



**inEMI**

International Electronics Manufacturing Initiative

# Pb-Free Wave Soldering Project

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*APEX 2007*

Advancing manufacturing technology

# Phase I Project Participants



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# 2007 iNEMI Wave Roadmap

Parameter	Metric	2005	2007	2009	2011	2017
Wave/Selective Solder Flux	VOC free (%)	25	40	50	60	90
	Halogen free (%)	90	95	95	95	95
Wave/ Selective Lead-Free Alloy	Utilization % LF	30	60	80	85	90
	% SAC vs. other LF alloy	95/5	90/10	80/20	80/20	70/30
Minimum feasible PTH pitch in wave/selective soldering	Mil [mm]	80 [2.00]	60 [1.50]	50 [1.27]	50 [1.27]	40 [1.00]
Conventional/Selective Wave Soldering	utilization % (conventional/selective)	80/20	75/25	70/30	70/30	65/35
SMT paste in hole/Wave Soldering	Utilization %	< 5 %	< 5 %	< 5 %	< 5 %	< 5-10 %
Pre-heat Process Temperature	<sup>0</sup> C	95-130	100-160	100-160	100-160	100-160
Wave pot Temperature	<sup>0</sup> C	255-265	260-275	260-275	260-275	260-275
Wave/Selective solder contact time	second	3-5	3-7	3-7	3-7	3-7
Environment process	N <sub>2</sub> /Air	50/50	60/40	60/40	50/50	50/50



# Lead Free Wave Soldering Project Goals

This investigation looks to determine the impact of process parameters and materials on the wave soldering process and solder joint formation.

This study aims to provide insight into the process issues that one will encounter so that a rational implementation strategy for a robust lead free wave soldering process can be achieved.

The Phase I iNEMI Lead Free Wave Soldering Project focused on three critical areas:

- *Materials Selection*  
Fluxes, alloys, components, and board complexity.
- *Process Optimization*  
Defined “Window of Opportunity” based on flux amount, preheat temperature, contact time, solder temperature, wave configuration, and atmosphere.
- *Solder Joint Yield*  
Defined failure levels and defect types using inspection criteria – IPC class 3 combined with best practices, yield determined by hole fill characterized by 5DX data analysis.

The result of Phase I is to lay the foundation for a broader effort to characterize the reliability of through-hole joints on a test vehicle specifically designed to test the norms and practices used in tin lead wave soldering and develop new standards for lead free wave soldering.



# *Getting Started*

“brainstorming”

**Experimental design and execution**

**Equipment setup and data reporting**

**Materials**

# Design of Experiment for Phase I

- Taguchi Methodology Chosen
  - Time and cost efficient for studying multiple variables.
  - DoE based on standard Taguchi L18 ( $2^1 \times 3^7$ ) orthogonal array.
- Variable Selection
  - Brainstorming to collect list of possible variables for wave solder process. This represented perspectives of many areas of assembly.
  - Review by team members to prioritize list.
  - Discussion and consensus vote to pick final selection.

## Inner Array Variables

**Atmosphere,  
conveyor speed,  
preheat temperature,  
flux quantity,  
flux type,  
chip wave,  
solder temperature,  
board thickness**

## Outer Array Noise Factors

**SAC 305,  
Sn100C,  
SACx,  
SnPb,  
  
CuOSP finish,  
Pb-free HASL finish**

**INEMI**

# Machine Configuration

## Delta Wave Solder machine Fluxer:

- Spray fluxer
- FC7 for Alcohol and OA
- FC16 for VOC free
- Pump supply system

## Preheat configuration:

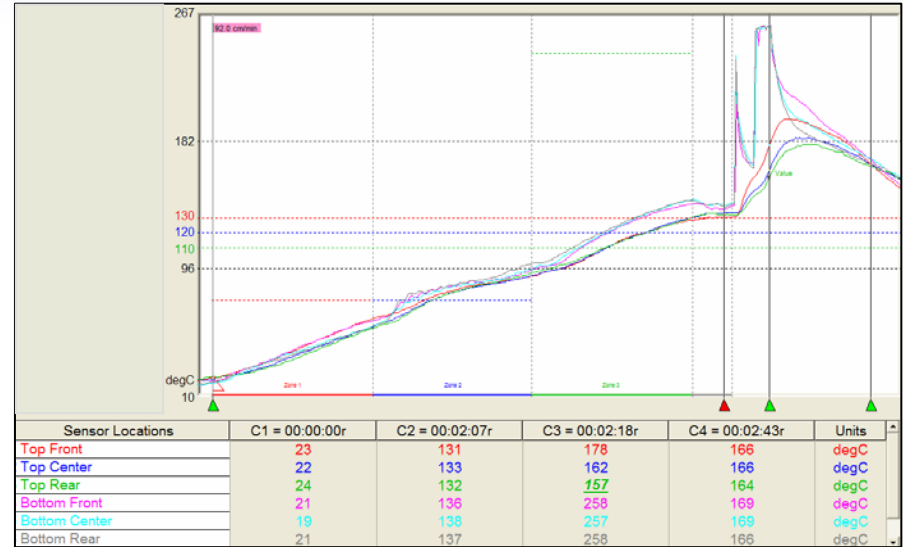
- Forced convection
- Forced convection
- Calrod

## Solder pot configuration:

- Chip wave
- Main wave

## Nitrogen:

- Inerting Blanket system between waves: 30-50-80 l/min



## Profiles Attributes

- Flux amount and penetration
- Mass measurement and pH paper
- Preheating Temp:
- ECD Super Mole
- Contact Time:
- ECD Wave Rider



# Test Vehicle "Skate"

(Cookson Design)

## Board Specification

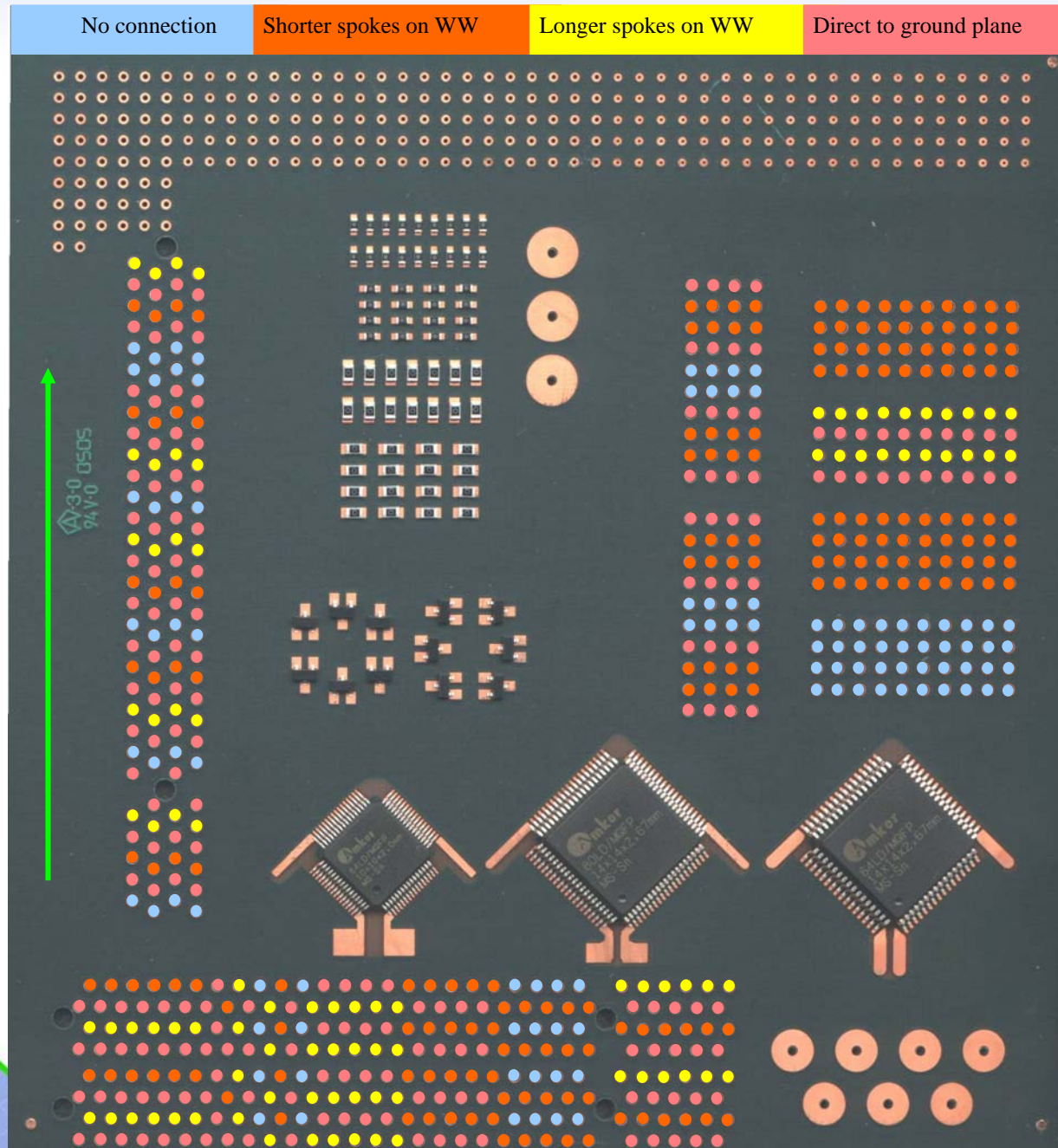
- 64 mil
- 93 mil
- 135 mil
- CuOSP
- HASL

