6. Phase 2: Accelerated Life, Vibration, Mechanical Shock, and Branch Water

6.1 Introduction. The test matrix in Figure 1.2 shows 160 LRSTF PWAs scheduled for a test sequence consisting of accelerated life (AL) test, vibration (Vib), and mechanical shock (MS). The purpose of these tests was to determine if these environments would compromise the integrity of the conformal coating.

As mentioned throughout this report (see Section 2.1), all previous tests (Sections 2 to 5) took place in two stages. The non-urethane PWAs (120) were tested in the first stage and urethane PWAs (40) were tested in the second stage. The reason two stages were used is that urethane was added to the test matrix after the non-urethane PWAs were either tested or were in the process of being testing.

A second build of LRSTF PWAs was required to supply PWAs to be coated with urethane. The use of PWAs from a second build introduced an element of uncertainty into the analysis of the test results that could not be resolved with certitude. That is, if a significant effect involves urethane, it is possible that this effect is actually attributable to something associated with the second built, such as a change in materials or changes due to new batches of components. Since the two sets of tests were conducted several months apart, this could also be a contributing factor to differences in test results. In statistical parlance, results for urethane are completely confounded with the second build. However, this is not an issue in the AL-Vib-MS test sequence since all PWAs used in this sequence came from the second build.

This homogenous nature of the PWAs in the AL-Vib-MS test sequence provided an opportunity to repeat the first portion of the BW test to resolve any ambiguities related to the performance of the urethane coated PWAs in the BW-SF test. These comparisons will be made throughout with the text highlighted in special boxes. The first portion of the BW test is the most strenuous as it requires the PWAs to be in a vertical position with both sides of the PWA soaking wet during the electrical test. Results of the vertical position can be extrapolated to the horizontal positions where only the uppermost side of the PWA is wet during the electrical test. Hence, only the worst case portion of the BW was repeated at the conclusion of the AL-Vib-MS test sequence.

The test protocol for the AL-Vib-MS-BW test sequence requires testing the LRSTF PWAs for electrical functionality a total of six times during the test sequence. Randomization procedures were followed during testing to control extraneous sources of variation. All electrical testing was performed at the RSC facility in McKinney, TX. The JTP test protocols for each of these tests are now summarized.

Test Protocol for Accelerated Life:
This test determines the long-term performance of a solder joint connection. It is designed to simulate eight years of actual operation. The specific test steps are as follows:

1. Place the specimens into a temp chamber
2. Decrease the temperature to -55°*C* at a rate of 15 ± 2°*C* / minute
3. When the temperature of the assembly reaches -40°*C*, begin increasing the temperature to 110°*C* at 15 ± 2°*C* / minute
4. When the temperature of the assembly reaches 95°*C*, begin decreasing the temperature to -55°*C* at 15 ± 2°*C* / minute
5. Repeat Steps 2 to 4 for 1800 cycles

Test Protocol for Vibration:
This test determines the effect of vibration on a specimen. Vibration testing is performed to determine the equipment resistance to vibrational stresses expected during its shipment and use. Vibration can cause wire chafing, loosening of fasteners, intermittent electrical contacts, touching and shorting of electrical parts, seal deformation, component fatigue, optical misalignment, cracking, and rupturing. The vibration test fixture held 10 PWAs at a time. The following parameters formed the basis for the vibration test:

- Use a random vibration on the X, Y, and Z axis
- Use a vibration rate of 5 Hz to 2000 Hz
- Test for 2 hrs per axis
- Use 8 g_{rms} to 10 g_{rms} loading on the PWAs

Test Protocol for Mechanical Shock:
This test determines a specimen's resistance to impact. It is performed as follows:

1. Mount a PWA in a rectangular fixture
2. From a height of 1 meter, drop the PWA onto a concrete surface as follows:
   - Five times on each of the nonconnector edges (15 drops total)
   - One time on each face (2 drops total)

Test Protocol for the Abbreviated Branch Water Test:
The BW test uses tap water having a conductance of 1000 ± 400 micromho. One *ml* of concentrated liquid dish detergent is added to a one-liter flask of tap water to reduce the surface tension of the mixture. This detergent solution is sprayed directly on the PWA during the BW vertical position test. The electrical functionality of the PWA is tested while it is wet with the mixture. The abbreviated test protocol for the BW test as follows (the test protocol for the full BW appears in Section 3.1):

1. Place the PWA in a vertical position in the CCAMTF ATS
2. Spray the detergent solution uniformly over both sides of the PWA until a continuous film is visible over the entire PWA. Allow the solution to penetrate around the components and run downward for 3 ± 0.5 *min*.
3. Test and record the electrical performance of the PWA
4. Spray the PWA with approximately 20 *ml* of deionized water to remove the detergent solution. Remove the PWA from the CCAMTF ATS and dry it with any mechanism that will not contaminate it.
5. Replace the PWA in the CCAMTF ATS and test and record its electrical performance

6.2 Overview of Test Results. Each of the 160 PWAs used in the AL-Vib-MS-BW test sequence was tested six times in the CCAMTF ATS.

1. Pre-test to determine electrical functionality after processing
2. Electrical functionality testing after 1800 cycles of the AL test
3. Electrical functionality testing after vibration testing
4. Electrical functionality testing after mechanical shock testing
5. Electrical functionality testing during the vertical position in the BW test
6. Electrical functionality testing after the vertical position in the BW test

At each of the test times, 160×23 = 3680 electrical test measurements were recorded. An overview of the test results for each of these test times is now given. Detailed results of the electrical performance for each of the 23 circuits listed in Table 1.1 appear in Sections 6.3 to 6.9. Summary and conclusions are given in Section 6.10.

Pre-test. The electrical measurements were compared to the JTP acceptance criteria given in Table 1.1 at each test time. The JTP acceptance criteria require a comparison to Pre-test for 11 of the 23 electrical circuits (responses 1, 2, 5, 6, 13-17, 22, and 23). Hence, comparisons could not be made to the JTP acceptance criteria for these 11 circuits at Pre-test, but their measurements were compared to baseline results in the CCAMTF GR&R study (Iman et al, 1998).

The remaining 23 - 11 = 12 electrical circuits produced 1920 Pre-test measurements. There were no anomalies among these measurements, as retesting eliminated all questionable response. The percentage of electrical responses meeting the JTP acceptance criteria at Pre-test was (1920 - 0)/(12 × 160) = 100.0% for the 12 circuits for which such comparisons could be made.

AL Test. Each of the 23 circuits on the LRSTF PWA was tested after 1800 cycles of AL as explained in the AL test protocol. There were 24 anomalous measurements that did not meet the JTP acceptance criteria following the AL test. These anomalies are summarized in Table 6.1 by surface finish, coating status, and flux type.

The 24 anomalies recorded after AL occurred on 22 PWAs that are summarized below by surface finish, coating status, and flux type. A chi-square analysis (see complete details in Chapter 10 of Iman, 1994) of the frequencies of the anomalies in this latter summary can be used to determine if the anomalies are independent of the experimental parameters. This test shows that immersion Ag had significantly more anomalies after AL (p-value = 0.028), but there were no effects due to either coating status or flux type. The p-value is a measure of statistical significance and should be < 0.05 to declare a statistical difference.

Surface Finish		Coating Status		Flux Type	
HASL	5	None	6	Low-residue	10
Benzimidazole	3	Parylene	4	Water soluble	12
Immersion Ag	11	Silicone	6		
Immersion Au/Pd	3	Urethane	6		

Twenty of the 24 anomalies after AL occurred for HF TLC circuits. HF TLC 50MHz (circuit 13 in Table 1.1) had nine anomalies and HF RNR (circuit 17 in Table 1.1) had seven. Only three of the 24 anomalies were severe enough to be considered for failure analysis and one of these returned to normal after the vibration test. In addition to the 24 anomalies, there were 11 HSD circuits that gave no response: HSD PTH (4) and HSD SMT (7). Such failures have been common with the HSD circuits and failure analyses have shown these problems to be due to either a damaged component or trace and not related to surface finish, coating status, or flux type.

Vibration Test. Each of the 23 circuits on the LRSTF PWA was tested after the vibration test as explained in the vibration test protocol. Forty-seven anomalies that did not meet the JTP acceptance criteria following the AL test. Only nine of these carried over from the AL test. These 47 anomalies are summarized in Table 6.2 by surface finish, coating status, and flux type. The 47 anomalies occurred on 37 PWAs, which are summarized below. The number of anomalies in this summary was independent of surface finish, coating status, and flux type.

Surface Finish		Coating Status		Flux Type	
HASL	9	None	13	Low-residue	24
Benzimidazole	9	Parylene	7	Water soluble	13
Immersion Ag	7	Silicone	8		
Immersion Au/Pd	12	Urethane	9		

Thirty-nine of the 47 anomalies after vibration occurred for HF TLC circuits. HF TLC 50MHz, HF TLC 500MHz, and HF TLC 1GHz (circuits 13-15 in Table 1.1) had 8, 17, and 8 anomalies, respectively. HF RNR had six anomalies. Only four of the 47 anomalies were severe enough to be considered for failure analysis. In addition to these 47 anomalies, there were 22 HSD circuits that gave no response: HSD PTH (7) and HSD SMT (15) with seven of these carrying over from the AL test.

