Design for Manufacturability in Lead Free Wave Solder Process

Ramon Mendez
Paper presented by **Craig Hamilton**

Celestica
Calle Octava # 102 Parque Industrial Monterrey
Apodaca - Nuevo Leon - 66600
Mexico
+52 81 8156 1500 ext 2099
rmendez@celestica.com

EXECUTIVE SUMMARY

The recent use of lead free alloys has made the wave solder process more challenging in terms of achieving acceptable solder joints for both SMT and PTH components. It has been found that the Design for Manufacturability (DFM) guidelines, which were established for tin lead processes, in many cases do not result in the same level of quality joints when soldering with lead free alloy. Therefore, in order to improve the process yields and reduce manufacturing costs when converting to lead free, it is essential to establish DFM guidelines specifically for lead free soldering. The effect of pin to hole ratio, quantity of large copper planes connected to a pin through hole barrel, connection types for PTH and land patterns for glue and wave chip components are some of the main features which require further investigation for design optimization.

As there are a variety of lead free alloys available on the market today, each with differing properties, it is also important to determine if a set of DFM guidelines result in similar results among these various alloys.

This paper will discuss the outcome of a study of several DFM features incorporated on an internally designed test vehicle, which was created to evaluate alternative lead free alloys for Celestica. The DFM features included land pattern design and varying component spacing for chip components, pin to hole ratio and its interaction with the quantity of large copper planes connected to a PTH, quantity of large copper planes connected to a PTH and its interaction with the type of connection either solid or four spokes. The test vehicle was assembled with four Pb-free alloys (Sn-Cu-Ni, Sn-Ag-Cu-Bi, Sn-Cu-X & SAC405) and 63Sn-37Pb alloy as a baseline. The quality level of each of the described DFM features will be discussed. In addition to this, a detailed barrel fill analysis for the PTH components will be shown.

Mario Moreno, German Soto, Jessica Herrera, Teng Hoon Ng, Juthathip Fangkangwanwong Celestica Corporate (Toronto) , Celestica Mexico, Celestica Thailand

Design for Manufacturability in the Lead Free Wave Solder Process

Celestica

Presenter: Craig Hamilton

Thursday, April 3rd, 2008

Authors: Ramon Mendez, Mario Moreno, German Soto, Craig Hamilton

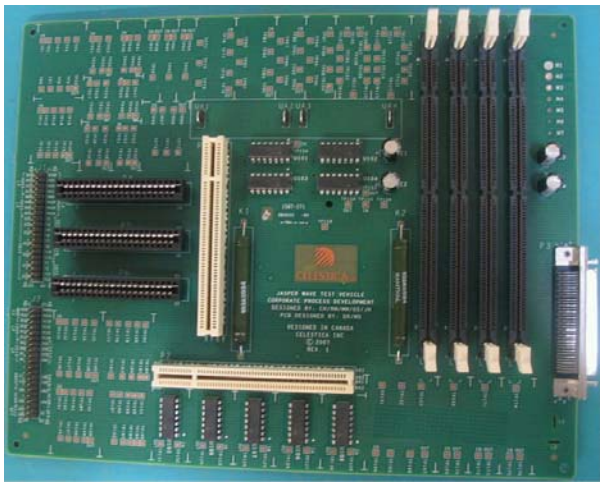
Background

It has been found that the Design for Manufacturability (DFM) guidelines for tin lead processes, in many cases do not result in the same quality level of solder joints when soldering with lead free alloys

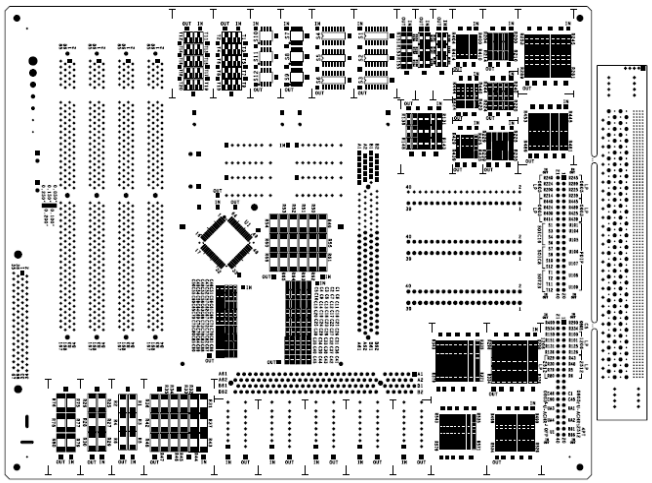
Objectives

- Evaluate the applicability of DFM guidelines established for SnPb in Pb-free process.
- Evaluate the performance of four Pb-free alloys through the DFM features studied.
- Set a reference to develop DFM guidelines for Pb-free wave soldering processes

Test Vehicle



Topside



Bottomside

- **Thickness:** 2.34mm (0.092”)
- **Dimensions:** 203.2mm x 254mm (8” x 10”)
- **Total Layers:** 12 layers
- **Ground Layers:** 4 layers (2oz Cu)
- **Surface Finish:** HighT OSP, Glicoat F2LX
- **Laminate:** High Tg FR4, Polyclad 370HR
- **Solder Mask:** Taiyo PSR-4000
- **Mid Complexity PCB**
- **Daisy chained**

Components Used for DFM Analysis

Component Type	Pin Count	Pitch	Lead finish
Power Connector	40	2.54mm	Matte Tin over Nickel
DIMM Connector	168	2.29mm	Gold over Palladium Nickel
0805 Resistor	2	N/A	Tin over Nickel
0603 Resistor	2	N/A	Tin over Nickel
0805 Capacitor	2	N/A	Tin over Nickel
0603 Capacitor	2	N/A	Tin

Experimental Details

ALLOYS		MELTING RANGE
95.5Sn-3.8Ag-0.7Cu	(SAC405)	217°C to 220°C
99.1Sn-0.7Cu-0.05Ni-(<0.01)Ge[1]	(Sn-Cu-Ni)	227°C
99.1Sn-0.7Cu-X-Y	(Sn-Cu-X)	227°C
98.6Sn-0.3Ag-0.7Cu-Bi-X-Y[2]	(Sn-Ag-Cu-Bi)	217°C to 228°C

Wave	Drilled Chip Bar and Lambda		
Preheaters		Top	Bottom
	Position 1	IR	IR
	Position 2	Convection	Convection
	Position 3		Concetion
Atmosphere	Air		
Fluxer	Selective Spray		
Flux Volume	Supplier recommendation		

