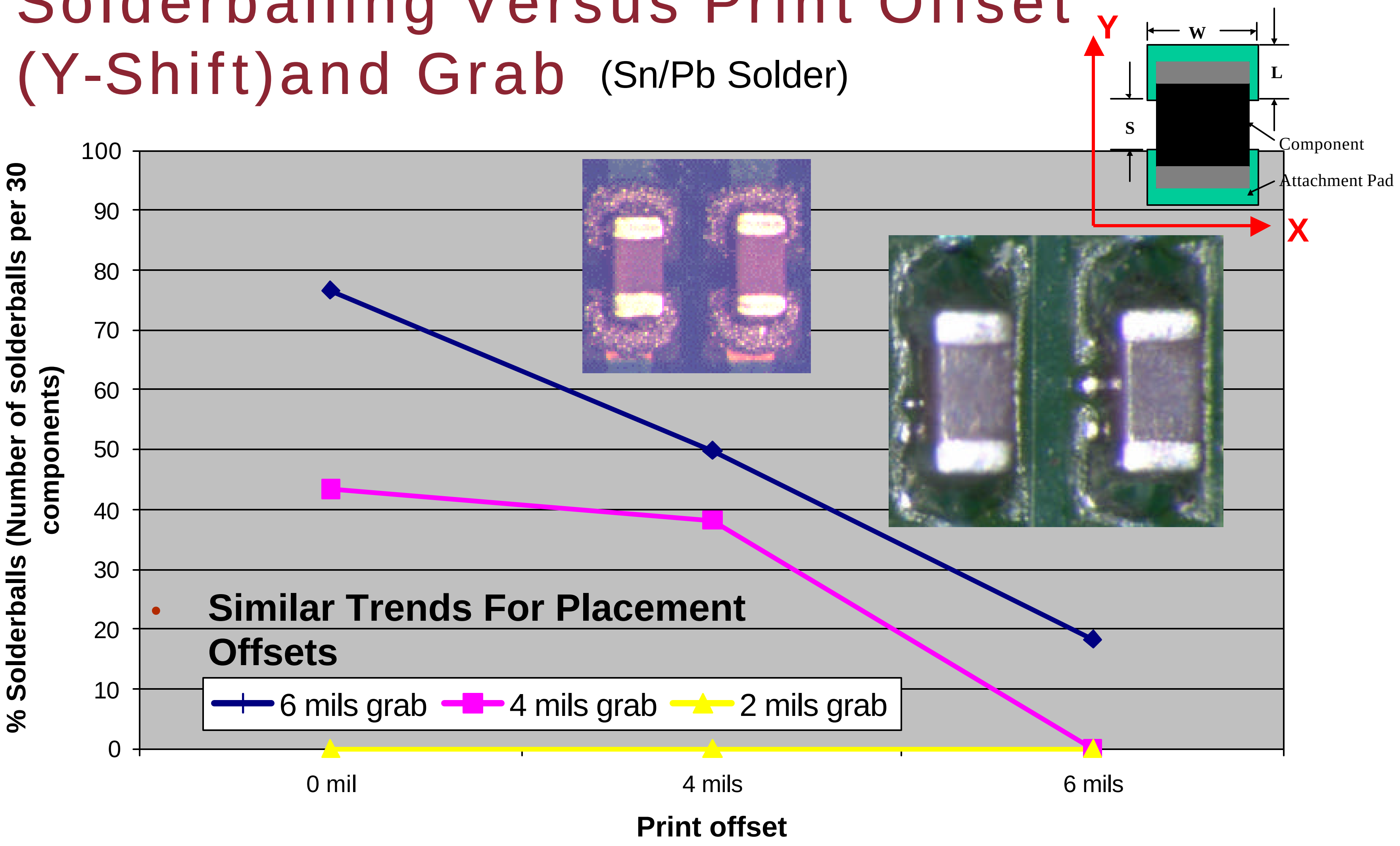


Solderballing Versus Placement Offset (X-Shift) and Grab (Sn/Pb Solder)