Mechanical Shock Test. Each of the 23 circuits on the LRSTF PWA was tested after the MS test as previously explained in the MS test protocol. There were 46 anomalies that did not meet the JTP acceptance criteria following the MS test. Only nine of these carried over from the vibration test. These 46 anomalies are summarized in Table 6.3 by surface finish, coating status, and flux type. The 46 anomalies occurred on 36 PWAs, which are summarized below. The number of anomalies in this summary was independent of surface finish, coating status, and flux type.

Surface Finish		Coating Status		Flux Type	
HASL	13	None	15	Low-residue	23
Benzimidazole	5	Parylene	7	Water soluble	13
Immersion Ag	8	Silicone	8		
Immersion Au/Pd	10	Urethane	6		

Twenty of the 46 anomalies after MS occurred for HF TLC circuits. HF TLC 50MHz and HF RNR had 10 and 8 anomalies, respectively. Only 13 of the 46 anomalies were severe enough to be considered for failure analysis. In addition to these 46 anomalies, there were 44 HSD circuits that gave no response: HSD PTH (12) and HSD SMT (32).

BW Test: PWAs in Vertical Position. Each of the 23 circuits on the LRSTF PWA was tested with the PWA placed in a vertical position in the CCAMTF ATS and then sprayed on both sides with a detergent mixture as described in Steps 2, 3, and 4 of the abbreviated BW test protocol. The PWAs were soaking wet during this test and, not surprisingly, there were a large number (983) of anomalies. In fact, every PWA had at least one anomaly and the median number of anomalies was six. The uncoated PWAs had an average of 6.1 anomalies per PWA and the coated PWAs (parylene, silicone, and urethane) averaged 6.2 anomalies. This contrasts with the corresponding results in the BW-SF test sequence (see Section 3) where the uncoated PWAs had an average of 11.2 anomalies per PWA and the coated PWAs (parylene, silicone, and urethane) averaged 8.1 anomalies. However, the reader needs to keep in mind that at the start of the BW-SF test there was a software problem that increased the number of HSD anomalies. As explained in Section 3.2, a factor to remove the extra cable length from the total propagation delay (TPD) measurement was not set correctly and this created inflated times for TPD.

Table 6.1 Tabulation of the 24 Test Measurements Over All 23 Electrical Circuits that did not Meet the JTP Acceptance Criteria after the AL Test

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (6)	**LR**	1			1	2
	WS	1		2	1	4
Benzimidazole (3)	**LR**	1				1
	WS			1	1	2
Immersion Ag (12)	**LR**	3	1	1	1	6
	WS	1	2	2	1	6
Immersion Au/Pd (3)	**LR**			1	1	2
	WS		1			1
LR = 11, WS = 13	**Totals**	7	4	7	6	24

Table 6.2 Tabulation of the 47 Test Measurements Over All 23 Electrical Circuits that did not Meet the JTP Acceptance Criteria after the Vibration Test

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (10)	**LR**	2	2		1	5
	WS	2		2	1	5
Benzimidazole (10)	**LR**	2	1	2	3	8
	WS	1		1		2
Immersion Ag (9)	**LR**	3	1		2	6
	WS	1	2			3
Immersion Au/Pd (18)	**LR**	1	2	4	3	10
	WS	4	1	1	2	8
LR = 29, WS = 18	**Totals**	16	9	10	12	47

Table 6.3 Tabulation of the 46 Test Measurements Over All 23 Electrical Circuits that did not Meet the JTP Acceptance Criteria after the Mechanical Shock Test

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (21)	**LR**	3	4	1		8
	WS	7		3	3	13
Benzimidazole (6)	**LR**	3		3		6
	WS					
Immersion Ag (9)	**LR**	4	1	1	1	7
	WS		2			2
Immersion Au/Pd (10)	**LR**	2		2	1	5
	WS	2	1		2	5
LR = 26, WS = 20	**Totals**	21	8	10	7	46

These 983 anomalies are summarized by surface finish, coating status, and flux type in Table 6.4. This table shows uncoated (280), silicone (271), and urethane (243) PWAs having the most anomalies and parylene (189) with the least. On the other hand, the anomalies were reasonably uniformly spread over surface finishes and flux types. The yield in the vertical position was only 2697/3680 = 73.3%.

Table 6.4 Tabulation of the 983 Test Measurements Over All 23 Electrical Circuits that did not Meet the JTP Acceptance Criteria during the BW Vertical Position Test

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (238)	**LR**	37	17	33	29	116
	WS	35	23	37	31	126
Benzimidazole (236)	**LR**	40	19	35	28	122
	WS	33	23	29	29	114
Immersion Ag (272)	**LR**	40	37	34	34	145
	WS	35	26	36	30	127
Imm Au/Pd (233)	**LR**	35	22	37	35	129
	WS	25	22	30	27	104
LR = 512, WS = 471	**Totals**	280	189	271	243	983

Table 6.5 Tabulation of the 96 Test Measurements Over All 23 Electrical Circuits that did not Meet the JTP Acceptance Criteria after the BW Vertical Position Test

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (27)	**LR**	3		2	2	7
	WS	8	1	7	4	20
Benzimidazole (21)	**LR**	5	1	3	3	12
	WS	6	1	2		9
Immersion Ag (27)	**LR**	6	4	4	3	17
	WS	6	1	2	1	10
Imm Au/Pd (21)	**LR**	3	1	3	3	10
	WS	5	1		5	11
LR = 46, WS = 50	**Totals**	42	10	23	21	96

Following the vertical position test, the PWAs were rinsed with DI water, dried, and retested as described in Steps 4 and 5 of the BW test protocol. There were 96 anomalies (yield = 3584/3680 = 97.4%) that did not meet the JTP acceptance criteria at this test time. This is an increase of 96 - 46 = 50 anomalies following the MS test, which indicates some permanent damage from the vertical BW test. Seventy-nine of these 96 anomalies affected the following four circuits: HVLC SMT (29), gull wing (16), HF TLC 50MHz (17), and HF RNR (17). All post-vertical test anomalies are summarized by surface finish, coating status, and flux type in Table 6.5.

A summary of the yields by circuit type after each segment of the All-Vib-MS-BW test sequence is given in Section 6.10. Results are now presented for the BW-SF test sequence by major circuit group.

6.3 HCLV Circuitry. The JTP acceptance criteria for HCLV PTH and HCLV SMT (responses 1 and 2 in Table 1.1) are based on the following differences between test measurements. Specifically, these differences are not to exceed 0.50V.

Delta 1 = AL - Pre-test
Delta 2 = Vibration - Pre-test
Delta 3 = MS - Pre-test
Delta 4 = BW vertical position - Pre-test
Delta 5 = Post vertical position - Pre-test

The Pre-test measurements and deltas were analyzed with the GLM in Equation 1.1. The base case for this GLM was defined in Section 1.9 as HASL surface finish processed with LR flux without conformal coating. Table I.1 in Appendix I summarizes the results of the GLM analyses for HVLC PTH. The second column in Table I.1 contains the GLM results for the actual Pre-test measurements. The remaining columns in Table I.1 contain the GLM results for the Deltas.

Summaries similar to Table I.1 have been constructed to summarize the GLM results for each of the 23 electrical responses of the LRSTF PWA. Since each summary table fills one page, these tables have been placed in Appendix I for ease of reference and to improve the readability of this section. Subsequent discussions of the GLM results for the remaining circuitry make reference to Tables I.1 to I.23.

The model R^2s given in Tables I.1 and I.2 for the HCLV circuitry are summarized as follows.

Summary of GLM R^2s for HCLV Circuitry by Test Time

Circuit	Pre-test	AL 1800 Cycles	Vibration	Mech. Shock	BW Vertical	BW Post Vertical
HCLV PTH	2.9%	16.6%	10.7%	14.4%	10.8%	4.7%
HCLV SMT	6.2%	6.5%	10.8%	2.6%	7.9%	2.5%

The magnitudes of the model R^2s are all quite low, which is an indication of no practical difference from the base case voltage measurements due to the experimental parameters of interest: surface finishes, coating status (i.e., no coating, parylene, or silicone), or flux type.

Comparison with Results in Section 3.3: The R^2 values for HCLV SMT are noticeably smaller than those summarized in Section 3.3 for the BW vertical test portion of the BW-SF test. A comparison of the coefficients in Tables C.1 and C.2 with those in Tables 6.1 and 6.2 shows that the higher R^2 values in Section 3.3 were attributable to urethane. This parameter is not significant in the AL-Vib-MS-BW test sequence, which is a strong indication that the results in Section 3.3 were reflective of something associated with the second build and not with urethane.

Displays. Boxplots for the BW-SF exposure sequence have been created in Appendix J for each of the 23 electrical responses listed in Table 1.1. Figure J.1 presents boxplots (see Section 1.10) for the HCLV PTH voltage measurements for the HASL surface finish. These measurements are plotted versus test time with LR flux results on the left and WS results on the right. Four overlapping boxplots are used at each test time to show the effect of coating status. Figures J.2, J.3, and J.4 present results for benzimidazole, immersion Ag, and immersion Au/Pd, respectively. Note that the measurements exhibit approximately the same amount of variability throughout and that the voltages in these figures vary over a reasonably small range. This behavior is consistent with the results of the GLM analyses. The corresponding boxplots for HCLV SMT appear in Figures J.5 to J.8. These boxplots are similar to those for HCLV PTH.