Machine Configuration

Process Optimization

DOE

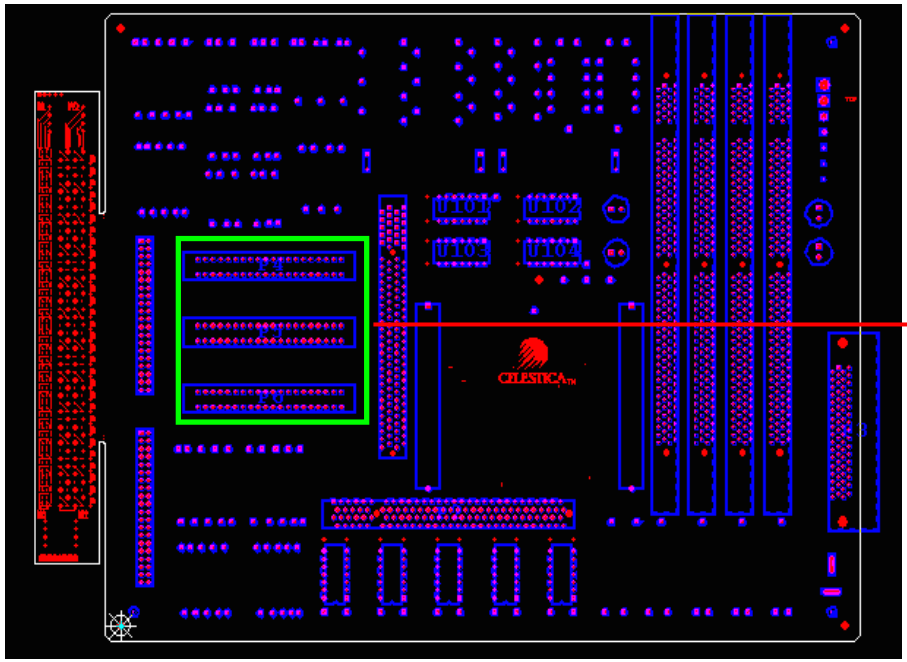
Factors	Levels		
	1	2	3
Pot Temperature	Low	Med	High
Preheat Temperature	Low	High	
Contact Time	Low	High	

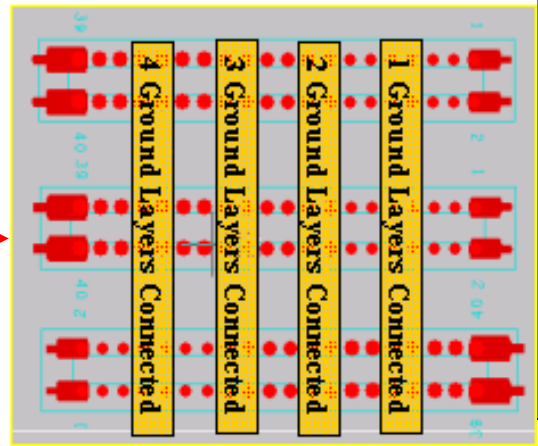
Optimal Setting

DFM Features

- Pin to hole ratio and qty. of large copper planes
- Quantity of large copper planes and PTH connection types
- Land pattern design
- Pad to pad spacing

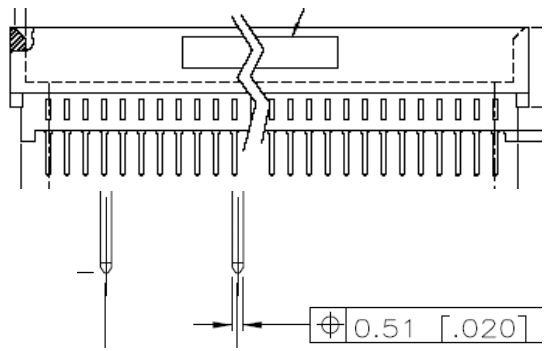
Pin to Hole Ratio and Large Copper Planes





P2H Ratio
0.71
0.63
0.60
0.57
0.56
0.50

Power Connector



Lead Diameter = 0.508mm ± 0.127mm
0.020” ± 0.005”

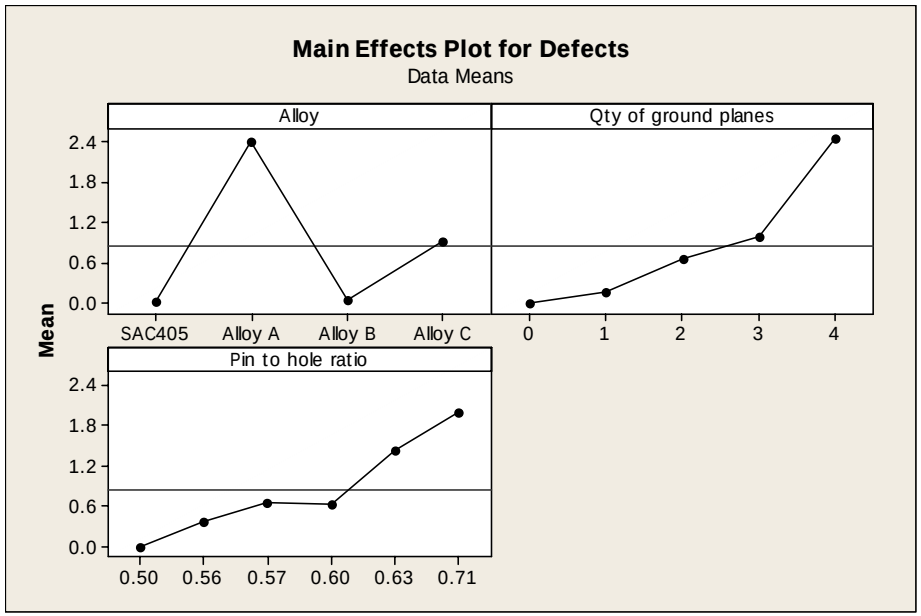
Pin to Hole Ratio and Large Copper Planes

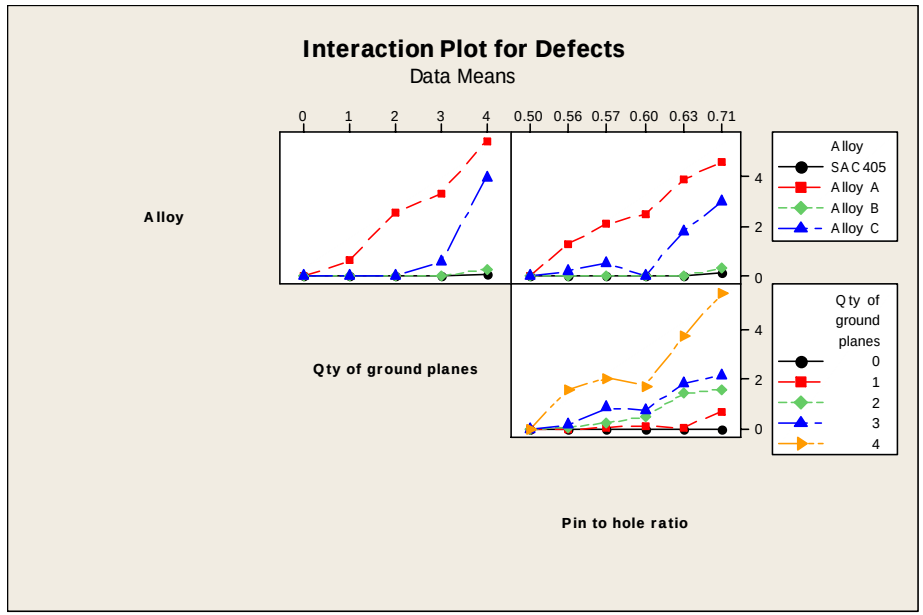
- A Full Factorial, 3 Factors DOE was used:

Factors	Levels					
	1	2	3	4	5	6
Alloy	SAC405	Alloy A	Alloy B	Alloy C		
Pin to Hole Ratio	0.50	0.56	0.57	0.60	0.63	0.71
Quantity of Ground Planes	0	1	2	3	4	