## Alloys

- SAC 305
- SACX
- Sn100C
- SnPb

## Components

- QFP's, SOT, Passives
- PCI, Berg Stick



# Experimental Execution

Actual Run Order	DOE Standard Order	Atmosphere	Speed Ft/min (cm/min)	Preheat Temp	Flux Quantity	Flux Type	Chip Wave	Solder Temp (°C)	Board Thickness
1	5	N <sub>2</sub>	4.5 (138)	med	med	OA	on	255	0.062
2	1	N <sub>2</sub>	3 (92)	low	low	Water	on	255	0.062
3	16	Air	6 (183)	low	high	Alcohol	on	255	0.094
4	12	Air	2 (61)	high	med	Alcohol	on	255	0.135
5	14	Air	3.5 (107)	med	high	Water	off	255	0.135
6	9	N <sub>2</sub>	6 (183)	high	low	OA	off	255	0.094
7	10	Air	3 (92)	low	high	OA	off	265	0.062
8	2	N <sub>2</sub>	3 (92)	med	med	Alcohol	off	265	0.094
9	15	Air	4.5 (138)	high	low	Alcohol	on	265	0.062
10	7	N <sub>2</sub>	5 (152)	low	med	Water	on	265	0.135
11	6	N <sub>2</sub>	4.5 (138)	high	high	Water	on	265	0.094
12	17	Air	5 (152)	med	low	OA	on	265	0.135
13	13	Air	4.5 (138)	low	med	OA	on	275	0.094
14	4	N <sub>2</sub>	3.5 (107)	low	low	Alcohol	off	275	0.135
15	8	N <sub>2</sub>	6 (183)	med	high	Alcohol	on	275	0.062
16	11	Air	3 (92)	med	low	Water	on	275	0.094
17	3	N <sub>2</sub>	2 (61)	high	high	OA	on	275	0.135
18	18	Air	6 (183)	high	med	Water	off	275	0.062

**Required for logistics reason**

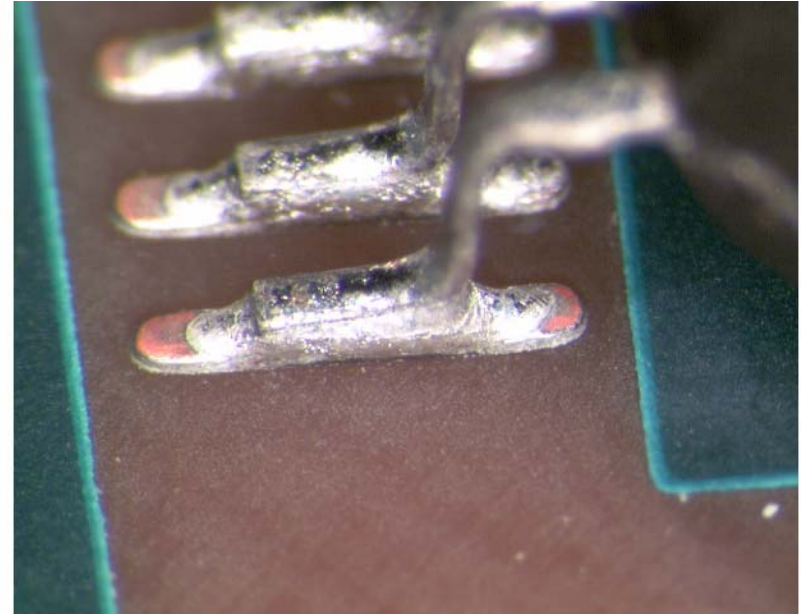
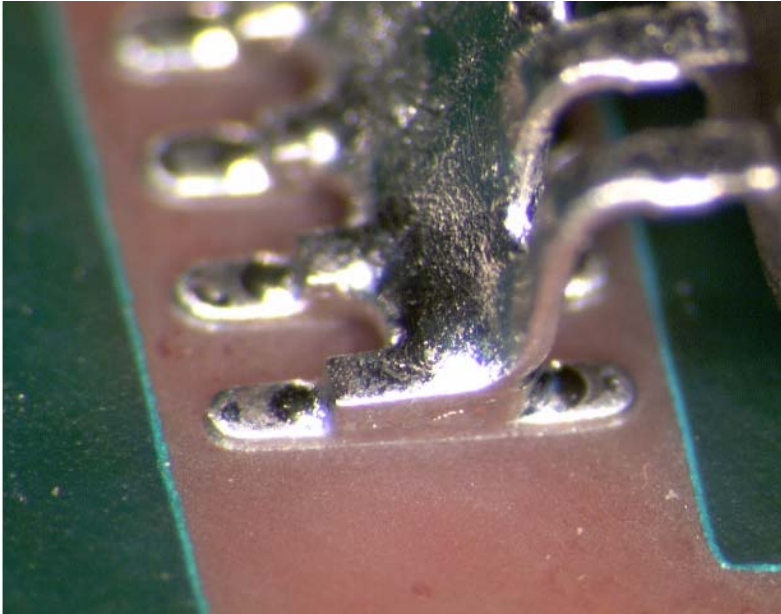
*Data Collection*  
“working hard”

