Mitigation of Pure Tin Risk by Tin-Lead SMT Reflow- Results of an Industry Round-Robin

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Abstract

The risk associated with whisker growth from pure tin solderable terminations is fully mitigated when all of the pure tin is dissolved into tin-lead solder during SMT reflow. In order to take full advantage of this phenomenon, it is necessary to understand the conditions under which such coverage can be assured. A round robin study has been performed by IPC Task group 8-81f, during which identical sets of test vehicles were assembled at multiple locations, in accordance with IPC J-STD-001, Class 3. All of the test vehicles were analyzed to determine the extent of complete tin dissolution on a variety of component types. Results of this study are presented together with relevant conclusions and recommendations to guide high reliability end-users on the applicability and limitations of this mitigation strategy.

Background

Manufacturers of high reliability electronics have been working for many years to mitigate the deleterious effects of tin whisker formation. One highly effective means to suppress the growth of tin whiskers is to replace the pure tin plating with reflowed tin lead solder. (This approach is only available to manufacturers whose products are not subject to RoHS.) One approach to achieve total replacement of tin with tin lead solder is to perform a special hot solder dip process on the piece parts prior to assembly. Another approach is to fully consume the tin plating by tin lead solder during the SMT reflow process that occurs during circuit card assembly. This phenomenon of tin replacement during SMT reflow has been termed "self-mitigation", because the components mitigate by themselves without the need of any special additional processing. Self-mitigation has many advantages over other forms of tin mitigation because it is: highly effective, adds no additional cost, and subjects the components to no additional handling.

The principal challenge to implementing self-mitigation as a standard practice is lack of confidence in the conditions under which components will reliably self mitigate. Prior work concluded that for a specific set of process conditions, board finish, and pad design, self-mitigation can be predicted by the geometry of the component terminations [1] . It is not clear, however, how these results apply for different manufacturing processes, board finishes, and pad sizes. Without this understanding, the only reliable means for systems integrators to be confident that self-mitigation has been achieved on a given set of assemblies is to duplicate the conditions of the prior study, or to perform direct measurements on the as-received hardware.

The existence of this knowledge gap prompted the Pb-free Electronics Risk Management Council (PERM, IPC Committee 8-81) to initiate a project in 2014 under IPC task group 8-81F, to perform a study. The first phase of that study has been completed, and this report describes that study and the results to date.

Design of Experiment

The task team agreed to perform a new set of experiments involving the manufacture of identical sets of test vehicles at a number of different locations, all assembled to the requirements of IPC J-STD 001, Class 3. For simplicity, and to permit direct comparison with the results of the prior study, it was decided to use the same board layout and components from the prior study. Many potential factors for inclusion in the DOE were considered. The factors chosen for consideration are described in Table 1 below.

Table 1. Design of Experiment

Experimental Factor	Settings
Component Packages	16 different part numbers (details below)
Board finish	OSP and Sn Pb HASL
Pad size	Per initial study and 25% smaller
Manufacturing site	Seven different locations

Each test vehicle consisted of a PCB with each of the package types attached (quantities of each described below). There were four "flavors" of boards for the four combinations of pad size/board finish. Each assembler was provided with two replicants of each board type, for a total of eight test vehicles.

Component Packages

The components used in this study are summarized on Table 2. Measurements of the length and height of the solderable terminations were measured as illustrated in Figures 2 or 3 below, for leaded and chip devices respectively.

Table 2 Component packages used in the study

Part Number	Package Style	Quantity per vehicle	Length (mils)	Height mils)
06035C103KAT2A	0603 chip	10	31	13
0603YD225KAT2A	0603 chip	10	31	13
A3PN030-ZVQG100	TQFP100-14mm	1	40	16
ADM213EARSZ	SSOP28-5.3mm	2	59	31
EPM7032AETC44-10N	A-TQFP44-10mm-.8mm	1	40	16
IR2156SPBF	SO14G-3.8mm	2	41	23
LM2901DG	SO14G-3.8mm	2	41	23
LTC3703EG_PBF	SSOP28-5.3mm	2	59	31
MBRM140T1G	DO-216AA	5	49/17	20
MC9S08GT16AMFBE	QFP44-.8mm	1	66	36
MC9S08QE4CLC	LQFP32-7mm-.8mm	1	42	25
OP482GSZ	SO14G-3.8mm	2	46	19
PZT2222AT1G	SOT223	5	69/73	20
STAC9200X5TAEB1X	LQFP48-7mm-.5mm	1	42	25
W3L1YC474MAT1AF	0612 chip	5	12	39
XC9572XL-5TQG100C	LQFP100-14mm-.5mm	1	39	23

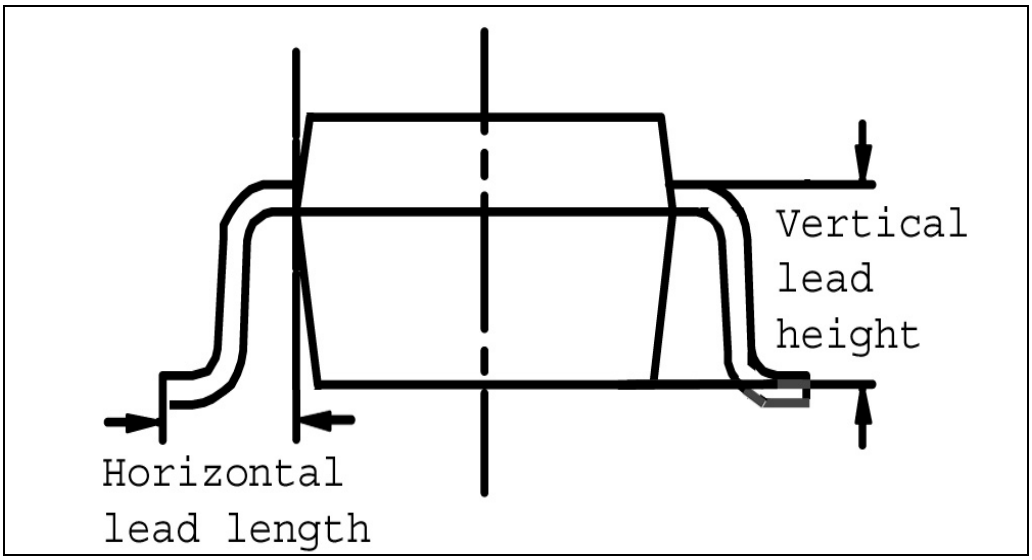

Figure 2. Termination height and length measurements for leaded devices

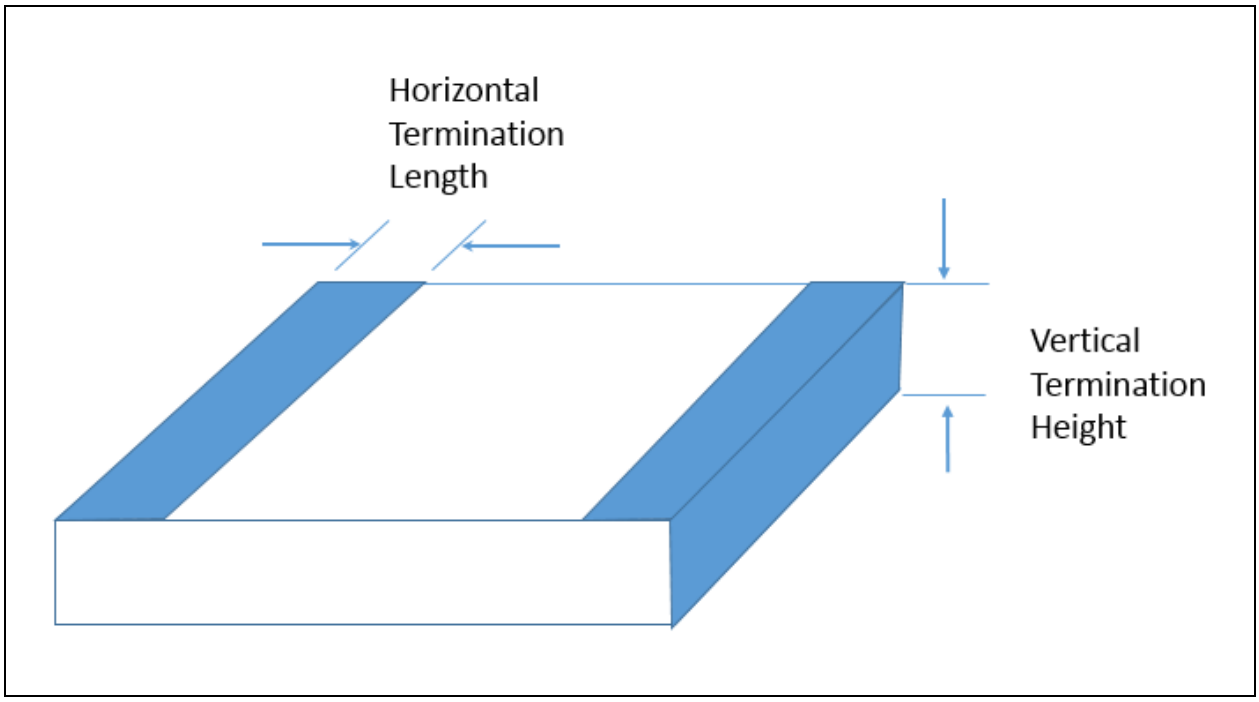

Figure 3. Termination height and length measurement for chip devices

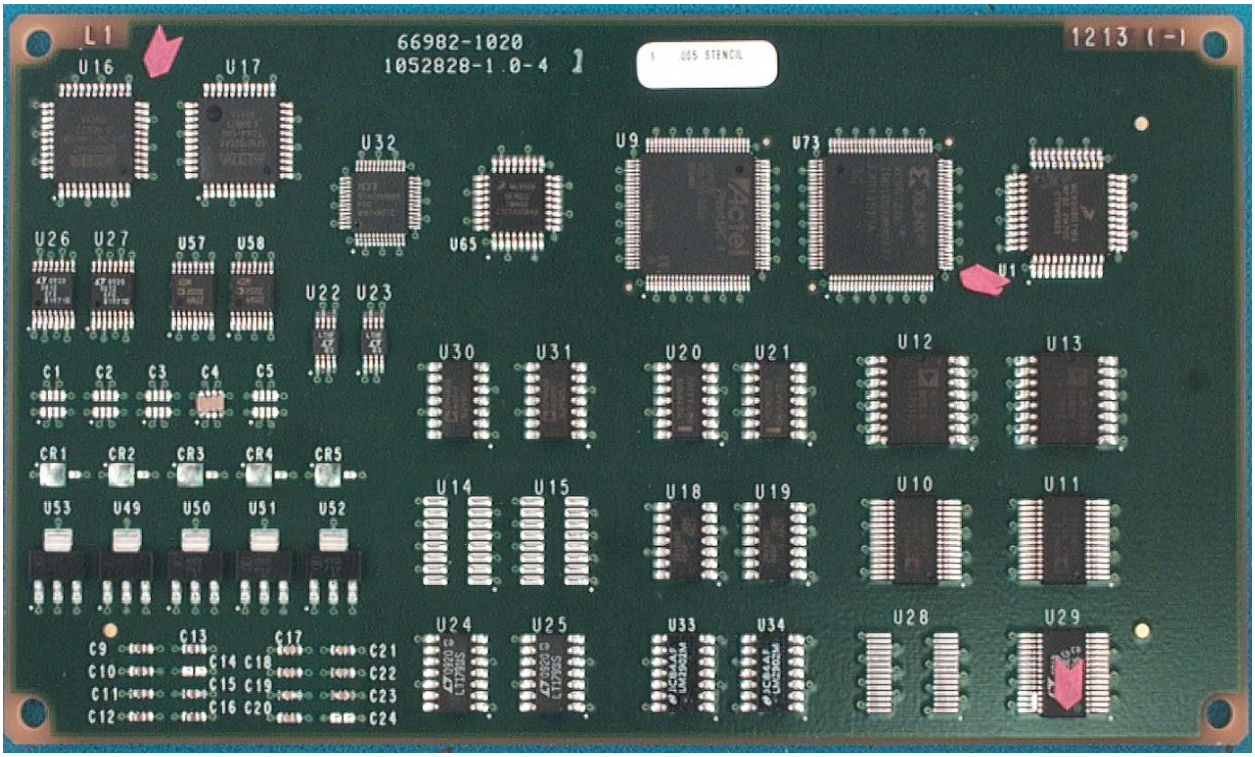

Figure 4: Photograph of an assembled test vehicle

Assembly processes

Each assembler was provided an identical kit with eight bare boards, together with the components needed to populate them. Unfortunately, delivery of the kits to one of the assemblers was delayed by the need for export compliance validation. Analysis of the results from this assembler were not available in time for this publication, so we can only report on six of the seven at this time.

