Moisture Sensitivity Level (MSL) Packaging Evaluation

Performed on the 5 Part Types in the NEPP/NEPAG PEMS Study

FY '03 Work

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1. Executive Summary

The five part types selected for the NEPAG/NEPP evaluations were stressed to the Packaging IPC/JEDEC J-STD-020B Specification entitled "Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Devices". All parts were tested in the "as received" condition from the vendor with no additional screening or testing (with the exception of initial electrical testing to insure that each part is electrically good prior to the testing). Each part type was stressed to the appropriate classification based on the manufacturers declared Moisture Sensitivity Level (MSL).

The purpose of this part of the NEPP/NEPAG PEMS evaluation was intended to verify that the plastic encapsulated packaging of the sample parts provides a moisture barrier to the industry standard level that each manufacturer claimed it could pass (Moisture Sensitivity Level – MSL). It is necessary to validate the MSL in order to ensure that the parts can be properly packaged, stored, and handled by flight projects in order to avoid damage during board assembly solder reflow attachment or repair operations. In addition, the MSL classification is applied to parts as a precondition prior to Qualification Stress Testing, thereby simulating the effects of the assembly process in the test samples prior to reliability validation testing. MSL validation is one portion of the overall packaging-related test plan which is a subset evaluation of the larger NEPP/NEPAG PEMS study.

For packaged parts to pass IPC/JEDEC J-STD-020B, they must pass two things: 1) electrical test (at room temperature - RT) and 2) an acoustic microscope (CSAM) inspection. In order to pass the test, both conditions must be satisfied. It is not a sufficient condition for a part to pass electrical test and fail CSAM inspection, for example. An overview of the parts tested, the sample size and the results is shown in Table 1. Electrical testing was conducted at room temperature both functional and parametric to the manufacturer's data sheet.

Table 1. Overview of Test Samples and Results

Part Type	Sample Size	Vendor	MSL	Lead Finish	Die Coat	Electrical Test (RT)	CSAM Inspection	Final Assessment
A/D	11	A	1	Lead-free	no	pass G	fail R	fail R
Multiplexer	11	B	1	Tin-lead	no	pass G	fail R	fail R
Op Amp	11	C	1	Tin-lead	yes	pass G	fail R	fail R
Reference	11	D	1	Lead-free	yes	pass G	pass G	pass G
Amplifier	11	E	3	Tin-lead	no	pass G	pass G	pass G

To summarize, 3 of the 5 device types did not meet the MSL criteria that the vendor stated the parts could survive. The A/D part manufactured by Vendor A was by far the worse part type as far as the amount of delamination observed. It was beyond the scope of this task to assess whether the package would have passed if they were reclassified to a MSL Class "2" Package.

2. Evaluation Details

a. Introduction

The JEDEC/IPC J-STD-020B classification procedure applies to all nonhermetic plastic encapsulated surface mount packages, which, because of absorbed moisture, could be sensitive to damage during solder reflow. The vapor pressure of moisture inside a nonhermetic package increases greatly when the package is exposed to the high temperature of solder reflow. Under certain conditions, this pressure can cause internal delamination of the packaging materials from the die and/or leadframe/substrate, internal cracks that do not extend to the outside of the package, bond damage, wire necking, bond lifting, die lifting, thin film cracking, or cratering beneath the bonds. In the most severe case, the stress can result in external package cracks. This is commonly referred to as the ''popcorn'' phenomenon because the internal stress causes the package to bulge and then crack with an audible ''pop.'' Surface Mount Devices (SMDs) are more susceptible to this problem than through-hole parts because they are exposed to higher temperatures during reflow soldering. The reason for this is that the soldering operation must occur on the same side of the board as the SMD device. For through-hole devices, the soldering operation occurs under the board that shields the devices from the heat of the solder.

The MSL categories are intended to be used by manufacturers to inform users (board assembly operators and other part handlers) about of the level of moisture sensitivity of their product devices, and by board assembly operations to ensure that proper handling precautions are applied to moisture/reflow sensitive devices. The JEDEC/IPC standard does not attempt to address all of the possible component, board assembly and product design combinations; however, the standard does provide a test method and criteria for commonly used technologies.

It should be noted that passing the criteria in this test method is not sufficient by itself to provide assurance of long-term reliability. Generally, the MSL level rating is used as a precondition (conditioning the package prior to qualification testing by applying JESD22-A113 **"***Preconditioning Procedures of Plastic Surface Mount Devices prior to Reliability Testing"*) so that the associated stress can stimulate latent defects created during production of the devices and/or through the interaction between the production and assembly processes.

b. Test Conditions

The MSL ratings used by the manufacturers in their datasheets are an important consideration for both the manufacturer and the customer. The better the rating (lower numeric value on the JEDEC scale), the more forgiving the part will be during the surface mount process. A packaged part with a J-STD-020 MSL rating of "1" is essentially the same as a hermetic part as far as the care that must be taken with regards to moisture exposure prior to the surface mount assembly process. Users of devices with MSL ratings other than 1 must take storage conditions and conditions on the factory floor into consideration. An MSL 1 rated device is less costly to use and easier to sell (all other variables being equal).

