Reliability of QFN's Reworked Using a Traditional Hot Gas Method Versus the StencilMate Method:

A summary of test results from the NASA-DoD Lead-Free Electronics Project 2

1. PROJECT SUMMARY

The proliferation of Pb-free electronics has created significant concerns over the reliability of electronic devices. Of this long list of concerns, the effect of reworking components originally assembled with Pb-free solder with SnPb solder is particularly important to the US Naval Supply Command (NAVSUP). Circuit card assemblies are frequently repaired using eutectic SnPb solder in order to maintain legacy equipment, maximize fleet readiness, and maximize cost avoidance.

The NASA-DoD Lead-Free Electronics (Project 2) study was formed to investigate some of the reliability concerns associated with the proliferation of Pb-free electronics. In support of this effort, 30 additional test-vehicles were commissioned for the purpose of evaluating the effect of reworking Pb-free assemblies with SnPb solder. Components that could be reworked at the organizational level (in the field) were reworked by NSWC Crane, including DIP-20's, TQFP-144's, TSOP-50's, and CLCC-20's. These components were all reworked by hand, using standard practices. Additionally, QFN-20's were reworked by Business Electronics Soldering Technologies (BEST). These components were reworked using two methods, a traditional hot gas method and BEST's patented StencilMate™ method.

Test vehicles were subjected to a variety of conditions to simulate the high stress environment required in military applications. Tests include vibration, drop shock, and thermal cycle testing. Results from these tests showed that reworking Pb-free assemblies with SnPb solder resulting in an assembly that was as reliable as the as-manufactured assembly. This was true regardless of the original solder and component finish. Review of the traditional hot gas method for reworking QFN's versus the StencilMate™ method showed that, within the scope of these tests, using either method resulted in equivalent reliabilities.

2. QFN REWORK PROCEDURE

All QFN's were reworked at Business Electronics Soldering Technologies (BEST) in Rolling Meadows, IL. Every QFN on Crane specific test vehicles were reworked either using a traditional hot gas method or with the aid of BEST's patented StencilMate™ method. The primary difference between these two methods is that the StencilMate™ method employs a polyimide stencil to aid in solder paste application and alignment for the replacement part. The stencil remains as part of the assembly after rework.

The traditional hot gas rework method is as follows:

1. As manufactured Lead-free QFN's were removed using profile QFN Lead Free Removal #000185. (IPC Bottom Terminated Device Removal procedure 3.11).
2. Residual solder was removed from lands with solder wick and Alpha UP-78 paste flux using IPC 7711 procedure 4.4.1 Surface Mount Land method.
3. Rework site was cleaned with isopropyl alcohol.
4. A 4 mil stainless steel stencil with 1:1 aperture aspect ratio and window-paned thermal slug was aligned over QFN land sites.
5. Site was pasted with Alpha OM-5100 no-clean tin-lead solder paste and stencil released.
6. Replacement QFNs were hand placed and reflowed on a Metcal/OK QX2 convection unit with QFN Tin Lead Place profile #000184. (IPC Bottom Terminated Device, Installation Pre-bump and place procedure 5.8.1.1).
7. Rework site spot cleaned with isopropyl alcohol and dried.
8. Batch aqueous cleaning was accomplished with an Aqueous Technologies AQ-400CL washer.
9. Device X-rayed per IPC Class II requirements with a VJ Electronix (Nicolet) model X-1525 x-ray unit.
10. Device area inspected per IPC Class II requirements.

