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The pins in items 1 through 4 were selectively plated by controlled depth immersion with the lead free finish system (tin-copper plating) over a nickel underplate (0.5 μm to 2.5 μm thick). Items 1 through 4 corresponded to different plating conditions through an extended manufacturing run; these were assigned pin types corresponding to the item number. Initial samples (items 1 and 2) were taken at the beginning of the manufacturing run with a new plating bath while items 3 and 4 were taken later, after approximately two (2) turnovers of metal (MTO) in the plating solution. These samples also encompassed diverse nominal values of tin-copper plating thickness within the specified range (0.08 μm to 1.5 μm thick). These lead free pins (items 1 through 4) were not lubricated. Item 5 represented standard product, PN 60047-102, plated with tin-lead alloy (0.08 μm to 1.5 μm thick, nominally 90 % mass fraction of tin) over a nickel underplate (0.5 μm to 2.5 μm thick) with lubricant; these standard pins were designated as pin type 0 to accentuate their distinction from the other samples (with lead free finish). The details of test item identity are listed in table 1.

Table 1. Description of Test Items

Item	Pin Type (P)	Finish Type	Reel Number	Bath Condition / MTO	Nominal Thickness Range
1	1	Lead Free (Sn-Cu)	1	0	Low (0.08 μm – 0.25 μm)
2	2		3	0	High (1.0 μm – 1.5 μm)
3	3		25	2	Low (0.08 μm – 0.25 μm)
4	4		27	2	High (1.0 μm – 1.5 μm)
5	0	Tin-Lead (90-10 Sn-Pb)		Production	0.08 μm – 1.5 μm

TEST BOARDS:

Testing was performed using printed wiring boards designed for individual pin insertion into plated through holes with dual electrical connections to facilitate measurement of low level compliant pin resistance. Each test board accommodated twenty-five (25) test pins. The test boards were multi-layer boards with copper conductors (0.025 mm minimum thickness) in four (4) layers (2 external and 2 internal) providing redundant paths for each of the two (2) electrical connections. The test board configuration is illustrated in figure 2.

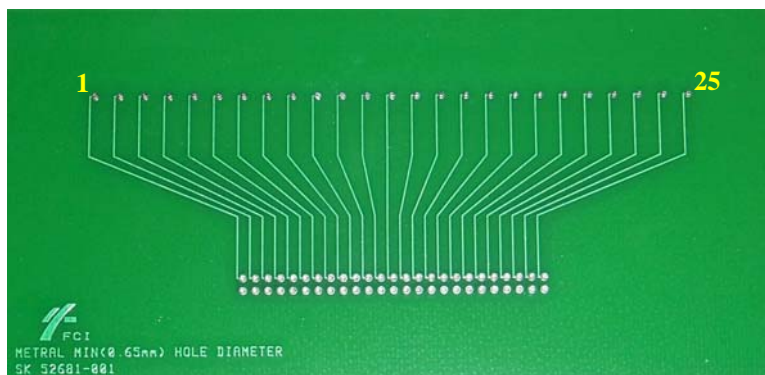


Figure 2. Example of Printed Wiring Board for Testing, Front View, Showing Position Numbering

Testing encompassed test boards with two (2) sizes of the plated through holes; these corresponded approximately to the minimum and maximum of the specified hole size for the METRAL® press fit pin. Testing was conducted with five (5) PWB finish systems. The details of PTH size and finish are given in tables 2 and 3, respectively.

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Table 2. Plated Through Hole Sizes in Test Boards

PTH Size Designation (<i>H</i>)	Nominal PTH Size	FCI Drawing	Drill Diameter / mm
N	Minimum	SK-52681	0.80
X	Maximum	SK-52685	0.85

Table 3. Printed Wiring Board Finish Systems

PWB Finish Designation (<i>B</i>)	PWB Finish Type	Finish Thickness / μm	PWB Part Number	
			Min. Size PTH	Max. Size PTH
L	Tin-Lead	5 – 15	SK52681-001	SK52685-001
C	OSP	NA	SK52681-002	SK52685-002
T	Immersion Tin	1 Max.	SK52681-003	SK52685-003
S	Immersion Silver	0.5 Max.	SK52681-004	SK52685-004
G	Immersion Gold / Electroless Nickel	0.05 – 0.15 3 – 5	SK52681-005	SK52685-005

Each printed wiring board was assigned a test board number based on the test group number, the PWB finish designation, the PTH size designation, and the pin type of the inserted pins. (Different pin types were not mixed on the same test board.) The resulting test board number has the form “*TBHJ.P*”, where *T* is the test group number, *B* is the PWB finish designation, *H* is the PTH size designation, *J* is a sequential, single digit number (starting with 1) provided to accommodate possible replication, and *P* is the pin type. The possible values of *P*, *H*, *B*, and *T* are given in tables 1 through 4, respectively. For example, test board **3SN1.2** was the first (1) silver (S) plated board in test group 3 (corrosion resistance) with pins of type 2 (lead free plating, 0 MTO, high thickness) in minimum (N) size holes.

Each test position (PTH) was assigned a sample number by appending a 2 digit number indicating the position (1 through 25) within the test board (as shown in figure 2) to the test board number. For example, sample **3SN1.2-08** was the 8th position (from the left side of the test board as viewed from the front with the text label upright) on test board **3SN1.2**.

SPECIFICATIONS:

The testing methodology is established by Telcordia GR-1217-CORE with reference to a variety of test procedures. A tabulation of the relevant documents follows.

Telcordia GR-1217-CORE, Generic Requirements for Separable Electrical Connectors Used in Telecommunications Hardware, Issue 1, 1995 Nov

EIA-364-05B, Contact Insertion, Release and Removal Force Test Procedure for Electrical Connectors, 1998 May

EIA-364-17B, Temperature Life with or without Electrical Load Test Procedure for Electrical Connectors and Sockets, 1999 Jun

EIA-364-23B, Low Level Contact Resistance Test Procedure for Electrical Connectors and Sockets, 2000 Dec

EIA-364-27B, Mechanical Shock (Specified Pulse) Test Procedure for Electrical Connectors, 1996 Jun

EIA-364-28D, Vibration Test Procedure for Electrical Connectors and Sockets, 1999 Jul

EIA-364-31B, Humidity Test Procedure for Electrical Connectors and Sockets, 2000 May

EIA-364-32C, Thermal Shock (Temperature Cycling) Test Procedure for Electrical Connectors and Sockets, 2000 May

EIA-364-65A, Mixed Flowing Gas, 1998 Jan

IEC 60352-5, Solderless Connections - Part 5: Press-In Connections - General Requirements, Test Methods and Practical Guidance, Rev. 1, 2001 Mar

MIL-C-28859B, Connector Component Parts, Electrical Backplane, Printed-Wiring, General Specification for, 1990 Jan 19

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TEST GROUPS:

Testing was conducted in four (4) test groups. The test group identity is detailed in table 4.

Table 4. Description of Test Groups

Test Group (T)	Stress Type	Main Exposures	Tested PTH Sizes
1	Mechanical	Vibration, Mechanical Shock	Min. (N) & Max. (X)
2	Thermo-Hydric	Thermal Shock, Moisture Resistance	Min. (N) & Max. (X)
4	Corrosive	Mixed Flowing Gas (UE)	Max. (X)
5	Maintenance	Pin Replacement, Temperature Life	Min. (N) & Max. (X)

For each tested PTH size (as indicated in table 4), each test group included one (1) test board for each combination of the five (5) board finish types (**L**, **C**, **T**, **S**, and **G**) and the five (5) pin types (**1**, **2**, **3**, **4**, and **0**). Consequently, test groups 1, 2, and 5 each consisted of 50 test boards (1250 test positions) total; test group 4 consisted of 25 test boards (625 test positions) total.