- **Similar Trends For Print Offsets**

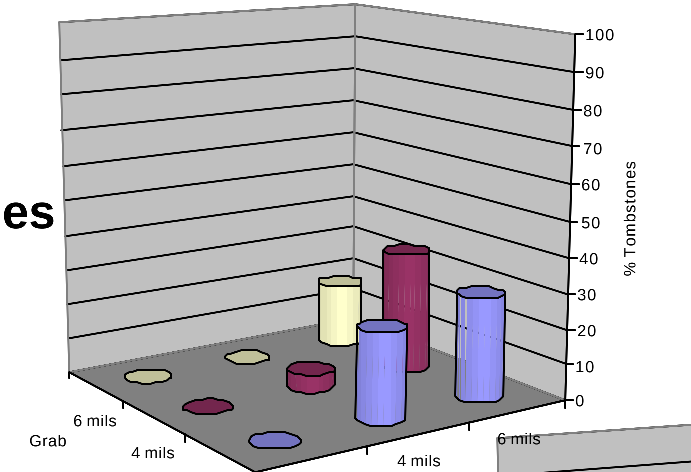
Solderballing Versus Print Offset (Y-Shift)and Grab (Sn/Pb Solder)



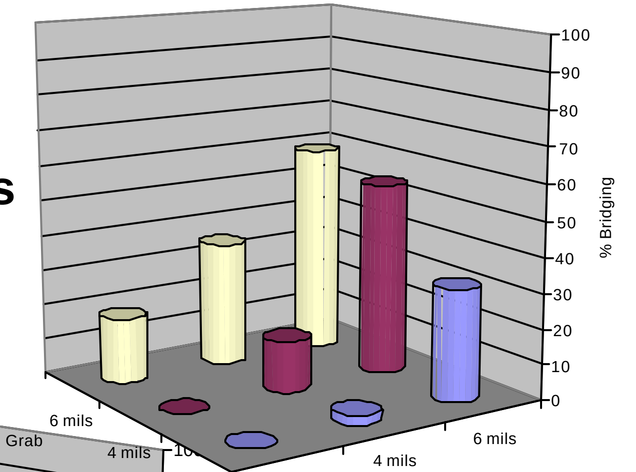
- **Similar Trends For Placement Offsets**

4-mil Pad Spacing Failures (Sn/Pb Solder)