The processes employed by each of the assemblers was recorded and are summarized in Table 3.

Table 3. Summary of assembly process details

Setting	Process A	Process B	Process C	Process D	Process F	Process G
Reflow type	Vapor Phase	Convection Oven	Convection Oven	Convection Oven	Convection Oven	Convection Oven
Flux	ROL0	ROL0	ORM0 63/37	ROL0	No clean	Tacky Flux
Stencil thickness	5 mils	5 mils	5 mils	4 mils	5 mils	5 mils
Time above Liquidus	90s	60-75s	66s	90s	60s	70s
Peak temperature	218C	215C	220C	225C	213C	220C
Atmosphere	Air	Nitrogen	Nitrogen	Nitrogen	Nitrogen	Nitrogen
Number of reflow cycles	1	1	1	1	1	2
Rework	None	None	None	None	None	Yes

X-Ray Fluorescence Measurements

Evaluation of the extent of solder coverage of component terminations was performed using X-Ray Fluorescence (XRF). All XRF measurements were performed using the production XRF instrument and a 97 wt% tin materials standard. This instrument's principal features include a PIN diode solid state X-ray detector, a capillary tube collimation for 3 micron X-ray beam size, a fine position controlled automatic sample stage, a 50 Kilo-electron-volt X-ray source, and X-ray fundamental parameters based quantitative analysis software. Data collected at each measurement location included: thickness of coating, weight fraction of tin and of lead in the coating, and count rate.

Measurements were performed in identical locations on each of the test vehicles. Measurements were performed on two leads from each of the leaded devices. For each lead analyzed, measurements were taken in three locations: at the toe of the lead adjacent to the pad, at the midpoint of the lead, and at the very top of the lead where it is protrudes from the package. For the non-leaded passive devices, measurements were performed at the pad and on the top of the device where the termination finish was farthest from the pad.

X-Ray Fluorescence Results

Raw data was collected at each measurement location for: weight percent tin, weight percent lead, and coating thickness. Information on the x-ray count rate for tin lead were also recorded.

Results of the XRF measurements for boards from Assembler A are summarized in Appendix A. This table summarizes the data for the eight test vehicles assembled using the same assembly process, as indicated in Table 3 above. A similar table was created for all of the test vehicles. (The complete data sets in digital format can be made available to investigators upon request.) Three measurements taken on the 97% tin calibration standard are shown in the last three rows of Appendix A. All thicknesses are given in micro inches. All compositions are given in weight percent tin (the remainder is lead). All tin measurements in excess of 97% are shaded pink, and all thickness measurements less than 10 micro inches are shaded blue(The locations for each measurement are indicated by abbreviations as follows):

"E"- Where the lead is protruding from the package

"M"- The midpoint of the lead

"P"- At the pad

"TL"- Top left side of the package

"BL"- Bottom left side of the package

"TP" – Tab where it meets the pad

"TE" Tab where it is protruding from the package

"EL", "ML", and "PL" For the lead, where it is protruding from the package, at its mid-point, and at the tab, respectively.

The data was reviewed for consistency and to determine the validity. Some measurements, particularly ones taken near where the lead protrudes out from the package (E) of certain components, were found to exhibit unreasonably low coating thickness readings. Inspection of some of the suspect components revealed that there was bare copper exposed at this locatione, resulting in the collection of no meaningful data on solder coverage at these locations.

Analysis of results

Preliminary data analysis has commenced to help with data summary. To begin with, the data was examined for suspect data readings, in light of the issue with unreasonably thin readings discussed above. For this preliminary summary any reading with a thickness measurement less than 15 was eliminated from the dataset. The tin and lead content from these samples were considered suspect and would need additional review to be considered accurate.

Some basic parameters were examined for significance. ANOVA analysis with backwards deletion was used to examine the significance of pad size, board type, and soldering process. Board type (HASL or OSP) was found to be an insignificant explanatory variable (F-value 2.34, Pr>F: 12.6%). While pad size was found to be significant during the analysis (F-value

5.8, Pr>5: 1.6%), the difference between means for the two sizes was less than 3% , so on a practical basis it is not expected to be a factor. The differences between soldering processes is significant, but will require more in depth analysis to determine the specific differences in the processes driving the differences in performance.

When rating the relative performance of the different packages and soldering processes, we were more interested in the extremes than in the average behavior. For example, we were concerned whether 99% of parts would be compliant in a production setting. Therefore, we performed our rating based on tolerance intervals. Tolerance intervals are confidence intervals for a covering of a fixed percentage of the population. For this analysis we used formulas for one-sided tolerance intervals for a normal distribution[2]. These were calculated for three difference confidence levels and looking at several different percentiles of interest.

The data was analyzed at three difference confidence levels: 60% confidence (little confidence over expected value), 80% confidence (adding some margin), 90% confidence (high confidence needed for critical systems). The results are summarized in Tables 4-6 that follow. The following color code is used:

- Green means the chance of being <97% tin is at least 0.99
- Yellow means the chance of being <97% tin is between 0.9 and 0.99
- Orange means the chance of being <97% is between 0.75 and 0.9
- Pink means the chance of being <97% is between 0.5 and 0.75
- Red means the chance of being <97% is less than 0.5
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For example, the 0603 chip is green for all processes at all confidence levels. That means that there is greater than 0.99 chance that a part will have the required <97% tin once soldered. On the other hand the SSOP28-5.3mm is colored yellow for process G at 60% confidence because we expect a greater than 0.9 chance that a part will have <97% tin. At higher confidence levels, however, this part process combination turns orange because at higher confidence, it is more likely to be between 0.75 and 0.9 chance of having <97% tin. Although the higher confidence levels have lower probabilities of parts having <97% tin, generally the part-process combinations stay in the same category regardless of confidence level. This suggests that the results are not being driven by a lack of sample size.

Table 4. Self-mitigation probabilities with 60% confidence

Termination				Assembly Process					
Length	Height	Package Style	Part_Number	A	B	C	D	F	G
31	13	0603 chip	06035C103KAT2A	0.996	1.000	1.000	1.000	1.000	1.000
31	13	0603 chip	0603YD225KAT2A	0.998	1.000	1.000	1.000	1.000	1.000
40	16	TQFP100-14mm	A3PN030-ZVQG100	0.836	0.770	0.779	0.822	0.810	0.995
59	31	SSOP28-5.3mm	ADM213EARSZ	0.729	0.692	0.736	0.710	0.710	0.892
40	16	A-TQFP44-10mm-.8mm	EPM7032AETC44-10N	0.863	1.000	0.847	0.792	0.820	0.985
41	23	SO14G-3.8mm	IR2156SPBF	0.996	1.000	1.000	1.000	1.000	1.000
41	23	SO14G-3.8mm	LM2901DG	1.000	1.000	1.000	1.000	1.000	1.000
59	31	SSOP28-5.3mm	LTC3703EG_PBF	0.729	0.692	0.717	0.721	0.684	0.904
49/17	20	DO-216AA	MBRM140T1G	1.000	0.777	0.866	0.776	0.762	0.955
66	36	QFP44-.8mm	MC9S08GT16AMFBE	0.767	0.505	0.687	0.678	0.691	0.745
42	25	LQFP32-7mm-.8mm	MC9S08QE4CLC	0.839	0.692	0.755	0.735	0.698	0.904
46	19	SO14G-3.8mm	OP482GSZ	1.000	1.000	1.000	1.000	1.000	1.000
69/73	20	SOT223	PZT22222AT1G	0.931	0.804	0.803	0.767	0.852	0.698
42	25	LQFP48-7mm-.5mm	STAC9200X5TAEB1X	0.781	0.713	0.774	0.767	0.736	1.000
12	39	0612 chip	W3L1YC474MAT1AF	0.743	0.000	0.000	0.430	0.001	0.432
39	23	LQFP100-14mm-.5mm	XC9572XL-5TQG100C	0.815	0.731	0.763	0.768	0.738	0.991

Table 5. Self-mitigation probabilities with 80% confidence

Termination				Assembly Process					
Length	Height	Package Style	Part_Number	A	B	C	D	F	G
31	13	0603 chip	06035C103KAT2A	0.995	1.000	1.000	1.000	1.000	1.000
31	13	0603 chip	0603YD225KAT2A	0.997	1.000	1.000	1.000	1.000	1.000
40	16	TQFP100-14mm	A3PN030-ZVQG100	0.816	0.748	0.757	0.802	0.790	0.993
59	31	SSOP28-5.3mm	ADM213EARSZ	0.707	0.669	0.712	0.688	0.688	0.876
40	16	A-TQFP44-10mm-.8mm	EPM7032AETC44-10N	0.837	1.000	0.816	0.762	0.792	0.978
41	23	SO14G-3.8mm	IR2156SPBF	0.995	1.000	1.000	1.000	1.000	1.000
41	23	SO14G-3.8mm	LM2901DG	1.000	1.000	1.000	1.000	1.000	1.000
59	31	SSOP28-5.3mm	LTC3703EG_PBF	0.707	0.668	0.695	0.697	0.659	0.888
49/17	20	DO-216AA	MBRM140T1G	0.999	0.758	0.850	0.757	0.743	0.945
66	36	QFP44-.8mm	MC9S08GT16AMFBE	0.736	0.471	0.654	0.645	0.658	0.714
42	25	LQFP32-7mm-.8mm	MC9S08QE4CLC	0.811	0.659	0.720	0.703	0.665	0.882
46	19	SO14G-3.8mm	OP482GSZ	1.000	1.000	1.000	1.000	1.000	1.000
69/73	20	SOT223	PZT22222AT1G	0.919	0.784	0.784	0.745	0.836	0.671
42	25	LQFP48-7mm-.5mm	STAC9200X5TAEB1X	0.749	0.681	0.739	0.736	0.705	0.999
12	39	0612 chip	W3L1YC474MAT1AF	0.719	0.000	0.000	0.404	0.000	0.406
39	23	LQFP100-14mm-.5mm	XC9572XL-5TQG100C	0.786	0.699	0.729	0.737	0.706	0.986

Table 6. Self-mitigation probabilities with 90% confidence

Termination				Assembly Process					
Length	Height	Package Style	Part_Number	A	B	C	D	F	G
31	13	0603 chip	06035C103KAT2A	0.993	1.000	1.000	0.999	1.000	1.000
31	13	0603 chip	0603YD225KAT2A	0.996	1.000	1.000	1.000	1.000	1.000
40	16	TQFP100-14mm	A3PN030-ZVQG100	0.801	0.732	0.739	0.787	0.774	0.991
59	31	SSOP28-5.3mm	ADM213EARSZ	0.689	0.651	0.693	0.670	0.670	0.863
40	16	A-TQFP44-10mm-.8mm	EPM7032AETC44-10N	0.815	1.000	0.791	0.739	0.769	0.970
41	23	SO14G-3.8mm	IR2156SPBF	0.993	1.000	1.000	1.000	1.000	1.000
41	23	SO14G-3.8mm	LM2901DG	1.000	1.000	1.000	1.000	1.000	1.000
59	31	SSOP28-5.3mm	LTC3703EG_PBF	0.690	0.649	0.677	0.679	0.640	0.874
49/17	20	DO-216AA	MBRM140T1G	0.999	0.743	0.837	0.742	0.728	0.937
66	36	QFP44-.8mm	MC9S08GT16AMFBE	0.712	0.446	0.629	0.620	0.633	0.689
42	25	LQFP32-7mm-.8mm	MC9S08QE4CLC	0.788	0.634	0.693	0.678	0.640	0.864
46	19	SO14G-3.8mm	OP482GSZ	1.000	1.000	1.000	1.000	1.000	1.000
69/73	20	SOT223	PZT22222AT1G	0.908	0.769	0.769	0.728	0.823	0.651
42	25	LQFP48-7mm-.5mm	STAC9200X5TAEB1X	0.724	0.656	0.711	0.711	0.680	0.998
12	39	0612 chip	W3L1YC474MAT1AF	0.701	0.000	0.000	0.385	0.000	0.387
39	23	LQFP100-14mm-.5mm	XC9572XL-5TQG100C	0.763	0.675	0.702	0.712	0.681	0.980

Conclusions

The data clearly indicates that the probability for self-mitigation is strongly dependent upon the component termination geometry, confirming the conclusion from the previous study. It is also clear that the assembly process has a meaningful effect on self mitigation, which is a new finding.