- **Response:** Barrel Fill Defects
- **Criteria:** IPC-A-610D Class 3

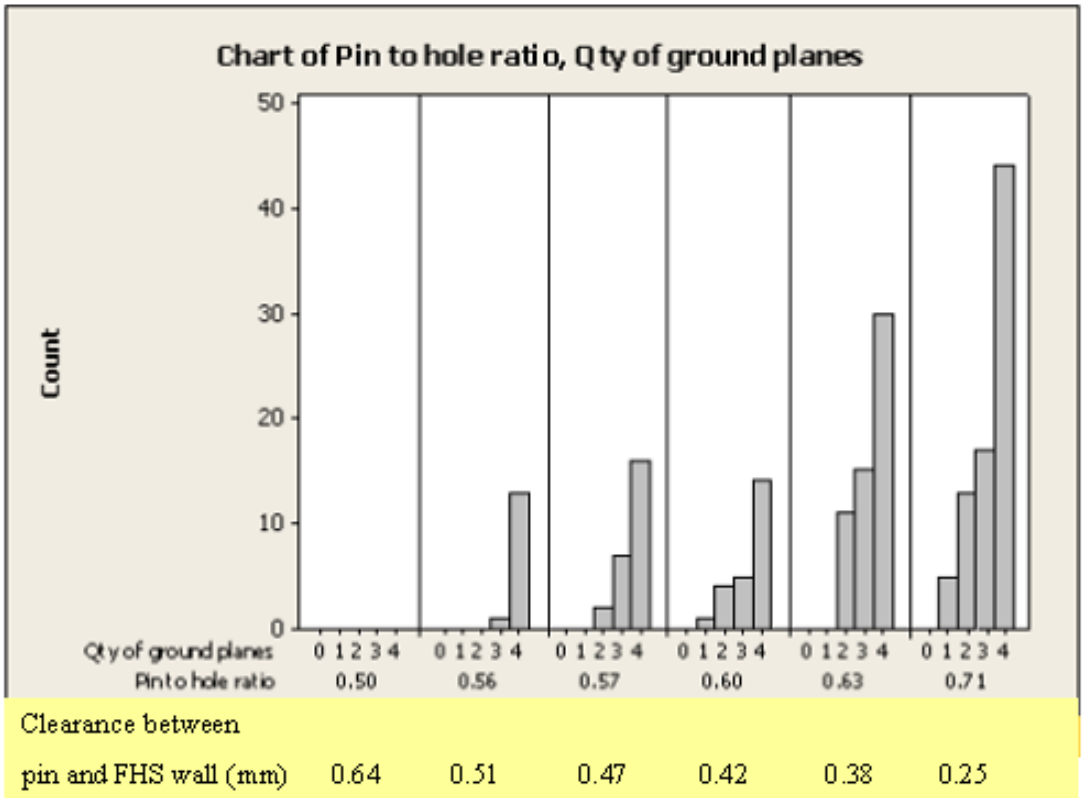
Pin to Hole Ratio and Large Copper Planes Results

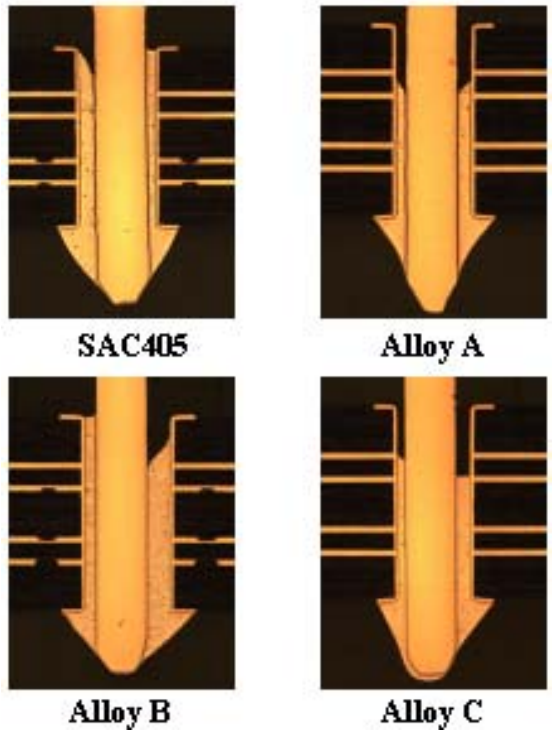




- **Alloy B is statistically similar to SAC405**
- **Alloy A showed the higher quantity of defects followed by Alloy C**
- **The higher the quantity of ground planes, the higher the quantity of defects**
- **As the finished hole size decreases (higher pin to hole ratio), the quantity of defects increases.**

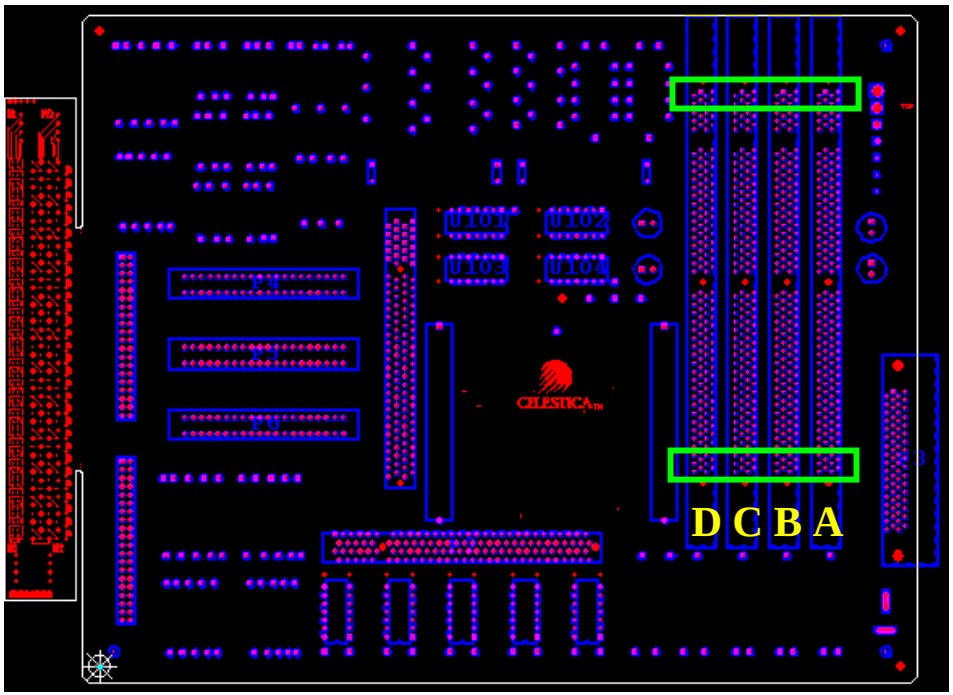
Pin to Hole Ratio and Large Copper Planes Results

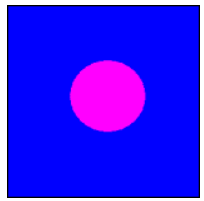




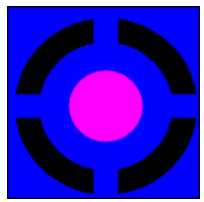
- **Barrel fill improves with decreasing P2H ratio**
- **With no ground planes connected, there is no effect of P2H ratio on defects**

