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Mitigation of Pure Tin Risk by Tin-Lead SMT Reflow

Results of an Industry Round-Robin

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Background

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- 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

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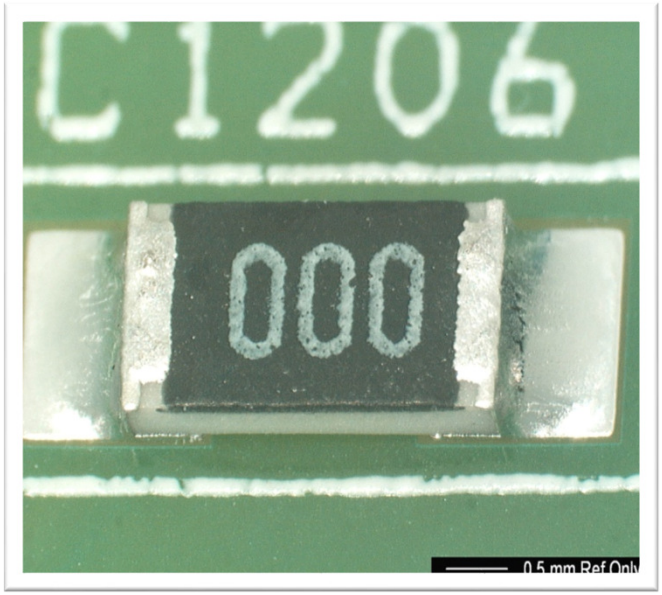
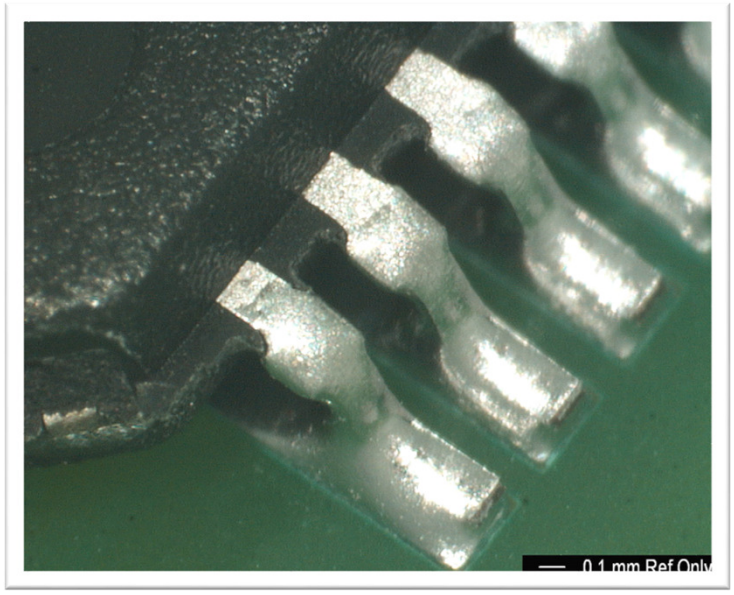


Solder covers the entire termination: self-mitigating



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

Previous Work

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- A study was performed in 2010 by Raytheon, 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

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- 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
- 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

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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 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

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- 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 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

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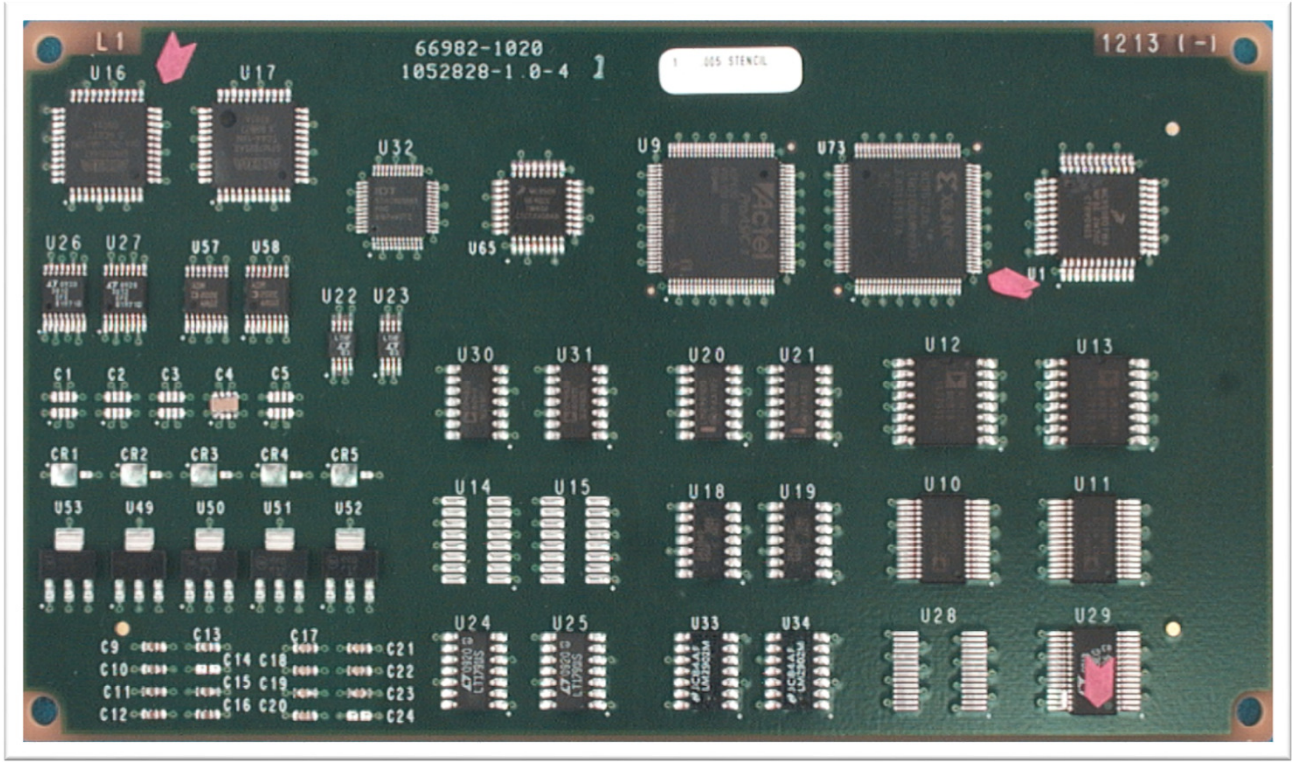

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Components Used

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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

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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	ROL0	No clean	Tac 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

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- 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 Matrix Metrologies

Sample of Raw XRF Data

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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

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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]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40	37	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
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	93.03	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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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	20.18	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	86.30	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

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- 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 lead egress
- Composition data associated with larger thicknesses
  appear to be valid

Data Analysis

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- 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

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- 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

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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

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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

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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

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- Some components were nearly certain to self mitigate under all process conditions
  - 0603 chips, and 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

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- 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

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- 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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