The difference between HASL and OSP pad finish has no significant impact on self mitigation.)

Variation in pad size exhibits a statistically significant, but very minor impact on self mitigation, for the range of pad sizes investigated in this study.

Self mitigation of the various packages in the study can be broken down into three broad groupings:

1. Packages that exhibit a near certain probability of self mitigation over the entire range of processes examined in this study (0603 chips, SO14G's)
2. Packages that exhibit a near certain probability of self mitigation, but only for one particular assembly process (TFQP100 and LQFP48 for Process G, and TQFP44 for Process B)

3. Packages that exhibit a very low probability of self mitigation under all conditions (0612 chip)
4. Packages that exhibit a moderate probability of self mitigation within the range of 0.6 to 0.9 (all other packages)

Readers should note that 0603 chip components are available in a wide variety of component heights and termination lengths, so the results shown here would only be applicable to chip components with heights and links that were equivalent or smaller than those used in this study.

Plans for future work

IPC task group 8-81f plans to continue investigating this hardware over the next year. The first activity will be to incorporate data from the seventh assembly process into the data we already have.

A comprehensive plan of cross sectioning and SEM/EDS analysis will be developed and implemented. The intent of this is to understand the causes for the very low thickness readings and determine which if any of this data is valid. Also, we will validate where the original tin finish has been completely consumed, and to cross check the composition measurements.

A detailed statistical analysis will be performed to identify any meaningful correlations between the various process parameters associated with the assembly processes and self mitigation behavior of the various components.

Two additional boards have been assembled using components that were in uncontrolled storage for a number of years. The effect of this storage on self mitigation will be investigated.

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References

1. T. Hester and D. Pinsky, “Tin Whisker Self-Mitigation in Surface Mount Components Attached with Leaded Solder Alloys”, SMT iConnect 007, October, 2015.
2. http://www.itl.nist.gov/div898/handbook/prc/section2/prc263.htm.

See page 1 for Export Restrictions Declaration.

Appendix A- Summary of XRF data from Assembler A

Part Number	Designator	Location	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn
Board Type			Large Pads/OSP		Small Pads/HASL		Large Pads/HASL		Small Pads/HASL		Small Pads/OSP		Large Pads/OSP		Large Pads/HASL		Small Pads/OSP	
Board Number			17		31		2		32		46		16		1		47	
MC9S08GT16AMFBE	U1	E, TL	168.87	94.74	258.41	99.04	247.50	99.69	362.84	98.46	140.81	90.34	181.71	95.70	201	98.86	231.87	74.75
MC9S08GT16AMFBE	U1	M, TL	102.54	96.41	114.12	99.52	136.09	99.03	117.58	98.10	102.80	96.85	121.91	97.18	119	97.70	141.41	76.35
MC9S08GT16AMFBE	U1	P, TL	205.33	63.12	264.64	59.14	148.98	57.49	157.97	57.76	181.65	65.37	222.72	67.25	189	60.14	228.51	67.13
MC9S08GT16AMFBE	U1	E, BL	136.53	91.96	147.26	98.81	187.80	98.62	140.11	99.48	148.72	98.78	127.86	89.30	140	99.22	229.54	73.41
MC9S08GT16AMFBE	U1	M, BL	140.54	98.36	515.38	98.47	182.29	99.38	182.79	98.78	141.66	99.39	145.37	96.32	153	99.34	148.73	81.15
MC9S08GT16AMFBE	U1	P, BL	104.90	67.47	248.87	62.05	227.48	63.31	191.40	69.90	212.78	59.31	231.19	67.44	260	72.64	326.18	74.22
ADM213EARSZ	U11	E, TL	91.97	91.61	104.89	99.13	120.15	96.11	90.44	100.00	105.38	98.66	104.57	99.22	106	99.05	112.80	98.19
ADM213EARSZ	U11	M, TL	119.05	93.01	157.23	97.12	144.59	99.29	114.47	99.48	104.92	99.26	128.84	98.62	109	99.39	108.36	98.90
ADM213EARSZ	U11	P, TL	67.45	43.65	57.88	41.84	60.51	42.65	59.04	42.95	71.43	39.24	82.93	50.36	92	48.78	68.55	48.86
ADM213EARSZ	U11	E, BL	116.18	99.12	127.08	99.36	118.35	98.13	131.81	97.17	111.06	99.50	121.93	99.62	124	99.16	125.64	99.63
ADM213EARSZ	U11	M, BL	142.17	99.52	182.99	98.50	208.90	98.34	153.50	98.19	132.74	99.53	139.26	99.12	146	98.25	146.82	99.02
ADM213EARSZ	U11	P, BL	82.85	47.75	65.28	42.40	70.33	45.48	68.01	46.37	91.63	50.61	138.13	58.14	97	51.76	77.02	54.05
LTC3703EG_PBF	U29	E, TL	107.94	93.04	113.27	98.53	98.53	98.56	88.12	98.09	96.17	99.08	61.71	98.51	95	99.28	103.89	98.73
LTC3703EG_PBF	U29	M, TL	98.01	97.73	102.49	98.44	90.65	98.42	92.66	98.52	87.45	99.07	93.19	98.77	87	99.01	106.41	97.17
LTC3703EG_PBF	U29	P, TL	76.94	46.19	78.67	50.53	62.48	46.31	64.50	45.32	80.54	44.15	130.97	54.01	92	51.23	72.20	44.16
LTC3703EG_PBF	U29	E, BL	36.55	98.19	74.21	99.41	84.86	98.49	83.76	98.17	80.66	99.45	78.94	98.66	79	99.33	82.85	98.75
LTC3703EG_PBF	U29	M, BL	84.53	100.00	102.36	98.21	95.07	98.79	92.96	98.93	89.60	99.49	87.68	100.00	95	98.43	93.98	97.42
LTC3703EG_PBF	U29	P, BL	68.03	44.55	71.23	42.46	54.65	48.42	54.80	42.80	68.55	44.91	106.52	57.62	72	49.65	69.98	46.72
LTC3703EG_PBF	U28	E, BL	107.70	99.41	111.84	99.57	107.84	99.45	107.99	99.32	102.57	99.69	117.00	98.17	100	99.49	107.59	98.82
LTC3703EG_PBF	U28	M, BL	134.03	98.14	138.40	94.99	122.19	87.00	118.80	98.44	116.58	99.24	121.85	98.98	123	99.45	128.63	94.18
LTC3703EG_PBF	U28	P, BL	52.10	82.93	127.00	50.38	46.06	59.75	40.83	58.20	52.09	63.91	90.14	62.11	44	67.77	62.53	59.91
LTC3703EG_PBF	U28	E, TL	118.99	97.29	112.24	99.60	98.31	100.00	99.69	98.81	96.71	100.00	114.65	97.31	101	99.21	107.76	98.38
LTC3703EG_PBF	U28	M, TL	98.84	97.91	107.95	97.08	89.53	98.16	92.79	99.19	137.43	69.02	92.98	98.00	92	98.92	90.55	99.08
LTC3703EG_PBF	U28	P, TL	106.80	54.44	121.73	48.25	117.88	46.94	87.53	43.27	94.99	43.02	92.39	55.91	98	45.82	95.91	42.58
ADM213EARSZ	U10	E, BL	120.00	99.19	128.60	99.40	115.93	99.62	110.23	100.00	117.73	99.66	123.57	99.24	121	99.01	115.58	99.30
ADM213EARSZ	U10	M, BL	117.88	100.00	133.07	98.54	113.31	98.84	120.88	98.96	131.34	97.69	143.30	97.43	137	96.99	142.21	96.93
ADM213EARSZ	U10	P, BL	140.51	57.59	101.99	48.96	91.16	54.28	80.60	45.84	92.25	57.11	110.69	57.04	101	50.24	112.36	52.50
ADM213EARSZ	U10	E, TL	130.39	95.65	133.82	98.57	125.74	98.63	139.92	98.15	116.48	99.29	128.13	99.52	132	98.53	128.94	98.67
ADM213EARSZ	U10	M, TL	113.42	98.08	115.48	99.54	118.28	98.29	117.53	98.22	101.95	98.77	113.14	98.97	115	98.27	98.31	91.73
ADM213EARSZ	U10	P, TL	114.16	48.44	99.44	44.72	98.50	44.44	98.12	49.22	116.10	47.41	125.76	46.79	111	51.76	94.66	41.90
XC9572XL-5TQG100C	U73	E, BL	26.08	82.66	66.58	98.32	91.66	99.36	80.24	99.40	66.59	87.34	73.09	80.80	88	99.07	91.83	85.27
XC9572XL-5TQG100C	U73	M, BL	183.98	61.48	92.33	99.17	89.81	90.02	83.43	99.58	160.58	65.67	75.24	84.53	83	100.00	130.01	66.09
XC9572XL-5TQG100C	U73	P, BL	106.96	51.13	92.38	44.30	72.37	45.96	58.06	38.54	87.18	49.07	80.40	53.79	72	42.49	77.86	42.70
XC9572XL-5TQG100C	U73	E, TL	17.64	82.29	41.69	96.58	106.44	98.68	95.00	99.25	49.90	76.95	78.09	97.49	98	99.12	99.71	99.20
XC9572XL-5TQG100C	U73	M, TL	127.13	65.19	95.35	97.29	99.48	98.87	90.74	98.92	109.40	73.79	101.94	97.71	90	98.84	89.13	90.90