TEST SEQUENCES:

Tests were performed in accordance with Telcordia GR-1217-CORE using test sequences as follows.

Group 1, Mechanical Stress (Vibration and Mechanical Shock)

1. Initial CPR (compliant pin resistance)
2. Vibration – 3 Axes
3. CPR (after Vibration)
4. Mechanical Shock – 3 Axes, 2 Directions, 3 Shocks/Direction/Axis
5. Final CPR
6. Final Compliant Pin Retention Force

Group2, Thermo-hydric Stress (Thermal Shock and Moisture Resistance)

1. Initial CPR
2. Thermal Shock
3. CPR (after Thermal Shock)
4. Moisture Resistance
5. Final CPR
6. Final Compliant Pin Retention Force

Group 4, Corrosive Stress (Mixed Flowing Gas)

1. Initial CPR
2. Mixed Flowing Gas Exposure, Class IIIA, 20 days
3. Final CPR
4. Final Compliant Pin Retention Force

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Group 5, Maintenance Stress (Repair)

1. Initial Pin Insertion Force
2. Initial CPR
3. 1st Pin Removal Force
4. 2nd Pin Insertion Force
5. 2nd Pin Removal Force
6. 3rd Pin Insertion Force
7. CPR (3rd Pin)
8. Temperature Life Exposure, 105 °C, 1000 hours
9. Final CPR
10. Final Pin Retention Force
11. PTH Deformation
12. PTH Wall Damage

PROCEDURES:

Table 5 gives a summary of the primary details of test conditions.

Table 5. Summary of Test Conditions

Test	Test Details
CPR	Low Level
Insertion Force	
Retention Force	
Vibration	EIA-364-28, Cond. II (10 g Sine), Prequalification: 8 hr/axis, 3 axes, 25 Pins
Mechanical Shock	EIA-364-27, Cond. H (30 g Half Sine), 3 shocks/direction/axis, 2 directions, 3 axes, 25 Pins
Thermal Shock	UE: EIA-364-32, Cond. II (-65 °C/105 °C, ≥ 5 cycles), 25 Pins
Moisture Resistance	UE: 5 °C/85 °C, ≥ 50 cycles, ≥ 500 hr, 25 Pins
Mixed Flowing Gas	UE: 200 ppb NO ₂ , 20 ppb Cl ₂ , 100 ppb H ₂ S, 200 ppb SO ₂ , 30 °C, 70 % RH, UE: 20 days Total
Temperature Life	UE: EIA-364-17, Cond. 4 (105 °C, ≥ 1000 hr)
PTH Deformation	Deformation Radius from Drilled Hole at Plane of Max. Compliant Pin Diameter MIL-C-28859, 10 Holes Min.
PTH Wall Damage	Remaining Copper Thickness, MIL-C-28859, 10 Holes Min.

Visual Examination

Prior to testing, the samples were examined at low magnification for visual defects to verify suitability for testing. Subsequent to treatment, the tested samples were examined at low magnification for evidence of damage or degradation.

Low Level Compliant Pin Resistance (CPR)

Low level compliant pin resistance was measured in accordance with EIA-364-23B, option 1. This is a four point measurement method with separate connections for current flow and voltage sensing on each side of the compliant interface. Thermal offsets were compensated automatically by the measuring instrument by means of null measurements during pulsed application of the test current. Measurement of resistance across the compliant interface was performed using a test fixture specifically designed for measurement of low level compliant pin resistance on the test boards employed. This test fixture is illustrated in figure 3. The fixture incorporates spring loaded pins with cup shaped tips for making electrical contact with the bottom (short) ends of the press fit pins; the test board is placed onto the test fixture and pressed and held against these spring loaded contact. The spring loaded contacts are electrically connected underneath the fixture and wired to the high (positive) side of the voltage sensing circuit. The top (long) ends of the press fit pins are connected individually (by mating to FCI PV™ receptacles with heavy springs) to the high (positive) side of the current supply. The low (negative) sides of the current supply and voltage sensing circuit are connected individually to the plated through holes by means of FCI BERGSTIK® press fit pin headers on the test board. Consequently, the measured CPR values include only the resistance across the compliant interface. The individually terminated connections are scanned sequentially by automated switching equipment. Figure 4 shows an example of a test board fixtured and cabled for low level compliant pin resistance measurement.



Figure 3. Fixture for Low Level Compliant Pin Resistance Measurement

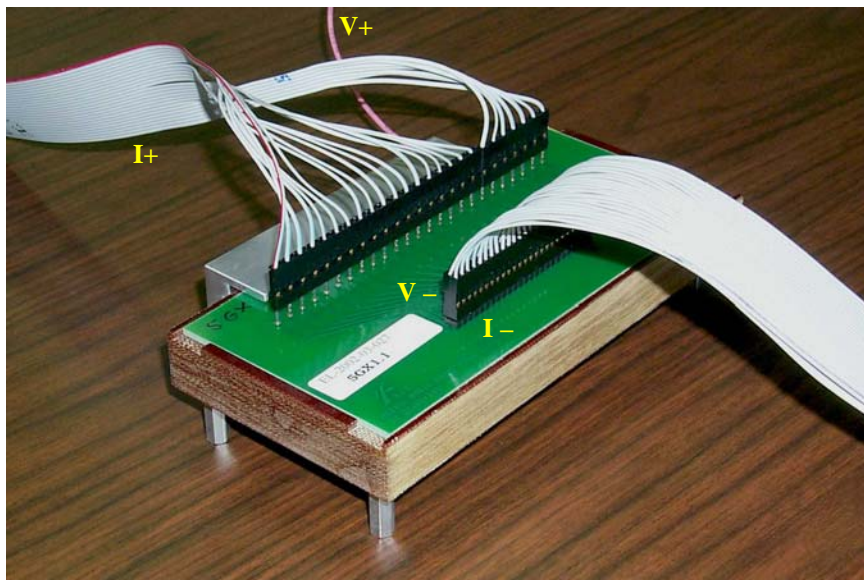


Figure 4. Fixtured Test Board Showing Electrical Connections for Compliant Pin Resistance Measurement

Pin Insertion Force

The force required to insert the press fit pin into the test board was measured in accordance with EIA-364-05B using a tensile/compression test instrument. The test board was placed (not clamped) horizontally on the plate of a stationary load cell. The pin to be inserted was held vertically in a contact holder (MF258.1) with the press fit end projecting downward from the moving crosshead. Insertion proceeded under machine control by pushing on the top of the pin at 0.5 inch per minute to a depth of 0.162 inch from the point at which the tip of the pin was at the top surface of the test board; this placed the middle of the EON compliant section at the center of the test board thickness. The pin insertion force was taken as the maximum force encountered during pin insertion. Pin insertion was performed in this manner regardless of whether or not the force was measured. The test setup for pin insertion is shown in figure 5.