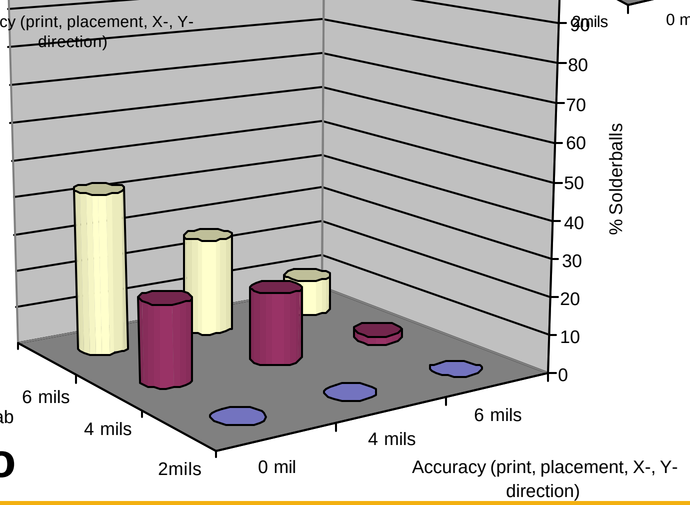
Tombstones



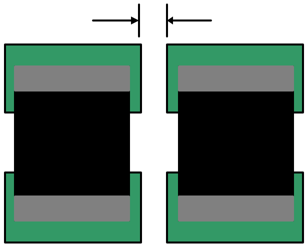
Bridges



Solderballs



Pad To Pad Spacing



- **Optimum Stencil Design Leads ToTrade-Off Scenario**

September 2000

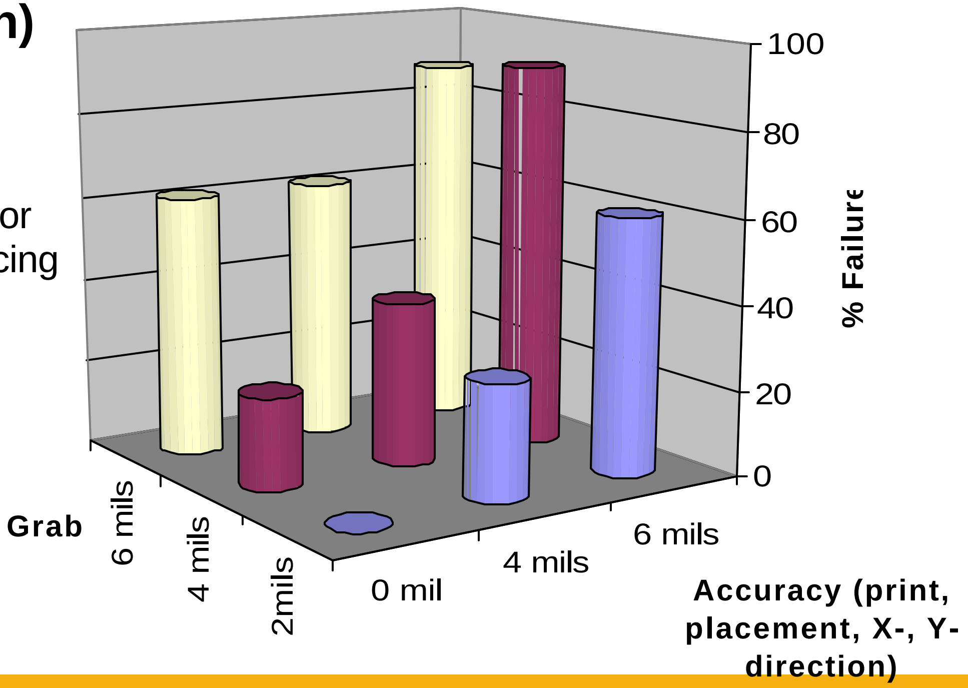
By Universal Instruments'
Advanced Process Laboratory

Printing and Placement Accuracy (Sn/Pb Solder)

- **X-Offset Causes No Increase In Tombstones, But In Bridging**
- **Y-Offset Causes Increased Tombstones (More Sensitive To Print Registration)**

- **Increased Printing & Placement Accuracy Will:**
  - Reduce Tombstoning & Bridging
  - Allow Tighter Component Spacing