Appendix A- Summary of XRF data from Assembler A

XC9572XL-5TQG100C	U73	P, TL	144.42	52.24	113.42	47.37	108.01	47.19	67.27	43.86	121.44	50.86	102.43	61.59	83	46.97	97.44	45.11
A3PN030-ZVQG100	U9	E, TL	1.20	53.50	26.96	92.94	123.38	98.48	117.31	96.28	113.61	81.04	122.80	98.55	107	95.95	146.85	68.06
A3PN030-ZVQG100	U9	M, TL	119.50	66.06	81.90	93.95	94.27	98.98	91.12	98.03	94.11	76.60	97.17	99.03	88	97.52	100.05	66.58
A3PN030-ZVQG100	U9	P, TL	141.20	62.68	116.98	57.69	70.99	49.82	47.61	42.29	148.94	59.41	85.69	51.98	47	42.08	84.93	49.30
A3PN030-ZVQG100	U9	E, BL	0.80	100.00	13.94	91.43	94.68	97.69	88.74	97.84	53.46	97.95	75.87	98.31	85	98.26	153.55	68.17
A3PN030-ZVQG100	U9	M, BL	134.92	64.65	99.79	94.64	91.49	97.29	87.23	96.88	88.60	98.25	96.73	98.99	87	96.38	131.03	68.03
A3PN030-ZVQG100	U9	P, BL	202.04	61.50	149.52	58.78	79.24	57.01	53.89	48.86	166.28	58.10	99.38	60.23	52	48.93	112.23	52.31
LM2901DG	U21	E, TL	24.90	42.31	84.06	84.06	2.48	56.07	1.94	51.86	70.54	64.56	43.42	49.59	2	56.61	1.92	58.11
LM2901DG	U21	M, TL	28.89	47.40	56.81	76.05	1.28	51.03	1.51	59.40	54.83	60.81	5.98	68.63	1	43.24	1.44	51.74
LM2901DG	U21	P, TL	118.80	49.15	149.13	50.23	194.65	52.50	192.49	51.96	268.21	56.58	252.40	55.69	194	52.35	225.47	52.25
LM2901DG	U21	E, BL	13.42	31.27	82.55	84.04	4.12	63.99	42.67	53.62	98.48	82.56	33.48	53.47	43	53.55	33.26	47.11
LM2901DG	U21	M, BL	30.73	48.32	102.39	82.98	17.34	49.05	2.10	66.12	73.78	83.74	42.76	46.83	4	65.67	1.59	52.67
LM2901DG	U21	P, BL	181.64	50.96	163.71	51.81	146.54	49.78	117.57	46.38	154.82	52.23	197.02	53.36	123	47.64	121.33	47.34
IR2156SPBF	U19	E, TL	57.35	74.17	96.13	77.93	80.54	78.17	43.55	83.49	50.37	69.29	11.14	77.73	27	83.21	20.18	66.48
IR2156SPBF	U19	M, TL	66.45	75.09	124.72	78.67	84.00	63.18	73.94	79.56	57.27	55.31	52.80	62.38	67	79.80	54.25	62.38
IR2156SPBF	U19	P, TL	158.97	50.30	150.68	55.60	77.49	53.39	106.80	50.39	159.71	53.28	167.48	52.26	115	49.89	137.60	48.45
IR2156SPBF	U19	E, BL	53.55	73.64	96.90	79.58	75.40	77.85	79.16	81.93	73.60	78.37	75.83	77.41	69	81.17	60.51	65.54
IR2156SPBF	U19	M, BL	63.33	68.17	72.46	76.76	66.88	72.67	63.77	79.27	74.01	71.73	62.02	74.87	69	78.06	50.96	65.32
IR2156SPBF	U19	P, BL	202.54	56.39	139.93	55.06	119.39	54.92	112.26	54.42	161.11	57.07	152.67	58.41	131	53.96	127.01	52.71
IR2156SPBF	U18	E, BL	74.60	76.32	88.06	82.31	70.59	82.49	80.02	81.73	71.73	64.74	80.13	86.90	72	81.25	86.53	58.92
IR2156SPBF	U18	M, BL	141.07	52.59	178.24	55.21	113.59	46.12	113.57	53.76	164.66	51.03	148.45	59.15	114	56.11	137.80	50.23
IR2156SPBF	U18	P, BL	177.00	51.45	165.65	49.30	152.25	49.22	140.66	48.73	166.37	50.29	176.72	53.49	140	49.27	154.55	50.23
IR2156SPBF	U18	E, TL	67.81	71.32	89.73	79.96	80.93	83.19	72.11	76.40	78.99	69.60	65.64	68.68	72	76.44	56.61	60.53
IR2156SPBF	U18	M, TL	63.34	61.87	77.46	75.84	87.37	61.61	86.47	60.24	71.17	60.52	63.48	57.45	76	62.33	71.31	51.47
IR2156SPBF	U18	P, TL	181.86	54.32	143.16	53.54	141.41	51.53	135.75	52.64	142.40	52.24	164.59	51.66	127	52.00	105.59	51.24
LM2901DG	U20	E, BL	46.64	47.51	137.61	78.39	1.36	50.23	34.39	61.70	65.89	59.92	35.63	51.96	36	61.38	38.41	52.10
LM2901DG	U20	M, BL	2.17	46.65	119.29	74.18	1.89	63.82	60.61	56.67	92.83	55.22	4.06	70.38	56	58.05	2.25	65.38
LM2901DG	U20	P, BL	214.57	53.39	213.20	52.30	185.88	50.82	177.84	52.58	225.66	55.56	124.14	52.43	173	52.48	173.20	52.19
LM2901DG	U20	E, TL	22.85	44.11	73.07	82.98	1.37	55.78	2.04	50.19	70.46	59.32	41.81	50.98	2	49.40	12.72	54.27
LM2901DG	U20	M, TL	51.40	40.21	164.29	65.17	4.16	64.55	141.04	60.30	101.13	56.41	61.27	49.00	122	58.66	65.19	59.50
LM2901DG	U20	P, TL	74.86	50.52	149.20	49.33	56.88	50.88	53.07	51.15	123.45	56.50	36.71	65.26	49	51.87	38.28	60.12
A3PN030-ZVQG100	U9	E, BL	5.24	88.19	64.14	91.14	87.47	98.04	97.90	95.59	39.11	97.15	22.45	96.38	93	95.24	65.18	87.04
A3PN030-ZVQG100	U9	M, BL	124.16	64.80	92.27	94.28	82.72	97.41	84.86	97.00	82.67	97.98	91.87	98.47	80	97.21	122.36	68.16
A3PN030-ZVQG100	U9	P, BL	98.93	61.40	97.84	55.55	77.80	48.39	83.74	50.27	108.91	54.04	62.39	53.74	81	49.77	85.46	51.19
A3PN030-ZVQG100	U9	E, TL	6.41	83.79	53.36	94.29	97.06	98.80	91.03	95.57	130.96	73.16	93.14	98.72	89	94.22	133.28	64.14
A3PN030-ZVQG100	U9	M, TL	108.75	70.31	80.99	96.83	100.59	85.39	86.21	91.62	176.87	66.59	85.74	98.83	86	92.20	202.43	72.95
A3PN030-ZVQG100	U9	P, TL	176.66	61.38	141.01	60.92	86.64	53.34	39.86	51.02	147.22	62.79	108.53	58.55	36	52.05	100.15	56.99
MC9S08QE4CLC	U65	E, TL	2.38	64.86	10.75	93.38	90.75	98.84	86.06	97.78	85.35	92.16	45.40	91.92	80	98.06	85.60	93.29
MC9S08QE4CLC	U65	M, TL	97.51	94.75	97.26	97.24	85.37	99.61	99.52	92.85	94.28	90.98	95.05	90.99	88	92.93	84.51	89.56

Appendix A- Summary of XRF data from Assembler A

MC9S08QE4CLC	U65	P, TL	169.54	68.66	162.45	56.38	272.33	65.32	100.58	56.26	188.46	60.76	108.59	60.89	84	53.85	130.60	56.09
MC9S08QE4CLC	U65	E, BL	8.75	92.79	36.66	94.16	92.56	96.41	94.39	97.27	54.16	86.48	25.43	91.09	93	98.29	197.39	73.82
MC9S08QE4CLC	U65	M, BL	106.02	92.53	96.25	78.89	90.67	91.27	91.92	90.61	118.36	65.97	99.18	92.32	94	90.14	165.30	67.23
MC9S08QE4CLC	U65	P, BL	125.82	59.58	171.00	59.64	181.52	55.23	145.47	53.65	186.27	62.09	149.25	63.56	133	52.77	173.30	57.13
OP482GSZ	U31	E, TL	26.61	52.82	1.55	52.22	1.39	55.27	1.65	47.37	17.99	47.24	19.95	45.51	1	46.21	16.70	40.44
OP482GSZ	U31	M, TL	7.98	55.98	2.16	41.45	159.12	52.03	23.14	47.96	36.56	46.27	5.24	72.13	19	49.98	2.54	58.83
OP482GSZ	U31	P, TL	234.11	53.39	213.05	53.61	188.54	52.88	188.00	52.92	201.46	52.91	203.33	53.07	174	52.38	187.28	51.75
OP482GSZ	U31	E, BL	28.02	55.62	1.49	52.01	2.26	42.32	1.36	57.50	10.91	57.05	32.35	51.07	2	59.27	32.58	44.63
OP482GSZ	U31	M, BL	85.25	48.33	95.64	44.56	154.24	49.70	95.48	50.38	127.83	47.03	21.77	50.21	75	48.43	91.29	39.96
OP482GSZ	U31	P, BL	41.33	67.38	168.96	54.81	170.77	52.36	99.29	50.87	171.71	51.76	35.53	64.17	72	49.86	115.55	50.77
OP482GSZ	U30	E, TL	5.36	59.01	1.63	63.68	1.76	64.82	1.67	58.08	1.75	59.71	1.72	55.18	2	53.69	2.13	61.31
OP482GSZ	U30	M, TL	63.21	51.32	1.37	57.31	3.29	63.51	5.31	73.32	1.91	57.41	2.19	52.64	8	65.42	15.66	40.13
OP482GSZ	U30	P, TL	39.35	64.13	39.81	60.96	36.07	63.07	27.31	66.83	35.47	64.59	33.36	66.74	26	68.73	34.53	62.75
OP482GSZ	U30	E, BL	34.69	48.63	1.90	53.36	38.66	53.93	30.96	56.21	1.85	50.93	29.47	45.20	36	58.66	1.66	53.07
OP482GSZ	U30	M, BL	11.69	48.10	5.94	69.21	62.12	56.04	65.99	58.16	60.58	43.61	7.08	64.62	60	59.22	24.31	43.24
OP482GSZ	U30	P, BL	115.79	54.80	34.31	67.24	38.32	58.72	68.05	50.83	32.33	65.49	47.51	59.95	60	49.96	34.22	62.79
STAC9200X5TAEB1X	U32	E, TL	0.43	0.00	0.60	100.00	109.78	98.71	101.85	96.54	107.19	94.00	44.44	97.79	106	95.67	102.37	96.79
STAC9200X5TAEB1X	U32	M, TL	97.68	97.98	89.46	98.98	90.80	98.06	89.59	96.29	89.74	88.00	92.93	98.42	91	96.01	80.90	78.29
STAC9200X5TAEB1X	U32	P, TL	2765.84	72.88	242.23	67.84	116.16	53.24	105.78	52.60	583.60	74.26	247.06	62.19	72	45.07	176.55	54.61
STAC9200X5TAEB1X	U32	E, BL	0.64	8.13	2.44	81.46	109.21	95.33	91.50	99.08	50.23	100.00	14.54	93.15	90	99.19	82.94	74.64
STAC9200X5TAEB1X	U32	M, BL	97.51	87.95	97.83	98.02	100.24	98.47	92.07	98.10	98.22	98.41	89.21	88.56	99	97.42	147.75	69.90
STAC9200X5TAEB1X	U32	P, BL	279.57	79.14	47802.39	68.66	197.52	58.42	124.80	51.82	48148.00	70.47	371.47	77.33	73	44.69	234.14	74.21
EPM7032AETC44-10N	U17	E, TL	0.89	0.00	3.91	68.31	101.68	96.40	86.57	92.23	111.66	84.30	98.54	86.88	93	93.10	87.63	90.23
EPM7032AETC44-10N	U17	M, TL	83.59	83.47	79.27	84.21	101.35	98.52	110.15	98.83	112.65	95.52	106.43	88.90	114	98.20	106.01	96.90
EPM7032AETC44-10N	U17	P, TL	420.45	75.66	204.62	69.17	163.63	61.97	142.85	60.83	148.75	66.06	171.30	73.10	136	60.25	140.05	64.03
EPM7032AETC44-10N	U17	E, BL	0.84	18.58	7.36	75.82	83.24	98.39	77.75	97.22	89.82	89.51	69.95	81.29	78	94.28	83.94	68.56
EPM7032AETC44-10N	U17	M, BL	33.79	75.88	75.43	89.11	90.61	95.10	97.66	99.29	104.84	89.61	97.65	85.54	98	99.12	81.53	78.44
EPM7032AETC44-10N	U17	P, BL	6426.18	72.13	393.44	74.55	166.86	66.66	229.73	64.95	279.57	67.87	269.18	69.91	180	62.93	182.84	68.30
W3L1YC474MAT1AF	C1		54.89	80.94	127.74	96.99	49.33	77.92	82.72	97.85	91.26	88.55	97.88	94.79	77	98.73	82.41	89.00
W3L1YC474MAT1AF	C1		137.49	94.47	107.89	97.84	70.70	80.09	110.09	95.32	91.62	97.88	122.98	97.40	102	94.34	103.18	97.92
W3L1YC474MAT1AF	C2		49.11	80.02	45.18	81.87	99.68	93.41	102.49	92.53	115.61	94.11	101.24	91.07	91	93.17	78.17	97.81
W3L1YC474MAT1AF	C2		48.68	79.22	99.55	98.37	86.93	96.09	80.35	98.36	85.41	98.46	73.79	97.26	75	98.32	83.03	94.20
W3L1YC474MAT1AF	C3		50.20	76.91	105.76	97.62	85.55	96.52	45.15	82.00	113.04	96.62	103.01	96.82	56	83.66	81.06	94.76
W3L1YC474MAT1AF	C3		116.44	93.16	93.35	98.34	74.19	93.86	87.89	89.74	88.83	98.55	83.01	98.63	65	90.97	79.26	95.94
W3L1YC474MAT1AF	C4		51.85	78.84	84.36	81.16	45.27	84.07	58.53	82.07	105.13	97.76	102.09	92.21	77	83.46	89.96	97.17
W3L1YC474MAT1AF	C4		126.68	92.65	118.95	98.40	96.86	96.84	108.78	97.75	120.17	98.66	106.69	98.14	96	96.53	99.47	95.47
W3L1YC474MAT1AF	C5		52.38	76.62	60.49	83.30	48.09	82.93	83.09	96.10	90.28	97.72	90.29	97.56	78	97.33	86.01	90.93
W3L1YC474MAT1AF	C5		146.12	95.01	107.67	96.66	102.03	93.61	51.45	81.71	99.80	98.63	101.30	98.15	57	80.05	110.29	96.33