A memo submitted to the NEPP/NEPAG team, dated November 20, 2002 and authored by Jeannette Plante, summarized each respective vendor's quoted moisture sensitivity levels for each of the five part types. The information was obtained by website review as well as email correspondence with Quality Assurance Personnel from the respective manufacturers, as necessary. Two of the part types have no-lead plating and were stated as passing the higher reflow temperature test condition. The J-STD-020B covers the differences between peak reflow temperatures for lead and lead-free solders. For small body devices (for which these parts qualify) the peak solder reflow temperatures are: lead solder -- 240 +0/-5°C and the lead-free solder -- 250 +0/-5°C (temperatures are to be measured at the topside of the part). The reflow method chosen for this evaluation was convection reflow as it is the preferred method called out by J-STD-020 and it is the most representative reflow method used by volume assembly manufacturers and NASA. Since this initial evaluation of these parts is to evaluate how well the manufacturers meet their own specifications, convection reflow was chosen. Also, since this is a "Package" Evaluation, room temperature electrical tests were performed (per J-STD-020B). A more in-depth look at the effect that Packaging Stresses have on the Electrical Performance of these devices will follow in FY'04.

The parts used in the MSL validation testing are listed below in Table 2 with their reported MSL rating:

Table 2. Test Samples and Their Manufacturer MSL Ratings.

Part Type	**Sample Size**	**Vendor**	**MSL**	**Moisture Condition** Time (hours)	Conditions	**Lead Finish**	**Reflow Temperature**
A/D	11	A	1	168 (+5/-0)	85 °C/85% RH	Lead-free	250 +0/-5°C
Multiplexer	11	B	1	168 (+5/-0)	85 °C/85% RH	Tin-lead	240 +0/-5°C
Op Amp	11	C	1	168 (+5/-0)	85 °C/85% RH	Tin-lead	240 +0/-5°C
Reference	11	D	1	168 (+5/-0)	85 °C/85% RH	Lead-free	250 +0/-5°C
Amplifier	11	E	3	192 (+5/-0)	30 °C/60% RH	Tin-lead	240 +0/-5°C

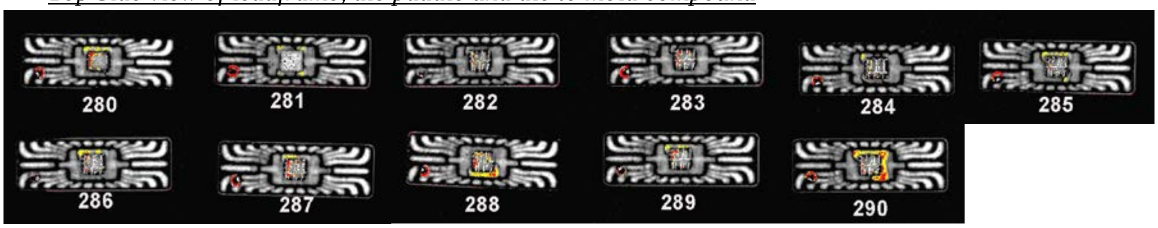
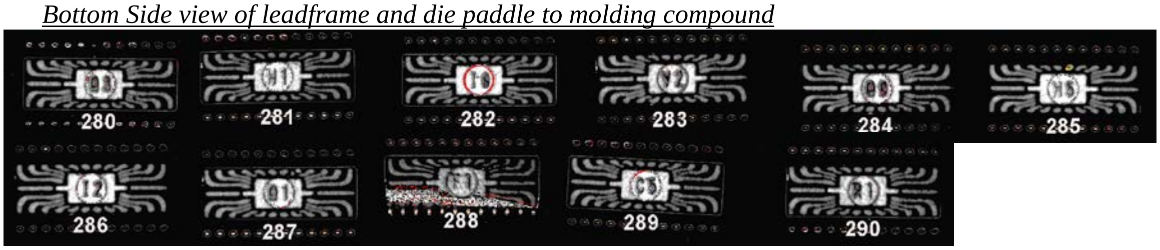
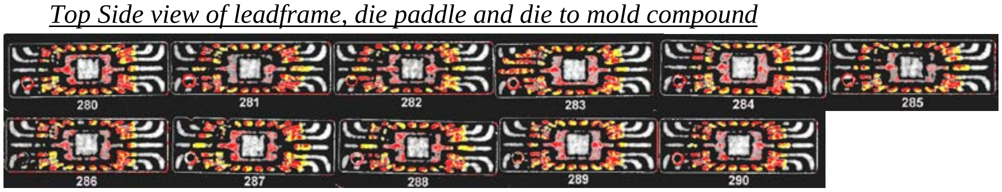
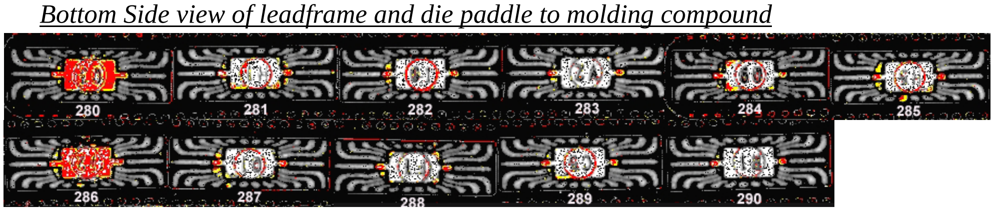
A sample of 11 units for each of the 5 Part Types were selected and tested to the JEDEC/IPC J-STD-020B Specification flow as follows:

1a. **Serialization**, not part of the JEDEC test flow, added for the NEPP/NEPAG investigation
1b. **Initial Electrical Test,** Test appropriate electrical parameters, e.g., data sheet values. Replace any devices that fail to meet this requirement.
2. **Initial Inspection,** 40X visual (required)
2a. **CSAM** (C-Mode Scanning Acoustic Microscopy), added for documentation of the part intial condition.
3. **Bake,** 24 hours minimum at 125 +5/-0°C
4. **Moisture Soak, Level 1**: 85ºC/85%RH for 168 hours +5/-0, **Level 3:** 30ºC/60%RH for 192 hours +5/-0
5. **Reflow,** Not sooner than 15 minutes and not longer than 4 hours after removal from the temperature/humidity chamber, subject the sample to 3 cycles of the appropriate reflow conditions. For details see Appendix A.
6. **Final External Visual,** 40X visual to examine for cracks.
7. **Final Electrical Test,** Test appropriate electrical parameters, e.g., data sheet values.
8. **Final Acoustic Microscopy,** Perform scanning acoustic microscope analysis on all devices (see Appendix A for failure criteria).

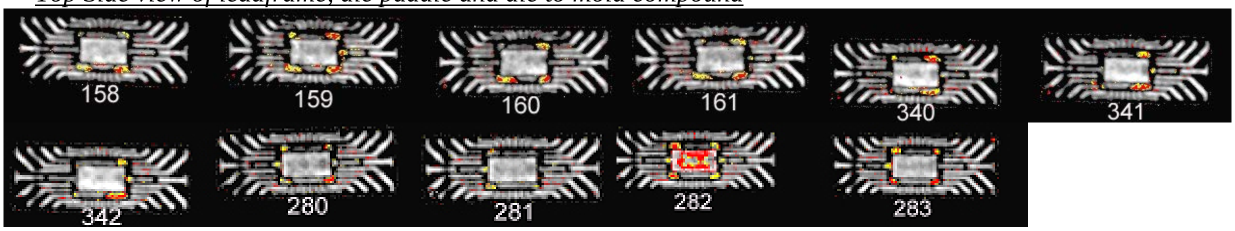
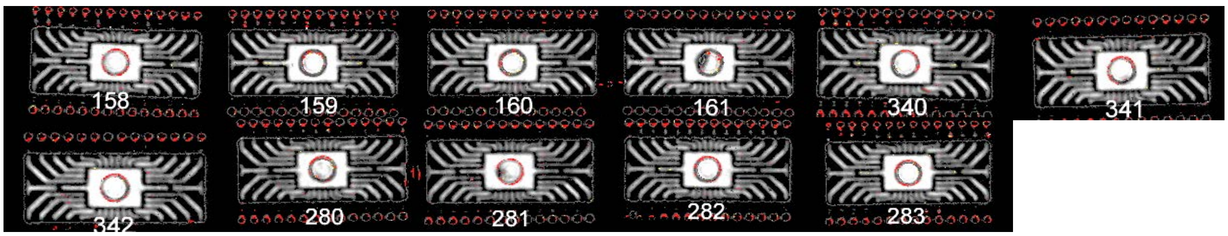
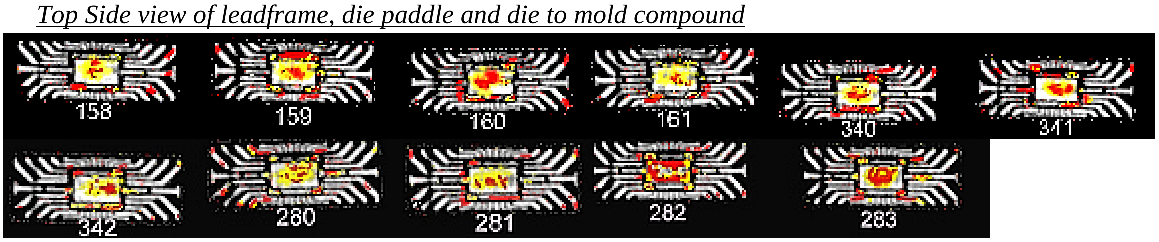
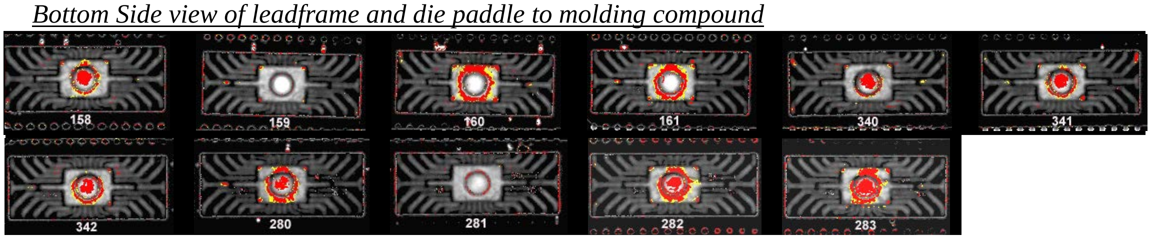
The results of this evaluation are presented next in tabular form for each part type with the results from the above flow summarized for each part type. Some of the details of J-STD-020B and the reflow profiles used in this evaluation are presented in Appendix A following the data presentation.