Total Failure for 4-mil Pad Spacing



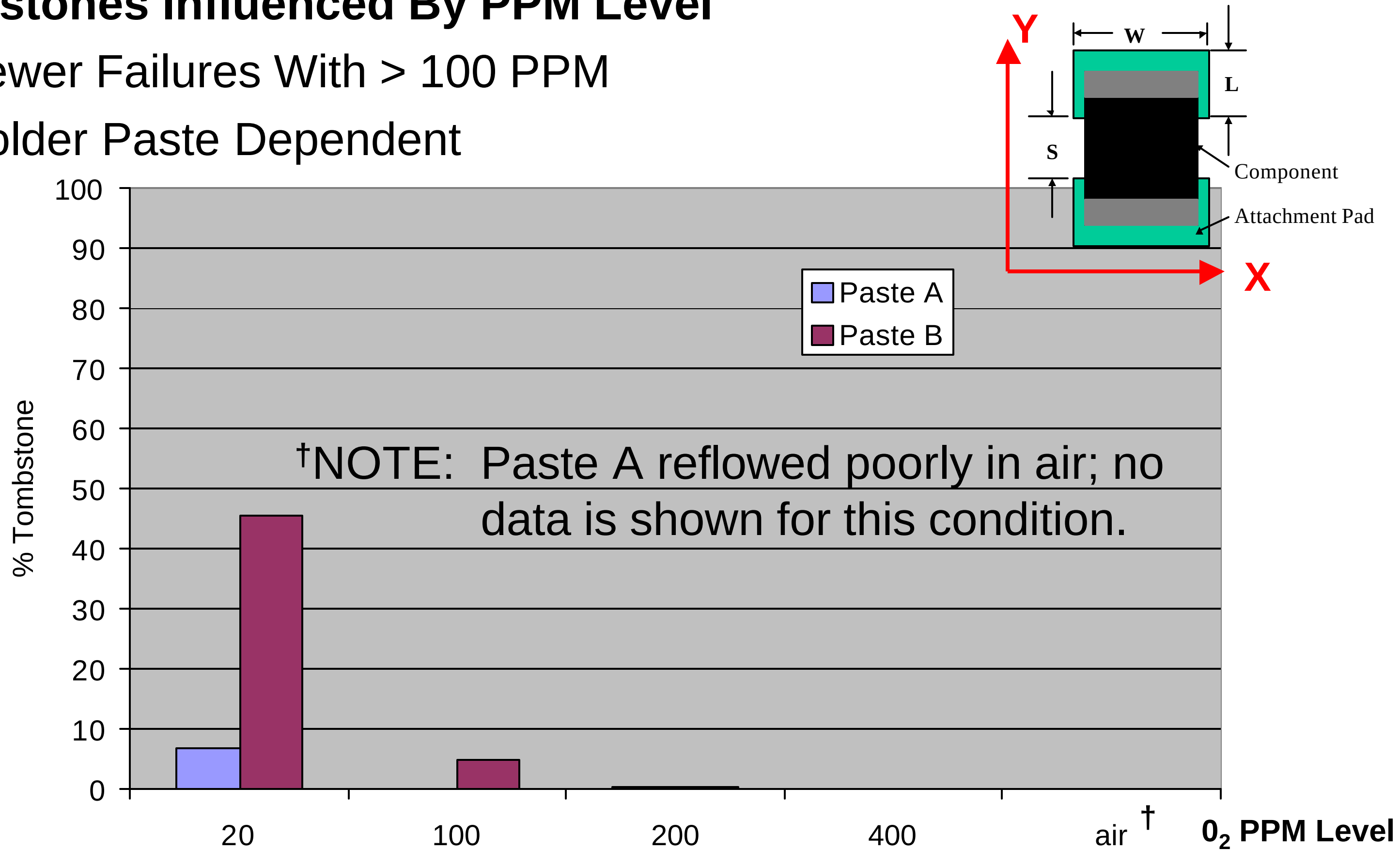
REFLOW

September 2000

By Universal Instruments'
Advanced Process Laboratory

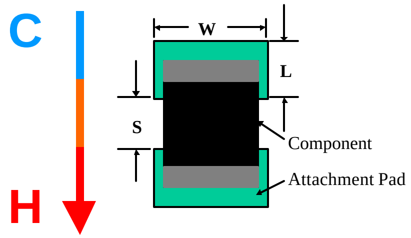
O_2 PPM Level Versus Defects
4 mil Print Offset (Y-Shift) (Sn/Pb Solder)

- **Tombstones Influenced By PPM Level**
  - Fewer Failures With > 100 PPM
  - Solder Paste Dependent



†NOTE: Paste A reflowed poorly in air; no data is shown for this condition.

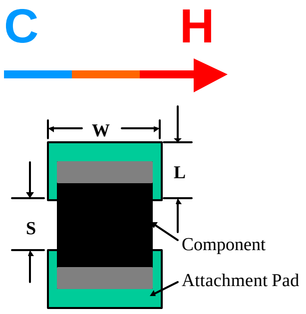
Reflow Direction (Sn/Pb Solder)