Appendix A- Summary of XRF data from Assembler A

MBRM140T1G	CR1		158.82	54.97	151.86	53.08	158.38	50.22	167.06	52.54	104.43	61.84	157.03	52.42	179	54.18	119.18	49.46
MBRM140T1G	CR1		126.49	86.83	62.79	57.43	114.19	67.23	142.51	76.42	102.99	78.03	139.81	74.14	164	75.62	154.67	71.42
MBRM140T1G	CR1		266.67	68.57	208.10	61.71	142.18	58.47	189.23	73.02	203.77	58.94	230.25	74.40	143	71.11	168.90	57.38
MBRM140T1G	CR2		63.20	62.15	37.15	38.51	197.97	54.52	172.70	54.44	201.66	61.41	130.92	56.13	157	53.99	78.45	48.20
MBRM140T1G	CR2		86.83	78.67	78.93	73.92	49.77	78.72	37.64	56.77	95.92	71.54	77.76	68.85	57	58.84	130.74	72.08
MBRM140T1G	CR2		129.67	67.67	126.56	59.10	172.31	64.35	199.28	63.18	156.51	63.19	139.42	62.40	188	63.38	164.26	57.70
MBRM140T1G	CR3		189.83	55.37	43.68	49.48	167.56	54.94	181.17	54.40	162.86	53.91	160.78	57.55	187	53.60	147.42	53.04
MBRM140T1G	CR3		104.87	85.80	103.36	76.08	61.02	86.10	64.19	72.35	185.45	67.72	135.31	74.61	75	71.17	143.33	66.51
MBRM140T1G	CR3		18.17	88.81	124.32	60.65	157.42	57.92	200.19	70.72	196.30	62.75	263.57	77.06	173	68.80	138.50	55.68
MBRM140T1G	CR4		48.41	59.49	192.11	54.68	181.05	54.96	161.76	47.55	113.36	53.34	26.75	53.96	168	47.56	5.03	77.72
MBRM140T1G	CR4		133.47	71.22	57.31	74.25	107.08	71.51	135.63	71.11	102.16	65.65	75.44	64.59	136	72.44	87.41	56.76
MBRM140T1G	CR4		251.02	71.93	166.58	64.69	177.21	70.88	148.58	74.30	189.01	60.19	158.46	61.61	132	72.75	185.59	58.05
MBRM140T1G	CR5		25.94	45.38	175.25	53.85	110.39	49.52	171.36	54.04	100.61	51.47	64.99	32.58	173	53.54	92.33	46.73
MBRM140T1G	CR5		125.68	85.38	139.00	56.16	66.06	67.06	24.14	71.21	170.05	70.74	155.62	75.35	41	67.52	194.82	67.99
MBRM140T1G	CR5		59.85	66.48	172.32	57.34	195.07	72.87	127.10	65.16	150.63	59.59	137.89	61.37	116	62.51	124.35	57.15
PZT22222AT1G	U52	TE	49.71	94.10	77.65	99.52	54.39	73.14	48.70	92.32	20.90	89.82	47.70	87.79	27	91.79	74.45	95.64
PZT22222AT1G	U52	TP	36.71	63.25	41.31	60.60	37.09	60.01	126.51	54.64	31.42	67.30	21.92	77.57	246	58.96	106.11	54.75
PZT22222AT1G	U52	EL	35.43	77.91	20.71	76.38	30.51	51.91	24.57	96.71	41.16	86.31	30.46	80.37	31	97.85	19.16	82.95
PZT22222AT1G	U52	ML	48.14	50.54	48.54	59.96	59.55	51.70	61.27	48.13	31.89	79.00	39.15	65.86	61	48.21	34.63	74.04
PZT22222AT1G	U52	PL	6.72	100.00	13.41	89.57	16.48	71.83	14.61	87.50	21.77	78.48	9.03	91.74	14	87.09	14.03	86.45
PZT22222AT1G	U50	TE	13.77	89.21	0.21	100.00	72.07	91.59	0.62	11.10	45.22	76.48	3.22	76.94	1	26.74	0.69	27.72
PZT22222AT1G	U50	TP	304.18	60.05	537.39	62.29	426.04	68.57	276.25	68.42	686.14	64.72	651.09	65.10	99	76.64	251.76	65.80
PZT22222AT1G	U50	EL	22.84	44.42	39.99	90.74	37.28	44.66	61.41	80.72	34.10	94.65	51.74	84.39	63	74.68	53.93	79.15
PZT22222AT1G	U50	PL	6.62	89.20	13.56	88.63	11.02	93.83	14.43	89.02	53.75	53.85	10.22	78.10	13	90.69	31.13	62.92
PZT22222AT1G	U51	TE	0.29	100.00	0.18	100.00	45.41	78.76	74.06	85.22	24.07	98.49	34.53	84.55	40	81.08	55.87	97.52
PZT22222AT1G	U51	TP	1191.16	64.60	17764.99	65.22	802.12	61.63	5196.37	67.74	679.00	63.92	20707.10	65.18	127	72.61	619.28	66.86
PZT22222AT1G	U51	EL	12.73	30.50	12.65	96.50	26.76	42.31	7.94	85.09	27.79	81.66	16.01	75.91	15	86.76	17.74	77.70
PZT22222AT1G	U51	PL	7.49	92.03	12.53	88.23	11.22	86.46	9.73	94.39	31.69	69.62	9.70	91.45	9	90.11	39.63	61.85
PZT22222AT1G	U49	TE	134.54	93.60	105.64	88.48	104.57	92.11	102.07	91.35	115.58	95.90	102.35	99.56	96	90.48	100.75	97.35
PZT22222AT1G	U49	TP	14.19	67.13	17.03	85.87	11.45	86.79	11.87	88.12	14.62	91.79	15.93	70.61	12	90.96	15.10	81.61
PZT22222AT1G	U49	EL	0.17	11.69	0.22	8.57	5.43	0.95	3.86	1.10	0.92	3.24	1.05	3.91	5	1.58	0.77	3.54
PZT22222AT1G	U49	PL	50.70	54.52	25.13	65.21	24.31	66.85	17.11	90.79	60.03	55.07	29.96	66.18	16	90.25	35.00	62.73
PZT22222AT1G	U53	TE	103.41	98.47	91.88	93.01	85.60	89.69	147.49	75.76	138.59	78.60	5.60	88.32	52	75.82	76.10	76.48
PZT22222AT1G	U53	TP	13.73	82.72	15.33	84.53	13.38	90.20	21.02	77.82	18.43	83.64	14.01	86.23	57	54.05	27.48	73.21
PZT22222AT1G	U53	EL	2.95	1.02	4.42	0.59	6.94	0.68	3.94	1.18	1.00	5.31	4.89	42.95	5	1.48	1.36	2.29
PZT22222AT1G	U53	PL	98.28	47.22	96.01	46.66	91.65	43.16	25.29	69.57	104.56	47.29	37.72	58.02	15	88.35	79.38	48.01
0603YD225KAT2A	C9		9.81	74.92	68.39	82.45	103.69	67.97	29.97	63.24	18.76	87.11	109.77	75.39	14	69.07	96.51	76.75
0603YD225KAT2A			82.19	67.53	102.27	70.99	97.69	77.68	63.93	71.02	94.31	74.91	102.02	72.48	63	69.86	89.10	64.93
0603YD225KAT2A	C10		6.73	64.53	109.33	72.34	90.10	61.17	35.06	66.23	93.64	72.71	6.34	64.88	13	73.41	105.71	85.51