**Bridging**

**Through Hole Penetration**

**iNEMI**

## *Analysis: Bridging with SAC 305*



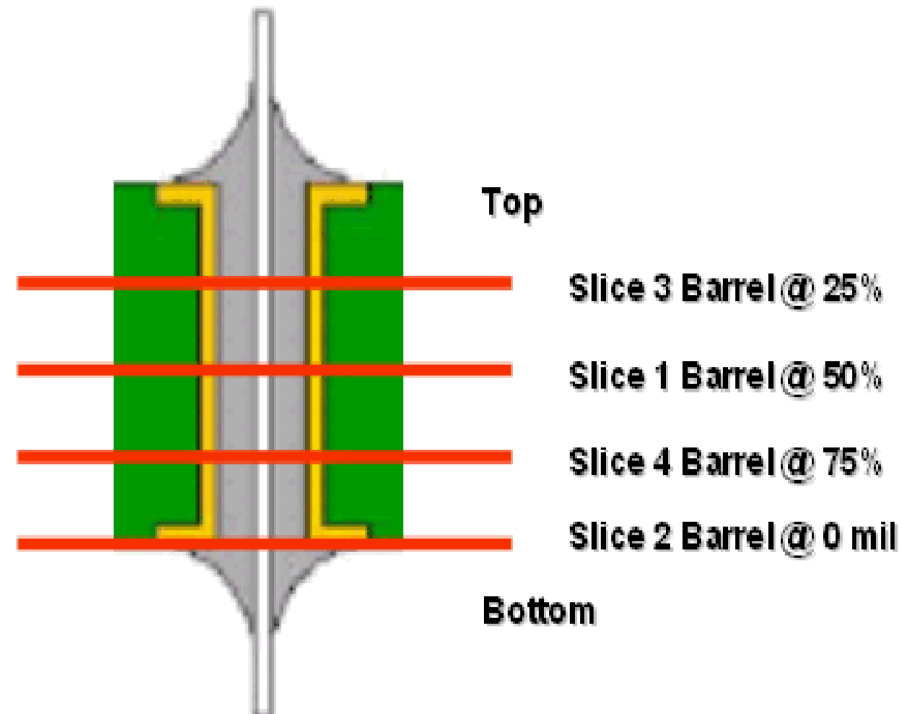
**SAC 305 on SAC 305 HASL**

**SAC 305 on OSP**

**Total shorts on HASL: 299**

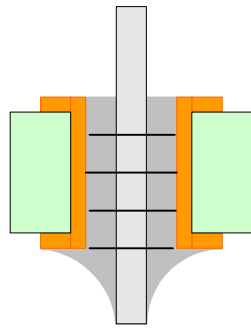
**Total shorts on OSP: 451**

# 5DX Measurement Calculation

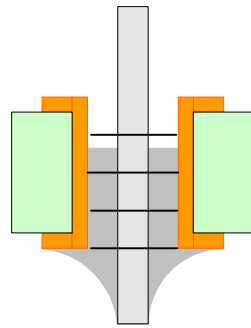


**Confirmed by select cross sectioning and typical X-Ray techniques**

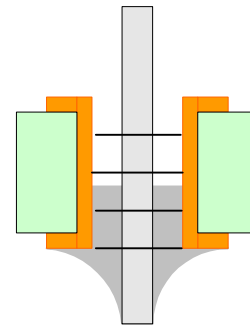
# Through Hole Inspection Criteria



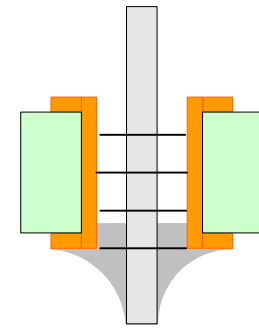
No defect



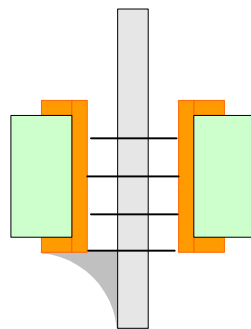
Defect  
S3-25%



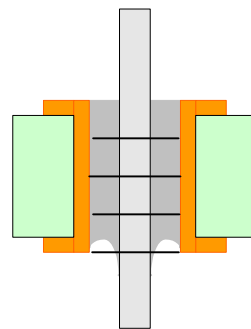
Defect  
S3-25%  
S1-50%



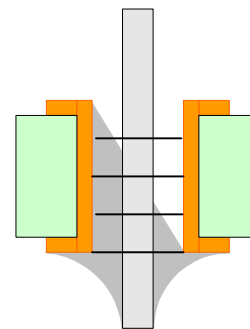
Defect  
S3-25%  
S1-50%  
S4-75%



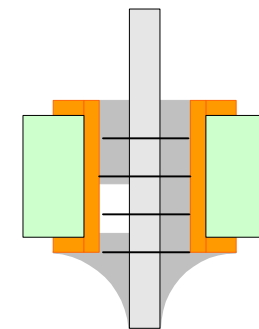
Defect  
All Slices



Defect  
S2-0%



Defect  
S3-25%  
S1-50%  
S4-75%



Defect  
S4-75%  
Void

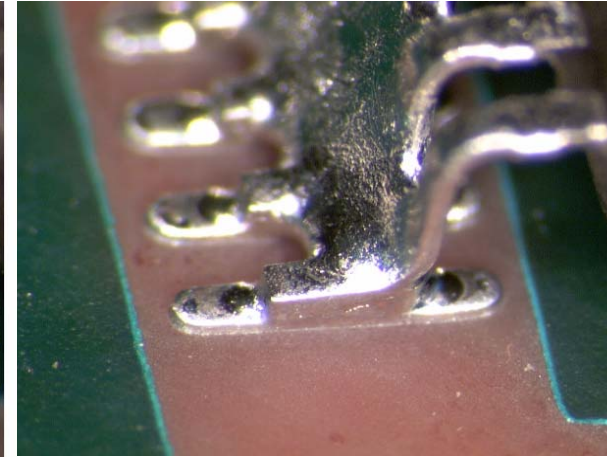
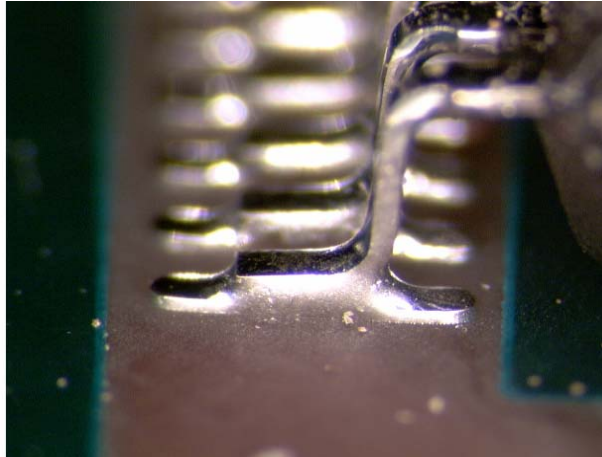
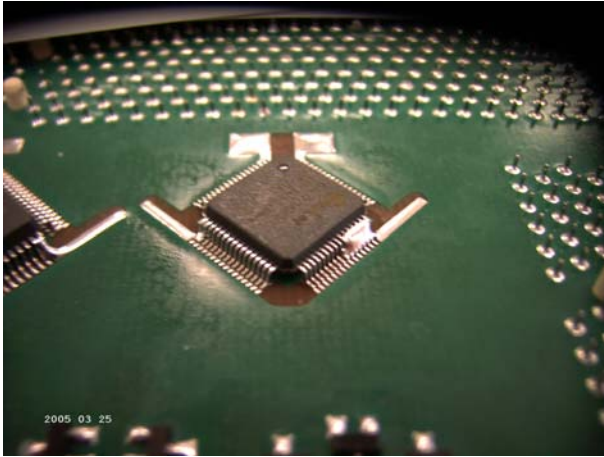
# *Analysis* “interesting”