3. Results

a. A/D, Vendor A

Test	Pass/Fail
Initial Electrical Test	Pass
Initial Visual Inspection	Pass
Initial Acoustic Microscopy	There is no pass or fail criteria applied here – this step is to document the initial conditions of the devices.
Top Side view of leadframe, die paddle and die to mold compound  	
Bottom Side view of leadframe and die paddle to molding compound  	
Final External Visual	Pass
Final Electrical Test	Pass
Final Acoustic Microscopy	Fail; No Popcorn but excessive delamination beyond the die area. Note that the mold compound-to-die adhesion is still intact. The bottom view shows some delamination but this is for information only as the failure criteria is specified for the top-side of the package.
Top Side view of leadframe, die paddle and die to mold compound  	
Bottom Side view of leadframe and die paddle to molding compound  	

b. Multiplexer, Vendor B

Test	**Pass/Fail**
Initial Electrical Test	Pass
Initial Visual Inspection	Pass
Initial Acoustic Microscopy	There is no pass or fail criteria applied here – this step is to document the initial conditions of the devices.
Top Side view of leadframe, die paddle and die to mold compound  *Bottom Side view of leadframe and die paddle to molding compound* 	
Final External Visual	Pass
Final Electrical Test	Pass
Final Acoustic Microscopy	Fail;
Top Side view of leadframe, die paddle and die to mold compound 	
Bottom Side view of leadframe and die paddle to molding compound 	

c. Op Amp, Vendor C

Test	Pass/Fail
Initial Electrical Test	Pass
Initial Visual Inspection	Pass
Initial Acoustic Microscopy	There is no pass or fail criteria applied here – this step is to document the initial conditions of the devices.

*Top Side view of leadframe, die paddle and die to mold compound**

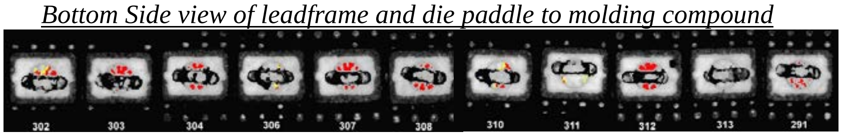
*The yellow and red which outlines the shape of the die, is the die coating material.