Appendix A- Summary of XRF data from Assembler A

0603YD225KAT2A			66.80	69.18	118.00	73.11	107.38	73.62	101.62	70.89	113.85	80.63	62.29	69.55	100	65.46	108.80	80.07
0603YD225KAT2A	C11		89.52	87.01	122.07	81.65	126.18	73.72	251.32	59.86	102.29	76.20	59.78	72.98	199	56.79	163.34	86.10
0603YD225KAT2A			113.60	74.09	125.86	74.63	51.42	69.30	114.98	99.34	110.51	74.30	59.41	72.56	118	98.99	112.95	80.38
0603YD225KAT2A	C12		45.14	80.88	94.29	81.25	75.03	71.87	57.41	71.81	93.89	77.30	12.23	74.66	47	71.98	76.65	79.29
0603YD225KAT2A			77.15	74.19	126.25	82.34	96.79	97.27	61.97	79.63	153.27	82.62	91.09	66.80	73	72.85	109.17	80.61
0603YD225KAT2A	C13		96.97	75.94	74.33	75.80	83.18	75.19	68.72	73.81	72.34	70.22	53.85	82.14	78	70.31	71.85	75.20
0603YD225KAT2A			111.60	73.68	103.11	75.62	52.65	75.39	53.97	67.50	97.91	82.52	83.04	68.80	52	68.81	99.86	70.79
0603YD225KAT2A	C14		54.76	81.29	85.53	67.93	77.33	66.62	88.99	72.08	81.23	81.90	7.14	62.68	79	70.69	81.84	76.35
0603YD225KAT2A			125.85	73.28	120.14	83.85	102.87	67.35	119.73	70.24	143.91	74.67	68.32	63.90	115	68.77	117.16	73.10
0603YD225KAT2A	C15		123.88	81.37	116.26	79.30	84.18	70.01	34.00	61.73	63.09	74.24	26.13	69.91	12	70.22	102.27	85.14
0603YD225KAT2A			176.50	83.08	134.00	81.26	99.58	72.81	94.33	63.06	108.19	80.27	101.24	56.50	93	55.05	83.08	61.63
0603YD225KAT2A	C16		68.90	87.57	102.89	76.83	93.83	72.17	98.04	69.93	86.41	81.34	76.83	84.35	96	63.19	91.08	80.70
0603YD225KAT2A			64.83	71.82	107.77	81.64	102.81	65.94	84.03	72.72	84.34	69.86	98.31	72.96	87	72.91	102.32	74.18
06035C103KAT2A	C17		100.58	78.58	96.66	65.31	52.53	71.11	130.27	98.98	113.64	80.46	20.26	82.56	119	99.26	98.36	77.24
06035C103KAT2A			110.83	79.23	99.89	77.46	81.91	63.47	171.31	54.17	93.58	69.76	69.77	66.10	171	54.18	111.10	60.81
06035C103KAT2A	C18		94.60	81.24	108.49	77.92	74.19	64.75	91.03	64.67	121.88	70.23	43.15	72.56	104	62.80	13.83	80.54
06035C103KAT2A			94.16	98.98	119.67	72.03	75.15	59.70	122.44	68.81	114.79	76.12	80.57	72.32	119	69.67	102.94	61.86
06035C103KAT2A	C19		77.35	67.63	103.92	78.18	62.61	64.22	93.72	91.91	135.15	74.08	21.41	80.72	125	67.10	94.55	76.61
06035C103KAT2A			106.28	80.92	28.58	75.33	56.35	66.67	178.83	54.86	119.98	85.61	69.88	67.41	163	55.27	114.55	72.75
06035C103KAT2A	C20		67.60	82.82	104.57	73.92	49.75	71.41	50.01	72.19	65.70	73.41	103.05	98.42	46	72.61	98.14	75.99
06035C103KAT2A			62.95	75.30	117.95	76.30	130.95	72.71	57.27	65.54	115.56	84.18	222.90	58.43	61	65.09	107.32	82.24
06035C103KAT2A	C21		105.21	78.71	97.88	73.54	94.90	67.06	46.48	70.70	94.11	76.29	120.35	73.10	40	70.99	97.12	71.39
06035C103KAT2A			114.82	79.32	101.67	77.77	90.66	73.91	51.15	68.01	109.96	83.37	86.93	75.69	52	66.93	88.49	74.69
06035C103KAT2A	C22		49.95	69.64	132.24	73.32	59.50	72.54	59.61	70.67	80.08	82.35	103.11	82.53	93	66.06	114.57	67.69
06035C103KAT2A			117.71	82.95	110.11	78.17	56.61	74.11	57.00	78.31	110.21	73.76	95.32	79.93	58	76.56	114.86	66.93
06035C103KAT2A	C23		6.06	58.95	93.91	75.23	67.45	62.69	58.15	77.89	105.09	74.70	72.79	71.74	65	76.93	98.57	77.29
06035C103KAT2A			54.71	70.09	142.93	83.64	70.71	66.06	59.06	72.34	125.15	84.94	70.24	70.27	64	71.62	83.89	72.76
06035C103KAT2A	C24		96.02	76.95	107.61	76.41	62.71	70.17	60.46	76.35	98.08	81.32	23.49	82.59	54	76.54	86.17	80.74
06035C103KAT2A			125.46	86.93	140.71	77.38	59.23	68.19	87.93	73.64	100.02	83.18	97.99	76.91	89	73.61	112.08	79.88
97 WT% tin Std							301.61	97.68			207.48	97.31						
97 WT% tin Std							323.06	97.61			312.02	97.74						
97 WT% tin Std							224.42	97.26			265.51	97.53						

Mitigation of Pure Tin Risk by Tin-Lead SMT Reflow

Results of an Industry Round-Robin

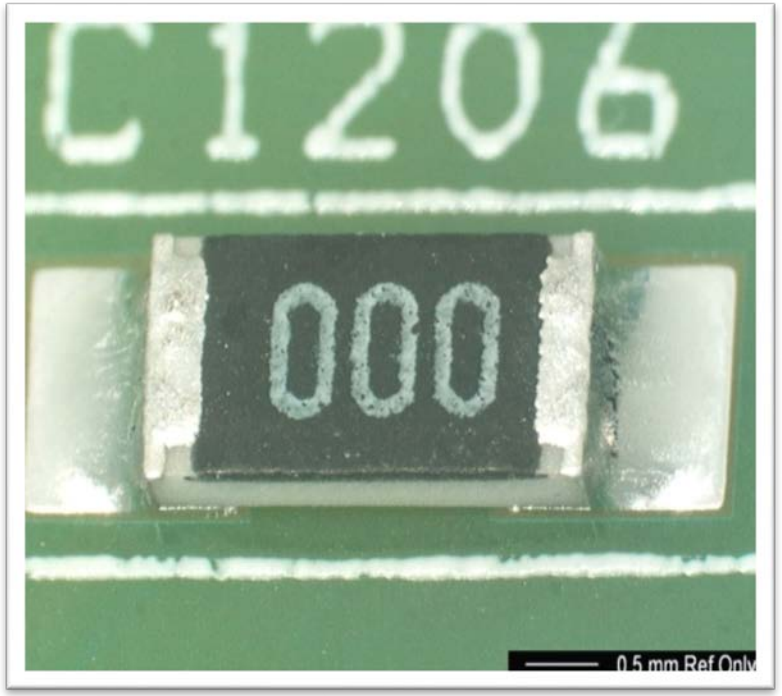
David Pinsky - Raytheon Integrated Defense Systems
Tom Hester - Raytheon Space and Airborne Systems
Dr. Anduin Touw - The Boeing Company
Dave Hillman - Rockwell Collins

March 2016

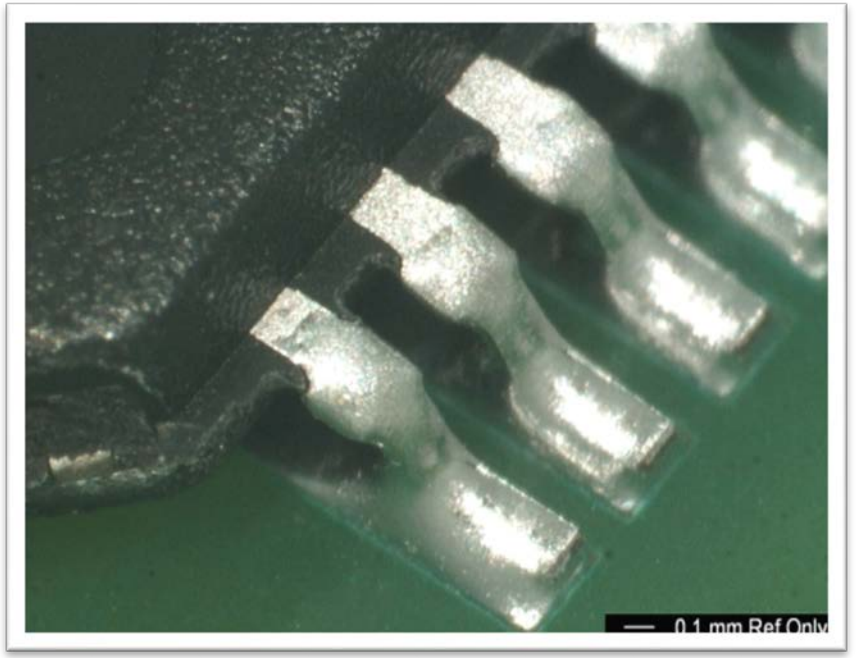
Background

- Components with pure tin finished terminations are at risk for tin whisker growth and potential unreliability.
- The addition of lead (Pb) is an effective means to mitigate tin whisker growth. Therefore, eutectic tin lead solder does not pose a meaningful risk of tin whisker growth provided the lead content is at least 3% by weight.
- Those portions of pure tin terminations that are replaced by eutectic tin lead solder during SMT processing no longer poses a risk of whisker formation.
- Therefore, components where eutectic tin lead solder has fully replaced all tin plating on the terminations are fully mitigated against tin whisker risks. Parts that can be mitigated in this fashion are said to be "self mitigating“.

Examples



Solder covers the entire termination: self-mitigating



Solder does not cover the entire termination: not self-mitigating

Previous Work

- A study was performed in 2010, the results of which have been published, concluding that:
  - Component termination geometry could be used to predict reliable self mitigation for components soldered to HASL finished boards, using a specific (fairly typical) SMT process
- The study did not address how these results may or may not apply to components soldered to boards using different manufacturing processes, surface finishes, or pad geometries

Aim of the Present Study

- If the conditions under which self mitigation is achieved reliably can be determined, it will be possible to use certain tin terminated parts without introducing the risk of whisker shorts, and without employing any other mitigating techniques
- IPC Task Group 8-81F was formed under the PERM Council (Committee 8-81) to investigate
- This study was performed to evaluate the conditions under which typical SMT components will achieve self mitigation

Design of Experiment

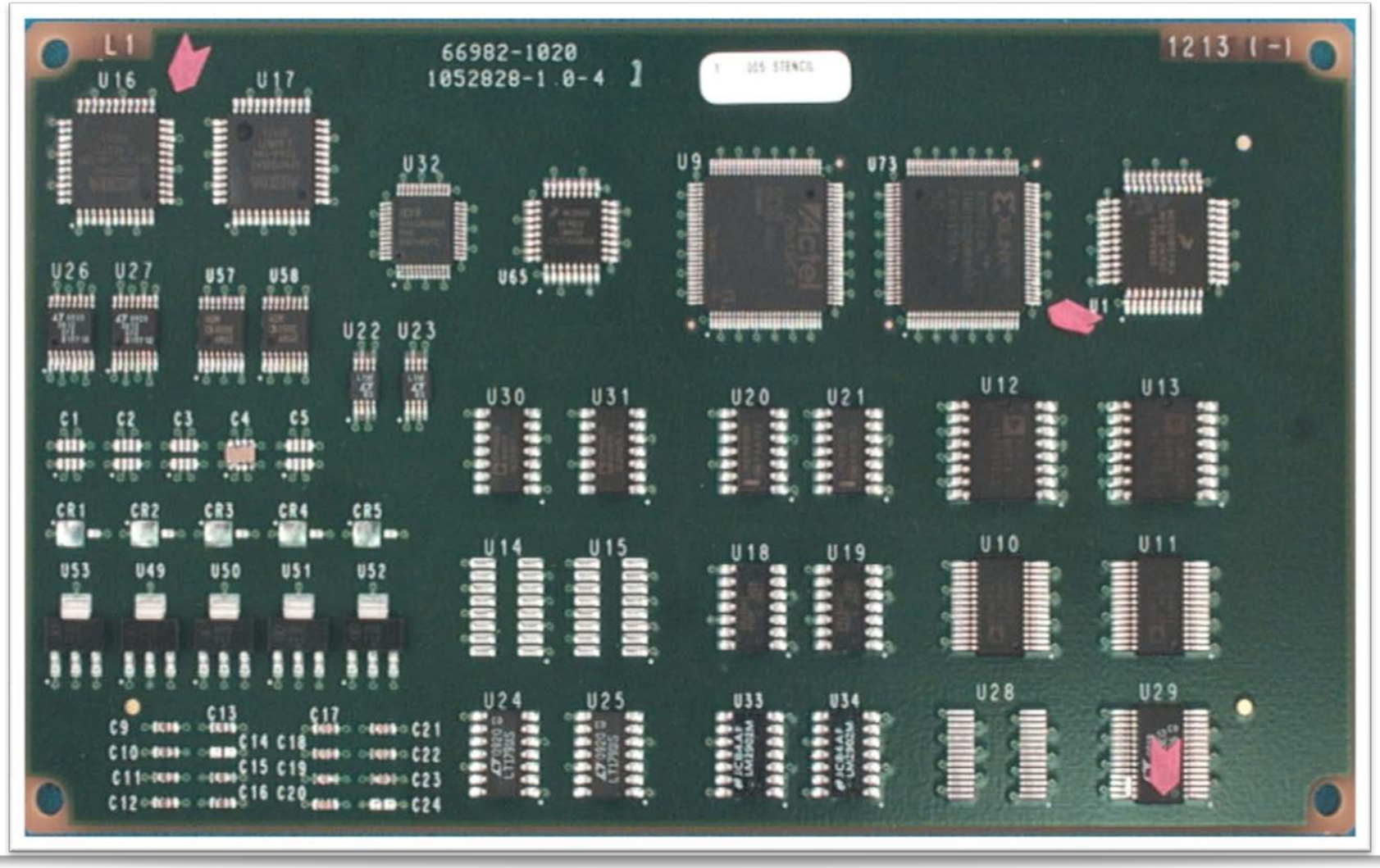
Many potential factors for consideration were considered for inclusion in the study. The four factors shown in the table below were selected. The layout of the board and the components were reused from the prior study, to permit direct comparison between the results of the two studies.