Comparison to JTP Acceptance Criterion. There were no HCLV PTH or HCLV SMT measurements that exceeded the JTP acceptance criterion of $\Delta V < 0.50V$ after the AL test. These two circuits had a combined three anomalies at all subsequent test times, but were not of sufficient magnitude to justify being subjected to failure analysis.

6.4 HVLC Circuitry. The JTP acceptance criteria for HVLC PTH and HVLC SMT (responses 3 and 4 in Table 1.1) require these measurements to be between 4µA and 6µA (no comparisons are made to Pre-test for HVLC circuits). All HVLC measurements met the JTP acceptance criteria at Pre-test. After AL and Vib, there was one HVLC SMT anomaly. The number of anomalies increased during the vertical position of the BW test and then decreased at Post-vertical. During the BW vertical test, the HVLC measurements ranged from 0.1µA (smallest reliable measurement for the CCAMTF ATS) to 5,513µA for HVLC PTH and 0.1µA to 9,911µA for HVLC SMT. Both PTH and SMT were punctuated with many extreme outlying observations during the BW vertical test. These outliers can greatly influence the GLM analyses, so the GLM analyses were performed on the logarithms of the observations in all cases (including Pre-test) to ameliorate the influence of the outliers. Results of the subsequent GLM analyses for HVLC PTH and HVLC SMT circuits are given in Tables I.3 and I.4, respectively. The model R^2s for the HVLC circuitry are summarized as follows.

Summary of GLM R^2s for HVLC Circuitry by Test Time

Circuit	Pre-test	AL 1800 Cycles	Vibration	Mech. Shock	BW Vertical	BW Post Vertical
HVLC PTH	2.5%	6.3%	5.3%	6.8%	27.9%	5.2%
HVLC SMT	5.9%	5.8%	5.8%	9.1%	45.3%	8.8%

HVLC PTH. The magnitudes of the model R^2 values for HVLC PTH are low at all test times with the exception of the vertical position of the BW test. It is of interest to review the predictions during the BW vertical test to see the role of surface finish, flux, and coating on the HVLC measurements. Table 6.6 contains the predicted currents for each surface finish/coating/flux combination when the PWAs were in the vertical position in the BW test. Note: the coefficients in Table I.3 are expressed in terms of logarithms and it is necessary to find the anti-log of the GLM prediction to obtain a prediction as given in terms of μA in Table 6.6.

Table 6.6 Predicted Current (μA) for HVLC PTH at BW Vertical

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**	21.9	21.9	21.9	21.9
	WS	7.4	7.4	45.7	7.4
Benzimidazole	**LR**	223.9	8.9	35.5	18.2
	WS	75.9	3.0	74.1	79.4
Immersion Ag	**LR**	21.9	21.9	199.5	93.3
	WS	7.4	7.4	14.5	31.6
Immersion Au/Pd	**LR**	63.1	12.3	63.1	63.1
	WS	21.4	4.2	131.8	21.4

Note that 30 of the 32 predictions in Table 6.6 exceed the upper JTP acceptance criterion of 6μA and one of the remaining two is below the lower limit of 4μA. A review of the table entries shows many interactions among surface finish, coating, and flux. For example, HASL and immersion Au/Pd perform best with WS flux unless the coating is silicone. Benzimidazole performs best with WS flux for uncoated and parylene coated PWAs, but is better with LR flux for silicone and urethane. Immersion Ag is better with WS for all coating conditions.

All HVLC PTH current measurements returned to normal at Post vertical so there was no permanent damage from the BW vertical test.

HVLC SMT. The magnitudes of the model R^2 values for HVLC SMT are similar to those for HVLC PTH. It is also interesting to review the predictions at BW vertical to see the role of surface finish, flux, and coating on the HVLC measurements. Table 6.7 contains the predicted currents for each surface finish/coating/flux combination when the PWAs were in the vertical position in the BW test.

Table 6.7 Predicted Current (μA) for HVLC SMT at BW Vertical

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**	261.8	5.1	261.8	261.8
	WS	261.8	5.1	261.8	261.8
Benzimidazole	**LR**	261.8	5.1	261.8	261.8
	WS	261.8	5.1	7.2	261.8
Immersion Ag	**LR**	261.8	5.1	41.5	261.8
	WS	261.8	5.1	41.5	261.8
Immersion Au/Pd	**LR**	261.8	5.1	261.8	261.8
	WS	48.8	1.0	48.8	48.8

Note that all non-parylene predictions in Table 6.7 exceed the upper JTP acceptance criterion of 6μA. All parylene cases meet the acceptance criterion except for immersion Au/Pd with WS flux. Uncoated and urethane coated PWAs have identical results with silicone being the same as these two except for three cases.

There were 29 anomalous HVLC SMT current measurements that did not return to normal at Post Vertical, with 23 of them being candidates for failure analysis.

Comparison with Results in Section 3.4: Tables C.3 and C.4 show that urethane is significant at Pre-test, BW vertical, and Post-vertical. However, urethane is not significant at these times in Tables I.3 and I.4. This is a strong indication that the results in Section 3.4 were reflective of something associated with the second build and not with urethane.

Displays. Figures J.9 to J.12 present boxplots for the HVLC PTH current measurements versus test time for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. The corresponding boxplots for HVLC SMT appear in Figures J.13 to J.16. These boxplots are based on the logs of the actual measurements. All of these figures exhibit stability up to the time of the BW vertical test where there is great variability due to the PWAs being soaked with the detergent mixture. The HVLC PTH measurements return to normal at Post-vertical as evidenced by the boxplots collapsing to single lines—the JTP acceptance criterion of 4μA to 6μA (not shown) would actually be just above and just below these single lines. There is also considerable variability associated with the HVLC SMT measurements at Post-vertical where the measurements contain 29 anomalies. These anomalies are now discussed in more detail.

Comparison to JTP Acceptance Criterion. The number of anomalous HVLC measurements not meeting the JTP acceptance criterion at each test time are summarized as follows:

Test Time	HVLC PTH	HVLC SMT
Pre-test	0	0
AL 1800 Cycles	0	1
Vibration	0	1
Mechanical Shock	0	14
BW Vertical Position	150	132
BW Post-Vertical	0	29

The AL, Vib, and MS tests did not cause any problems for the HVLC PTH circuit. The HVLC SMT circuit fared well through Vib, but had 14 anomalies after MS (most likely due to a loosening of the SMT components). All HVLC anomalies increased when the PWAs were soaking wet in the BW vertical test, but the HVLC SMT circuit did not fully recover at Post vertical as did the HVLC PTH circuit. There were no HVLC PTH anomalies at the conclusion of the BW test. Hence, the BW test did not cause any permanent damage that affected the performance of the HVLC PTH circuit.

On the other hand, there were 29 HVLC SMT anomalies at the end of the BW vertical test, with 16 of these anomalies being severe enough to be candidates for failure analysis. Results of failure analysis for the 16 anomalous circuits are summarized by surface finish, coating status, and flux type in Table 6.8.

Table 6.8 Failure Analysis Results for HVLC SMT Circuits after the BW Test

MSN	Surface Finish	Coating	Flux	Current (μA)	Failure Analysis Results
647	HASL	None	WS	0.000	
668	HASL	Silicone	WS	0.005	
678	HASL	Silicone	WS	11.773	
691	Benzimidazole	None	LR	0.470	
701	Benzimidazole	None	LR	0.714	
733	Benzimidazole	None	WS	0.708	
717	Benzimidazole	Silicone	LR	13.237	
773	Immersion Ag	None	LR	0.000	
793	Immersion Ag	None	LR	0.782	
786	Immersion Ag	Parylene	LR	0.725	
783	Immersion Ag	Silicone	LR	10.086	
866	Immersion Au/Pd	None	LR	0.688	
870	Immersion Au/Pd	None	LR	12.780	
902	Immersion Au/Pd	None	WS	0.703	
896	Immersion Au/Pd	Parylene	WS	0.000	
898	Immersion Au/Pd	Urethane	WS	0.622	

6.5 HSD Circuitry. The JTP acceptance criterion for HSD PTH and HSD SMT (responses 5 and 6 in Table 1.1) requires the increase in total propagation delay (TPD) (*nanoseconds*) to be less than 20% from Pre-test measurements. As explained in Section 2.5, Pre-test measurements for the urethane PWAs showed that the TPD was approximately 4*ns* longer for the PWAs used in the DF-HF test sequence than for the PWAs that were either uncoated, coated with parylene, or coated with silicone in that sequence. However, this is not a concern in the All-Vib-MS-BW test sequence since these PWAs were all built at the same time and used the same batch of components.

Tables I.5 and I.6 present the results of the GLM analyses for the HSD circuits. These analyses were based on the actual TPDs at Pre-test while the analyses at other test times were based on the percentage change as specified in the JTP acceptance criterion. The model R^2s for the HSD circuitry are summarized below. Note that the model R^2 values at Pre-test in the AL-Vib-MS-BW test sequence are quite small in contrast to the corresponding model R^2 values at Pre-test for the other test environments (Sections 2.5, 3.5, 4.5, and 5.5). This dramatic decrease is directly attributable to same batch of HSD components being used on all PWAs in the AL-Vib-MS-BW test sequence. This eliminates "urethane" as a major significant factor or more correctly stated, it eliminates the second build as a factor.