The StencilMate™ rework method is as follows:

1. As manufactured Lead-free QFN's were removed using profile QFN Lead Free Removal #000185. (IPC Bottom Terminated Device Removal procedure 3.11)
2. Residual solder was removed from lands with solder wick and Alpha UP-78 paste flux using IPC 7711 procedure 4.4.1 Surface Mount Land method.
3. Rework site was cleaned with isopropyl alcohol.
4. (IPC Bottom Terminated Device Installation Pre-bump and place with stay in place stencil procedure 5.8.1.2)
5. A 4 mil thick 1:1 aperture aspect ratio StencilMate™ stencil for the part was aligned and applied to the component lands.
6. Component lands were pasted with Alpha OM-5100 no-clean tin-lead solder paste.
7. Solder was reflowed on QFN lands with a Metcal/OK QX2 convection unit with QFN Tin Lead Place profile #000184.
8. StencilMate™ stencil removed from part and cleaned with isopropyl alcohol.

9. "Bumped" QFN inspected for solder consistancy and coplanarity.
10. A 4 mil thick 1:1 aperture aspect ratio StencilMate™ stencil was aligned to the board lands and pressure applied to activate the adhesive.
11. Stencil aperatures were pasted with Alpha OM-5100 no-clean Tin-Lead solder paste.
12. "Bumped" QFN were hand placed into the pasted apertures of the board stencil.
13. QFNs were reflowed on a Metcal/OK QX2 convection unit with QFN Tin Lead Place profile #000184.
14. Rework site spot cleaned with isopropyl alcohol and dried.
15. Batch aqueous cleaning was accomplished with an Aqueous Technologies AQ-400CL washer.
16. Device X-rayed per IPC Class II requirements with a VJ Electronix (Nicholet) model X-1525 x-ray unit.
17. Device area inspected per IPC Class II requirements

The number of QFN's reworked is organized by board location (site) and rework method in Table .

Table : Number of QFN's reworked once or twice for vibration, drop, and thermal cycle testing using a traditional hot gas method or the StencilMate™ method.

	Vibration			Drop			Thermal Cycle - SAC305			Thermal Cycle – SN100C	
	Traditional		Stencil	Traditional		Stencil	Traditional		Stencil	Traditional	
Site	1X	2X	1X	1X	2X	1X	1X	2X	1X	1X	2X
U15	5	4	--	4	5	--	1	2	1	1	2
U27	4	5	--	5	4	--	1	1	2	1	1
U28	5	4	--	4	4	1	2	1	1	2	1
U47	5	--	4	5	--	4	1	2	1	1	2
U54	4	--	5	4	--	5	1	1	2	1	1

3. TEST RESULTS

Reworked QFN's were subjected to vibration, drop shock, and thermal cycling testing. In general, QFN's proved to be of the most reliable components on the test vehicles. These components had comparatively low failure rates. Failures that did occur happened at the later stages of testing. Differences between test locations during vibration testing and the limited number of test vehicles evaluated during drop shock testing prevented the comparison of as-manufactured QFN's to reworked QFN's. Also, the high reliability of these components prevented in depth analysis comparing the effect of rework methods. However, within the scope of the performed tests, reworking QFN's with the traditional hot gas method versus the StencilMate method resulted in equivalently reliable assemblies.

3.1 VIBRATION

Vibration testing was conducted at two locations with the general consortium boards tested at Boeing and test vehicles specific to the rework effort (containing the reworked QFN's) tested at Celestica.

Detailed reports concerning the specifics of the vibration testing are available at the NASA-TEERM website (http://teerm.nasa.gov) for the NASA-DOD Lead-Free Electronics (Project 2).

Test-vehicles were evaluated at 8 intensity levels, 8, 10, 12, 14, 16, 18, 20, and 28 G. Each intensity level was evaluated consecutively, starting with 8G and increasing in intensity every 60 minutes. All intensity levels are with respect to the normal direction of the board (z-axis). The vibration profile for each level, as programmed for the shaker table, is outline in Table . Electrical continuity was measured continuously during testing and failures were recorded at the time of failure.

Table : Composite vibration intensity and profile as a function of test time. For all levels, the power spectral density (PSD) increased at the rate of 6db/octave between 20 and 50Hz and decreased at the rate of 6dB/octave between 1000 and 2000Hz.