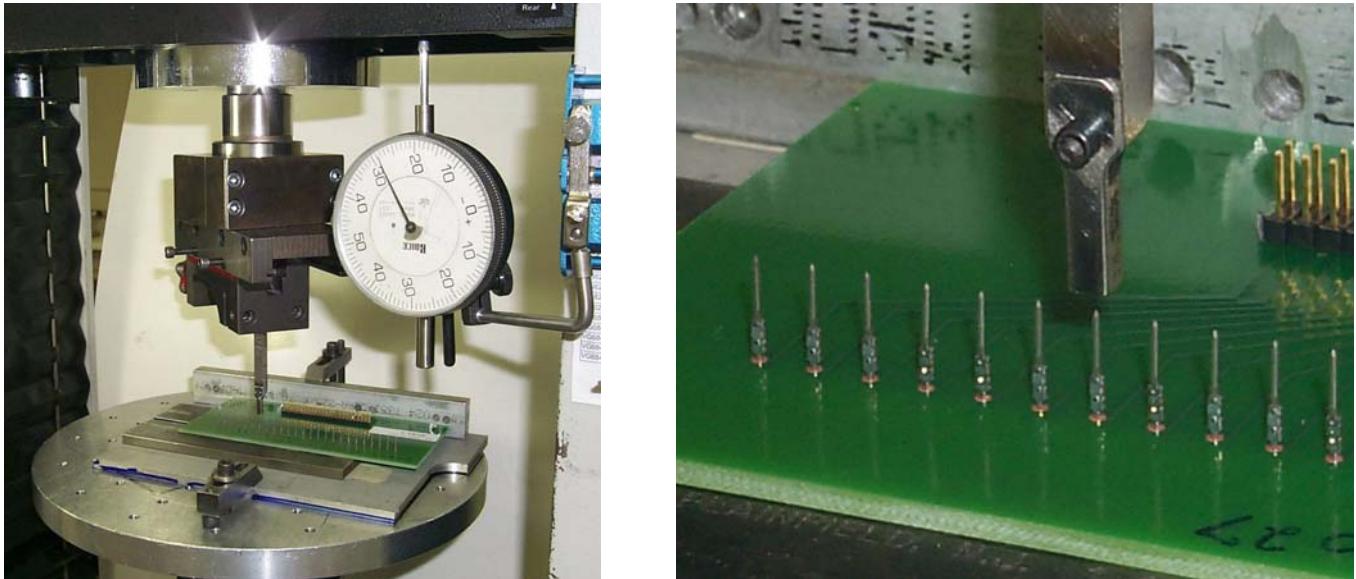


Figure 5. Test Setup for Pin Insertion

Pin Retention Force

The force required to remove the press fit pin from the test board was measured in accordance with EIA-364-05B using a tensile/compression test instrument. The test board was held horizontally on the plate of a stationary load cell in a slotted fixture. The top (long) end of the pin to be removed was clamped in a vise attached to the moving crosshead. The pin was pulled from the board under machine control at 0.5 inch per minute. The pin retention force was taken as the maximum force encountered during pin removal. The test setup for pin removal is shown in figure 6.

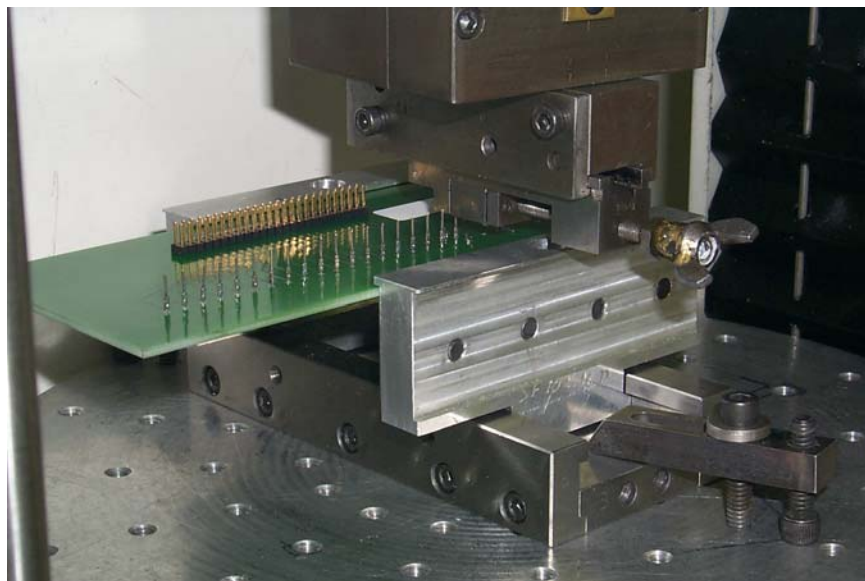


Figure 6. Test Setup for Pin Removal

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Temperature Life

The populated test boards were exposed to elevated temperature in accordance with EIA-364-17B, Method A (no load), Temperature Condition 4 (105 °C), Time Condition D (1000 hours). No monitoring was performed during the exposure.

Thermal Shock

The populated test boards were subjected to five (5) cycles of thermal excursions between -65 °C and 105 °C in accordance with EIA-364-32C, Condition II. Dwell time was 30 minutes at each temperature. No monitoring was performed during the exposure.

Moisture Resistance

The populated test boards were subjected to cyclic temperature and humidity exposure in accordance with requirement R6-65 of Telcordia GR-1217-CORE. The testing consisted of 50 cycles of double temperature excursions from 5 °C to 85°C over a total of 500 hours. In each cycle, the temperature was raised from the low level to the high level, held at the high level, lowered to the low level, immediately raised back to the high level, held at the high level, and lowered again to the low level. The transition times between temperatures were 1 hour. The temperature was held at the high level for 3 hours with the relative humidity between 90 % and 95 %. The identification of a cycle with a double temperature excursion is in accordance with EIA-364-31B, Method III, which was applied with the exceptions of the temperature limits, transition times, and the lack of low temperature dwell; no cold shock or vibration subcycles were performed. No monitoring was performed during the exposure.

Vibration

The component level vibration treatment consisted of subjecting the samples to sinusoidal vibration in accordance with EIA-364-28D, Condition II (10 G peak acceleration at frequencies of 10 Hz to 500 Hz). The populated test boards were mounted in fixtures as shown in figure 7. Vibration was limited to a peak acceleration of 10 G (acceleration of gravity) and a double amplitude (peak to peak displacement) of 0.06 inch, the former controlling at high frequency and the latter at low frequency with the crossover at approximately 70 Hz. The frequencies were swept logarithmically from low to high frequency and back; each cycle (bidirectional sweep) was accomplished in 15 minutes. The samples were subjected to thirty-two (32) cycles of vibration (8 hours) along each of three (3) axes. No monitoring was performed during the exposure.