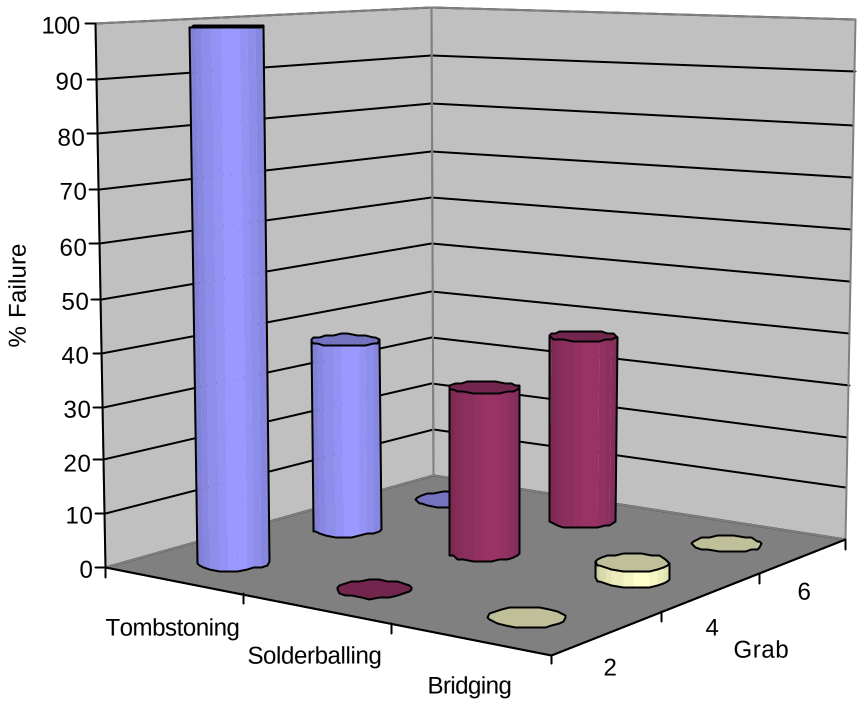


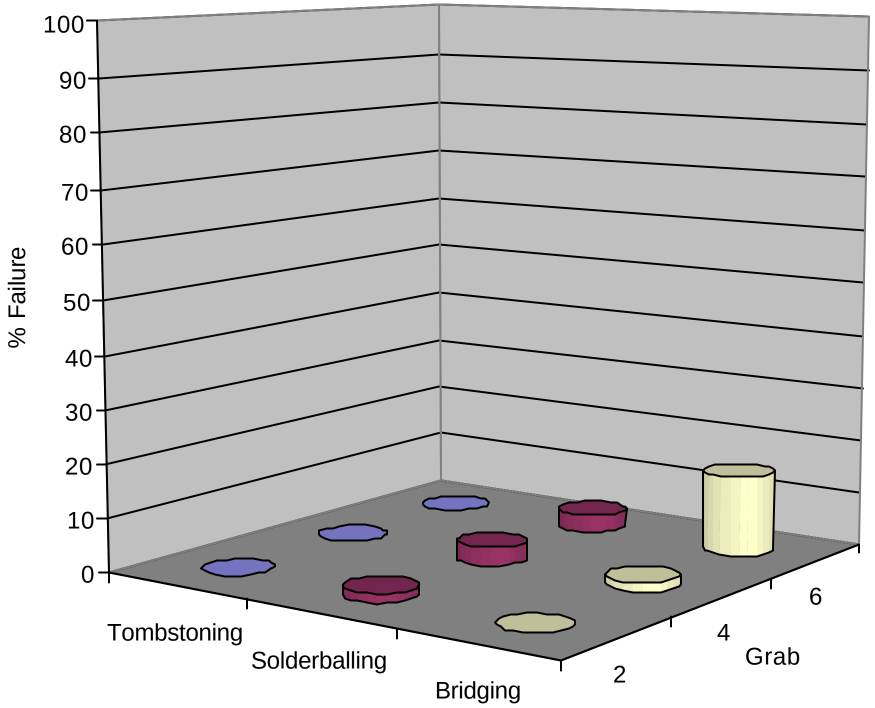
4-mil Print Offset

(Y-Shift)

20 PPM O_2







Vitronics Soltec
Our reliability is your productivity

DEK

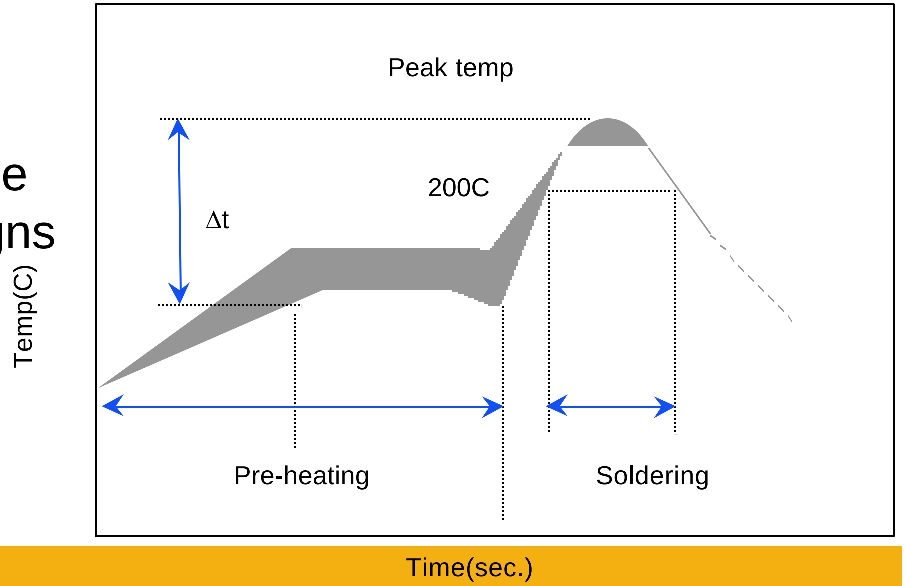
Universal

September 2000

By Universal Instruments'
Advanced Process Laboratory

Reflow Criteria (Sn/Pb Solder)