Experimental Factor	Settings
Component Packages	16 different part numbers (details below)
Board finish	OSP and Sn Pb HASL
Pad size	Per initial study and 25% smaller
Manufacturing Process	Seven different locations

Design of Experiment

- Each of the seven assembly locations were provided with a kit containing eight bare boards (Four types, two replicants) and all of the components necessary to populate them. Each assembler chose process conditions as they would deem appropriate to achieve compliance with IPC J-STD-001, Class 3 requirements
  - HASL finish/large pads
  - HASL finish/small pads
  - OSP finish/large pads
  - OSP finish/small pads

Assembled Test Vehicle



Components Used

Part Number	Package Style	Quantity per vehicle	Termination Length (mils)	Termination Height (mils)
06035C103KAT2A	0603 chip	10	31	13
0603YD225KAT2A	0603 chip	10	31	13
A3PN030-ZVQG100	TQFP100-14mm	1	40	16
ADM213EARSZ	SSOP28-5.3mm	2	59	31
EPM7032AETC44-10N	A-TQFP44-10mm-.8mm	1	40	16
IR2156SPBF	SO14G-3.8mm	2	41	23
LM2901DG	SO14G-3.8mm	2	41	23
LTC3703EG_PBF	SSOP28-5.3mm	2	59	31
MBRM140T1G	DO-216AA	5	49/17	20
MC9S08GT16AMFBE	QFP44-.8mm	1	66	36
MC9S08QE4CLC	LQFP32-7mm-.8mm	1	42	25
OP482GSZ	SO14G-3.8mm	2	46	19
PZT2222AT1G	SOT223	5	69/73	20
STAC9200X5TAEB1X	LQFP48-7mm-.5mm	1	42	25
W3L1YC474MAT1AF	0612 chip	5	12	39
XC9572XL-5TQG100C	LQFP100-14mm-.5mm	1	39	23

Assembly Process Details

Setting	Process A	Process B	Process C	Process D	Process F	Process G
Reflow type	Vapor Phase	Convection Oven	Convection Oven	Convection Oven	Convection Oven	Convection Oven
Flux	ROL0	ROL0	ORM0 63/37	ROL0	No clean	Tacky Flux
Stencil thickness	5 mils	5 mils	5 mils	4 mils	5 mils	5 mils
Time above Liquidus	90s	60-75s	66s	90s	60s	70s
Peak temperature	218C	215C	220C	225C	213C	220C
Atmosphere	Air	Nitrogen	Nitrogen	Nitrogen	Nitrogen	Nitrogen
Number of reflow cycles	1	1	1	1	1	2
Rework	none	none	none	none	none	Yes

Boards from assembly process “E” were not completed in time for inclusion in this report - See slide below on Future Plans

XRF Evaluations

- Finished sample boards solder terminations were inspected by X-Ray Fluorescence (XRF)
  - All measurements performed on the same machine, using the same program
  - Three locations measured of each of two terminations for every leaded device
  - Two locations measured on each leadless device
- The quantitative analysis procedures were performed according to details provided in MIL-STD-1580B, requirement nine, dated 15 November 2010
  - Specified minimum requirements for instruments, calibration checks, data recording, and measurement conditions
  - Specified use of 97 wt% Sn, 3 wt% Pb materials standard materials standards
  - SEM-EDS and XRF quantitative analysis data were adjusted for accuracy using a 97 wt% Sn, 3 wt% Pb materials standard issued by a supplier of ROHS verification equipment

Sample of Raw XRF Data

A small slice of the raw data from a single test vehicle

	A	B	C	D	E	F	H	I	K	L	M	N	O	P	Q	R
1		Designator	Location	MeasurementID	Thickness1	Sn	CountRate2	Pb	CountRate3	Date	Time	XYZSiteNu	StageX	StageY	StageZ	Comments
2						Wt%		Wt%								
3	1	U1	E, TL	383	445	99.03	1153.49	0.97	18.63	7/16/2015	12:04:43 PM	1	4070.906	4199.961	5375.213	51
4	2	U1	M, TL	384	145	98.46	1074.53	1.54	16.01	7/16/2015	12:05:07 PM	2	4084.488	4199.961	5350.775	51
5	3	U1	P, TL	385	127	63.44	519.57	36.56	366.54	7/16/2015	12:05:31 PM	3	4104.843	4200.945	5355.45	51
6	4	U1	E, BL	386	169	99.22	1111.75	0.78	9.06	7/16/2015	12:05:55 PM	4	4075.276	3884.173	5365.85	51
7	5	U1	M, BL	387	199	99.47	1134.33	0.53	6.87	7/16/2015	12:06:21 PM	5	4086.85	3884.882	5369.763	51
8	6	U1	P, BL	388	163	66.73	563.45	33.27	391.87	7/16/2015	12:06:44 PM	6	4110.276	3886.378	5361.9	51
9	7	U11	E, TL	389	116	100.00	1053.15	0.00	0.00	7/16/2015	12:07:12 PM	7	4000.748	2752.441	5364.575	51
10	8	U11	M, TL	390	123	97.59	1028.76	2.41	22.41	7/16/2015	12:07:37 PM	8	4011.142	2752.441	5365.325	51
11	9	U11	P, TL	391	115	53.91	412.21	46.09	439.47	7/16/2015	12:08:01 PM	9	4030.039	2752.717	5360.725	51
12	10	U11	E, BL	392	121	100.00	1065.79	0.00	0.00	7/16/2015	12:08:25 PM	10	4000.197	2420.118	5376.65	51
13	11	U11	M, BL	393	148	98.80	1085.23	1.20	12.76	7/16/2015	12:08:55 PM	11	4010.472	2420.433	5376.725	51
14	12	U11	P, BL	394	111	51.69	389.15	48.31	451.83	7/16/2015	12:09:32 PM	12	4029.449	2420.433	5378.3	51
15	13	U29	E, TL	395	112	99.06	1025.98	0.94	8.02	7/16/2015	12:09:57 PM	13	4009.252	2162.795	5361.588	51
16	14	U29	M, TL	396	94	97.15	941.83	2.85	21.27	7/16/2015	12:10:22 PM	14	4015.472	2162.48	5350.038	51
17	15	U29	P, TL	397	109	60.16	478.25	39.84	360.79	7/16/2015	12:10:45 PM	15	4037.362	2162.874	5362.788	51
18	16	U29	E, BL	398	73	98.86	877.33	1.14	6.83	7/16/2015	12:11:10 PM	16	4007.874	1830.748	5342.238	51
19	17	U29	M, BL	399	105	98.06	991.14	1.94	15.80	7/16/2015	12:11:34 PM	17	4016.969	1830.551	5351.238	51
20	18	U29	P, BL	400	105	56.04	432.90	43.96	391.33	7/16/2015	12:12:09 PM	18	4037.677	1830.118	5353.775	51
21	19	U28	E, BL	401	117	98.85	1035.06	1.15	10.23	7/16/2015	12:12:35 PM	19	4714.685	1833.071	5365.163	51
22	20	U28	M, BL	402	153	98.30	1079.00	1.70	18.45	7/16/2015	12:12:59 PM	20	4724.409	1833.031	5375.038	51
23	21	U28	P, BL	403	133	61.64	499.21	38.36	399.67	7/16/2015	12:13:23 PM	21	4749.646	1833.031	5358.625	51
24	22	U28	E, TL	404	98	98.75	981.78	1.25	9.64	7/16/2015	12:13:49 PM	22	4713.858	2164.843	5363.663	51
25	23	U28	M, TL	405	102	97.37	971.18	2.63	21.02	7/16/2015	12:14:13 PM	23	4721.024	2165.63	5354.913	51
26	24	U28	P, TL	406	106	63.66	516.88	36.34	320.22	7/16/2015	12:14:38 PM	24	4752.323	2165.079	5371.163	51
27	25	U10	E, BL	407	144	99.12	1087.26	0.88	9.11	7/16/2015	12:15:02 PM	25	4695.984	2423.11	5376.3	51
28	26	U10	M, BL	408	117	100.00	1056.22	0.00	0.00	7/16/2015	12:15:33 PM	26	4703.976	2423.622	5373.35	51

Sample Text Slide

A slice of the data summary for eight boards from a single assembler – device U19 mitigates for all eight, U9 does not