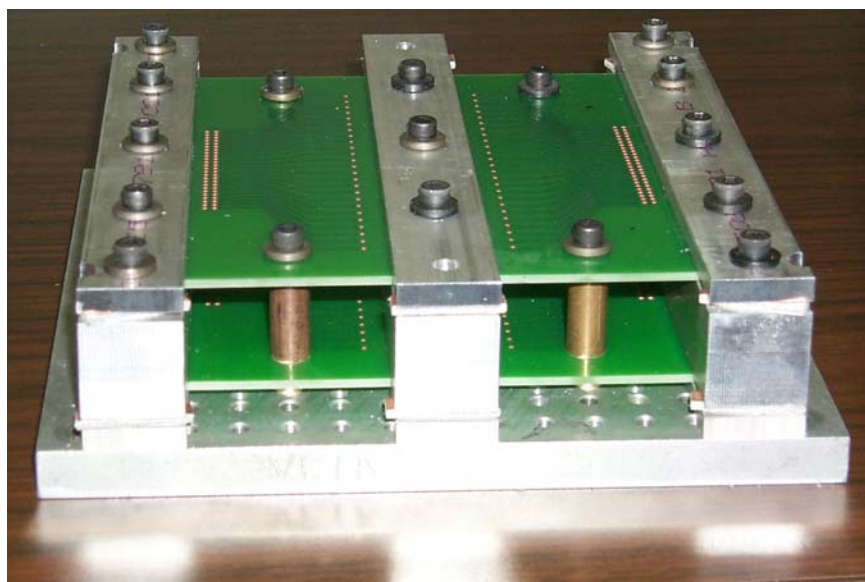


Figure 7. Fixturing of Test Boards for Vibration and Mechanical Shock

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Mechanical Shock

The test samples were subjected to mechanical shock in accordance with EIA-364-27B, Condition H (half-sine pulse, 30 G peak acceleration, 11 ms duration). The test boards were fixtured as in the vibration test. Three (3) half-sine shock pulses were applied in each of two (2) directions along each of three (3) axes. No monitoring was performed during the exposure.

Mixed Flowing Gas Exposure (Corrosion Resistance)

The populated test boards were exposed to mixed flowing gas in accordance with specification EIA-364-65A, Class IIIA for 20 days. This test consists of an environment of approximately 30 °C and 70 % relative humidity with four (4) corrosive gases: chlorine (Cl₂), nitric oxide (NO₂), hydrogen sulfide (H₂S), and sulfur dioxide (SO₂) in nominal concentrations of 20, 200, 100, and 200 nL/L (ppb) respectively. The bottom tips and mating surfaces of the press fit pins were covered during exposure to facilitate electrical connection for low level compliant pin resistance measurement after exposure; these covers did not approach the surface of the PWB thereby assuring ingress of the corrosive atmosphere to the compliant pin in the PTH.

PTH Integrity (Deformation and Wall Damage)

Plated through hole integrity was assessed by measurement of the deformation radius of the drilled hole and the remaining thickness of copper plate in accordance with sections 5.2.2.5.1 and 5.2.2.5.2 of IEC 60352-5 and sections 3.5.2.7.1 and 3.5.2.7.2 of MIL-C-28859B with the following exceptions. Due to the large redundancy in pin sampling (multiple hole sizes, PWB finishes, and pin plating conditions), the sample size for PTH integrity was restricted to five (5) pins per test board for each section (transverse and longitudinal). Deformation radius and hole wall damage (remaining copper) were measured on transverse sections (normal to the axis of the hole) as specified in section 5.2.2.5.1 of IEC 60352-5. In accordance with the requirements of section R5-38 of Telcordia GR-1217-CORE, the transverse sections were made in the plane corresponding to the maximum diameter of the compliant section of the pin (the middle of the PWB thickness). Longitudinal sections (in the EON plane) were examined for evidence of damage but were not measured; copper layer deformation at the connections of PWB traces to the PTH barrel was not measured since qualitative examination revealed no observable deviation. Since final retention force measurements were made on all samples, the PTH integrity was assessed on sections of empty holes after removal of the press fit pins.

In an effort to reduce the subjectivity inherent in manual assessment of PTH deformation, an automated procedure was employed to extract the deformation radius from the image of the transverse section. To facilitate analysis, the image was obtained under conditions of high contrast (bright copper layer on a dark background) in a specific sample orientation (deformed axis horizontal). After conversion to a grayscale image, the points delineating the perimeter of the copper layer were extracted by image analysis; although the threshold for object identification was adjusted manually, the high contrast of the image rendered the procedure insensitive to the threshold value. Since the axis of deformation was kept horizontal, perimeter points near the vertical represented the undisturbed outline of the drilled hole. Consequently, the radius and center position of the drilled hole were determined by fitting a circular section to the perimeter points excluding those sufficiently close to the horizontal that they might be vulnerable to interaction with the compliant section of the pin. For the present case, it was deemed that points above 55° from the horizontal were not subject to deformation. The deformation radius was then computed by subtracting the radius of the drilled hole (undisturbed) from the maximum distance of all perimeter points from the center of the drilled hole. In a few cases, poor fits to the undisturbed segments of the drilled hole were encountered due to sample anomalies (e.g., substantial departure of the drilled hole from circularity); in these instances, the PTH deformation values were determined manually.

The perimeter of the plated through hole is subject to localized anomalies related to defects induced during drilling of the hole in the PWB. Localized fracture of the PWB material and removal of fibers from the composite may yield outward excursions of the perimeter from the circular form cut by the drilling operation. In manual measurement of PTH deformation (performed by fitting a circular overlay of known radius to a magnified image of the PTH section), the effect of localized anomalies is mitigated by operator judgment. However, such judgment is lacking in the automated procedure involving image analysis, which uses the largest excursion from the PTH center regardless of probable origin. Consequently, the automated procedure yields results that are biased high relative to those from the traditional manual method (by approximately 0.0005 inch as estimated from direct comparison of the methods on a sampling of the measured sections). Therefore, all sections yielding high PTH deformation values (in excess of 0.0015 inch) were checked manually by the traditional procedure, the results of which are reported in those cases.

TEST RESULTS:

Initial Low Level Compliant Pin Resistance

Initial low level compliant pin resistance was measured for all pins on all test boards in each of the four (4) test groups. Table 6 presents a statistical summary of the combined results from all test groups for the lead free and standard (tin-lead plated) pins. The estimated value of the combined uncertainty of the low level compliant pin resistance measurements is 0.046 milliohm at the 95% confidence level (coverage factor 2). There were no substantial differences in initial low level compliant pin resistance among different PWB finishes. No substantial difference was observed in initial low level compliant pin resistance between lead free and tin-lead plated pins.

Table 6. Summary of Combined Results for Initial Low Level Compliant Pin Resistance

	Initial Low Level Compliant Pin Resistance / milliohm			
	Lead Free Pins		Tin-Lead Plated Pins	
	Min. Size PTH	Max. Size PTH	Min. Size PTH	Max. Size PTH
Count	1500	2000	375	500
Average	0.064	0.046	0.055	0.045
Standard Deviation	0.041	0.043	0.034	0.047
Minimum	0.006	0.006	0.006	0.006
Maximum	0.527	0.534	0.392	0.447
Count	3500		875	
Average	0.054		0.050	
Standard Deviation	0.043		0.042	
Minimum	0.006		0.006	
Maximum	0.534		0.447	

Low Level Compliant Pin Resistance after Exposure

Low level compliant pin resistance was measured for all pins on all test boards in each of the four (4) test groups. Table 7 presents statistical summaries of the measured values of low level compliant pin resistance; changes of low level compliant pin resistance from initial values are summarized statistically in table 8. The estimated values of the combined uncertainties are 0.046 milliohm and 0.064 milliohm for the measured resistance values and resistance changes, respectively, at the 95% confidence level (coverage factor 2). There were no substantial differences in low level compliant pin resistance among different PWB finishes. Overall, no significant difference was observed between lead free and tin-lead plated pins in either measured values or changes of low level compliant pin resistance after treatment (by 2 mean Student's t test).