Quantity of Large Copper Planes and PTH Connection Types

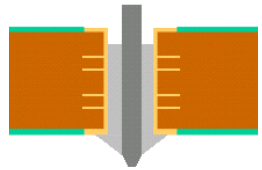




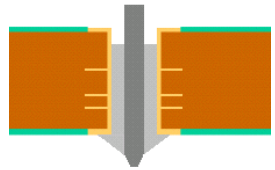
Solid Copper



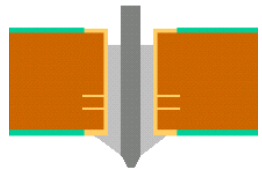
Four Spokes



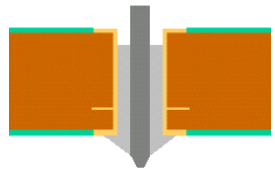
(A) 4 Ground planes



(B) 3 Ground planes



(C) 2 Ground planes



(D) 1 Ground plane

Drill

Copper

Quantity of Large Copper Planes and PTH Connection Types

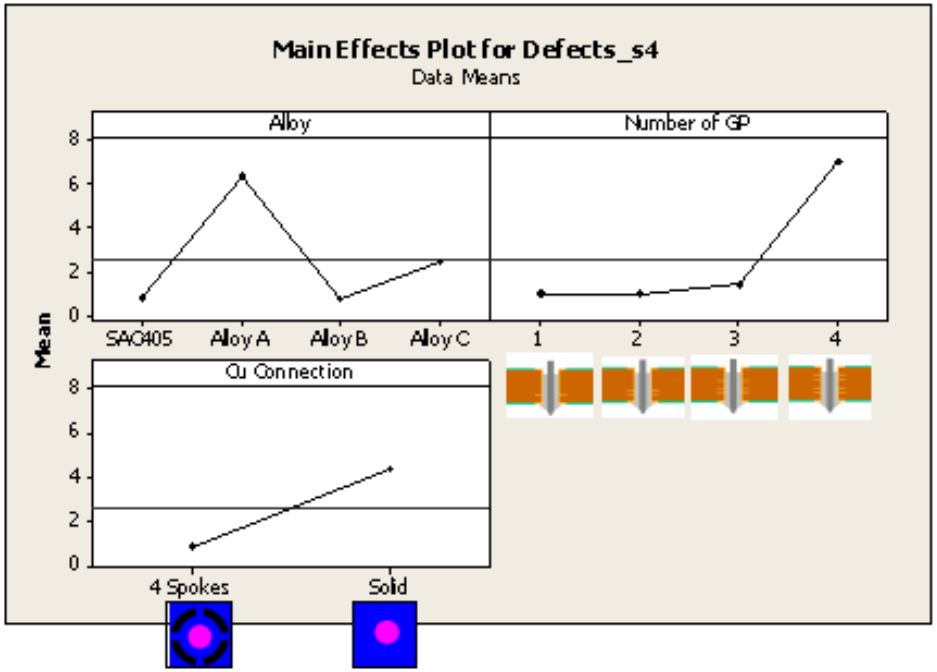
- A Full Factorial, 3 Factors DOE was used:

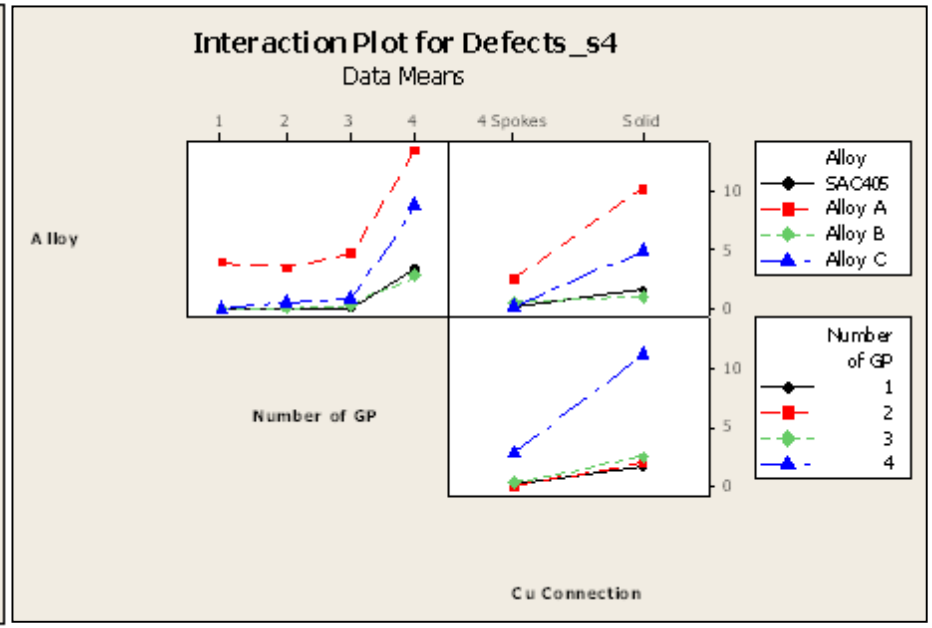
Factors	Levels			
	1	2	3	4
Alloy	SAC405	Alloy A	Alloy B	Alloy C
Quantity of Ground Planes	1	2	3	4
Ground Connection Type	4 spokes	Solid		