**Influence of process parameters and materials**

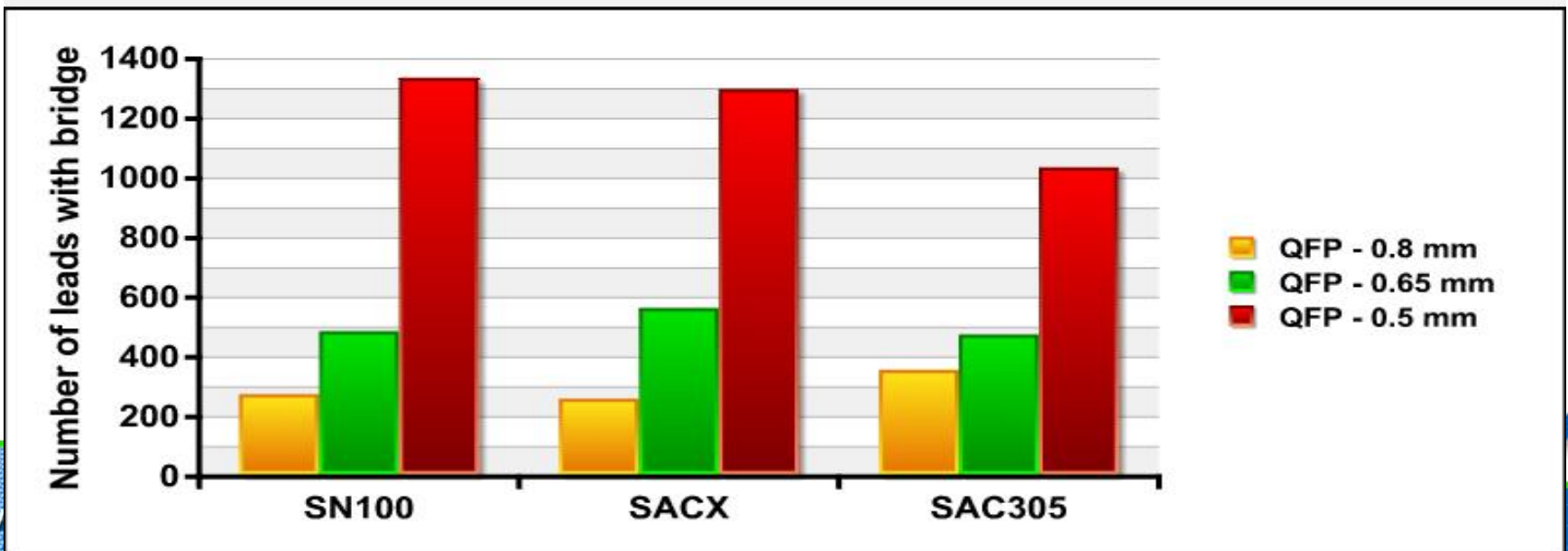
**Optimized Process**

**Confirmation**

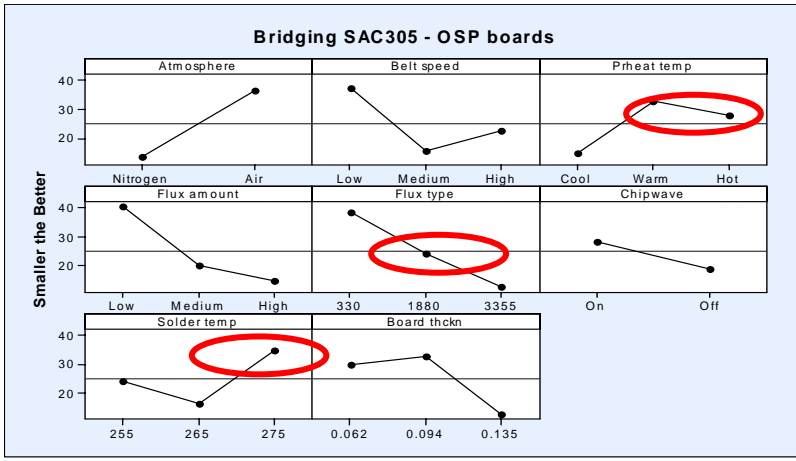
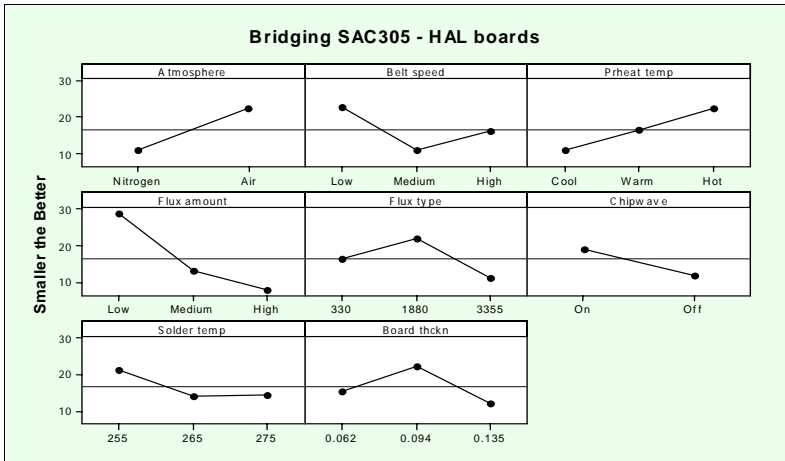
# Occurrence of Bridging on QFP



**Bridging on QFP**  
Pitch 0.8 - 0.65 - 0.5 mm



# Determination of Optimized Parameters for Minimal Bridging



## General Remark

For the PCI connector, as the board thickness increased, the lead protrusion decreased.

For the Berg Stick connector, the lead protrusion was kept constant over the three board thicknesses by mechanical means.

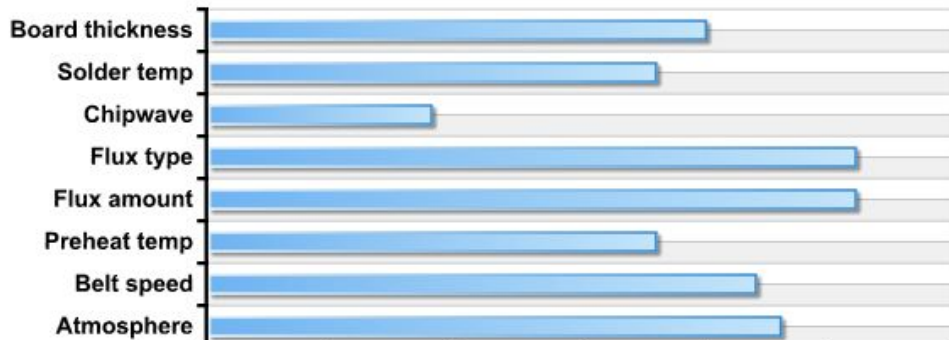
Bridging was found to be correlated to lead protrusion.