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Table 7. Summary of Results for Low Level Compliant Pin Resistance after Exposure

Group	after Exposure to		Low Level Compliant Pin Resistance / milliohm			
			Lead Free Pins		Tin-Lead Plated Pins	
			Min. Size PTH	Max. Size PTH	Min. Size PTH	Max. Size PTH
1	Vibration	Count	500	500	125	125
		Avg.	0.054	0.036	0.052	0.037
		Std. Dev.	0.033	0.021	0.029	0.023
		Min.	0.006	0.006	0.006	0.006
		Max.	0.168	0.110	0.145	0.133
	Vibration + Mechanical Shock	Count	500	500	125	125
		Avg.	0.083	0.064	0.062	0.094
		Std. Dev.	0.072	0.036	0.023	0.081
		Min.	0.006	0.006	0.009	0.015
		Max.	0.361	0.215	0.118	0.285
2	Thermal Shock	Count	500	500	125	125
		Avg.	0.055	0.039	0.046	0.035
		Std. Dev.	0.031	0.020	0.027	0.022
		Min.	0.006	0.006	0.006	0.008
		Max.	0.135	0.100	0.102	0.136
	Thermal Shock + Moisture Resistance	Count	500	500	125	125
		Avg.	0.042	0.032	0.036	0.031
		Std. Dev.	0.030	0.023	0.023	0.022
		Min.	0.005	0.006	0.006	0.006
		Max.	0.279	0.169	0.169	0.103
4	Corrosion Resistance (MFG)	Count	X	500	X	125
		Avg.		0.049		0.068
		Std. Dev.		0.058		0.088
		Min.		0.005		0.005
		Max.		0.750		0.461
5	Pin Repair (3 rd Pin)	Count	500	500	125	125
		Avg.	0.060	0.041	0.048	0.037
		Std. Dev.	0.022	0.020	0.025	0.023
		Min.	0.006	0.006	0.006	0.008
		Max.	0.119	0.109	0.109	0.109
	Pin Repair (3 rd Pin) + Temperature Life	Count	500	500	125	125
		Avg.	0.047	0.040	0.038	0.028
		Std. Dev.	0.030	0.046	0.039	0.023
		Min.	0.006	0.006	0.006	0.006
		Max.	0.375	0.585	0.297	0.120
All	Combined	Count	3000	3500	750	875
		Avg.	0.057	0.043	0.047	0.047
		Std. Dev.	0.042	0.036	0.029	0.054
		Min.	0.005	0.005	0.006	0.005
		Max.	0.375	0.750	0.297	0.461
		Count	6500		1625	
		Avg.	0.049		0.047	
		Std. Dev.	0.040		0.044	
		Min.	0.005		0.005	
		Max.	0.750		0.461	

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Table 8. Summary of Changes in Low Level Compliant Pin Resistance after Exposure

Group	After Exposure To		Change in Low Level Compliant Pin Resistance / milliohm			
			Lead Free Pins		Tin-Lead Plated Pins	
			Min. Size PTH	Max. Size PTH	Min. Size PTH	Max. Size PTH
1	Vibration	Count	500	500	125	125
		Avg.	-0.006	-0.001	0.002	-0.001
		Std. Dev.	0.022	0.016	0.016	0.019
		Min.	-0.274	-0.039	-0.033	-0.045
		Max.	0.101	0.096	0.074	0.094
	Vibration + Mechanical Shock	Count	500	500	125	125
		Avg.	0.023	0.027	0.012	0.057
		Std. Dev.	0.084	0.050	0.042	0.090
		Min.	-0.335	-0.075	-0.064	-0.051
		Max.	0.353	0.191	0.094	0.255
2	Thermal Shock	Count	500	500	125	125
		Avg.	-0.014	-0.004	-0.013	-0.007
		Std. Dev.	0.044	0.017	0.034	0.018
		Min.	-0.424	-0.051	-0.302	-0.049
		Max.	0.073	0.063	0.073	0.100
	Thermal Shock + Moisture Resistance	Count	500	500	125	125
		Avg.	-0.026	-0.010	-0.023	-0.011
		Std. Dev.	0.053	0.027	0.048	0.025
		Min.	-0.440	-0.089	-0.373	-0.058
		Max.	0.273	0.148	0.158	0.087
4	Corrosion Resistance (MFG)	Count	X	500	X	125
		Avg.		-0.013		0.005
		Std. Dev.		0.084		0.075
		Min.		-0.431		-0.333
		Max.		0.684		0.401
5	Pin Repair (3 rd Pin)	Count	500	500	125	125
		Avg.	-0.003	-0.001	-0.008	-0.001
		Std. Dev.	0.028	0.021	0.034	0.019
		Min.	-0.078	-0.073	-0.097	-0.053
		Max.	0.089	0.063	0.076	0.063
	Pin Repair (3 rd Pin) + Temperature Life	Count	500	500	125	125
		Avg.	-0.017	-0.001	-0.018	-0.009
		Std. Dev.	0.039	0.049	0.050	0.024
		Min.	-0.099	-0.084	-0.105	-0.083
		Max.	0.364	0.573	0.273	0.109
All	Combined	Count	3000	3500	750	875
		Avg.	-0.007	0.000	-0.008	0.005
		Std. Dev.	0.052	0.046	0.041	0.052
		Min.	-0.440	-0.431	-0.373	-0.333
		Max.	0.364	0.684	0.273	0.401
		Count	6500		1625	
		Avg.	-0.004		-0.001	
		Std. Dev.	0.049		0.048	
		Min.	-0.440		-0.373	
		Max.	0.684		0.401	

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Insertion Force

Insertion force was measured on each of the three (3) pins inserted into the PWBs of test group 5. Table 9 presents a statistical summary of the results for the lead free and standard (tin-lead plated) pins. The estimated value of the combined uncertainty of the insertion force measurements is 0.3 pounds at the 95% confidence level (coverage factor 2). Insertion force differed significantly between PWB finishes (by ANOVA) with highest and lowest average forces for tin-lead and gold plated boards, respectively; averages by PWB finish are given in table 12. Overall, the average value of insertion force for the lead free pins was slightly higher (by 16 %) than that for the standard tin-lead plated pins (statistically significant at the 95% confidence level by 2 mean Student's t test).

Table 9. Summary of Measured Pin Insertion Force

Group	Pin		Pin Insertion Force / pound			
			Lead Free Pins		Tin-Lead Plated Pins	
			Min. Size PTH	Max. Size PTH	Min. Size PTH	Max. Size PTH
5	1 st	Count	500	500	125	125
		Avg.	9.31	7.88	7.94	6.80
		Std. Dev.	1.64	1.43	0.84	1.14
		Min.	6.4	5.1	6.4	5.1
		Max.	13.1	12.2	9.9	9.3
	2 nd	Count	500	500	125	125
		Avg.	8.26	7.73	7.09	6.64
		Std. Dev.	1.39	1.42	0.89	1.15
		Min.	5.2	5.0	5.3	4.8
		Max.	12.6	11.3	10.2	9.8
	3 rd	Count	500	500	125	125
		Avg.	7.49	6.72	6.39	5.94
		Std. Dev.	1.21	1.09	0.63	0.92
		Min.	5.0	4.5	4.8	4.4
		Max.	12.0	11.0	8.1	8.7
	Combined	Count	1500	1500	375	375
		Avg.	8.35	7.44	7.14	6.46
		Std. Dev.	1.42	1.32	0.79	1.08
		Min.	5.0	4.5	4.8	4.4
		Max.	13.1	12.2	10.2	9.8
Count		3000		750		
Avg.		7.90		6.80		
Std. Dev.		1.46		1.02		
Min.		4.5		4.4		
Max.		13.1		10.2		

Retention Force

The force to remove the pin from the PWB was measured at the end of each test sequence as well as for removal of the first and second pins in test group 5. Table 10 presents a statistical summary of the results for the lead free and standard (tin-lead plated) pins. The estimated value of the combined uncertainty of the retention force measurements is 0.3 pounds at the 95% confidence level (coverage factor 2). Retention force differed significantly between PWB finishes (by ANOVA) in a pattern similar to that for insertion force; averages by PWB finish are given in table 11. Overall, the average value of retention force for the lead free pins was slightly higher (by 10 %) than that for the standard tin-lead plated pins (statistically significant at the 95% confidence level by 2 mean Student's t test).