- **Response:** Barrel Fill Defects
- **Criteria:** IPC – 610D Class 3

Quantity of Large Copper Planes and PTH Connection Types

Results

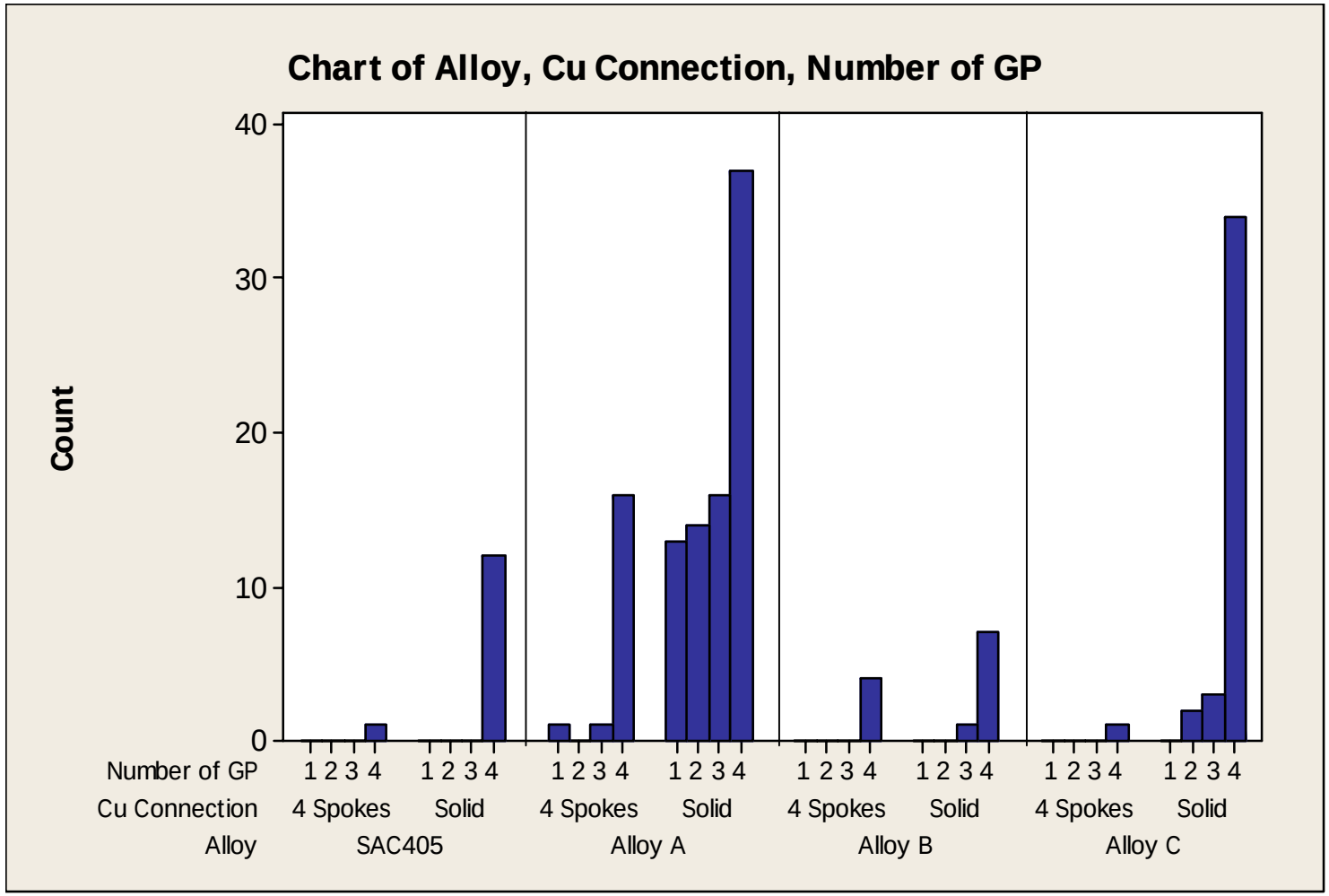




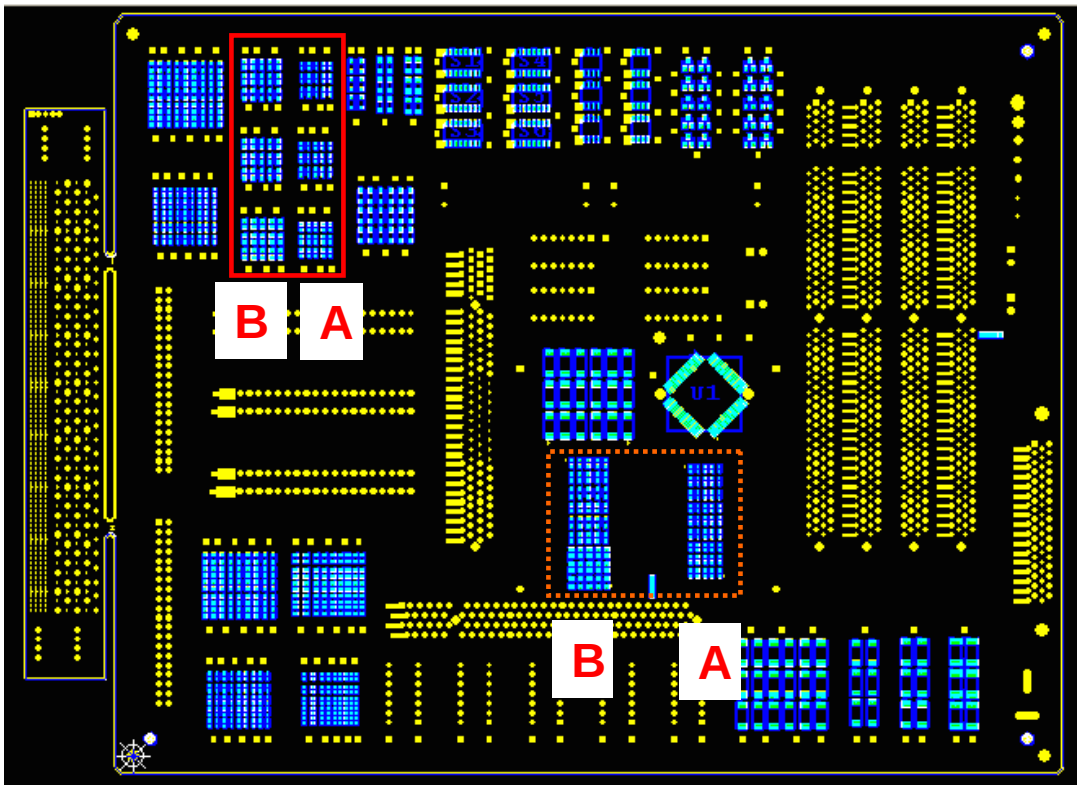
- **Alloy A showed the higher quantity of defects followed by Alloy C, SAC405 and Alloy B performed the best**
- **With four ground planes the quantity of defects increases dramatically**
- **4 spokes thermal relief helps to improve barrel fill, specially for 4 or more ground planes**

Quantity of Large Copper Planes and PTH Connection Types

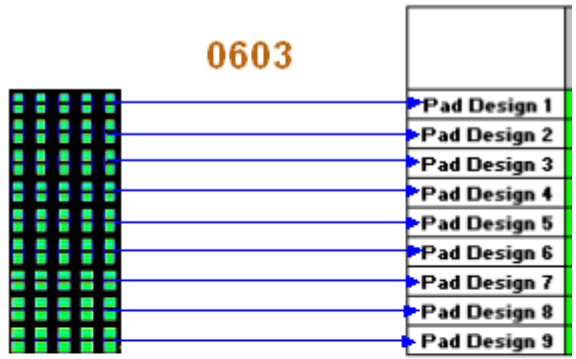
Results



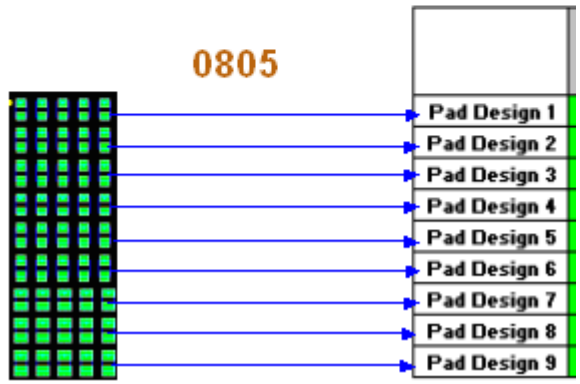
Land Pattern Design Variation



A



B



Resistors

Capacitors

Land Pattern Design Variation

DOE

Pad Design	X Width	Y Length
1	Low	Low
2	Low	Med
3	Low	High
4	Med	Low
5	Med	Med
6	Med	High
7	High	Low
8	High	Med
9	High	High

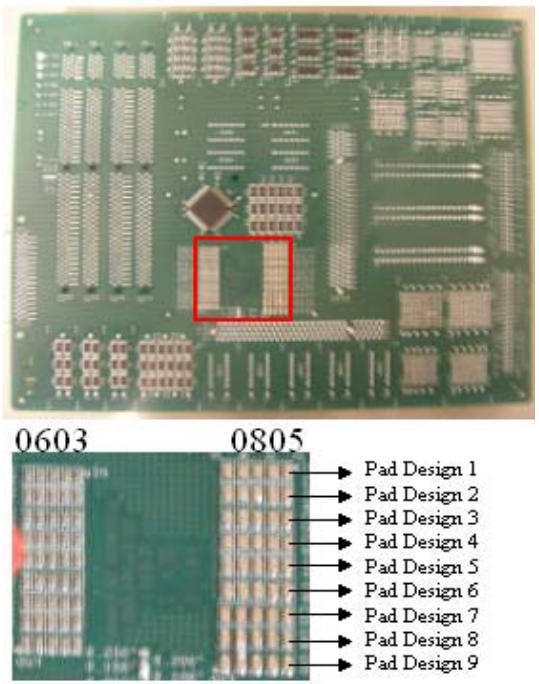
- X Low: Dimension below standard guideline for reflow pad design
- X Med: Dimension slightly below standard guideline for reflow pad design
- X High: Dimension at standard guideline for reflow pad design