# Interactions of Process Parameters on Bridging

## Parameters impact on bridging

SAC305 - OSP boards

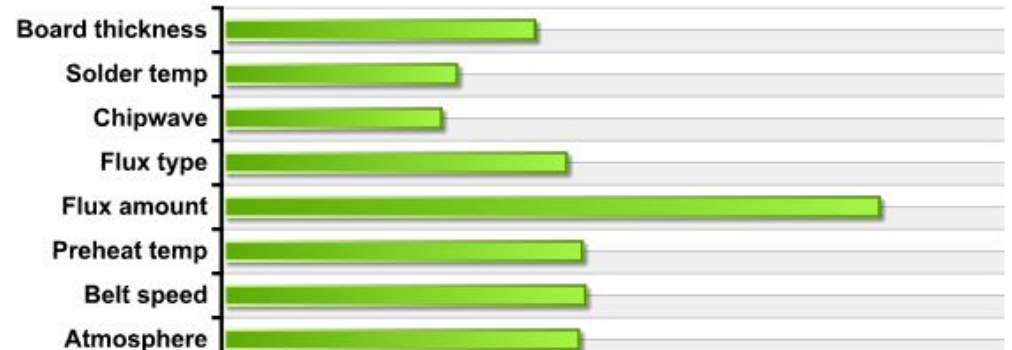


## To avoid bridging

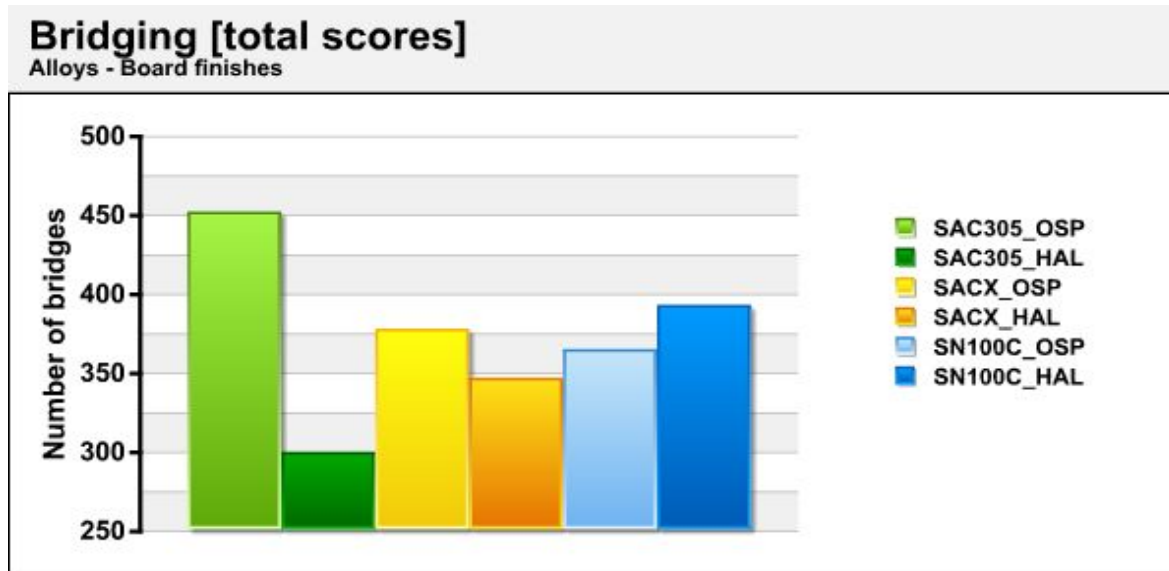
Select a proper flux, amount, and inert soldering environment

## Parameters impact on bridging

SAC305 - HAL boards



# How to Minimize Bridging Based on Process and Materials



## Recommended Settings

Atmosphere: Nitrogen

Belt speed: Med/High

Preheat temp: Cool

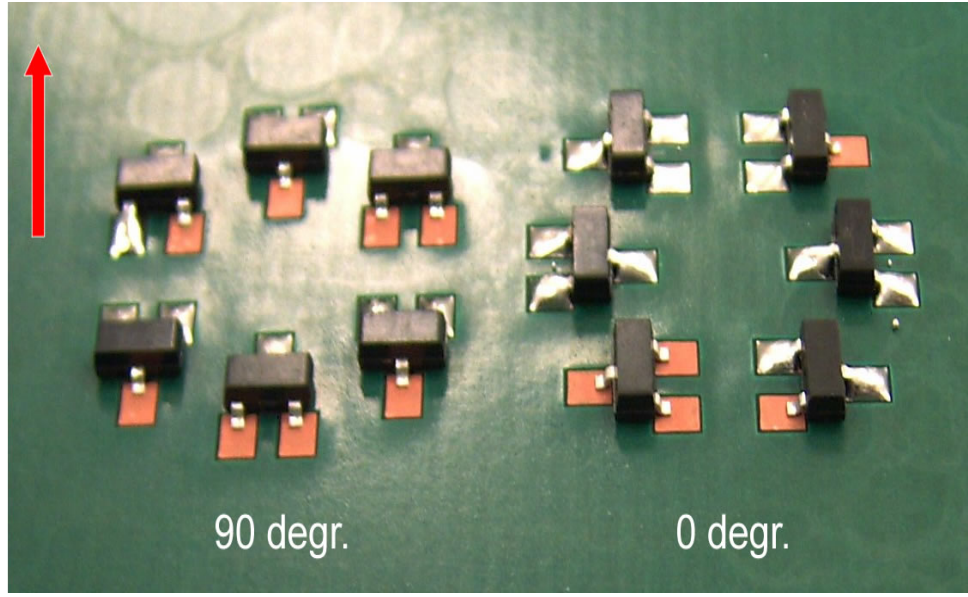
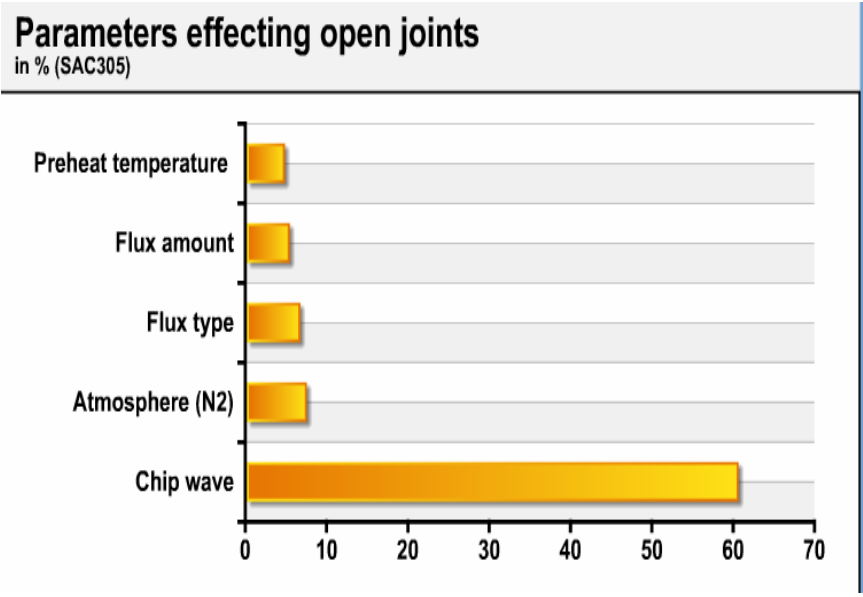
Flux amount: High

Chip wave: Off

Solder temperature: 265°C

# Open Joints/Skip on SOT's

- The orientation of the SOT is a critical design factor.  
(1.5x more defects)
- Chip wave operation results in improved soldering results.  
(Double wave former prevents shadow effects)