Summary of GLM R^2s for HSD Circuitry by Test Time

Circuit	Pre-test	AL 1800 Cycles	Vibration	Mech. Shock	BW Vertical	BW Post Vertical
HSD PTH	3.5%	5.9%	3.4%	5.8%	2.8%	10.1%
HSD SMT	1.6%	8.0%	13.7%	28.3%	9.0%	19.7%

The model R^2s are small at all test times, which indicates that surface finish, coating status, and flux type do not have an influence on TPD.

HSD PTH. HSD PTH circuits behaved normally throughout the AL-Vib-MS-BW test sequence, except when they were soaking wet during the vertical position of the BW test. The number of HSD PTH circuits not giving a response due to either damaged components or traces increased as the AL-Vib-MS-BW test sequence progressed as shown in Table 6.9. At each instance of a PTH failure there was a corresponding SMT failure with the exception of two PWAs at BW vertical, but the converse was not true. Thus, the HSD SMT failures are not independent of HSD PTH failures. At Post BW vertical, the 13 failed HSD PTH circuits were distributed across coating status as: uncoated (6), parylene (5), silicone (1), and urethane (1). These differences are not statistically significant (p-value = 0.074). The failed HSD PTH circuits were also independent of surface finish and flux type.

HSD SMT. HSD SMT circuits also behaved normally throughout the AL-Vib-MS-BW test sequence, except when they were soaking wet during the vertical position of the BW test. There were more HSD SMT circuits not giving a response due to either damaged components or traces than for HSD PTH circuits and these numbers increased as the test progressed as shown in Table 6.9. At Post BW vertical, the 32 failed circuits were distributed across coating status as: uncoated (14), parylene (6), silicone (8), and urethane (4). These differences are statistically significant at the 0.05 level of significance (p-value = 0.033). The failed HSD SMT circuits were independent of surface finish and flux type.

Table 6.9 Summary of the Number of Anomalies and Non-Functioning HSD Circuits by Test Time

	Anomalies		Non-Functioning	
Test Time	**HSD PTH**	**HSD SMT**	**HSD PTH**	**HSD SMT**
AL 1800 Cycles			4	7
Vibration		1	7	15
Mechanical Shock		1	12	32
BW Vertical Position	150	132	10	17
BW Post-Vertical		1	13	32

Comparison with Results in Section 3.5: Tables C.5 and C.6 show that urethane is significant at Pre-test, BW vertical, and Post-vertical. However, urethane is not significant at these times in Tables I.5 and I.6. This is a strong indication that the results in Section 3.5 were reflective of something associated with the second build and not with urethane.

Displays. Figures J.17 to J.20 present boxplots for the HSD PTH total propagation delay measurements for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. These boxplots show an increase of approximately 6*ns* during the vertical position of the BW test. However, this increase affects all PWAs and there is very little variability for all combinations of surface finish, coating, and flux at each test time.

The corresponding boxplots for HSD SMT appear in Figures J.21 to J.24. These boxplots show very little variability for all combinations of surface finish, coating, and flux at Pre-test and after AL. However, there is a noticeable increase in variability starting at the conclusion of the vibration test. The combination of immersion Au/Pd and WS flux gives the best results overall as can be seen in the low variability at all test times in Figure J.24.

Comparison to JTP Acceptance Criterion. There were no anomalies at Pre-test and, as shown in Table 6.9, there was only one HSD SMT anomaly at the Post-vertical position of the BW test. On the other hand, at the conclusion of the AL-Vib-MS-BW test sequence, there were 13 HSD PTH and 32 HSD SMT non-functioning circuits. Each of the 13 HSD PTH anomalies was accompanied by a HSD SMT anomaly, so the failures were not independent of one another. Failure analysis was conducted on a sample of these PWAs and revealed that the non-functioning HSD circuits were attributable to either a damaged component or trace as has been the case in the other environmental tests. These 32 anomalies are summarized by surface finish, coating status, and flux type below. The number of anomalies was not related to surface finish, coating status, or flux type although coating status is very close to being significant.

Surface Finish		Coating Status		Flux Type	
HASL	8	None	14	Low-residue	15
Benzimidazole	11	Parylene	6	Water soluble	17
Immersion Ag	6	Silicone	7		
Immersion Au/Pd	7	Urethane	5		

6.6 HF LPF Circuitry. The JTP acceptance criteria for HF LPF PTH 50MHz and HF LPF SMT 50MHz (responses 7 and 10 in Table 1.1) are based on deviations from the average response of the five HASL PWAs at the current test time that are coated with parylene and processed with LR flux. Specifically, these deviations must be within ±5dB of this average.

The JTP acceptance criteria for HF LPF PTH f(-3dB), HF LPF PTH f(-40dB), HF LPF SMT f(-3dB), and HF LPF SMT f(-40dB) (responses 8, 9, 11, and 12 in Table 1.1) are also based on deviations from the average response of the five HASL PWAs at the current test time that are coated with parylene and processed with LR flux. Specifically, these deviations must be within ±50MHz of this average.

Pre-test measurements for all six HF LPF circuits were subjected to GLM analyses, as were the deltas. The results of the GLM analyses are given in Tables I.7 to I.12 and the model R^2s from those tables are given below. These model R^2s range from quite small up to 37%. However, the estimated coefficients in all models were too small to be of practical significance relative to the JTP acceptance criteria.

Summary of GLM R^2s for HF LPF Circuitry by Test Time

Circuit	Pre-test	AL 1800 Cycles	Vibration	Mech. Shock	BW Vertical	BW Post Vertical
PTH 50MHz	12.7%	1.4%	10.9%	20.7%	10.4%	10.3%
PTH f(-3dB)	10.7%	2.6%	10.0%	12.0%	10.7%	13.8%
PTH f(-40dB)	8.5%	2.6%	10.2%	7.0%	9.7%	9.8%
SMT 50MHz	34.4%	7.0%	17.3%	29.0%	1.0%	21.6%
SMT f(-3dB)	27.5%	22.7%	3.0%	33.8%	5.7%	35.1%
SMT f(-40dB)	36.9%	23.2%	21.4%	31.7%	5.7%	36.0%

Comparison with Results in Section 3.6: Tables C.7 to C.12 differ considerably on the significance of urethane at Pre-test, BW vertical, and Post-vertical relative to its significance at these times in Tables I.7 and I.12. This is a strong indication that the results in Section 3.6 were reflective of something associated with the second build and not with urethane.

Displays. Figures J.25 to J.48 present boxplots for the HF LPF measurements grouped by surface finish for each HF LPF circuit. Most boxplots for HF PTH 50MHz (Figures J.25 to J.28) vary over only 0.1dB with the biggest range being only 0.4dB, all well within the JTP acceptance criterion. The boxplots for HF PTH f(-3dB) and HF PTH f(-40dB) in Figures J.29 to J.36 overlap throughout with a range of 10 to 25 MHz. The boxplots for HF SMT 50MHz in Figures J.37 to J.40 vary over only 0.1dB except for BW vertical where the variation increases to 0.5dB. Boxplots in Figures J.41 to J.44 vary over 5MHz to 10MHz with vibration and BW vertical having the greatest variation. Boxplots for HF SMT f(-40dB) in Figures J.45 to J.48 overlap throughout with a range of 10 to 40 MHz. The patterns in all boxplots are in agreement with the corresponding GLM analyses.

Comparison to JTP Acceptance Criterion. The HF LPF circuits were robust with respect to the environments in the AL-Vib-MS-BW test sequence. These six circuits produce 6×160 = 960 test measurements at each test time. Table 6.10 gives the number of anomalies observed at each test time for each HF LPF circuit.

Table 6.10 Summary of the Number of HF LPF Anomalies by Test Time

Circuit	Pre-test	AL 1800 Cycles	Vibration	Mech. Shock	BW Vertical	BW Post Vertical
PTH 50MHz			1		1	
PTH f(-3dB)					2	1
PTH f(-40dB)					1	
SMT 50MHz		1	1	3	2	2
SMT f(-3dB)		1	1	3	5	2
SMT f(-40dB)		1		1	2	1
Totals	0	3	3	7	13	6

The summary in Table 6.10 shows an increase in anomalies during the BW vertical test, but a return to the previous number of anomalies at Post-vertical. Examination of the anomalies showed no effect due to surface finish, coating, or flux. Table 6.11 contains the failure analysis results for the six anomalies at Post-vertical.

Table 6.11 Summary of Anomalies for HF LPF Circuits after BW Vertical

MSN	Surface Finish	Coating	Flux	Deviation	Failure Analysis Results
			HF LPF PTH f(-3dB)		
664	HASL	None	WS	-104.7MHz	
			HF LPF SMT 50MHz		
644	HASL	Parylene	WS	-24.3dB	
709	Benzimidazole	Silicone	LR	-31.8dB	
			HF LPF SMT f(-3dB)		
644	HASL	Parylene	WS	304.2MHz	
709	Benzimidazole	Silicone	LR	340.5MHz	
			HF LPF SMT f(-40dB)		
644	HASL	Parylene	WS	-79.1MHz	

6.7 HF TLC Circuitry. The JTP acceptance criteria for HF TLC circuitry (responses 13 to 17 in Table 1.1) are all based on changes from their Pre-test measurements. The changes for HF TLC 50MHz, HF TLC 500MHz, and HF TLC 1GHz must be within ±5dB of the Pre-test values. The changes for HF TLC RNF must be within ±50MHz. Finally, the increase for the HF TLC RNR must be less than 5dB if the current response and the Pre-test response are both greater than -50dB, otherwise the increase must be less than 10dB.