Bottom Side view of leadframe and die paddle to molding compound

Test	Pass/Fail
Final External Visual	Pass
Final Electrical Test	Pass
Final Acoustic Microscopy	Pass

Top Side view of leadframe, die paddle and die to mold compound

Bottom Side view of leadframe and die paddle to molding compound

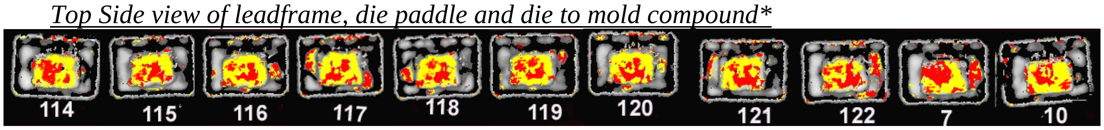


Ovals are artifacts of ID stickers that were left on during analysis

d. Reference, Vendor D

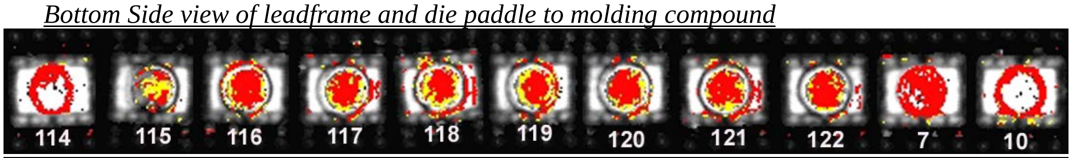
Test	Pass/Fail
Initial Electrical Test	Pass
Initial Visual Inspection	Pass
Initial Acoustic Microscopy	There is no pass or fail criteria applied here – this step is to document the initial conditions of the devices.

*Top Side view of leadframe, die paddle and die to mold compound**



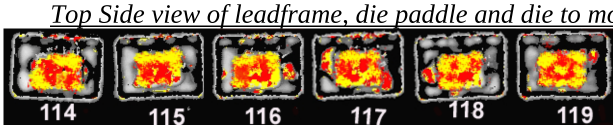
*The yellow and red which outlines the shape of the die, is the die coating material.

Bottom Side view of leadframe and die paddle to molding compound

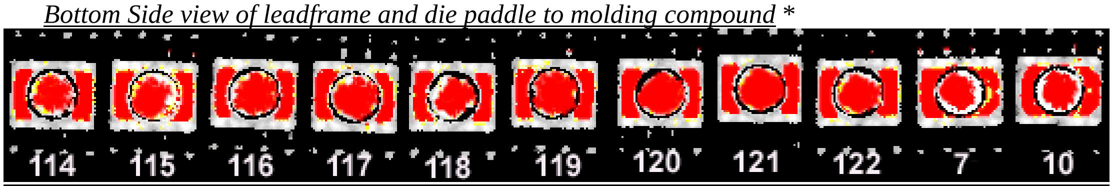


Test	Pass/Fail
Final External Visual	Pass
Final Electrical Test	Pass
Final Acoustic Microscopy	Pass

Top Side view of leadframe, die paddle and die to mold compound

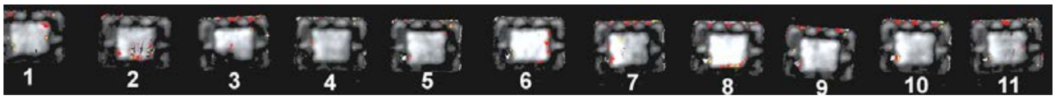
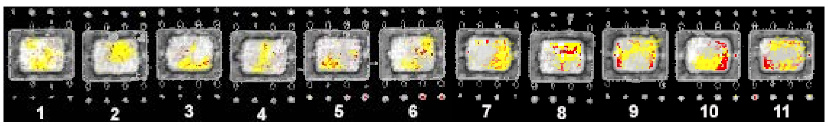
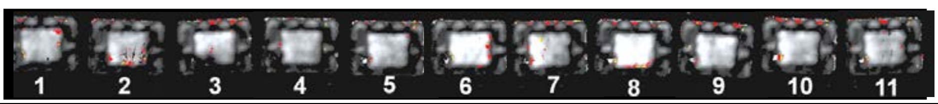
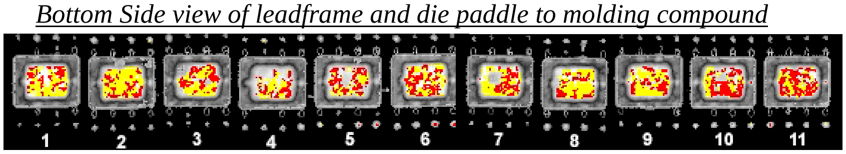


Bottom Side view of leadframe and die paddle to molding compound *



** J-STD-020 states: "If the SMD Packages pass electrical tests and there is delamination on the back side of the die paddle, heat spreader, die back side (lead on chip only) but there is no evidence of cracking, or other delamination, and they still meet specified dimensional criteria, the SMD Packages are considered to pass that level of moisture sensitivity."*

e. Amplifier, Vendor E

Test	**Pass/Fail**
Initial Electrical Test	Pass
Initial Visual Inspection	Pass
Initial Acoustic Microscopy	There is no pass or fail criteria applied here – this step is to document the initial conditions of the devices.
Top Side view of leadframe, die paddle and die to mold compound  *Bottom Side view of leadframe and die paddle to molding compound*  	
Final External Visual	Pass
Final Electrical Test	Pass
Final Acoustic Microscopy	Pass
Top Side view of leadframe, die paddle and die to mold compound  	
Bottom Side view of leadframe and die paddle to molding compound  	