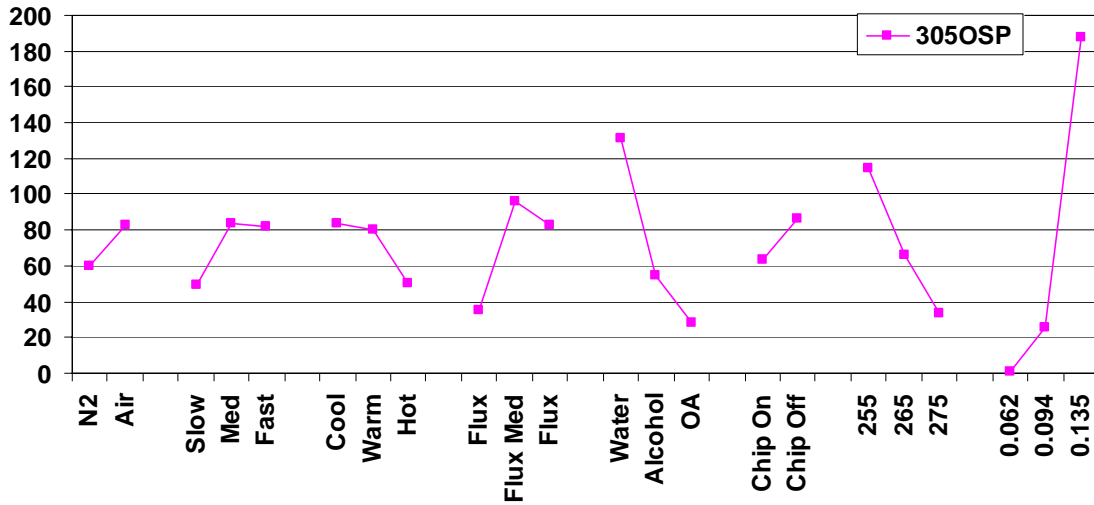


# Hole Fill Defect Analysis

## SAC 305

Actual Run Order	DOE Standard Order	Atmosphere	Speed Ft/min (cm/min)	Preheat Temp	Flux Quantity	Flux Type	Chip Wave	Solder Temp (°C)	Board Thickness	SAC 305	
										HASL	OSP
1	5	N <sub>2</sub>	4.5 (138)	med	med	OA	on	255	0.062	0.0	0.0
2	1	N <sub>2</sub>	3 (92)	low	low	Water	on	255	0.062	2.0	2.7
3	16	Air	6 (183)	low	high	Alcohol	on	255	0.094	41.0	44.0
4	12	Air	2 (61)	high	med	Alcohol	on	255	0.135	32.7	200.0
5	14	Air	3.5 (107)	med	high	Water	off	255	0.135	399.0	394.3
6	9	N <sub>2</sub>	6 (183)	high	low	OA	off	255	0.094	48.0	44.3
7	10	Air	3 (92)	low	high	OA	off	265	0.062	0.0	0.0
8	2	N <sub>2</sub>	3 (92)	med	med	Alcohol	off	265	0.094	3.0	0.0
9	15	Air	4.5 (138)	high	low	Alcohol	on	265	0.062	0.0	0.0
10	7	N <sub>2</sub>	5 (152)	low	med	Water	on	265	0.135	358.3	350.3
11	6	N <sub>2</sub>	4.5 (138)	high	high	Water	on	265	0.094	0.3	0.3
12	17	Air	5 (152)	med	low	OA	on	265	0.135	56.3	47.3
13	13	Air	4.5 (138)	low	med	OA	on	275	0.094	6.0	25.0
14	4	N <sub>2</sub>	3.5 (107)	low	low	Alcohol	off	275	0.135	56.7	80.3
15	8	N <sub>2</sub>	6 (183)	med	high	Alcohol	on	275	0.062	2.3	3.0
16	11	Air	3 (92)	med	low	Water	on	275	0.094	1.7	37.0
17	3	N <sub>2</sub>	2 (61)	high	high	OA	on	275	0.135	58.7	55.0
18	18	Air	6 (183)	high	med	Water	off	275	0.062	1.0	1.0

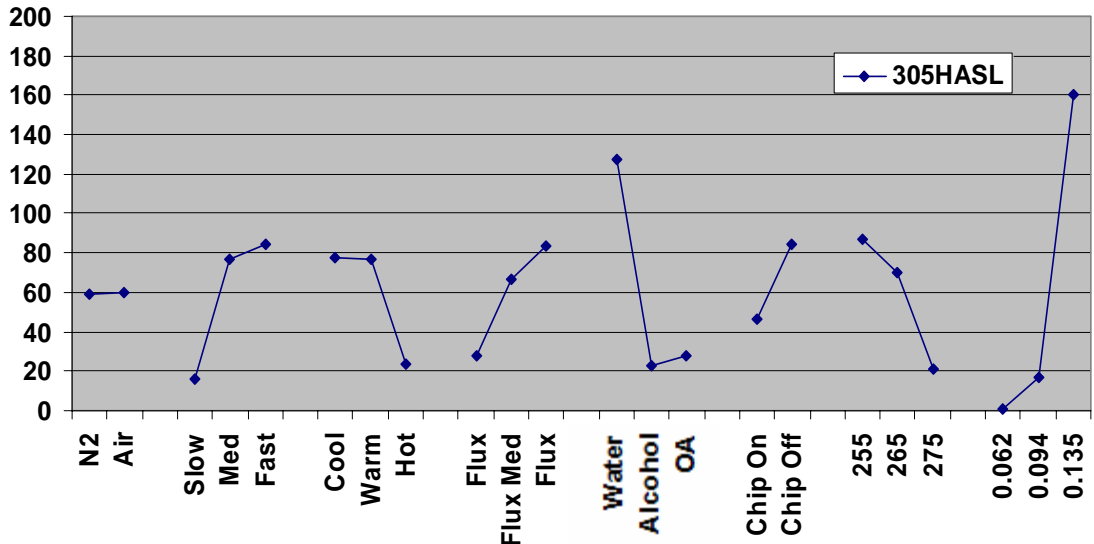
Response: Mean Count  
Average Number of Holes per Board w/<75% Fill  
SAC305



## Impact of Process Parameters on Hole Fill

SAC 305

Response: Mean Count  
Average Number of Holes per Board w/<75% Fill  
SAC305



# Confirmed Optimized Process

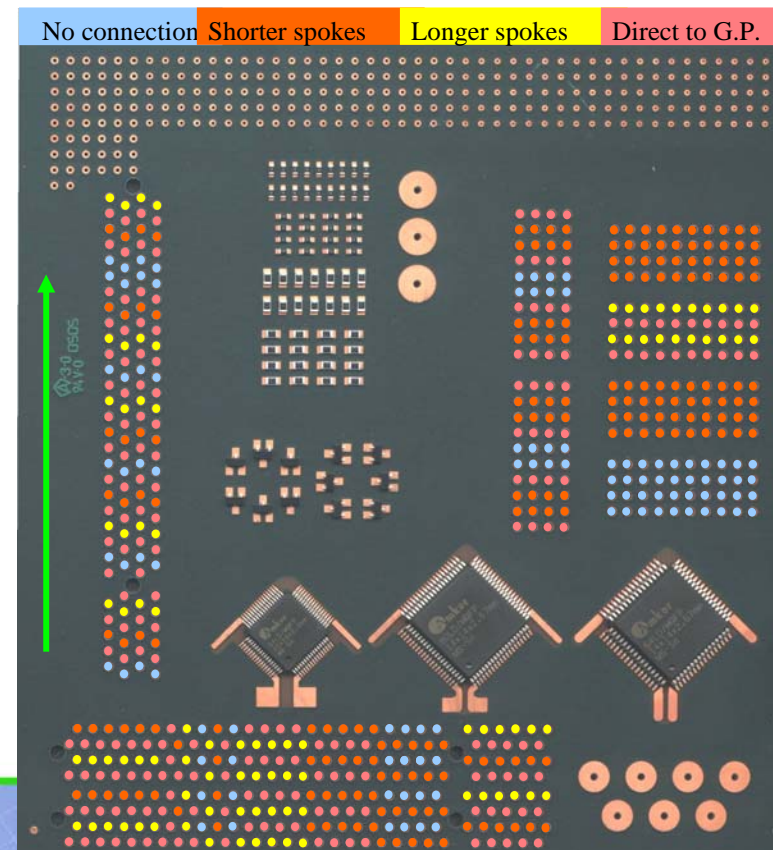
Alloy	Atmosphere	Speed	Preheat Temperature	Flux Amount	Flux Type	Solder Temperature	Board Thickness
		(ft/min)	(°C)			(°C)	(mil)
SAC 305	N <sub>2</sub>	3	130	Med	Alcohol	265	62, 93, 135
SACx	N <sub>2</sub>	3	110	Med	Alcohol	265	62, 93, 135
SN100C	N <sub>2</sub>	3	110	Med	Alcohol	265	62, 93, 135

- **Process was confirmed by soldering at the defined process settings and materials.**

# Confirmation Results

- **Process confirmation was not positive for the 135 mil board indicating the influence of board complexity and lead protrusion.**