Pre-test measurements for all five HF TLC circuits were subjected to GLM analyses, as were the deltas. The results of the GLM analyses are given in Tables I.13 to I.17. The model R^2s in those tables are summarized below.

The model R^2s at Pre-test are high for the first four HF TLC circuits at Pre-test. These analyses were performed on the raw measurements and the high R^2 values are primarily attributable to the different electrical properties of conformal coatings as previously shown in Table 2.5 and illustrated in Figure 2.5. The model R^2s at the remaining times are based on differences from Pre-test, which eliminates the differences in electrical properties of conformal coatings. The delta R^2 values are all small and the estimated coefficients in the GLMs are too small to be of

Summary of GLM R^2s for the HF TLC Circuitry by Test Time

HF TLC Circuit	Pre-test	AL 1800 Cycles	Vibration	Mech. Shock	BW Vertical	BW Post Vertical
50MHz	71.0%	23.9%	5.2%	1.7%	8.2%	18.8%
500MHz	75.5%	13.4%	5.9%	1.7%	3.7%	4.4%
1GHz	60.9%	3.7%	4.8%	2.8%	1.5%	0.7%
RNF	65.1%	3.1%	4.2%	15.5%	19.5%	11.3%
RNR	44.4%	20.2%	1.9%	5.8%	14.7%	1.9%

practical concern relative to the JTP acceptance criteria. This indicates that surface finish, coating status, and flux type do not have a significant influence on the HF TLC measurements.

Comparison with Results in Section 3.7: Tables C.13 to C.17 differ considerably on the significance of urethane at Pre-test, BW vertical, and Post-vertical relative to its significance at these times in Tables I.13 and I.17. This is a strong indication that the results in Section 3.7 were reflective of something associated with the second build and not with urethane.

Displays. Figures J.49 to J.68 present boxplots for the HF TLC measurements at each test time. For the most part, these boxplots reflect the differences in the electrical properties of conformal coatings. The greatest variation in the HF TLC measurements occurs after vibration and during the vertical position of the BW test for all but the HF RNR circuit. The reason for the increased variation during the vertical position of the BW test is that the HF TLC circuit utilizes transmission lines on the backside of the PWA. The transmission lines were covered with detergent mixture during the BW vertical test.

Table 6.12 Summary of Anomalies for HF TLC Circuits after the BW Vertical Test

MSN	Surface Finish	Coating	Flux	Deviation	Failure Analysis Results
			HF TLC 50MHz		
668	HASL	Silicone	WS	11.95	
623	HASL	Silicone	LR	12.60	
666	HASL	Silicone	WS	15.44	
703	Benzimidazole	Urethane	LR	-38.13	
			HF TLC RNR		
637	HASL	None	LR	17.70	
644	HASL	None	WS	15.06	
659	HASL	Urethane	WS	29.50	
666	HASL	Silicone	WS	30.67	
630	HASL	Urethane	LR	30.56	
719	Benzimidazole	Urethane	LR	24.63	
786	Immersion Ag	Parylene	LR	16.56	
839	Immersion Ag	Urethane	WS	25.82	
842	Immersion Au/Pd	Parylene	LR	17.17	
876	Immersion Au/Pd	Urethane	LR	15.81	
885	Immersion Au/Pd	Urethane	WS	17.65	

Comparison to JTP Acceptance Criterion. There were 39 anomalies for the HF TLC circuitry that did not meet the JTP acceptance criteria after the BW vertical test. Of these 39 anomalies, 15 were far enough outside the JTP acceptance criteria to warrant being subjected to failure analysis while two others were marginal candidates for failure analysis. Failure analysis results are given in Table 6.12.

6.8 Leakage Measurements. Four features were included in the design of the LRSTF PWA to specifically check for current leakage: 10-mil pads, PGA socket (PGA-A, PGA-B), and a gull wing component (responses 18 to 21 in Table 1.1). The JTP acceptance criteria for the leakage measurements require the resistance to be greater than 7.7 when expressed as $\log_{10}$ ohms. The leakage measurements were subjected to GLM analyses after the BW and SF tests. The results of the GLM analyses are given in Tables I.18 to I.21. The model R^2s from those tables are summarized as follows.

Summary of GLM R^2s for the Leakage Circuits by Test Time

Leakage Circuit	Pre-test	AL 1800 Cycles	Vibration	Mech. Shock	BW Vertical	BW Post Vertical
10-Mil Pads	77.8%	72.0%	61.7%	68.6%	30.4%	5.8%
PGA-A	72.5%	39.2%	73.9%	41.8%	34.0%	50.0%
PGA-B	78.5%	82.9%	82.0%	81.7%	21.4%	45.9%
Gull Wing	56.0%	52.0%	47.9%	39.9%	42.3%	34.6%

10-Mil Pads: AL 1800 Cycles. The predicted base case value following 1800 cycles in the AL test is given in Table I.18 as 12.83, which is well above the JTP acceptance criterion of 7.70. It is also above the predicted base case value 11.88 at Pre-test. Predicted resistances based on the estimated coefficients in Table I.18 ranged from 12.20 to 14.06 over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. As shown in Table 6.13, there were no 10-mil pad leakage anomalies at either Pre-test or after 1800 cycles of AL.

10-Mil Pads: Vibration. The predicted base case value following the vibration test is given in Table I.18 as 12.62, which is well above the JTP acceptance criterion. Predicted resistances based on the estimated coefficients in Table I.18 ranged from 12.08 to 13.94 over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. As shown in Table 6.13, there were no 10-mil pad leakage anomalies after vibration.

Table 6.13 Summary of the Number of Anomalies that did not Meet the JTP Acceptance Criterion for the Leakage Circuits by Test Time

Test Time	10-Mil Pads	PGA-A	PGA-B	GW
Pre-test	0	0	0	0
AL 1800 Cycles	0	0	0	0
Vibration	0	0	0	0
Mechanical Shock	0	1	0	1
BW Vertical Position	46	62	83	131
BW Post-Vertical	2	0	0	16

10-Mil Pads: Mechanical Shock. The predicted base case value following the vibration test is given in Table I.18 as 12.50, which is well above the JTP acceptance criterion. Predicted resistances based on the estimated coefficients in Table I.18 ranged from 11.95 to 14.14 over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. As shown in Table 6.13, there were no 10-mil pad leakage anomalies after MS.

10-Mil Pads: BW Vertical. The predicted base case value during the vertical position of the BW test is given in Table I.18 as 8.82, which is still above JTP acceptance criterion. Predicted resistances based on the estimated coefficients in Table I.18 ranged from 7.71 to 9.35 over all combinations of surface finish, coating, and flux, all of which are exceed the acceptance criterion. As shown in Table 6.13, there were 46 leakage anomalies for the 10-mil pads during the BW vertical test. These anomalies were evenly spread over surface finishes and flux types. However, they were not evenly spread over coating status: none (18), parylene (0), silicone (15), and urethane (14). At Post vertical, there were two anomalies, only one of which was severe enough to be a candidate for failure analysis.

The upper portion of Table 6.14 summarizes the *predicted* resistance for 10-mil pads for the BW vertical position test. Shaded cells in this table identify surface finish/coating/flux combinations that did not meet the JTP acceptance criterion of 7.70. There are no shaded cells for 10-mil pads. Parylene coated PWAs had the highest predicted resistance for this adverse environment while the other coating categories were very similar to one another with a few exceptions. Surface finish and flux type had little, if any, influence on the predicted resistance for 10-mil pads.

Table 6.14 Comparison of the Predicted Resistance for 10-Mil Pads by Surface Finish, Coating, and Flux During the Vertical Position of the BW Test for the AL-Vib-MS-BW and BW-SF Test Sequences (shaded cells indicate a failure to meet the JTP acceptance criterion)

10-Mil Pads		**AL-Vib-MS-BW Test Sequence**			
		No Coating	**Parylene**	**Silicone**	**Urethane**
HASL	**LR**	8.82	10.61	8.82	8.82
	WS	8.82	11.93	8.82	8.82
Benzimidazole	**LR**	8.04	9.83	8.04	8.04
	WS	8.04	11.15	8.04	8.04
Immersion Ag	**LR**	7.71	9.50	9.99	7.71
	WS	7.71	10.82	9.99	9.54
Immersion Au/Pd	**LR**	8.82	10.61	8.82	8.82
	WS	8.82	11.93	8.82	8.82
		BW-SF Test Sequence			
HASL	**LR**	6.02	8.33	9.12	11.20
	WS	6.02	8.33	9.12	11.20
Benzimidazole	**LR**	6.02	8.33	9.12	11.20
	WS	6.02	8.33	9.12	11.20
Immersion Ag	**LR**	6.02	8.33	10.20	11.20
	WS	6.02	8.33	10.20	11.20
Immersion Au/Pd	**LR**	6.02	8.33	9.12	9.30
	WS	6.02	8.33	9.12	9.30

Comparison with 10-mil pad Results in Section 3.8: The lower portion of Table 6.14 contains predictions for the 10-mil pads previously given in Table 3.30 for the BW vertical test during the BW-SF test sequence. The base case during the BW-SF test is 2.8 orders of magnitude lower than base case for the AL-Vib-MS-BW test and there are many other differences between the two sets of predictions. There are two possible explanations for these differences. First, all PWAs in the AL-Vib-MS-BW test came from the second build of LRSTF PWAs, whereas only the urethane PWAs in the BW-SF test came from the second build. Secondly, the AL-Vib-MS-BW predictions were made after the PWAs had been exposed to AL, vibration, and MS while there was no prior environmental exposure for the BW-SF PWAs.