- **Solders:** SAC405, SnPb and the three alternative alloys were evaluated
- **Response:** DPMO on Visual Inspection (Class 2, IPC-A-610D) and Maximum Shear Force

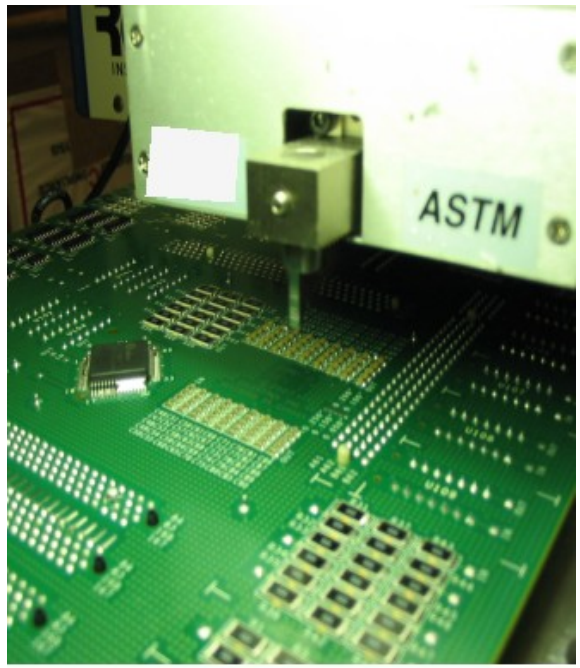
Land Pattern Design Variation

Shear Force Test

- SAC405, SnPb, Alloy A, Alloy B & Alloy C evaluated
- Five components of both 0805 and 0603 were tested for each of the 9 land pattern designs
- ASTM F1269 standard followed

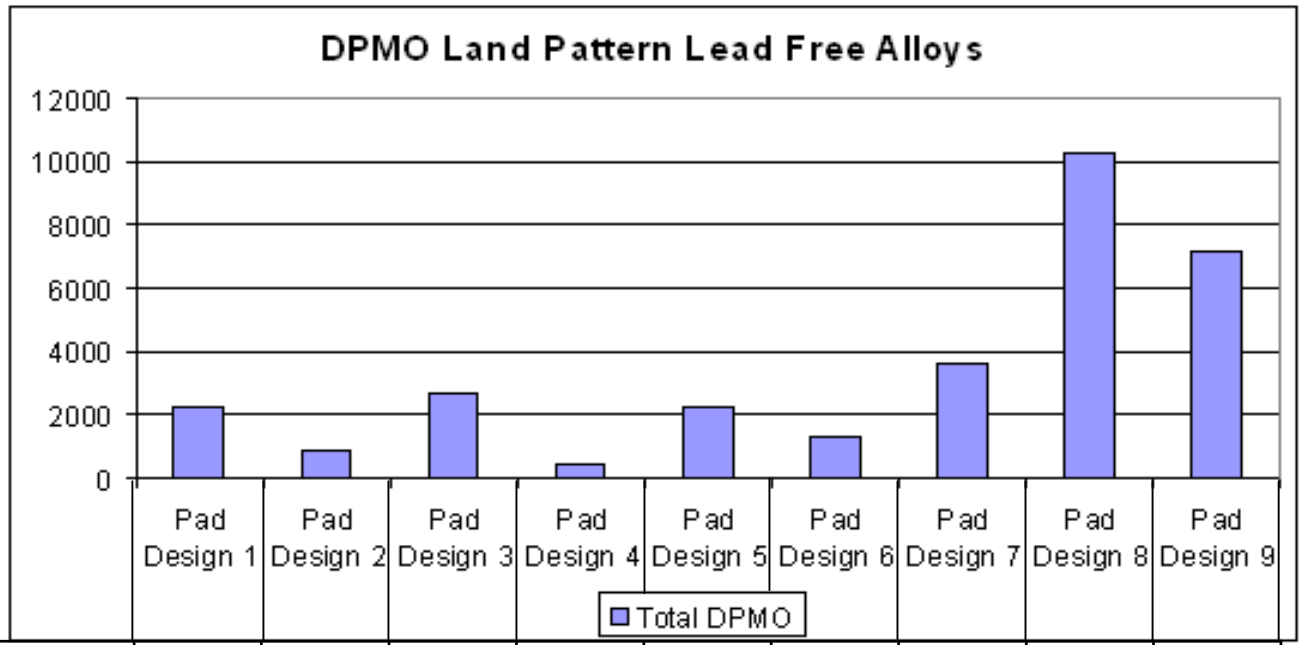


Alloy	Land pattern design	Component	Sample Size
SnPb SAC405 Alloy A Alloy B Alloy C	1	0603	5
		0805	5
	2	0603	5
		0805	5
	3	0603	5
		0805	5
	4	0603	5
		0805	5
	5	0603	5
		0805	5
	6	0603	5
		0805	5
	7	0603	5
		0805	5
	8	0603	5
		0805	5
	9	0603	5
		0805	5



Land Pattern Design Results

Combined results for the 9 different land patterns (0603 and 0805)

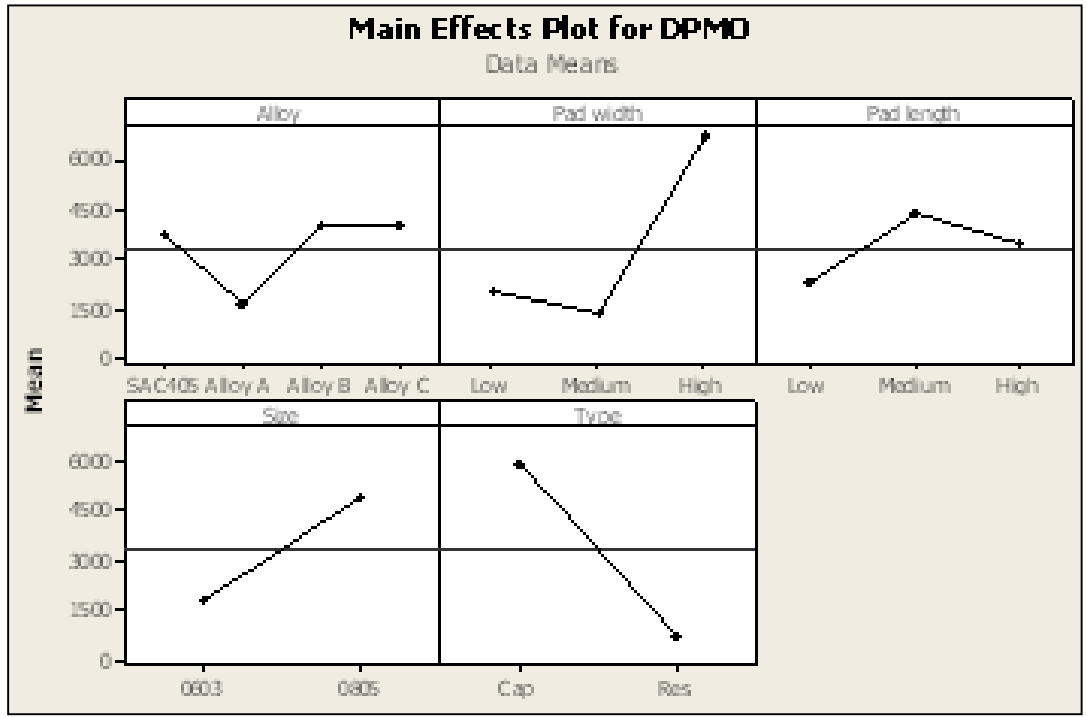


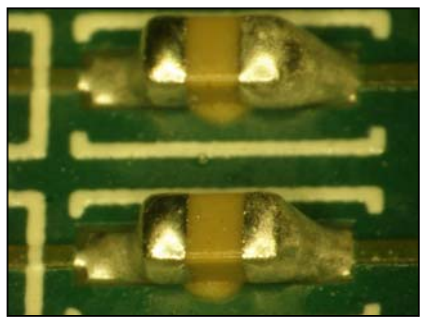
Width	Low	Low	Low	Med	Med	Med	High	High	High
Length	Low	Med	High	Low	Med	High	Low	Med	High