Board Thickness	SAC305	SACx	Sn100C
62 mil	0	0	0
93 mil	0	0	0
135 mil	2	7	3



# *Trends*

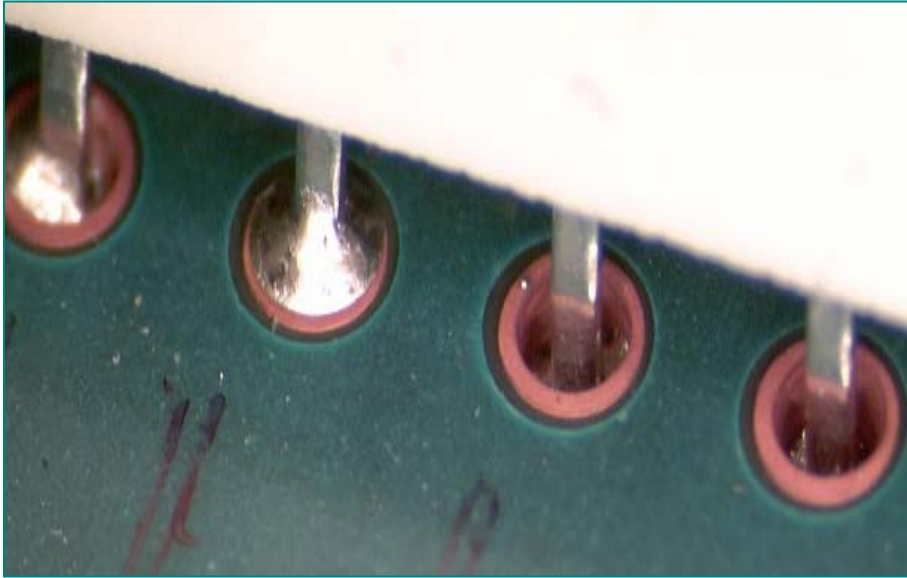
“learning as we go”

## Points of Interest

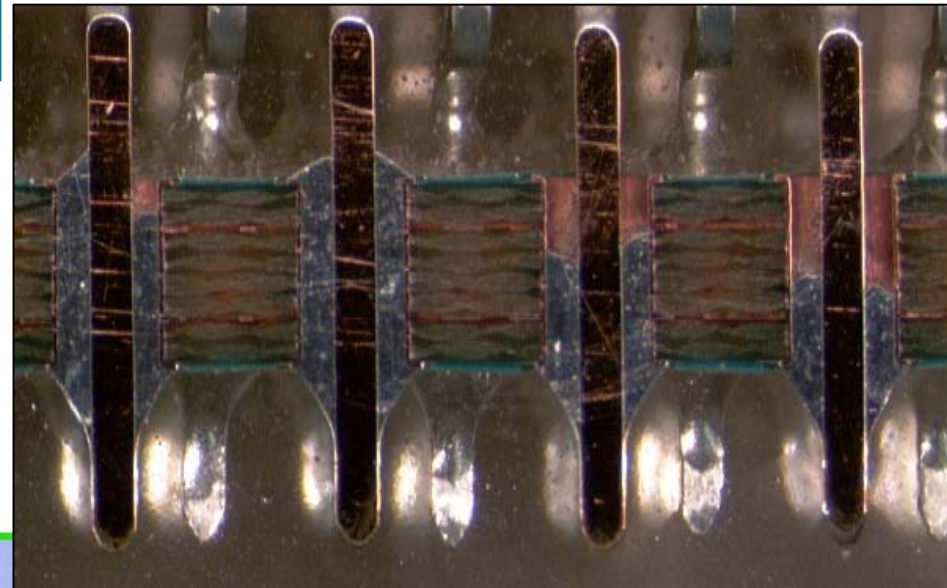
# Influence of Copper Tie-In

## Root Cause Analysis

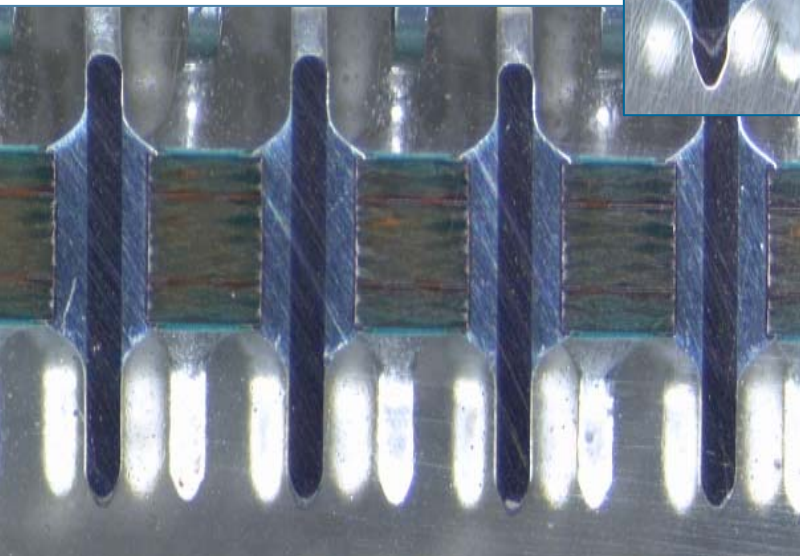
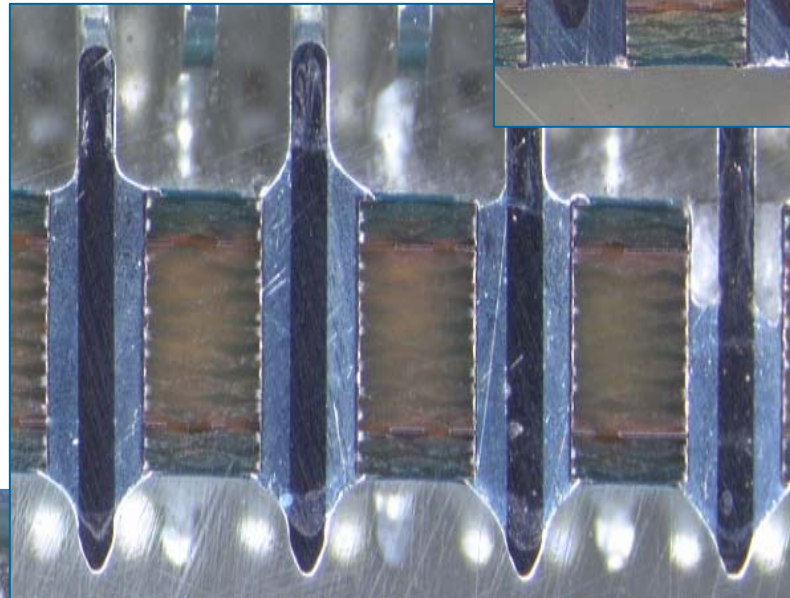
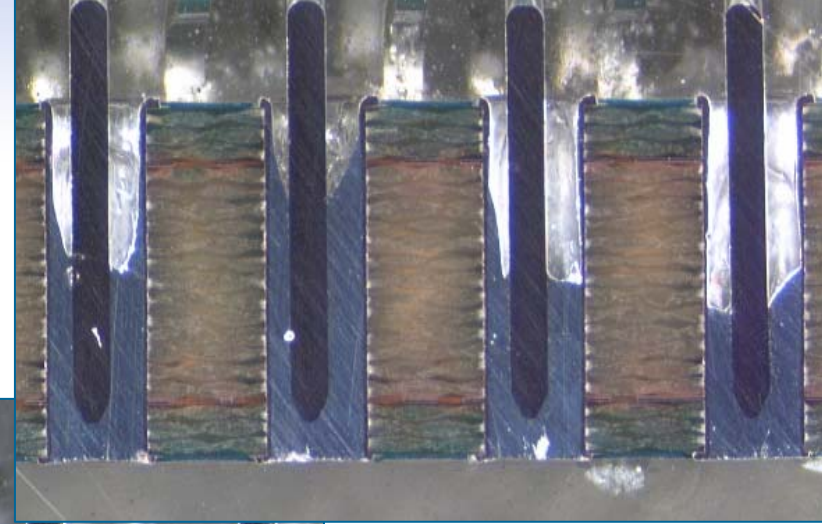
- An un-optimized process will produce such results.
- Board complexity – thickness and layers – will significantly influence the process' window of opportunity.