4. Discussion and Conclusions

To summarize, 3 of the 5 device types did not meet the MSL criteria that the vendor stated the parts could survive. All 3 device types failed the criteria of more than a 10% change (from before reflow compared to post reflow) as described in Appendix A. The A/D part manufactured by Vendor A was by far the worse part type as far as the amount of delamination observed. It was beyond the scope of this task to assess whether the package would have passed if they were reclassified to a MSL Class "2" Package.

The main purpose of this evaluation was to take devices from various manufacturers and processes in the as-received (from the manufacturer) condition and expose them to the rated moisture conditions prior to assembly and evaluate how they perform to JEDEC/IPC J-STD-020B. The fact that these devices did not exhibit any electrical failures does not mean that they are reliable parts following the (simulated) board assembly process. The board assembly process can contribute to latent electrical (reliability) failures. The qualification testing portion of the NEPP/NEPAG evaluations will report on reliability of these part types in a separate evaluation.

Regardless of the electrical performance of all of the parts and part types, the fact is that three out of the four MSL level 1 device types failed to meet the CSAM requirements of J-STD-020B. It is probable that the manufacturers were over zealous in the rating of their respective parts. It is the goal of all manufacturers of PEMS to manufacture parts that meet MSL level 1. However, the jeopardy of misrating parts is that delamination of the mold compound from the die/leadframe can occur and set the devices up for latent failures in actual use conditions. The fact that Vendor 3 rated their part type as an MSL Level 3 and that the results showed passing performance is more comforting than over rating the devices and jeopardizing the reliability of the parts in future usage. A level 3 part must be cared for more carefully than a level 1 or 2 device but the end user will know to exercise greater care during the assembly process and still have a reliable product.

5. *Appendix A.*

a. Reflow Conditions:

The conditions from the IPC/JEDEC J-STD-020B Specification state that the solder reflow occur not sooner than 15 minutes and not longer than 4 hours after removal from the temperature/humidity chamber, subject the sample to 3 cycles of the appropriate reflow conditions as defined in Table A-1 and Figure A-2. If the timing between removal from the temperature/humidity chamber and initial reflow cannot be met then the parts must be rebaked and resoaked . The time between reflows shall be 5 minutes minimum and 60 minutes maximum.

Table A-1: Reflow conditions from the IPC/JEDEC J-STD-020B Specification

Profile Feature	Sn-Pb Eutectic Assembly		Pb-Free Assembly	
	Large Body	Small Body	Large Body	Small Body
Average ramp-up rate (T_L to Tp)	3°C/second max.		3°C/second max.	
Preheat – Temperature Min (Ts_{min}) – Temperature Max (Ts_{max}) – Time (min to max) (ts)	100°C 150°C 60-120 seconds		150°C 200°C 60-180 seconds	
Tsmax to T_L – Ramp-up Rate			3°C/second max	
Time maintained above: – Temperature (T_L) – Time (t_L)	183°C 60-150 seconds		217°C 60-150 seconds	
Peak Temperature (Tp)	225 +0/-5°C	240 +0/-5°C	245 +0/-5°C	250 +0/-5°C
Time within 5°C of actual Peak Temperature (tp)	10-30 seconds	10-30 seconds	10-30 seconds	20-40 seconds
Ramp-down Rate	6°C/second max.		6°C/second max.	
Time 25°C to Peak Temperature	6 minutes max.		8 minutes max.	

Note: All temperatures refer to topside of the package, measured on the package body surface.