- **Atmosphere**
  - Nitrogen Reflow Increases Tombstone Defects
  - Threshold For Acceptable O_2 PPM Level Dependent On Solder Paste
- **Board Layout**
  - Component Orientation In Reflow Oven Affects Yield
- **Profile**
  - Further Work To Optimize Profile For Real Production PCB Designs Necessary
    - Ramp Up
    - Peak Temperature



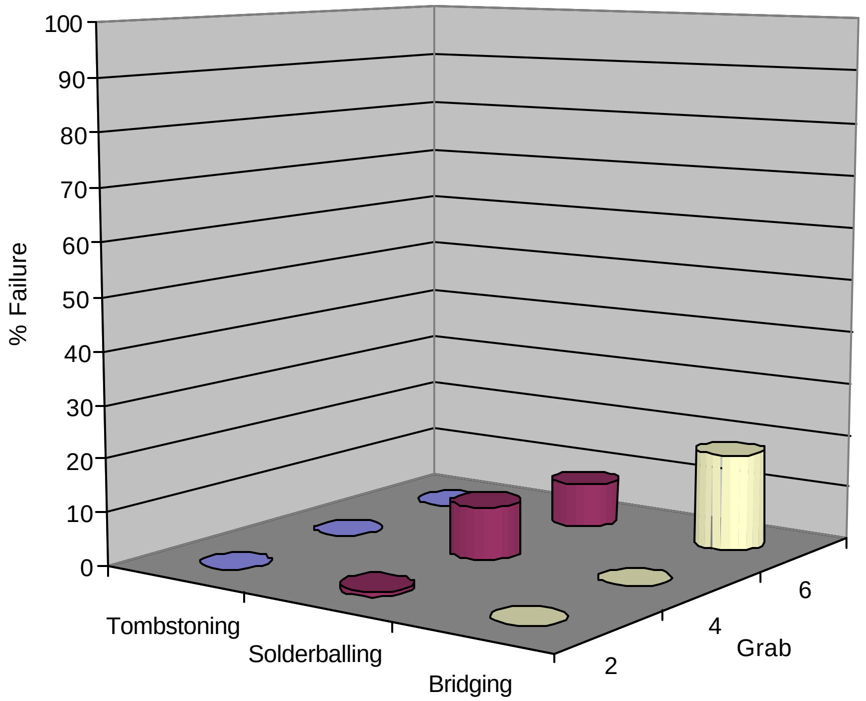
LEAD-FREE ASSEMBLY

September 2000

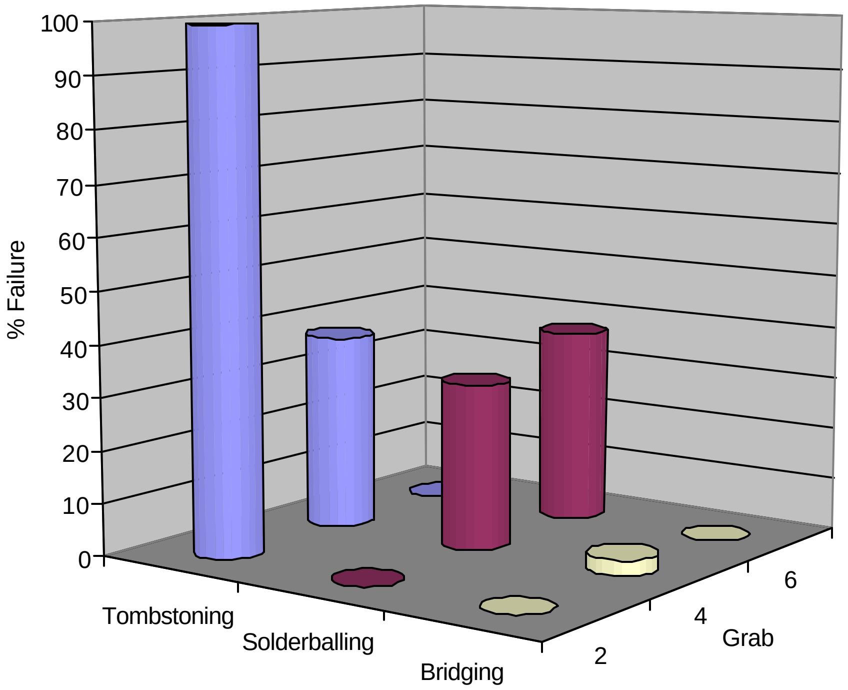
By Universal Instruments'
Advanced Process Laboratory