Note that the predicted resistances for urethane coated PWAs in the AL-Vib-MS-BW test are up to three orders of magnitude lower than the corresponding predictions for BW-SF. This difference may also reflect the different environmental exposures for the two sets of PWAs, but is not influenced by the second build.

Displays. Figures J.69 to J.72 present boxplots for the 10-mil pad resistance measurements versus test time for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. These graphs support the conclusions of the GLM analyses and provide useful information relative to the influence of surface finish, coating status, and flux. These figures are summarized as follows.

- The BW vertical position was the most strenuous for 10-mil pad leakage measurements
- Parylene coating is beneficial during the BW vertical test when the PWAs are soaked with the detergent mixture, however, silicone and urethane do not appear to be any better than uncoated PWAs
- After the completion of the BW vertical test, the resistance for all surface finish/coating/flux combinations was well above the JTP acceptance criterion
- There did not appear to be any difference in performance of the four surface finishes

Comparison to JTP Acceptance Criterion. There were two anomalous 10-mil resistance measurements that did not meet the JTP acceptance criterion after the BW vertical test. These anomalies are summarized in Table 6.15. Only one of these anomalies was severe enough to be a candidate for failure analysis.

PGA-A: AL 1800 Cycles. The predicted base case value following 1800 cycles in the AL test is given in Table I.19 as 12.20, which is well above the JTP acceptance criterion. It is also above the predicted base case value 11.25 at Pre-test. Predicted resistances based on the estimated coefficients in Table I.19 ranged from 11.93 to

13.80 over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. Parylene coated PWAs had the highest overall performance and urethane had the lowest. As show in Table 6.13, there were no PGA-A leakage anomalies at either Pre-test or after 1800 cycles of AL.

PGA-A: Vibration. The predicted base case value following the vibration test is given in Table I.19 as 12.02, which is well above the JTP acceptance criterion. Predicted resistances based on the estimated coefficients in Table I.19 ranged from 11.74 to 13.69 over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. Parylene coated PWAs had the highest overall performance and urethane had the lowest. As show in Table 6.13, there were no PGA-A leakage anomalies after vibration.

PGA-A: Mechanical Shock. The predicted base case value following the vibration test is given in Table I.19 as 12.04, which is well above the JTP acceptance criterion. Predicted resistances based on the estimated coefficients in Table I.19 ranged from 10.13 to 13.61 over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. Parylene coated PWAs had the highest overall performance and urethane had the lowest. From Table 6.13, there were no PGA-A anomalies after MS (however, one measurement was missing).

PGA-A: BW Vertical. The predicted base case value during the vertical position of the BW test is given in Table I.19 as 6.95, which is below the JTP acceptance criterion. Predicted resistances based on the estimated coefficients in Table I.19 ranged from 6.53 to 11.53 taken over all combinations of surface finish, coating, and flux. The predicted resistance for all parylene and urethane coated PWAs was above the JTP acceptance criterion. However, six of the eight cases for uncoated PWAs and five of the eight cases for silicone coated PWAs did not meet the acceptance criterion. As shown in Table 6.13, there were 62 anomalies for the PGA-A during the BW vertical test. These anomalies were evenly spread over surface finishes and flux types. However, they were not evenly spread over coating status: none (26), parylene (2), silicone (21), and urethane (13). There were no anomalies at Post vertical.

The upper portion of Table 6.15 summarizes the predicted resistance for PGA-A for the BW vertical position test. Shaded cells in this table identify several surface finish/coating/flux combinations that did not meet the JTP acceptance criterion of 7.70. Surface finish and flux type had little influence on the predicted resistance for PGA-A except for some interesting interactions involving benzimidazole and immersion Au/Pd with WS flux.

Displays. Figures J.73 to J.76 present boxplots for the PGA-A resistance measurements versus test time for the HASL, benzimidazole, immersion Ag, and immersion Au/Pd surface finishes, respectively. These graphs support the conclusions of the GLM analyses and provide useful information relative to the influence of surface finish, coating status, and flux. The summary for these graphs is similar to that for 10-mil pads.

Comparison to JTP Acceptance Criterion. All PGA-A resistance measurements met the JTP acceptance criterion after the BW vertical test.

PGA-B: AL 1800 Cycles. The predicted base case value following 1800 cycles in the AL test is given in Table I.20 as 12.21, which is well above the JTP acceptance criterion. It is also above the predicted base case value 10.93 at Pre-test. Predicted resistances based on the estimated coefficients in Table I.20 ranged from 11.62 to 13.66 over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. Parylene coated PWAs had the highest overall performance and urethane had the lowest. As show in Table 6.13, there were no PGA-B leakage anomalies at either Pre-test or after 1800 cycles of AL.

PGA-B: Vibration. The predicted base case value following the vibration test is given in Table I.20 as 12.18, which is well above the JTP acceptance criterion. Predicted resistances based on the estimated coefficients in Table I.20 ranged from 11.51 to 13.55 over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. Parylene coated PWAs had the highest overall performance and urethane had the lowest. As show in Table 6.13, there were no PGA-B leakage anomalies after vibration.

PGA-B: Mechanical Shock. The predicted base case value following the vibration test is given in Table I.20 as 12.08, which is well above the JTP acceptance criterion. Predicted resistances based on the estimated coefficients in Table I.20 ranged from 11.34 to 13.60 over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. Parylene coated PWAs had the highest overall performance and urethane had the lowest. From Table 6.13, there were no PGA-B anomalies after MS.

Table 6.15 Comparison of the Predicted Resistance for PGA-A by Surface Finish, Coating, and Flux During the Vertical Position of the BW Test for the AL-Vib-MS-BW and BW-SF Test Sequences (shaded cells indicate a failure to meet the JTP acceptance criterion)

PGA-A		AL-Vib-MS-BW Test Sequence			
		No Coating	**Parylene**	**Silicone**	**Urethane**
HASL	**LR**	6.95	10.23	6.95	8.89
	WS	6.95	10.23	9.43	8.89
Benzimidazole	**LR**	6.95	10.23	6.95	8.89
	WS	8.30	11.58	10.78	10.24
Immersion Ag	**LR**	6.95	10.23	6.95	8.89
	WS	6.95	10.23	6.53	8.89
Immersion Au/Pd	**LR**	6.95	10.23	6.95	8.89
	WS	9.05	9.53	11.53	10.99
		BW-SF Test Sequence			
HASL	**LR**	5.52	7.23	8.67	8.39
	WS	6.33	8.04	6.45	9.20
Benzimidazole	**LR**	5.52	7.23	8.67	8.39
	WS	6.33	8.04	8.78	9.20
Immersion Ag	**LR**	5.52	7.23	8.67	8.39
	WS	6.33	8.04	6.45	9.20
Immersion Au/Pd	**LR**	5.52	7.23	8.67	8.39
	WS	6.33	8.04	9.07	9.20

Comparison with PGA-A Results in Section 3.8: The lower portion of Table 6.15 contains predictions for PGA-A previously given in Table 3.30 for the BW vertical test during the BW-SF test sequence. The base case during the BW-SF test is 1.4 orders of magnitude lower than base case for the AL-Vib-MS-BW test and there are many other differences between the two sets of predictions. As with 10-mil pads, these differences may be due to the second build of LRSTF PWAs or to different environmental exposure histories. Both sets of predictions contain several anomalies that do not meet the JTP acceptance criterion

Note that unlike the situation for 10-mil pads, the predicted resistances for urethane coated PWAs in the AL-Vib-MS-BW test are close to the corresponding predictions in the BW-SF test.

PGA-B: BW Vertical. The predicted base case value during the vertical position of the BW test is given in Table I.20 as 6.78, which is below the JTP acceptance criterion. Predicted resistances based on the estimated coefficients in Table I.20 ranged from 6.78 to 10.80 over all combinations of surface finish, coating, and flux. The predicted resistance for all parylene and urethane coated PWAs was above the JTP acceptance criterion as were all four immersion Au/Pd cases with WS flux. However, seven of the eight cases for both uncoated and silicone coated PWAs had predicted resistances about 0.9 orders of magnitude below the acceptance criterion. As shown in Table 6.13, there were 83 anomalies for the PGA-B during the BW vertical test. These anomalies were evenly spread over surface finishes. However, they were not evenly spread over coating status: none (26), parylene (2), silicone (21), and urethane (13). They were also not evenly spread over flux type: LR (50) and WS (33). There were no anomalies at Post vertical.

The upper portion of Table 6.16 summarizes the predicted resistance for PGA-B for the BW vertical position test. Shaded cells in this table identify seven cases for both uncoated and silicone coated PWAs that did not meet the JTP acceptance criterion of 7.70. Surface finish and flux type had little influence on the predicted resistance for PGA-B except for some interesting interactions between immersion Au/Pd and WS flux.

Displays. Figures J.77 to J.80 present boxplots for the PGA-B resistance measurements versus test time for the HASL, benzimidazole, immersion Ag, and immersion Au/Pd surface finishes, respectively. These graphs support the conclusions of the GLM analyses and provide useful information relative to the influence of surface finish, coating status, and flux. The summary for these graphs is similar to that for 10-mil pads.