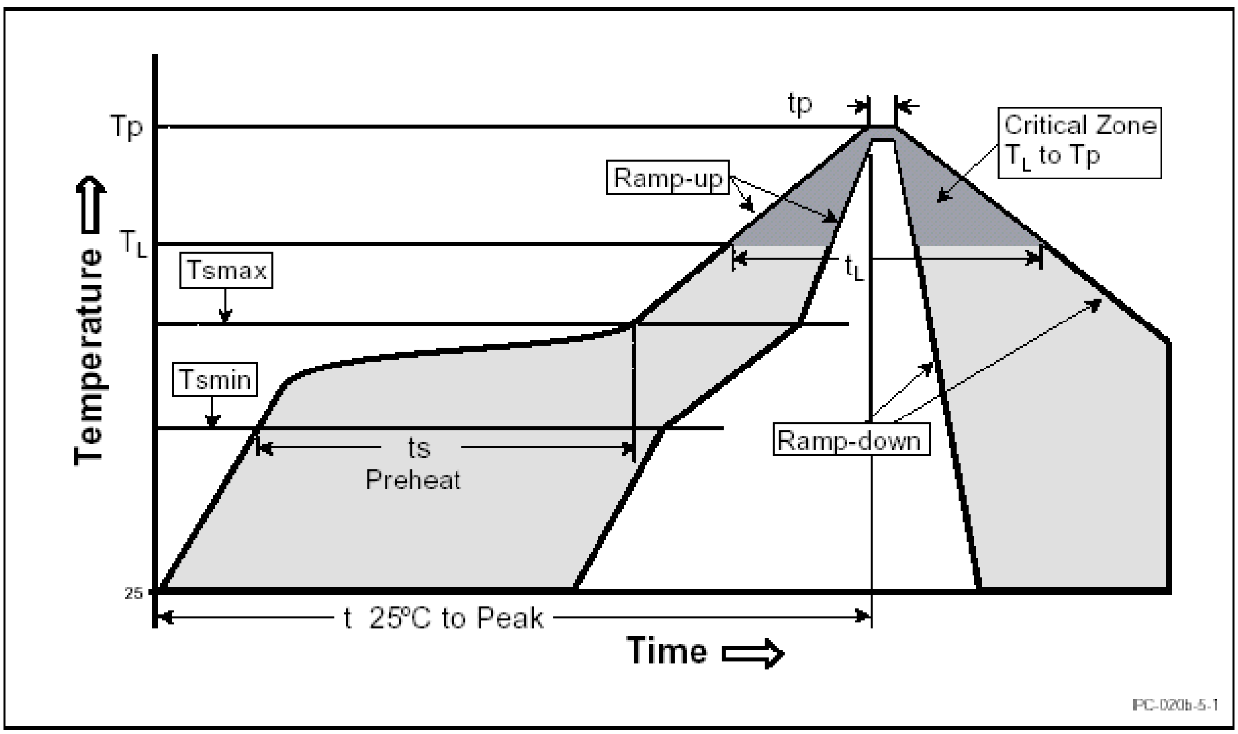


Figure A-2: Graphic representation of the reflow conditions from the IPC/JEDEC J-STD-020B Specification

b. Profiles used in this Evaluation

The convection reflow profiles were performed in a 5 zone Heller (100%) convection (production worthy) furnace. Particular care was exercised for furnace loading and to simulate the conditions used for the evaluation parts. The parts were 'reflowed' on PWB material or pallets and a thermocouple was mounted on top of similar parts to obtain the correct profiles. J-STD-020 specifies that the temperature is to be measured at the top of the parts as the heat contacts the outside surfaces prior to penetrating to the inside of the part.

Representative profiles used in this evaluation are shown below in Figures A-3 and A-4 for the tin-lead and lead-free parts, respectively.