Short spoke; no tie-in; long spoke; direct tie-in



# *Influence of Lead Protrusion*



Hole fill and Bridging are directly affected and trends were quantified

# Conclusions

This investigation determined the impact of process parameters and materials on the wave soldering process and solder joint formation.

This study provided insight into the process issues that one will encounter during so that a rational implementation strategy for a robust lead free wave soldering process can be achieved.

Phase I of this project provided information of each of the critical areas that was the focus.

## ***Materials Selection***

The interaction of the various materials on the formation of defects was quantified.

## ***Process Optimization***

Determined and tested the optimized process based on materials and parameter control.

## ***Solder Joint Yield***

Defined failure levels and defect types using inspection criteria – IPC class 3 combined with best practices, yield determined by hole fill characterized by 5DX data analysis.

The result of Phase I was to lay the foundation for a broader effort to characterize the reliability of through-hole joints on a test vehicle specifically designed to test the norms and practices used in tin lead wave soldering and develop new standards for lead free wavesoldering.

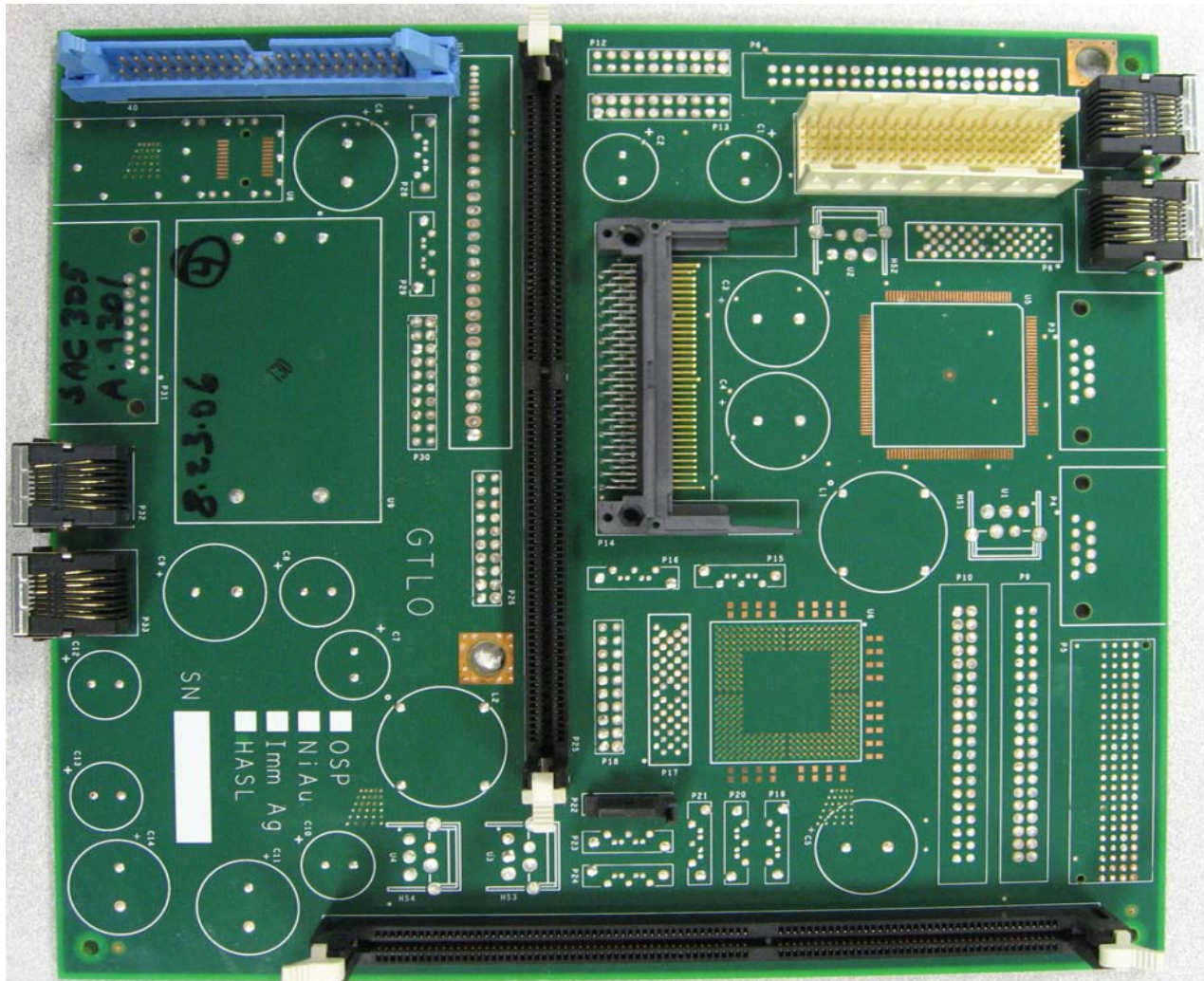
*Phase II*  
“the end goal”

**Unique Board Design**

**Fixed Process**

**Lead Free Solder Joint Performance**

# GTLO Test Vehicle



Test Condition	Alloy	Thickness	Surface Finish
Initial Analysis (X-section, X-ray, Pull, Shear, etc...)	SnPb	0.062	OSP
			NiAu
			ImmAg
		0.093	HASL
			OSP
			NiAu
	SAC	0.062	ImmAg
			HASL
			OSP
		0.093	NiAu
			ImmAg
			HASL
SnCuNi	0.062	OSP	
	0.093	NiAu	
SACx	0.062	OSP	
	0.093	NiAu	
ATC -40 to 125C	SnPb	0.062	OSP
			NiAu
			ImmAg
		0.093	HASL
			OSP
			NiAu
	SAC	0.062	ImmAg
			HASL
			OSP
		0.093	NiAu
			ImmAg
			HASL
SnCuNi	0.062	OSP	
	0.093	NiAu	
SACx	0.062	OSP	
	0.093	NiAu	
ATC 0 to 100C	SnPb	0.062	OSP
		0.093	NiAu
		OSP	
	SAC	0.062	NiAu
		0.093	OSP
		OSP	
Drop	SnPb	0.062	NiAu
		0.093	OSP
		OSP	
	SAC	0.062	NiAu
		0.093	OSP
		OSP	
Vibration	SnPb	0.062	NiAu
		0.093	OSP
		OSP	
	SAC	0.062	NiAu
		0.093	OSP
		OSP	
SnCuNi	0.062	NiAu	
		OSP	
		OSP	
	0.093	NiAu	
		OSP	
		OSP	

# Scope

Interest	Test	Alloy	Thickness	Surface Finish
Core - Baseline	-	-	-	-
Temp Age	-40 to 125C	SAC	0.093	OSP
Selective Solder	-40 to 125C	SAC	0.093	OSP
other	-40 to 125C	SAC	0.093	OSP

- 600 boards
- 300,000 components
- 3 alloys, 4 finishes, 1 flux, 2 thicknesses



# Acknowledgements

- **The authors and project members would like to gratefully thank the following people for support during the execution of Phase I and its analysis: *John Norton, Norm Faucher, Gerjan Diepstraten, and Bruce Quigley* for build support, *Ursula Marquez de Tino* for the many cross sections, *Sam Greenfield* for performing all of the 5DX analysis.**
- **The authors would also like to thank the management of each participating company for their support in this endeavor. Without their continued support, this project would not have achieved its Phase I goals.**



**inEMI**

International Electronics Manufacturing Initiative

# Lead-Free Rework Optimization Project

*Project Chair: Jasbir Bath  
Solectron Corporation*

*Project Co-Chair: Craig  
Hamilton,  
Celestica*

*IPC APEX 2007  
February 20, 2007*

*Advancing manufacturing technology*