Table 6.16 Comparison of the Predicted Resistance for PGA-B by Surface Finish, Coating, and Flux During the Vertical Position of the BW Test for the AL-Vib-MS-BW and BW-SF Test Sequences (shaded cells indicate a failure to meet the JTP acceptance criterion)

PGA-B		AL-Vib-MS-BW Test Sequence			
		No Coating	**Parylene**	**Silicone**	**Urethane**
HASL	**LR**	6.78	8.13	6.78	9.36
	WS	6.78	8.13	6.78	9.36
Benzimidazole	**LR**	6.78	8.13	6.78	9.36
	WS	6.78	8.13	6.78	9.36
Immersion Ag	**LR**	6.78	8.13	6.78	9.36
	WS	6.78	8.13	6.78	9.36
Immersion Au/Pd	**LR**	6.78	8.13	6.78	9.36
	WS	8.22	9.57	8.22	10.80
		BW-SF Test Sequence			
HASL	**LR**	6.89	6.89	6.89	6.89
	WS	6.16	7.24	6.16	8.41
Benzimidazole	**LR**	5.25	7.17	7.40	6.65
	WS	5.67	6.61	7.82	9.32
Immersion Ag	**LR**	6.89	6.89	6.89	6.89
	WS	6.88	7.96	6.88	9.13
Immersion Au/Pd	**LR**	6.89	6.89	6.89	6.89
	WS	6.16	7.24	6.16	7.01

Comparison with PGA-B in Section 3.8: The lower portion of Table 6.16 contains predictions for PGA-B previously given in Table 3.30 for the BW vertical test during the BW-SF test sequence. The base case during the BW-SF test (6.89) is almost identical to the corresponding base case for the AL-Vib-MS-BW test (6.78). Both sets of predictions contain several anomalies that do not meet the JTP acceptance criterion. All parylene and urethane predictions meet the JTP acceptance criterion for the AL-Vib-MS-BW test while only one parylene and three urethane do so for the BW-SF test. As with 10-mil pads, these differences may be due to the second build of LRSTF PWAs or to different environmental exposure histories.

Note that the predicted resistances for urethane coated PWAs in the AL-Vib-MS-BW test are one to three orders of magnitude higher than the corresponding predictions for BW-SF. This difference may also reflect the different environmental exposures for the two sets of PWAs.

Comparison to JTP Acceptance Criterion. All PGA-B resistance measurements met the JTP acceptance criterion after the BW test.

Gull Wing: AL 1800 Cycles. The predicted base case value following 1800 cycles in the AL test is given in Table I.21 as 13.01, which is well above the JTP acceptance criterion. It is also above the predicted base case value 11.48 at Pre-test. Predicted resistances based on the estimated coefficients in Table I.21 ranged from 11.87 to 13.30 taken over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. Parylene coated PWAs had the highest overall performance. As show in Table 6.13, there were no GW leakage anomalies at either Pre-test or after 1800 cycles of AL.

Gull Wing: Vibration. The predicted base case value following the vibration test is given in Table I.21 as 13.10, which is well above the JTP acceptance criterion. Predicted resistances based on the estimated coefficients in Table I.21 ranged from 11.76 to 13.10 taken over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. Uncoated and parylene coated PWAs had the highest overall performance and both had predicted resistances about an order higher than those for silicone and urethane. As show in Table 6.13, there were no GW leakage anomalies after vibration.

Gull Wing: Mechanical Shock. The predicted base case value following the vibration test is given in Table I.21 as 12.64, which is well above the JTP acceptance criterion. Predicted resistances based on the estimated

Table 6.17 Comparison of the Predicted Resistance for the Gull Wing by Surface Finish, Coating, and Flux During the Vertical Position of the BW Test for the AL-Vib-MS-BW and BW-SF Test Sequences (shaded cells indicate a failure to meet the JTP acceptance criterion)

Gull Wing		**AL-Vib-MS-BW Test Sequence**			
		No Coating	**Parylene**	**Silicone**	**Urethane**
HASL	**LR**	4.48	7.33	4.48	4.48
	WS	4.48	7.33	4.48	4.48
Benzimidazole	**LR**	4.48	7.33	4.48	6.01
	WS	4.48	7.33	6.85	6.01
Immersion Ag	**LR**	4.48	7.33	4.48	4.48
	WS	4.48	9.14	4.48	6.45
Immersion Au/Pd	**LR**	4.48	7.33	4.48	4.48
	WS	5.60	8.45	5.60	5.60
		BW-SF Test Sequence			
HASL	**LR**	4.12	8.19	4.12	4.12
	WS	4.12	8.19	4.12	4.12
Benzimidazole	**LR**	4.12	8.19	4.12	4.12
	WS	4.12	8.19	4.12	4.12
Immersion Ag	**LR**	4.12	8.19	4.12	4.12
	WS	4.12	10.47	4.12	4.12
Immersion Au/Pd	**LR**	4.12	8.19	4.12	4.12
	WS	4.12	8.19	5.63	4.12

Comparison with the Gull Wing in Section 3.8: The lower portion of Table 6.17 contains predictions for the GW previously given in Table 3.30 for the BW vertical test during the BW-SF test sequence. The base case during the BW-SF test (4.12) is very close to the corresponding base case for the AL-Vib-MS-BW test (4.48). Both sets of predictions contain several anomalies that do not meet the JTP acceptance criterion. Only two surface finish/coating/flux combinations meet the JTP acceptance criterion for the AL-Vib-MS-BW test while all eight parylene cases do so for the BW-SF test. As with 10-mil pads, these differences may be due to the second build of LRSTF PWAs or to different environmental exposure histories.

Note that the predicted resistances for urethane coated PWAs in the AL-Vib-MS-BW test up to 2.3 orders of magnitude higher than the corresponding predictions for BW-SF. This difference may also reflect the different environmental exposures for the two sets of PWAs.

coefficients in Table I.21 ranged from 10.26 to 13.36 taken over all combinations of surface finish, coating, and flux, all of which are well above the acceptance criterion. Parylene coated PWAs had the highest overall performance and silicone had the lowest. From Table 6.13, there were no GW anomalies after vibration.

Gull Wing: BW Vertical. The predicted base case value during the vertical position of the BW test is given in Table I.21 as only 4.48, which is below the JTP acceptance criterion. Predicted resistances based on the estimated coefficients in Table I.21 ranged from 4.48 to 9.14 taken over all combinations of surface finish, coating, and flux. The predicted resistance was above the JTP acceptance criterion for only two cases: immersion Ag and immersion Au/Pd both coated with parylene and processed with WS flux. As shown in Table 6.13, there were 131 anomalies for the GW during the BW vertical test. These anomalies were evenly spread over surface finishes and flux types. They were more evenly spread over coating status than was the case for the other three leakage circuits: none (37), parylene (22), silicone (37), and urethane (35). There were 16 anomalies at Post vertical.

The upper portion of Table 6.17 summarizes the predicted resistance for the GW for the BW vertical position test. Shaded cells in this table show that only two met the JTP acceptance criterion of 7.70. Surface finish and flux type had little influence on the predicted resistance for the GW except for interactions between immersion Ag and WS flux and between immersion Au/Pd and WS flux.

Table 6.18 Summary of Anomalies for Leakage Circuits after the AL-Vib-MS-BW Test Sequence

MSN	Surface Finish	Coating	Flux	Resistance	Failure Analysis Results
			10-Mil Pads		
902	Immersion Au/Pd	None	WS	6.58	Failure analysis not required
918	Immersion Au/Pd	Urethane	WS	3.69	
			Gull Wing		
665	HASL	None	WS	7.42	Failure analysis not required
740	Benzimidazole	None	WS	7.07	Failure analysis not required
795	Immersion Ag	None	LR	7.69	Failure analysis not required
818	Immersion Ag	None	WS	6.88	Failure analysis not required
819	Immersion Ag	None	WS	6.87	Failure analysis not required
821	Immersion Ag	None	WS	7.69	Failure analysis not required
790	Immersion Ag	Silicone	LR	6.93	Failure analysis not required
779	Immersion Ag	Urethane	LR	6.54	Failure analysis not required
789	Immersion Ag	Urethane	LR	3.69	
870	Immersion Au/Pd	None	LR	7.04	Failure analysis not required
900	Immersion Au/Pd	None	WS	6.24	Failure analysis not required
919	Immersion Au/Pd	None	WS	6.25	Failure analysis not required
875	Immersion Au/Pd	Silicone	LR	3.69	
880	Immersion Au/Pd	Silicone	LR	6.66	Failure analysis not required
845	Immersion Au/Pd	Urethane	LR	7.02	Failure analysis not required
848	Immersion Au/Pd	Urethane	LR	6.78	Failure analysis not required

Displays. Figures J.81 to J.84 present boxplots for the gull wing resistance measurements versus test time for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. These graphs support the conclusions of the GLM analyses and provide useful information relative to the influence of surface finish, coating status, and flux. The summary for these graphs is similar to that for 10-mil pads.

Comparison to JTP Acceptance Criterion. Sixteen gull wing resistance measurements did not meet the JTP acceptance criterion after the BW vertical test. These anomalies are summarized in Table 6.18. This summary shows the anomalies were distributed over surface finishes as follows: HASL (1), benzimidazole (1), immersion Ag (7), and immersion Au/Pd (7). These differences are significantly different (p-value = 0.019). The anomalies were distributed over coating as: none (9), parylene (0), silicone (3), and urethane (4). These differences are also significantly different (p-value = 0.009). However, only two of the GW anomalies were severe enough to warrant failure analysis as was one 10-mil pad anomaly.