Test Time [min]	Power Spectral Density, PSD, [G^2/Hz]		
	20Hz	50-1000Hz	
0-60	0.00698	0.0438	0.0109
61-120	0.0107	0.067	0.0167
121-180	0.0157	0.0984	0.0245
181-240	0.0214	0.134	0.0334
241-300	0.0279	0.175	0.0436
301-360	0.03354	0.2215	0.0552
361-420	0.0437	0.2734	0.0682
421-480	0.0855	0.536	0.133

The actual intensity varied as a function of position on the board. The test location (Boeing vs. Celestica) also resulted in times to failure that were determined to be statistically different when comparing identically manufactured components. For these reasons, analysis of QFN time to failure was conducted only comparing components tested at Celestica and located at the same site. All QFN's tested at Celestica were reworked so it was not possible to compare reworked QFN's to as-manufactured QFN's. Only rework methods were compared. It should be noted that a comparison of other component types on the test vehicles showed that other SnPb reworked components were as reliable as their as-manufactured Pb-free equivalents.

3.1.1 Results

Results from the comparison of percent failure and time to failure for reworked QFN's are shown in Table . Percent failure was calculated by dividing the number of components in a group that failed during testing by the total number of components in that group. Average time to failure was calculated considering components that did and did not fail during testing. A failure time of 480 minutes (the total test time) was assigned to components that did not fail to prevente skewing the average time to failure towards lower failure times. Statistical p-values were calculated by comparing the average times to failure via a Student t-test, again assigning a failure time of 480 minutes to components that did not fail. Groups were considered significantly different if the percent failure differed by at least 40%, or if the calculated p-value was less than 0.05.

Table : Percent failure, average time to failure, and p-values for reworked QFN's during vibration testing. Differences in time to failure are considered significant if the percent failure differs by at least 40% or for a p-value of 0.05 or less.

	Percent Failure, [%]			Average Time to Failure, [min]		
	Traditional		Stencil	Traditional		Stencil
Site	1X	2X	1X	1X	2X	1X
U15	100	100	--	117	90	--
U27	25	0	--	478	DNF	--
U28	**60**	**100**	--	446	421	--
U47	100	--	75	389	--	419
U54	**100**	--	**0**	366	--	DNF

Two of the five rework comparisons were determined to be significantly different. The second traditional hot gas rework of U28 resulted in an increase in percent failure from 60% to 100% when compared to the first traditional hot gas rework. However, a review of the raw data showed that four of the five 2X reworked samples did not fail until the final 28G test and that the average times to failure for both groups is still in the final 28G timeframe.

The StencilMate rework of U54 resulted in a drastic decrease in the percent failure from 100% to no failures when compared to the 1X traditional hot gas rework. None of the five StencilMate reworked QFN's at site U54 failed during testing. Review of the raw data shows three of the four 1X hand reworked QFN's did not fail until the final 28G cycle and that there was one early failure at 115 minutes (10G) that significantly affected the average time to failure.

The two other 1X versus 2X hand reworked groups and the other 1X hand rework versus StencilMate rework were not significantly different.

Failure analysis of QFN's after vibration testing was conducted by Celestica. A detailed report containing all failure analysis micrographs is available at the NASA-TEERM website (http://teerm.nasa.gov) for the NASA-DOD Lead-Free Electronics (Project 2). For the most part, components failed due to crack propagation through the solder or along the solder/QFN interface with no correlations between the crack path and number of reworks. Cross-sections through QFN U28 on board 61 did show missing or partial solder on two of the QFN leads. This particular component was reworked twice using the traditional hot gas method and, unexpectedly, did not fail until 450 minutes into the test (28G).

DROP SHOCK

Drop shock testing was conducted at Celestica. Detailed reports concerning the specifics of the drop shock testing are available at the NASA-TEERM website (http://teerm.nasa.gov) for the NASA-DOD Lead-Free Electronics (Project 2).