For comparison of the effects of pin plating and PTH size, the combined values of retention force from all groups and conditions are presented graphically as a normal probability plot in figure 8.

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Table 10. Summary of Measured Pin Retention Force

Group	After Exposure To		Pin Retention Force / pound			
			Lead Free Pins		Tin-Lead Plated Pins	
			Min. Size PTH	Max. Size PTH	Min. Size PTH	Max. Size PTH
1	Vibration + Mechanical Shock	Count	500	500	125	125
		Avg.	7.43	7.01	7.30	6.34
		Std. Dev.	2.79	2.34	2.45	2.50
		Min.	0.9	2.72	1.12	1.78
		Max.	13.92	11.6	11.15	10.72
2	Thermal Shock + Moisture Resistance	Count	500	500	125	125
		Avg.	8.13	8.33	7.31	7.03
		Std. Dev.	2.54	2.86	1.83	2.44
		Min.	1.8	2.1	1.4	2.4
		Max.	13.2	13.9	11.4	12.6
4	Corrosion Resistance (MFG)	Count	X	500	X	100
		Avg.		7.56		7.45
		Std. Dev.		2.53		2.51
		Min.		2.55		3.28
		Max.		13.25		11.98
5	1 st Pin	Count	500	500	125	125
		Avg.	7.49	6.82	6.88	6.25
		Std. Dev.	2.60	2.27	2.10	2.10
		Min.	1.1	0.9	1.2	1.4
		Max.	13.7	12.1	10.3	10.3
	Pin Repair (2 nd Pin)	Count	500	500	125	125
		Avg.	6.63	6.19	5.70	5.71
		Std. Dev.	1.84	1.95	1.36	1.82
		Min.	2.8	2.4	3.1	1.8
		Max.	12	11.8	9.6	9.8
	Pin Repair (3 rd Pin) + Temperature Life	Count	500	500	125	125
		Avg.	6.94	6.78	6.18	6.63
		Std. Dev.	1.71	1.96	1.70	1.45
		Min.	1.6	1	1.1	0.8
		Max.	10.4	11.5	10.4	9.6
All	Combined	Count	2500	3000	625	750
		Avg.	7.32	7.11	6.67	6.48
		Std. Dev.	2.34	2.34	1.92	2.17
		Min.	0.9	0.9	1.1	0.8
		Max.	13.92	13.9	11.4	12.6
		Count	5500		1375	
		Avg.	7.21		6.57	
		Std. Dev.	2.36		2.11	
		Min.	0.9		0.8	
		Max.	13.92		12.6	

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Table 11. Average Measured Forces by PWB Finish

Group	Condition	PWB Finish	Average Force / pound			
			Lead Free Pins		Tin-Lead Plated Pins	
			Min. Size PTH	Max. Size PTH	Min. Size PTH	Max. Size PTH
5	1 st Pin Insertion	Sn-Pb	9.99	9.56	8.65	8.67
		OSP/Cu	7.68	6.10	7.24	5.36
		Sn	10.44	8.34	7.93	6.74
		Ag	10.96	8.51	8.78	6.87
		Au/Ni	7.47	6.87	7.12	6.34
	2 nd Pin Insertion	Sn-Pb	9.35	9.45	8.30	8.55
		OSP/Cu	8.03	7.32	6.91	5.94
		Sn	8.95	8.15	7.24	6.90
		Ag	8.76	7.65	6.96	6.13
		Au/Ni	6.23	6.06	6.04	5.68
	3 rd Pin Insertion	Sn-Pb	8.14	7.68	7.10	7.41
		OSP/Cu	7.68	6.51	6.12	5.50
		Sn	8.03	6.85	6.62	6.11
		Ag	7.48	6.81	6.39	5.24
		Au/Ni	6.11	5.75	5.71	5.42
5	1 st Pin Removal	Sn-Pb	9.20	9.10	9.40	8.29
		OSP/Cu	5.59	4.77	5.31	4.54
		Sn	9.53	8.27	8.44	8.47
		Ag	8.66	7.30	7.04	5.86
		Au/Ni	4.49	4.68	4.20	4.09
	2 nd Pin Removal	Sn-Pb	8.80	8.74	7.34	8.58
		OSP/Cu	6.26	5.31	5.42	4.91
		Sn	6.94	6.55	6.18	6.06
		Ag	6.98	6.33	5.57	5.59
		Au/Ni	4.15	4.00	3.96	3.40
	3 rd Pin Removal	Sn-Pb	7.58	8.39	6.28	8.16
		OSP/Cu	7.60	6.96	7.29	6.70
		Sn	7.54	7.64	6.70	7.08
		Ag	7.72	6.68	6.98	6.56
		Au/Ni	4.24	4.21	3.66	4.67
1	Retention after Vibration & Mech. Shock	Sn-Pb	8.44	9.34	9.68	9.58
		OSP/Cu	5.97	5.02	5.26	4.93
		Sn	9.43	8.50	9.34	7.97
		Ag	8.98	7.82	8.09	6.05
		Au/Ni	4.34	4.34	4.12	3.18
2	Retention after Thermal Shock & Humidity	Sn-Pb	9.71	10.43	8.71	9.92
		OSP/Cu	7.86	7.72	7.24	5.72
		Sn	9.96	10.26	8.06	9.28
		Ag	8.85	9.31	7.81	6.20
		Au/Ni	4.28	3.92	4.72	4.01
4	Retention after MFG	Sn-Pb	X	10.26	X	10.01
		OSP/Cu		4.83		3.98
		Sn		9.19		9.21
		Ag		8.13		6.58
		Au/Ni		5.42		4.88