Sn/Ag/Cu Versus Sn/Pb

- **4-mil Print Offset (Y-Shift), 20 PPM O_2**



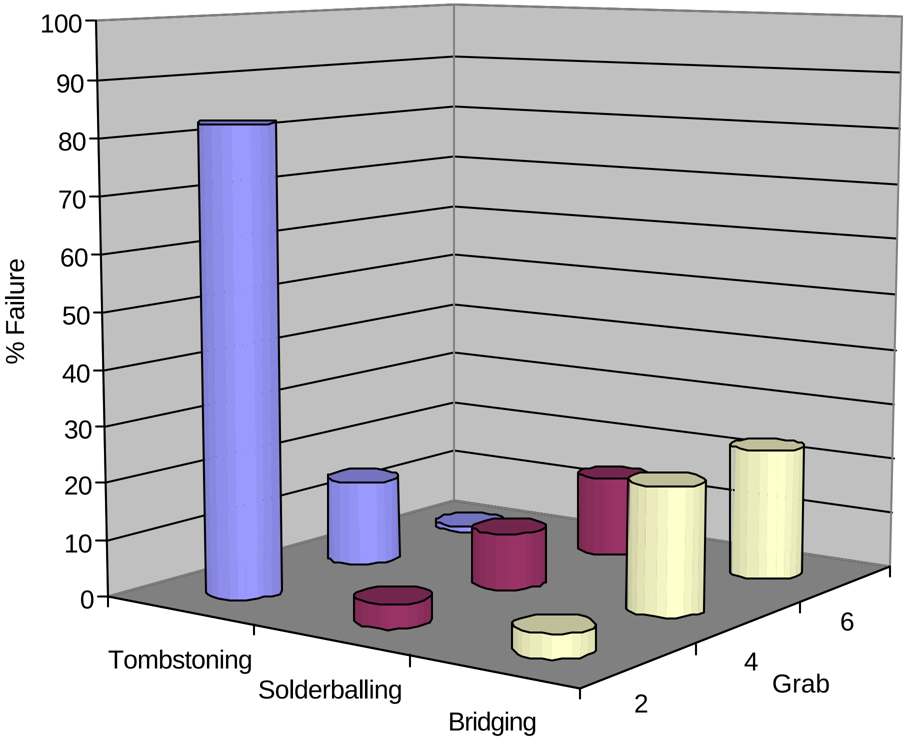
Sn95.5/Ag4.0/Cu0.5



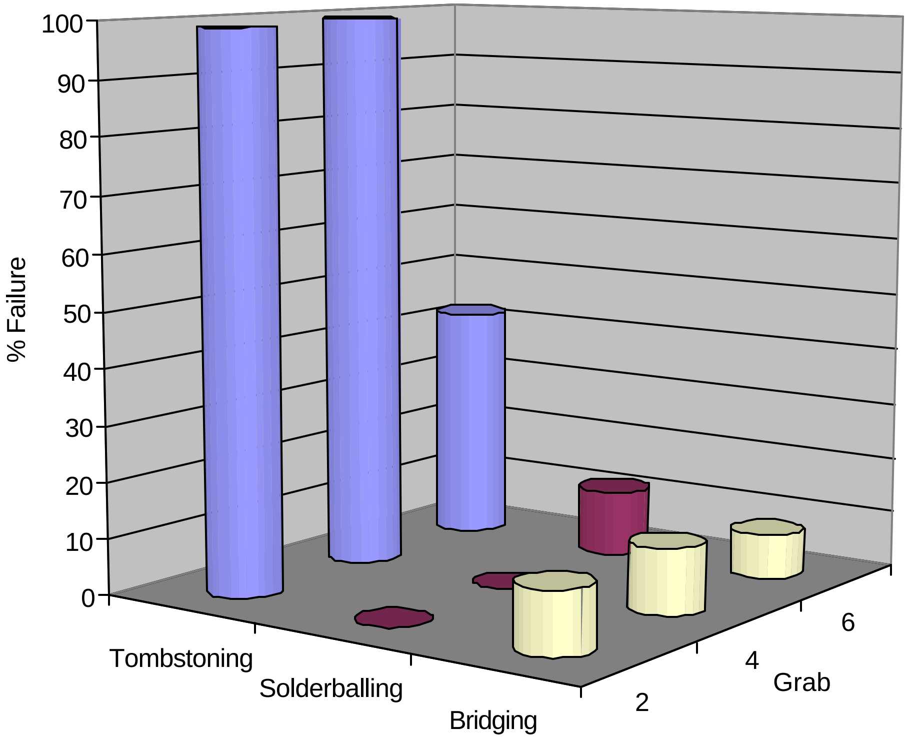
Pb37/Sn63

Sn/Ag/Cu Versus Sn/Pb

- **6-mil Print Offset (Y-Shift), 20 PPM O_2**



Sn95.5/Ag4.0/Cu0.5



Sn63/Pb37

CONCLUSIONS

Vitronics Soltec
Our reliability is your productivity

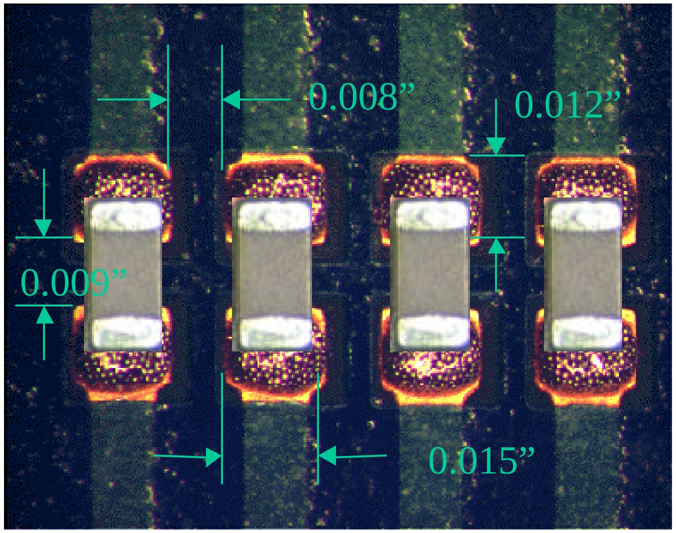
DEK

Universal
EQUIPMENT IN ELECTRONIC ASSEMBLY

September 2000

By Universal Instruments'
Advanced Process Laboratory

Testing Results



- **Pad Size**
  - 12 x 15 x 9 mils
- **Stencil**
  - 11 x 15 mil Aperture
  - 5-mil Thick Foil
- **Defect Sensitivity**
  - To Minimize Tombstones: High Accuracy / All Grab Levels
  - To Minimize Bridges: High Accuracy / Low Grab Levels
  - To Minimize Solderballs: Tolerates Inaccuracy / Low Grab Levels
  - Best Scenario: High Accuracy / Low Grab Levels
  - Fewer Defects With Sn/Ag/Cu
  - Fewer Defects With Air Reflow
  - High Yield Assembly At 4-mil Pad Spacing Achieved

0201 Process Guidelines

- **Printing**
  - Paste Material Has High Impact On Yield
    - Particle Size, No Clean / Water Soluble, Alloy (Sn/Pb, Lead Free), Vendor