Two different tests were conducted. One set of test vehicles (3 boards) were subjected to ten 340G drops followed by ten 500G drops. Another set (6 boards) were subjected to twenty 500G drops. A lack of component failures during the first ten 340G drops was the reason for the two different test conditions.

Only reworked specific test vehicles were subjected to drop shock testing. Because all QFN's on reworked specific test vehicles were reworked, no comparison was made between drops to failure for as-manufactured QFN's and reworked QFN's. It should be noted that a comparison of other component types on the test vehicles showed that other SnPb reworked components were as reliable as their as-manufactured Pb-free equivalents. Like vibration testing, the actual strain is dependent on board location, so only a direct site-to-site comparison was practical.

3.2.1 Results

Only one of the 45 QFN's evaluated failed during drop shock testing. This QFN failed on the 18th 500G drop and was reworked twice using the traditional hot gas method. Failure analysis was only conducted on QFN's reworked once or twice using the traditional hot gas method. Solder cracks were observed on QFN's, but the cracks had not propagated far enough to lead to electrical failure. No correlations were observed between the number of reworks and the presence of solder cracks.

Table : Percent failure of QFN's during twenty 500G drop shock tests. Only one failure occurred during testing for a 2X reworked QFN at site U15.

	Percent Failure, [%]	
	Traditional	
Site	1X	2X
U15	0	20
U27	0	0
U28	0	0
U47	0	--
U54	0	--

THERMAL CYCLE

Thermal cycle testing between -55°C and 125°C was conducted at Rockwell-Collins. Detailed reports concerning the specifics of the thermal cycle testing are available at the NASA-TEERM website (http://teerm.nasa.gov) for the NASA-DOD Lead-Free Electronics (Project 2). It should be noted that reports containing results prior to December, 2011 were written using a dataset containing significant errors and that this issue has been resolved.

General consortium and rework specific test vehicles were all evaluated together. The temperature was cycles between -55°C and 125°C at a maximum rate of 10°C/min and a dwell time of 30 minutes at 125°C and 10 minutes at -55°C. A total of 4068 cycles were completed. Electrical continuity was measured continuously during testing and failure was recorded by the corresponding total number of cycles.

3.3.1 Results

Very few QFN's failed during testing. The percent failure of QFN's originally soldered with SAC305 or SN100C is shown in Table . The QFN's originally soldered with SN100C and reworked once using the traditional hot gas methods had the highest percent failure at 33%. However, this represents only 2 failures. Review of the raw data shows one failure occurred after only 277 cycles. This early failure is not characteristic of all other failures that occurred after a minimum of 1400 cycles. Based on this observation, it appears that all QFN groups, regardless of rework history and original solder, performed equivalently within expected variation.

Table : Percent failure of QFN's during 4068 thermal cycles from -55°C to 125°C.

	SAC305			SN100C	
	Total Tested	Total Failures	Percent Failure	Total Tested	Total Failures
As-Manufactured	25	2	8	25	3
1X Traditional	7	0	0	6	2
2X Traditional	6	0	0	7	0
1X StencilMate	7	1	14	7	1

Failure analysis was also conducted at Rockwell-Collins. These results are available in the final test report available at the NASA-TEERM website (http://teerm.nasa.gov) for the NASA-DOD Lead-Free Electronics (Project 2). It was noted that QFN's reworked using the StencilMate method had a larger stand-off distance from the board. No other observations were specific to the rework of QFN's.

4. CONCLUSIONS

1) QFN's were of the most reliable component type on the test vehicle with comparatively low overall failure rates. Failures that did occur happened in the later stages of testing.

2) The low failure rates of QFN's and unexpected differences in results between test sites prevented an in-depth analysis of the effect of reworking QFN's via either method

3) Within in the scope of this testing, QFN's reworked using the StencilMate™ method were as reliable as QFN's reworked using the traditional hot gas method.

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