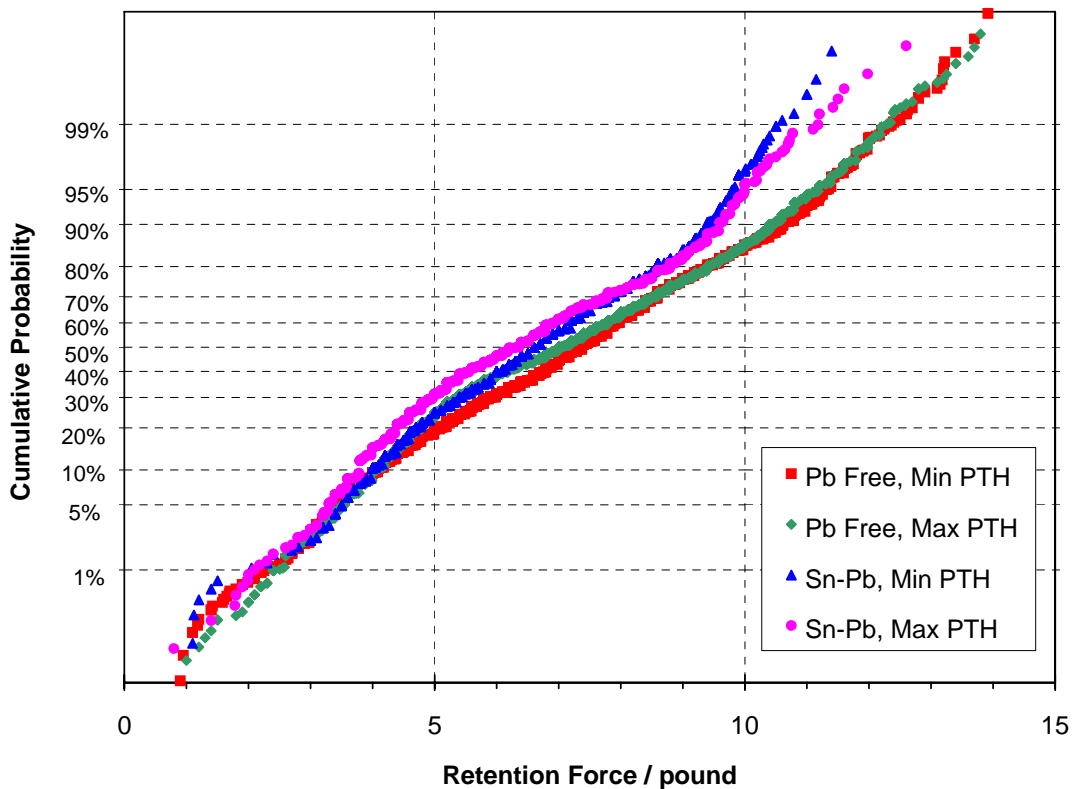


Figure 8. Normal Probability Plot of Combined Retention Force Values from All Groups and Conditions

Several aspects of the observed force behavior are enigmatic. The lower retention forces are not associated with correspondingly low insertion forces as might be anticipated were they related to product attributes. The lower retention forces are not restricted to or predominated by pins in maximum diameter holes as would be expected on general principles. It is believed that such occurrence of low retention force is a consequence of the testing methodology. To facilitate testing a large sampling of press fit interfaces, the pins were applied individually rather than loaded in connector housings in the normal manner. Although this should not (and apparently does not) adversely affect the insertion of the pins, it leaves the pins vulnerable to mechanical damage after insertion. Anecdotal evidence from general observations during retention testing indicates that some pins were bent noticeably and suggests that such pins tended to exhibit lower retention forces. Direct correlation of pin bending with lower forces was not feasible in this test since, due to the large sample size, no attempt was made to scrutinize individual pins prior to removal, to formally document the condition of individual pins at the end of the test, or to retain the identity of individual pins after removal from the test boards.

In an attempt to test the hypothesis of pin bending as a cause of lower retention force, an ancillary experiment was conducted (FCI US Product Test Laboratory number EL-2002-03-027A) with the same test boards (gold plated) and press fit pins (standard tin-lead plated). In this experiment, after inserting pins into boards with minimum and maximum size PTHs, randomly selected pins were intentionally bent to target angles of 15 ° and 30 ° from the board normal both in-plane (in the plane of the EON press fit feature, i.e., the plane of the material strip from which the pin is stamped) and out-of-plane (perpendicular to the in-plane bend). Retention force was then measured on both bent and unbent pins. The results showed that pin bending had a pronounced effect on retention force particularly for in-plane bends, which exhibited retention forces as low as 3 % of the unbent average. With a 15 ° in-plane bend, the retention force averaged 17 % of the unbent case (with an individual as low as 6 %). The relative sensitivity of retention force to angle at the board normal was estimated to be approximately -8 %/° for in-plane bending (and approximately half of that for out-of-plane bending). Examination of the pins after removal from the PWB revealed severe deformation of the EON feature (i.e., crushing of the compliant section) by in-plane bending.

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PTH Deformation

PTH deformation was measured on transverse sections through the middle of five (5) holes in each board of test group 5. Due to the sampling limitation, each subgroup consisted of the five (5) holes in each test board (rather than 10 holes). The subgroup averages and maximum individuals of measured PTH deformation are given in tables 12 and 13, respectively. The estimated value of the combined uncertainty of the PTH deformation measurement (by the automated procedure) is 0.0014 inch at the 95% confidence level (coverage factor 2). There were no significant differences in PTH deformation among different PWB finishes (by main effect ANOVA). Overall, no significant difference was observed between lead free and tin-lead plated pins in either average or maximum PTH deformation (by 2 mean Student's t test).

Table 12. Subgroup Averages of Measured PTH Deformation (5 PTHs/PWB)

Group	PWB Finish	Average PTH Deformation / inch				
		Lead Free Pins		Tin-Lead Plated Pins		
		Min. Size PTH	Max. Size PTH	Min. Size PTH	Max. Size PTH	
5	Tin-Lead	0.00092	0.00111	0.00094	0.00092	
		0.00112	0.00102			
		0.00083	0.00071			
		0.00110	0.00076			
	OSP (Copper)	0.00088	0.00106	0.00097	0.00091	
		0.00109	0.00081			
		0.00128	0.00080			
		0.00084	0.00077			
	Tin	0.00090	0.00093	0.00067	0.00082	
		0.00116	0.00098			
		0.00074	0.00092			
		0.00053	0.00094			
	Silver	0.00072	0.00092	0.00115	0.00145	
		0.00061	0.00097			
		0.00074	0.00108			
		0.00098	0.00094			
	Gold over Nickel	0.00089	0.00077	0.00089	0.00072	
		0.00093	0.00070			
		0.00106	0.00097			
		0.00101	0.00088			
	Combined	Count	20	20	5	5
		Avg.	0.00092	0.00090	0.00092	0.00096
		Std. Dev.	0.00019	0.00012	0.00017	0.00028
		Min.	0.00053	0.00070	0.00067	0.00072
		Max.	0.00128	0.00111	0.00115	0.00145
		Count	40		10	
		Avg.	0.00091		0.00094	
		Std. Dev.	0.00016		0.00022	
Min.		0.00053		0.00067		
Max.		0.00128		0.00145		

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Table 13. Maximum Values of Measured PTH Deformation for Individual PTHs by Subgroup (PWB)

Group	PWB Finish	Maximum PTH Deformation / inch			
		Lead Free Pins		Tin-Lead Plated Pins	
		Min. Size PTH	Max. Size PTH	Min. Size PTH	Max. Size PTH
5	Tin-Lead	0.00110	0.00135	0.00145	0.00104
		0.00131	0.00130		
		0.00126	0.00116		
		0.00137	0.00094		
	OSP (Copper)	0.00109	0.00142	0.00120	0.00148
		0.00140	0.00100		
		0.00150	0.00125		
		0.00128	0.00093		
	Tin	0.00137	0.00120	0.00118	0.00125
		0.00132	0.00185		
		0.00092	0.00125		
		0.00067	0.00120		
	Silver	0.00111	0.00142	0.00149	0.00200
		0.00087	0.00115		
		0.00092	0.00140		
		0.00140	0.00132		
	Gold over Nickel	0.00126	0.00090	0.00141	0.00120
		0.00108	0.00101		
		0.00131	0.00147		
		0.00123	0.00119		
Combined	Count	20	20	5	5
	Avg.	0.00119	0.00124	0.00135	0.00139
	Std. Dev.	0.00021	0.00023	0.00015	0.00037
	Min.	0.00067	0.00090	0.00118	0.00104
	Max.	0.00150	0.00185	0.00149	0.00200
	Count	40		10	
	Avg.	0.00121		0.00137	
	Std. Dev.	0.00022		0.00027	
	Min.	0.00067		0.00104	
	Max.	0.00185		0.00200	

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PTH Wall Damage

PTH wall damage was measured on the same sections as was PTH deformation. Due to the sampling limitation, each subgroup consisted of the five (5) holes in each test board (rather than 10 holes). The subgroup averages of the measured values of remaining copper thickness are given in table 14. The estimated value of the combined uncertainty of the measurement of remaining copper thickness is 15 microinches at the 95% confidence level (coverage factor 2). PTH wall damage differed significantly between PWB finishes (by ANOVA) with the greatest damage (lowest remaining copper thickness) occurring on gold plated boards and the least damage (highest remaining copper thickness) occurring on tin plated boards. Overall, no significant difference was observed between lead free and tin-lead plated pins in average remaining copper thickness (by 2 mean Student's t test). The tested samples exhibited no qualitative defects (e.g., cracking, separation, delamination) in the PTH or attached conductive traces.