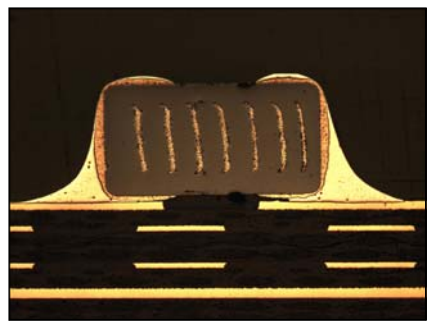
- **Land pattern designs 7, 8 and 9 (widest pad) have the higher quantity of defects**
- **Pad designs 4 and 2 performed the best**

Land Pattern Design Results

- **Best Pad width is the medium level (slightly lower than pad width used for reflow)**
- **Pad lengths used were statistically similar**
- **0603 capacitors and resistors deliver the lowest defect count**
- **Alloys B, C and SAC405 performed statistically at the same level. Alloy A performed the best**

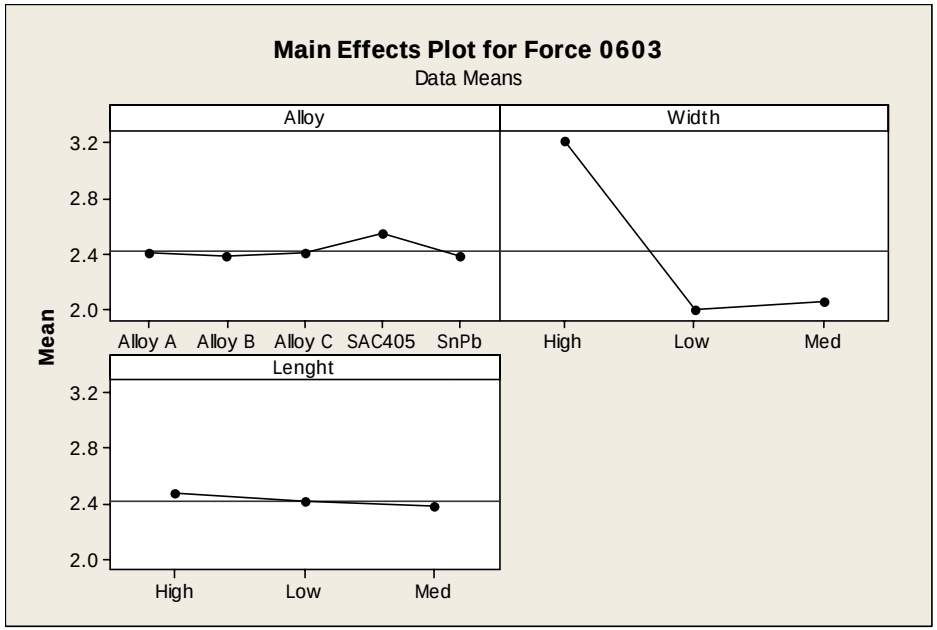


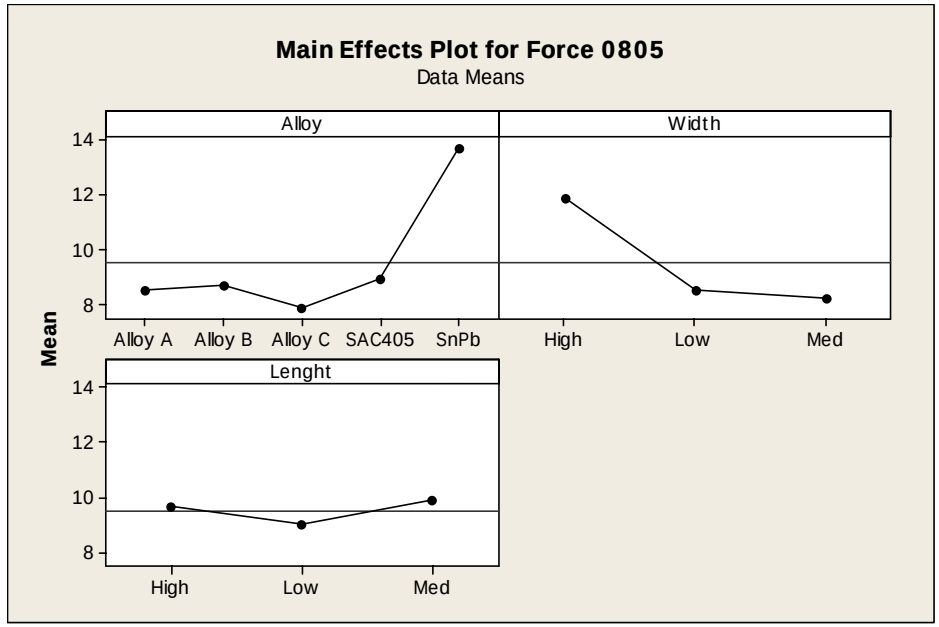




Land Pattern Design Results

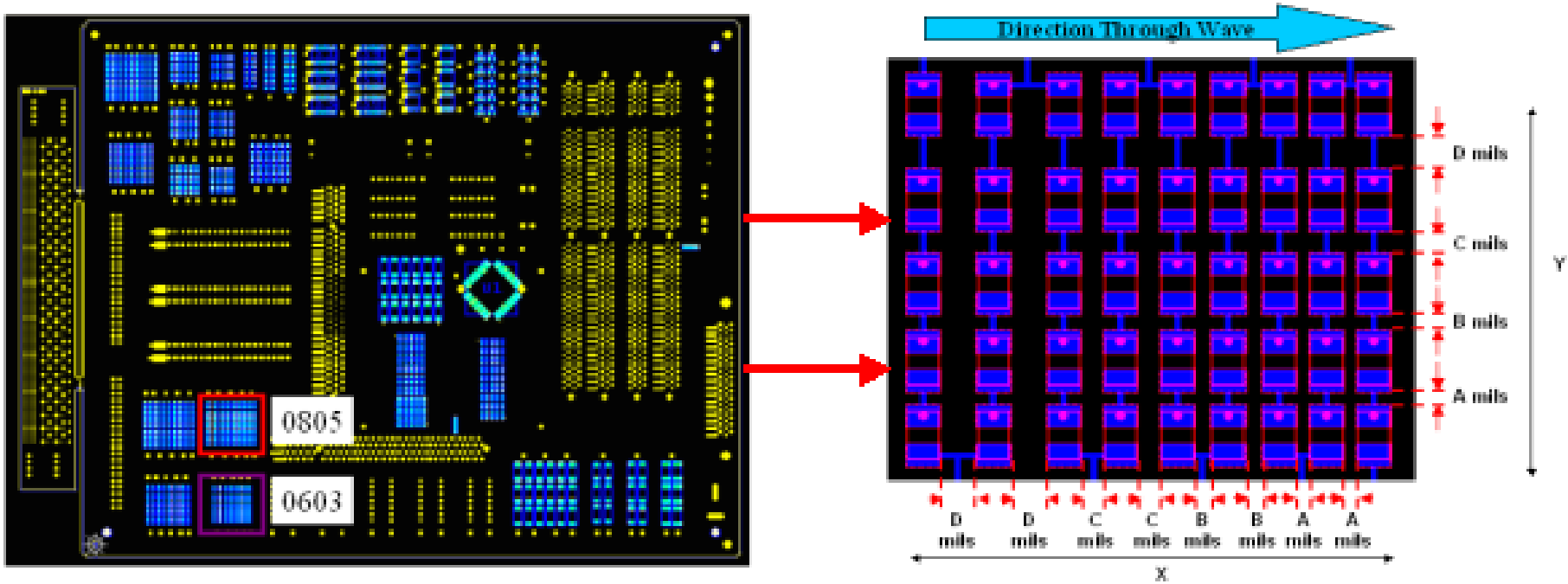
Shear Force Test





- **High width levels provided the largest strength for both, 0603 and 0805**
- **0805 strength larger than 0603 due to more contact area for the solder joint**
- **SnPb behaves statistically similar than SAC alloys for 0603 component**
- **For 0805 component, SnPb is the alloy with the higher strength.**

Pad to Pad Spacing Variation



- 0805 and 0603 components tested
- Four distances used on the X and Y axis

Pad to Pad Spacing Variation

- A Full Factorial, 3 Factors DOE was used:

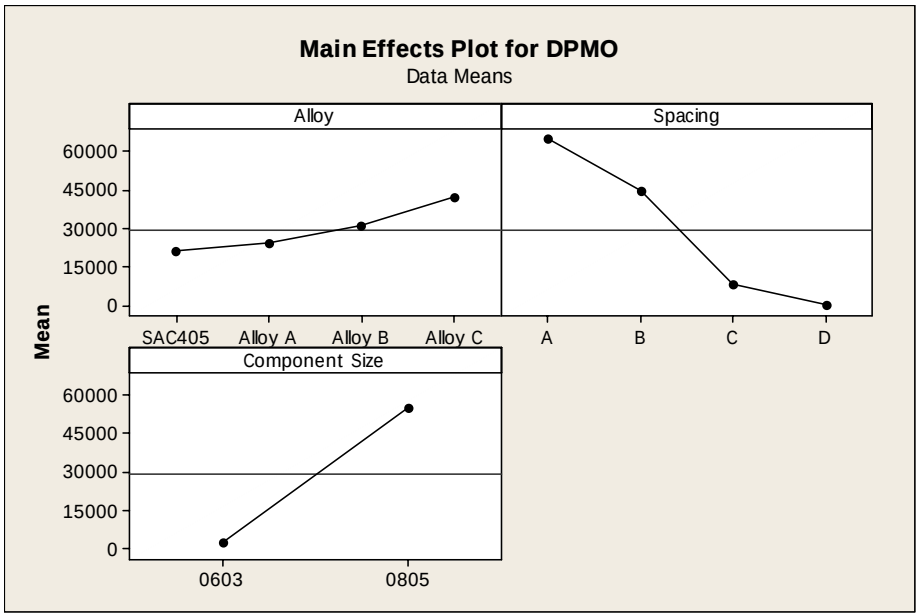
DOE

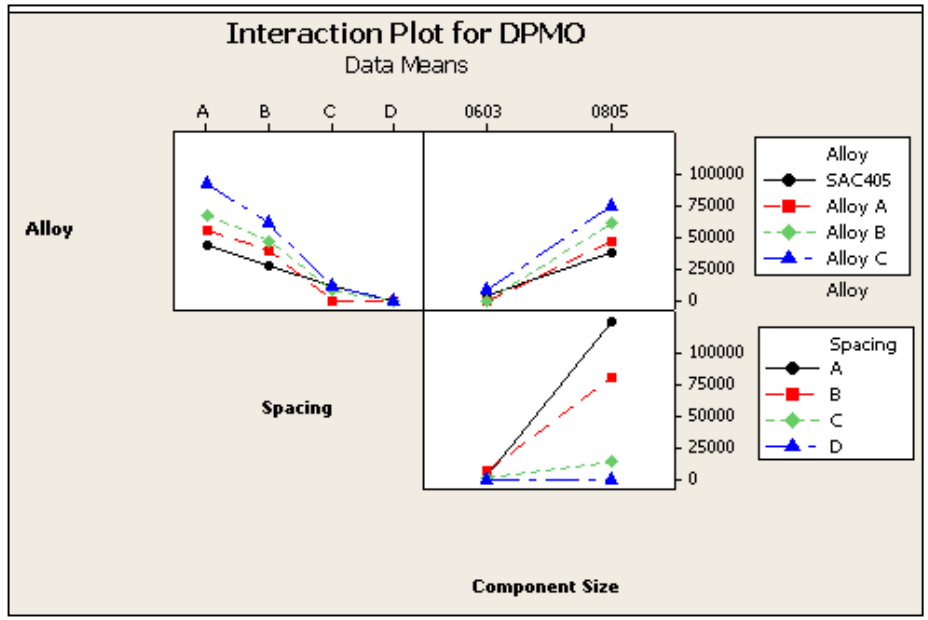
	Component	
Alloy	**0603**	**0805**
SAC405	A	A
	B	B
	C	C
	D	D
Alloy A	A	A
	B	B
	C	C
	D	D
Alloy B	A	A
	B	B
	C	C
	D	D
Alloy C	A	A
	B	B
	C	C
	D	D

A: Spacing slightly below 0.64mm