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		Part Number	Designator	Location	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn	Thickness1	Sn
2		Board Type			Large Pads/OSP		Small Pads/HASL		Large Pads/HASL		Small Pads/HASL		Small Pads/OSP		Large Pads/OSP		Large Pads/HASL		Small Pads/OSP	
3		Board Number			17		31		2		32		46		16		1		47	
39	36	[illegible]	[illegible]	[illegible]	[illegible]	52.24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43.86	[illegible]	50.86	[illegible]	61.59	[illegible]	[illegible]	[illegible]	45.11
40	37	A3PN030-ZVQG100	U9	E, TL	1.20	53.50	26.36	92.94	123.38	98.48	117.31	96.28	113.61	81.04	122.80	98.55	107	95.95	146.85	68.06
41	38	A3PN030-ZVQG100	U9	M, TL	119.50	66.06	81.90	93.95	94.27	98.98	91.12	98.03	94.11	76.60	97.17	99.03	88	97.52	100.05	66.58
42	39	A3PN030-ZVQG100	U9	P, TL	141.20	62.68	116.98	57.69	70.99	49.82	47.61	42.29	148.94	59.41	85.69	51.98	47	42.08	84.93	49.30
43	40	A3PN030-ZVQG100	U9	E, BL	0.80	100.00	13.94	91.43	94.68	97.69	88.74	97.84	53.46	97.95	75.87	98.31	85	98.26	153.55	68.17
44	41	A3PN030-ZVQG100	U9	M, BL	134.92	64.65	99.79	94.64	91.49	97.29	87.23	96.88	88.60	98.25	96.73	98.99	87	96.38	131.03	68.03
45	42	A3PN030-ZVQG100	U9	P, BL	202.04	61.50	149.52	58.78	79.24	57.01	53.89	48.86	166.28	58.10	99.38	60.23	52	48.93	112.23	52.31
46	43	LM2901DG	U21	E, TL	24.90	42.31	84.06	84.06	2.48	56.07	1.94	51.86	70.54	64.56	43.42	49.59	2	56.61	1.92	58.11
47	44	LM2901DG	U21	M, TL	28.89	47.40	56.81	76.05	1.28	51.03	1.51	59.40	54.83	60.81	5.98	68.63	1	43.24	1.44	51.74
48	45	LM2901DG	U21	P, TL	118.80	49.15	149.13	50.23	194.65	52.50	192.49	51.96	268.21	56.58	252.40	55.69	194	52.35	225.47	52.25
49	46	LM2901DG	U21	E, BL	13.42	31.27	82.55	84.04	4.12	63.99	42.67	53.62	98.48	82.56	33.48	53.47	43	53.55	33.26	47.11
50	47	LM2901DG	U21	M, BL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	66.13	[illegible]	83.74	[illegible]	46.83	[illegible]	65.67	[illegible]	53.67
51	48	LM2901DG	U21	P, BL	181.64	50.96	163.71	51.81	146.54	49.78	117.57	46.38	154.82	52.23	197.02	53.36	123	47.64	121.33	47.34
52	49	IR2156SPBF	U19	E, TL	57.35	74.17	96.13	77.93	80.54	78.17	43.55	83.49	50.37	69.29	11.14	77.73	27	83.21	20.16	66.48
53	50	IR2156SPBF	U19	M, TL	66.45	75.09	124.72	78.67	84.00	63.18	73.94	79.56	57.27	55.31	52.80	62.38	67	79.80	54.25	62.38
54	51	IR2156SPBF	U19	P, TL	158.97	50.30	150.68	55.60	77.49	53.39	106.80	50.39	159.71	53.28	167.48	52.26	115	49.89	137.60	48.45
55	52	IR2156SPBF	U19	E, BL	53.55	73.64	96.90	79.58	75.40	77.85	79.16	81.93	73.60	78.37	75.83	77.41	69	81.17	60.51	65.54
56	53	IR2156SPBF	U19	M, BL	63.33	68.17	72.46	76.76	66.88	72.67	63.77	79.27	74.01	71.73	62.02	74.87	69	78.06	50.96	65.32
57	54	IR2156SPBF	U19	P, BL	202.54	56.39	139.93	55.06	119.39	54.92	112.26	54.42	161.11	57.07	152.67	58.41	131	53.96	127.01	52.71
58	55	IR2156SPBF	U18	E, BL	74.60	76.32	88.06	82.31	70.59	82.49	80.02	81.73	71.73	64.74	80.13	86.90	72	81.25	86.53	58.92
59	56	IR2156SPBF	U18	M, BL	141.07	52.59	178.24	55.21	113.59	46.12	113.57	53.76	164.66	51.03	148.45	59.15	114	56.11	137.80	50.23
60	57	IR2156SPBF	U18	P, BL	177.00	51.45	165.65	49.30	152.25	49.22	140.66	48.73	166.37	50.29	176.72	53.49	140	49.27	154.55	50.23
61	58	IR2156SPBF	U18	E, TL	67.81	71.32	89.73	79.96	80.93	83.19	72.11	76.40	78.99	69.60	65.64	68.68	72	76.44	56.61	60.53
62	59	IR2156SPBF	U18	M, TL	63.34	61.87	77.46	75.84	87.37	61.61	86.47	60.24	71.17	60.52	63.48	57.45	76	62.33	71.31	51.47
63	60	IR2156SPBF	U18	P, TL	181.86	54.32	143.16	53.54	141.41	51.53	135.75	52.64	142.40	52.24	164.59	51.66	127	52.00	105.59	51.24
64	61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Data Validity

- Measurements with unreasonably low thicknesses are suspect and were omitted from the analysis below:
  - Thicknesses of 15 micro-inches or less are not consistent with tin plating or with a solder fillet
  - Readings are associated with low count rate for tin
  - Visual inspection suggests that many of these readings are due to exposed bare copper at the location where the lead protrudes out from the package
- Composition data associated with larger thicknesses appear to be valid

Data Analysis

- ANOVA analysis with backwards deletion was used to examine the significance of the following:
  - Pad finish: not significant
  - Pad size: significant, but very minor effect
  - Soldering process: significant
- Based on this analysis the data for all of the boards assembled by a single process were combined, to enhance the statistics for evaluating differences between the packages and the processes
- Confidence bounds were established for probability of parts with <97% tin using one-sided tolerance intervals

Results Summary

- The results are summarized in the charts that follow
- The following color code is used:
  - Green means the chance of being <97% tin is at least 0.99
  - Yellow means the chance of being <97% tin is between 0.9 and 0.99
  - Orange means the chance of being <97% is between 0.75 and 0.9
  - Pink means the chance of being <97% is between 0.5 and 0.75
  - Red means the chance of being <97% is less than 0.5
- Three different confidence intervals were used: 60%, 80%, and 90%, with the results for each shown on its own chart

Data Summary

60% Confidence Interval

Termination				Assembly Process					
Length	Height	Package Style	Part_Number	A	B	C	D	F	G
31	13	0603 chip	06035C103KAT2A	0.996	1.000	1.000	1.000	1.000	1.000
31	13	0603 chip	0603YD225KAT2A	0.998	1.000	1.000	1.000	1.000	1.000
40	16	TQFP100-14mm	A3PN030-ZVQG100	0.836	0.770	0.779	0.822	0.810	0.995
59	31	SSOP28-5.3mm	ADM213EARSZ	0.729	0.692	0.736	0.710	0.710	0.892
40	16	A-TQFP44-10mm-.8mm	EPM7032AETC44-10N	0.863	1.000	0.847	0.792	0.820	0.985
41	23	SO14G-3.8mm	IR2156SPBF	0.996	1.000	1.000	1.000	1.000	1.000
41	23	SO14G-3.8mm	LM2901DG	1.000	1.000	1.000	1.000	1.000	1.000
59	31	SSOP28-5.3mm	LTC3703EG_PBF	0.729	0.692	0.717	0.721	0.684	0.904
49/17	20	DO-216AA	MBRM140T1G	1.000	0.777	0.866	0.776	0.762	0.955
66	36	QFP44-.8mm	MC9S08GT16AMFBE	0.767	0.505	0.687	0.678	0.691	0.745
42	25	LQFP32-7mm-.8mm	MC9S08QE4CLC	0.839	0.692	0.755	0.735	0.698	0.904
46	19	SO14G-3.8mm	OP482GSZ	1.000	1.000	1.000	1.000	1.000	1.000
69/73	20	SOT223	PZT22222AT1G	0.931	0.804	0.803	0.767	0.852	0.698
42	25	LQFP48-7mm-.5mm	STAC9200X5TAEB1X	0.781	0.713	0.774	0.767	0.736	1.000
12	39	0612 chip	W3L1YC474MAT1AF	0.743	0.000	0.000	0.430	0.001	0.432
39	23	LQFP100-14mm-.5mm	XC9572XL-5TQG100C	0.815	0.731	0.763	0.768	0.738	0.991

Data Summary

80% Confidence Interval

Termination				Assembly Process					
Length	Height	Package Style	Part_Number	A	B	C	D	F	G
31	13	0603 chip	06035C103KAT2A	0.995	1.000	1.000	1.000	1.000	1.000
31	13	0603 chip	0603YD225KAT2A	0.997	1.000	1.000	1.000	1.000	1.000
40	16	TQFP100-14mm	A3PN030-ZVQG100	0.816	0.748	0.757	0.802	0.790	0.993
59	31	SSOP28-5.3mm	ADM213EARSZ	0.707	0.669	0.712	0.688	0.688	0.876
40	16	A-TQFP44-10mm-.8mm	EPM7032AETC44-10N	0.837	1.000	0.816	0.762	0.792	0.978
41	23	SO14G-3.8mm	IR2156SPBF	0.995	1.000	1.000	1.000	1.000	1.000
41	23	SO14G-3.8mm	LM2901DG	1.000	1.000	1.000	1.000	1.000	1.000
59	31	SSOP28-5.3mm	LTC3703EG_PBF	0.707	0.668	0.695	0.697	0.659	0.888
49/17	20	DO-216AA	MBRM140T1G	0.999	0.758	0.850	0.757	0.743	0.945
66	36	QFP44-.8mm	MC9S08GT16AMFBE	0.736	0.471	0.654	0.645	0.658	0.714
42	25	LQFP32-7mm-.8mm	MC9S08QE4CLC	0.811	0.659	0.720	0.703	0.665	0.882
46	19	SO14G-3.8mm	OP482GSZ	1.000	1.000	1.000	1.000	1.000	1.000
69/73	20	SOT223	PZT22222AT1G	0.919	0.784	0.784	0.745	0.836	0.671
42	25	LQFP48-7mm-.5mm	STAC9200X5TAEB1X	0.749	0.681	0.739	0.736	0.705	0.999
12	39	0612 chip	W3L1YC474MAT1AF	0.719	0.000	0.000	0.404	0.000	0.406
39	23	LQFP100-14mm-.5mm	XC9572XL-5TQG100C	0.786	0.699	0.729	0.737	0.706	0.986

Data Summary

90% Confidence Interval

Termination				Assembly Process					
Length	Height	Package Style	Part_Number	A	B	C	D	F	G
31	13	0603 chip	06035C103KAT2A	0.993	1.000	1.000	0.999	1.000	1.000
31	13	0603 chip	0603YD225KAT2A	0.996	1.000	1.000	1.000	1.000	1.000
40	16	TQFP100-14mm	A3PN030-ZVQG100	0.801	0.732	0.739	0.787	0.774	0.991
59	31	SSOP28-5.3mm	ADM213EARSZ	0.689	0.651	0.693	0.670	0.670	0.863
40	16	A-TQFP44-10mm-.8mm	EPM7032AETC44-10N	0.815	1.000	0.791	0.739	0.769	0.970
41	23	SO14G-3.8mm	IR2156SPBF	0.993	1.000	1.000	1.000	1.000	1.000
41	23	SO14G-3.8mm	LM2901DG	1.000	1.000	1.000	1.000	1.000	1.000
59	31	SSOP28-5.3mm	LTC3703EG_PBF	0.690	0.649	0.677	0.679	0.640	0.874
49/17	20	DO-216AA	MBRM140T1G	0.999	0.743	0.837	0.742	0.728	0.937
66	36	QFP44-.8mm	MC9S08GT16AMFBE	0.712	0.446	0.629	0.620	0.633	0.689
42	25	LQFP32-7mm-.8mm	MC9S08QE4CLC	0.788	0.634	0.693	0.678	0.640	0.864
46	19	SO14G-3.8mm	OP482GSZ	1.000	1.000	1.000	1.000	1.000	1.000
69/73	20	SOT223	PZT22222AT1G	0.908	0.769	0.769	0.728	0.823	0.651
42	25	LQFP48-7mm-.5mm	STAC9200X5TAEB1X	0.724	0.656	0.711	0.711	0.680	0.998
12	39	0612 chip	W3L1YC474MAT1AF	0.701	0.000	0.000	0.385	0.000	0.387
39	23	LQFP100-14mm-.5mm	XC9572XL-5TQG100C	0.763	0.675	0.702	0.712	0.681	0.980

Results Summary

- Some components were nearly certain to self mitigate under all process conditions
  - 0603 chips, SO14G's
- Some components were nearly certain to self mitigate but only for a particular process
  - TFQP100 and LQFP48 for Process G, and TQFP44 for Process B
- Most components exhibited a moderate probability of self mitigation within the range of 0.6 to 0.9
- One component exhibited a very low probability of self mitigation (0612 chip)

Conclusions

- The probability that a given component will self mitigate is strongly dependent upon the package geometry
- Assembly process can have a significant effect on whether or not a particular component will self mitigate
- Within the range covered by this study, relative pad size exerts a very weak affect on self mitigation
- The choice of HASL or OSP pad finish had no effect on self mitigation

Next Steps

- Add the data from the seventh assembly process to the data set and update the results
- Perform cross section and SEM/EDS to evaluate the solder coverage and determine validity of measurements associated with unusually low thickness readings
- Investigate correlation between various process parameters and self mitigation of different components
- Investigate effect of aged part solderability

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