Table 14. Subgroup Averages of Remaining Copper Thickness (5 PTHs/PWB)

Group	PWB Finish	Average Remaining Copper Thickness / microinch			
		Lead Free Pins		Tin-Lead Plated Pins	
		Min. Size PTH	Max. Size PTH	Min. Size PTH	Max. Size PTH
5	Tin-Lead	1302	2465	2552	4273
		1464	2579		
		2220	5632		
		1050	4062		
	OSP (Copper)	3036	2348	4623	4620
		3057	3810		
		3060	2202		
		3445	3080		
	Tin	2486	3007	3951	5494
		3102	3124		
		4014	3298		
		3221	4099		
	Silver	3645	449	3121	410
		3563	571		
		3600	822		
		2926	441		
	Gold over Nickel	2570	807	2710	1222
		2937	1073		
		2631	1073		
		1469	988		
Combined	Count	20	20	5	5
	Avg.	2740	2297	3391	3204
	Std. Dev.	847	1480	876	2243
	Min.	1050	441	2552	410
	Max.	4014	5632	4623	5494
	Count	40		10	
	Avg.	2518		3297	
	Std. Dev.	1211		1609	
	Min.	441		410	
	Max.	5632		5494	

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EQUIPMENT:

ITEM NAME	MANUFACTURER	V.G. NUMBER	CALIBRATION DUE DATE
Microscope	Olympus SZH	VG7399	Not Calibrated
Digital Camera	Polaroid (DMC Ie)	VG7555	Not Calibrated
Microscope	Cambridge (SZ-6 Plus)	VG7401	Not Calibrated
Microscope	Unitron (ZSB)	(SN 913546)	Not Calibrated
Microscope	Nikon (Measurescope 10, MC-102)	VG5949	2002 May
Hygrothermometer	Control Co. (SN 21259463)	VG7814	2003 Jun
Micro-Ohmmeter	Keithley (Model 580)	S56825	2003 May
Micro-Ohmmeter	Keithley (Model 580)	VG6851	2002 Jul
Micro-Ohmmeter	Keithley (Model 580)	VG7024	2002 Sep
Micro-Ohmmeter	Keithley (Model 580)	VG6106	2003 Jan
Scanner	Keithley (Model 706)	Q316352	Not Calibrated
Scanner	Keithley (Model 706)	VG7145	Not Calibrated
Tensile/Compression Tester	Instron (Model 1122, SN 5112)	VG6463	2003 Aug
Tensile/Compression Tester	Instron (Model 1122, SN 4664)	VG6464	2002 Aug
Tensile/Compression Tester	Instron (Model 1122, SN 4471)	VG7171	2002 Aug
Load Cell	Instron (1000 lb, SN 1693)	VG6452	2002 Aug
Load Cell	Instron (1000 lb, SN 1281)	VG6460	2002 Aug
Load Cell	Instron (1000 lb, SN 1978)	VG6449	2003 Aug
Load Cell	Instron (50 kg, SN 216)	VG6457	Cal. Before Use
Calibration Mass	Instron (10 lb, #3)	VG6251	2002 May
Calibration Mass	Instron (10 lb, #4)	VG6252	2002 May
Calibration Mass	Instron (10 lb, #1)	VG6253	2003 May
Calibration Mass	Instron (10 lb, #2)	VG6254	2003 May
Calibration Mass	Instron (20 lb, #1)	VG6842	2003 May
Calibration Mass	Instron (20 lb, #5)	VG6846	2003 May
Linear Gauge	Boice (Model J48D-1)	FO0908	2002 Jun
Dry Heat Oven	Blue M (Model DC-1506C G0P, SN DC-5518)	VG6930	2003 May
Thermal Shock Chamber	Thermotron (Model AT5-320-V-10-705-LN)	VG6931	2002 Nov
Chart Recorder	Moytek (Model 2702)	VG6983	2002 Nov
Vibrator	Ling Dynamic Systems (V810)	(SN S1505-001)	Not Calibrated
Vibration Controller	LDS (DVC4000)	Q316734	2002 Dec
Amplifier	LDS (DPA20K)	VG7436	Not Calibrated
Accelerometer	Endevco (2213E, SN NT57)	VG7437	2003 Feb
Humidity Chamber	Blue M (FR-251B-MP1, SN F1-169)	VG6474	2003 May
Shock Machine	Avex (SM110 MP)	(SNED0107)	Not Calibrated
Shock Amplifier	Endevco (2740B)	VG6926	2003 Feb
Low Pass Filter	Krohn-Hite (3200R)	VG6925	2003 Feb
Digital Oscilloscope	Hi-Techniques (IQ400)	VG6924	2003 Feb
Accelerometer	Columbia Research Laboratories (5011, SN 522)	VG6961	2003 Feb

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ITEM NAME	MANUFACTURER	V.G. NUMBER	CALIBRATION DUE DATE
Corrosion Chamber	(# 2, Class IIIA)	VG7896	Not Calibrated
Corrosion Chamber	(# 3, Class IIIA)	VG7897	Not Calibrated
Permeation Rack	InterFact Associates	VG6944	2003 Mar
Thermometer	Fisher	SN 3433	2012 Nov
Balance	Mettler (SN A99909)	VG6543	2003 Mar
Fluorescent Analyzer	Monitor Labs (Model 8850) SO ₂	VG7008	Not Calibrated
Permeation Tube	SO ₂	33-9549	2004 Jul
Chamber Gas	NO ₂	CC44805	Not Calibrated
Chamber Gas	SO ₂	CC1132	Not Calibrated
Chamber Gas	H ₂ S	CC23469	Not Calibrated
Chamber Gas	Cl ₂	CC11187	Not Calibrated
Metallographic Microscope	Reichert-Jung (Polyvar-MET, SN 392265)	VG7398	Not Calibrated
Digital Camera	Diagnostics Instruments (Insight Model 3.2.0)	VG7749	Not Calibrated
Stage Micrometer	SPI (2266)	VG7648	2010 Oct
Comparator	Nikon (Profile Projector Model V-12)	VG6416	2002 Dec

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REVISION RECORD

Rev. #	Revision Date	Page(s)	Description
	2002 Nov 26	All	Original Issue
1	2002 Dec 02	All	Added Confidentiality Label per Request by S. Kleinle
<i>(System for revision designation changed from numerical to alphabetical.)</i>			
B	2003 Apr 23	2	Corrected typographical errors in thickness values in Table 1
C	2004 Jun 28	3	Corrected values of drill diameter in Table 2
D	2006 May 08	1	Updated Corporate Logo