6.9 Stranded Wires. Two stranded wires were hand soldered on the LRSTF PWA (responses 22 and 23 in Table 1.1). One wire was soldered into plated through holes and the other was soldered to two terminals. The JTP acceptance criterion requires changes in voltage to be within 0.356V of their Pre-test measurements. There were no anomalous measurements for stranded wires throughout the AL-Vib-MS-BW test sequence.

Pre-test measurements for both stranded wires were subjected to GLM analyses, as were the deltas after each segment of the BW test. The results of the GLM analyses are given in Tables I.22 and I.26. The model R^2s from those tables are summarized as follows.

Summary of GLM R^2s for the Stranded Wire Circuits by Test Time

Circuit	Pre-test	AL 1800 Cycles	Vibration	Mech. Shock	BW Vertical	BW Post Vertical
St. Wire 1	2.5%	2.4%	1.1%	2.6%	9.3%	12.4%
St. Wire 2	16.3%	3.1%	6.9%	5.7%	1.2%	8.9%

These R^2 values are all quite small. This implies that the experimental parameters do not differ significantly from the base case in terms of their impact on the stranded wire voltages.

Displays. Figures J.85 to J.88 present boxplots for stranded wire 1 voltage measurements versus test time for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. All boxplots in these figures overlap considerably at all test times with a range of approximately 12mV. The corresponding boxplots for stranded wire 2 voltage measurements appear in Figures J.89 to J.92. The boxplots in these figures appear to show more variability than those for stranded wire 1, but this is mainly due to just a few outlying measurements.

Comparison to JTP Acceptance Criterion. There were no anomalies for the stranded wire measurements throughout the AL-Vib-MS-BW test sequence.

6.10 Summary and Conclusions. Detailed results of the electrical performance of 160 LRSTF PWAs after exposure to an AL-Vib-MS-BW test sequence have been presented in this section. These PWAs were each tested at Pre-test, after AL, after vibration, after MS, during the BW vertical test, and at Post-vertical. At each test time, 3680 electrical measurements were recorded and compared to the JTP acceptance criterion.

Summary of Yields by Circuit Type. Yields for the AL-Vib-MS-BW test sequence are given in Table 6.19 by major circuit group for each test time. The overall yields in this table are high for each case except the vertical position of the BW test. As demonstrated in Section 3 with the BW-SF test sequence, the BW test presents an extreme environmental condition. The yields in Table 6.19 reaffirm the results given in Table 3.3 of Section 3, which showed that the HVLC, HSD, HF TLC, and ON circuits experienced the most difficulty.

Table 6.19 Yields During the AL-Vib-MS-BW Test Sequence

Circuit Group	AL	Vib	MS	BW Vertical	Post BW Vertical
HCLV	320/320 = 100.0%	317/320 = 99.1%	318/320 = 99.4%	317/320 = 99.1%	317/320 = 99.1%
HVLC	319/320 = 99.7%	319/320 = 99.7%	306/320 = 95.6%	48/320 = 15.0%	291/320 = 90.9%
HSD	320/320 = 100.0%	319/320 = 99.7%	319/320 = 99.7%	38/320 = 11.9%	319/320 = 99.7%
HF LPF	957/960 = 99.7%	957/960 = 99.7%	953/960 = 99.3%	947/960 = 98.6%	954/960 = 99.4%
HF TLC	780/800 = 97.5%	761/800 = 95.1%	780/800 = 97.5%	709/800 = 88.6%	761/800 = 95.1%
ON	640/640 = 100.0%	640/640 = 100.0%	638/640 = 99.7%	318/640 = 49.7%	622/640 = 97.2%
SW	320/320 = 100.0%	320/320 = 100.0%	320/320 = 100.0%	320/320 = 100.0%	320/320 = 100.0%
Totals	3656/3680 = 99.3%	3633/3680 = 98.7%	3634/3680 = 98.8%	2697/3680 = 73.3%	3584/3680 = 97.4%

Table 6.19 shows high yields through the AL, Vib, and MS tests with a noticeable drop for HVLC at MS. There were four problem circuits during the BW vertical test: HVLC, HSD, HF TLC, and ON (leakage). The low yield for the HVLC circuit is not surprising, as the detergent mixture comprises a significant portion of the circuit path and hence a significant portion of the circuit resistance. The lower resistance results in increased current for fixed voltage input. The HSD total propagation delay and current leakage measurements (ON) are affected in a similar manner. The HF TLC measurements are made on the transmission lines located on the backside of the PWA. Each of the problem circuits recovered nicely at Post-test, so very little permanent damage was caused by the BW vertical test.

Table 6.20 breaks down the overall yield summaries in Table 6.19 for the BW vertical test by surface finish and coating status. Table 6.20 shows that the HCLV, HF LPF, and SW circuits all had high yields during the BW vertical test. The yields for the other four circuits (HVLC, HSD, HF TLC, and ON) are noticeably lower. The yields for these latter four circuits have a range of 1.5% for HSD and a range of 3.2% for ON over all surface finishes.

On the other hand, the yields across coating status have a range of 9.4% for HVLC and a range of 10.5% for ON. The yields for uncoated, silicone, and urethane are essentially the same for HVLC, but parylene has a significantly higher yield. The yields for parylene, silicone, and urethane are essentially the same for HSD, but uncoated has a slightly higher yield. The yields across coating status for HF TLC have a range of only 1.8%. Parylene has the highest yield for ON with uncoated and silicone having the lowest while urethane is somewhat in the middle.

Table 6.20 Yields by Surface Finish and Coating Status Relative to the JTP Acceptance Criteria During the BW Vertical Test Sequence

	Surface Finish				Coating Status			
Circuitry	**HASL**	**Benzi**	**Imm Ag**	**Imm Au/Pd**	**Uncoated**	**Parylene**	**Silicone**	**Urethane**
HCLV	99.7%	99.4%	100.0%	100.0%	99.7%	100.0%	100.0%	99.4%
HVLC	78.4%	80.3%	78.4%	78.4%	76.9%	85.3%	76.9%	75.9%
HSD	76.9%	78.4%	77.5%	76.9%	80.0%	77.8%	77.2%	76.9%
HF LPF	99.5%	99.9%	100.0%	99.3%	99.7%	99.5%	99.9%	99.9%
HF TLC	98.0%	97.8%	95.1%	97.8%	96.1%	96.8%	97.9%	97.9%
ON	88.0%	87.3%	85.6%	88.8%	83.3%	93.8%	83.9%	88.8%
SW	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Totals	93.4%	93.6%	92.6%	93.7%	92.4%	94.9%	92.9%	93.4%

Table 6.21 Yields by Surface Finish and Coating Status Relative to the JTP Acceptance Criteria at the Conclusion of the AL-Vib-MS-BW Test Sequence

	Surface Finish				Coating Status			
Circuitry	**HASL**	**Benzi**	**Imm Ag**	**Imm Au/Pd**	**Uncoated**	**Parylene**	**Silicone**	**Urethane**
HCLV	99.7%	100.0%	100.0%	98.8%	100.0%	100.0%	98.8%	100.0%
HVLC	98.1%	97.5%	97.5%	97.5%	95.0%	98.8%	96.3%	97.5%
HSD	99.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
HF LPF	99.6%	100.0%	98.3%	99.2%	100.0%	100.0%	98.3%	96.7%
HF TLC	98.3%	99.5%	98.5%	100.0%	99.5%	99.5%	98.0%	99.5%
ON	99.8%	99.4%	97.5%	99.4%	99.4%	99.4%	98.8%	100.0%
SW	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Totals	99.3%	99.4%	99.3%	99.4%	98.9%	99.7%	99.4%	99.4%

Table 6.21 breaks down the overall yield summaries in Table 6.19 for Post-vertical by surface finish and coating status. Table 6.21 shows that all surface finishes are virtually identical with the total yields ranging only from 99.3% to 99.4%. The total yields range from 98.9% (uncoated) to 99.7% (parylene).

Tabulation of the Anomalies by PWA. At the conclusion of the AL-Vib-MS-BW test sequence, there were 96 anomalies that did not meet the JTP acceptance criterion. These 96 anomalies occurred on 67 PWAs. The complete frequency distribution of the 67 PWAs with anomalies is given in Table 6.22 by surface finish, coating status, and flux type. There is no significant difference due to either surface finish or flux type, but there is a strong significant difference due to coating status, with the uncoated PWAs having significantly more anomalies and parylene having significantly fewer.

Table 6.22 Tabulation of the PWAs with Anomalies that did not Meet the JTP Acceptance after the AL-Vib-MS-BW test sequence

		No Coating	**Parylene**	**Silicone**	**Urethane**	**Totals**
HASL (15)	**LR**	2		1	2	5
	WS	3	1	4	2	10
Benzimidazole (16)	**LR**	4	1	2	2	9
	WS	4	1	2		7
Immersion Ag (19)	**LR**	5	2	2	3	12
	WS	3	1	2	1	7
Immersion Au/Pd (17)	**LR**	2	1	3	3	9
	WS	4	1		3	8
LR = 35, WS = 32	**Totals**	27	8	16	16	67

References

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2. Iman, R. L. (1994). **A Data-Based Approach to Statistics**, Duxbury Press.