B: 0.64 mm **(0.025")**
C: Spacing slightly above 0.64mm
D: Spacing above 0.64mm **(0.025")**

- Response: DPMO on Visual Inspection (Class 3, IPC-A-610D)

Pad to Pad Spacing Variation Results





- **SAC405 performed the best followed closely by Alloy A**
- **0603 components show a lower quantity of defects among the 4 different spacing used**
- **With spacing A (0.5mm) and spacing B (0.64mm) the quantity of defects increased a lot**

Conclusions

Pin to Hole Ratio	P2H ratio between 0.50 & 0.60 (equivalent to a clearance of 0.64 mm to 0.42 mm) is recommended May not apply for larger pin areas	
Ground Planes (from 0 to 4 used)	3 or less ground planes are recommended when using four spokes thermal relief and the P2H ratios mentioned above	
PTH Connection Types	Recommend incorporating 4 spokes thermal relief to minimize barrel fill defects. This recommendation takes more relevance as the quantity of ground planes increases	
Land Pattern Design	<u>Visual Inspection</u> Pad Width slightly below reflow design standard is recommended Pad Length doesn't affect	<u>Shear Force</u> Shear Force increases with increasing pad width No statistical difference for 0603 components among SnPb and LF Alloys
Pad to Pad Spacing	Recommend having distances higher than 0.64mm to minimize solder bridges	
Alloys	Alloy B resulted as the more robust Pb-free alloy among the three alternatives, performing very similar to the SAC405	