  - Print Direction Can Contribute To More Uniform Paste Deposits
  - Print Registration More Sensitive To Tombstones Than Placement
- **Placement**
  - Minimize Placement Pressure
- **Reflow**
  - Atmosphere: O_2 PPM > 100
  - Board Design: Component Orientation, Thermally Balanced Design
  - Profile: Slower Ramp-Up

What’s Next?

- **Printing**
  - ProFlow Enclosed Print Head
  - Aperture Size & Shape
- **Placement**
  - Placement Pressure
- **Reflow**
  - Optimize Profile For Real Production PCB Designs
    - Ramp Up
    - Peak Temperature
- **Yield**
  - Large Scale Experiment To Determine “Real” PPM Level Using Optimized Design & Process Parameters

Contact Information

Wilhelm Prinz von Hessen
Manager Process Support
Universal Instruments Corp.
(607) 779-4970
vonhesse@uic.com

Jim Adriance
Process Research Engineer
Universal Instruments Corp.
(607) 779-5298
adriance@uic.com

George R. Westby
Director Area Array Consortium
Director SMT Laboratory
Universal Instruments Corp.
(607) 779-5258
westby@uic.com

Jeff Schake
Advanced Technologies Engineer
DEK Printing Machines, Ltd.
(607) 779-4384
jschake@dek.com

Dr. Denis Barbini
Manager Advanced Technologies
Vitronics Soltec, Inc.
(607) 779-5016
dbarbini@us.vitronics-soltec.com