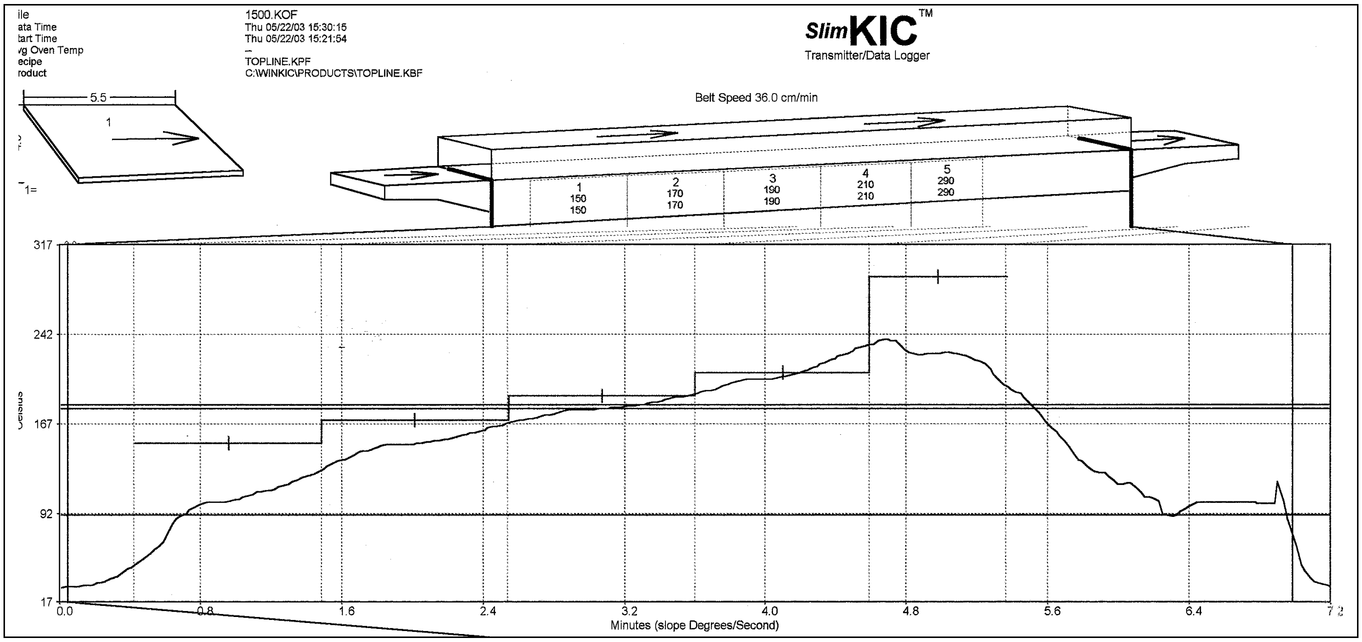


Figure A-3: Furnace profile used for parts with tin-lead lead-finish. The peak top-side component temperature was 238.1 ºC which meets the specification for small bodied components of between 235 ºC and 240 ºC.

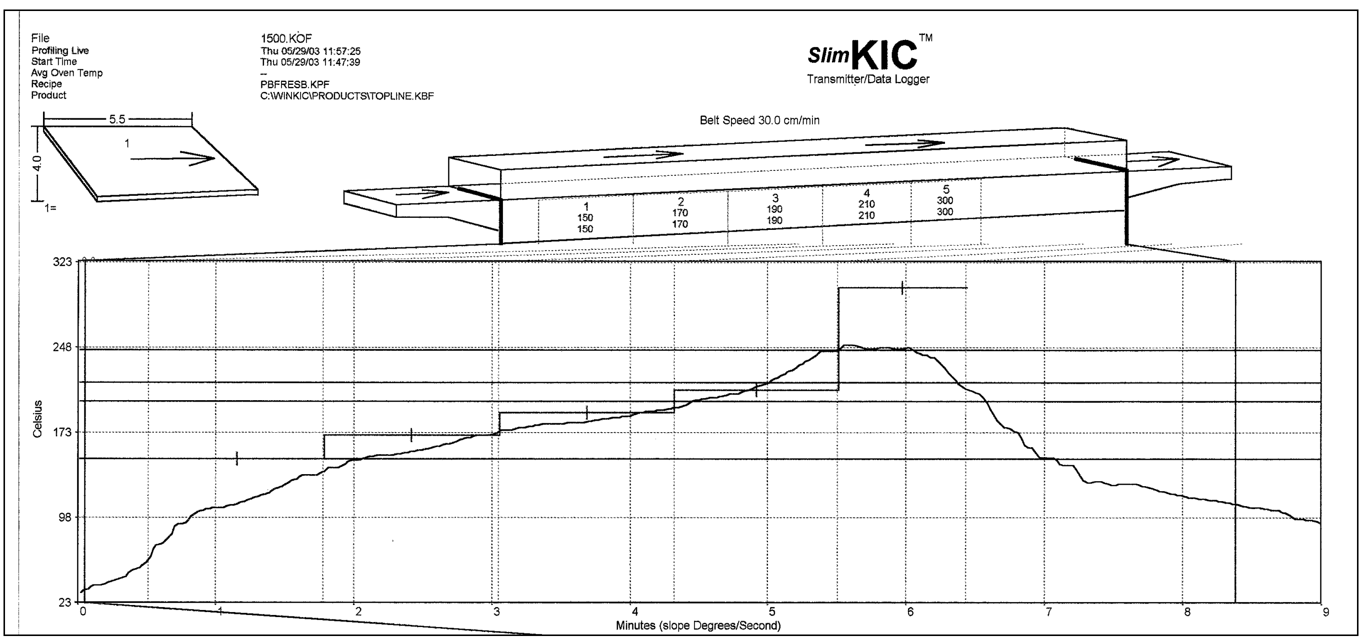


Figure A-4: Furnace profile used for parts with tin-lead lead-finish. The peak top-side component temperature was 248.9 ºC which meets the specification for small bodied components of between 245 ºC and 250 ºC.

c. *Acoustic Microscopy Accept criteria:*

Failure Criteria If one or more devices in the test sample fail, the package shall be considered to have failed the tested level.

A device is considered a failure if it exhibits any of the following:
a. External crack visible using 40X optical microscope.
b. Electrical test failure.
c. Internal crack that intersects a bond wire, ball bond, or wedge bond.
d. Internal crack extending from any lead finger to any other internal feature (lead finger, chip, die attach paddle).
e. Internal crack extending more than two-thirds (2/3) the distance from any internal feature to the outside of the package.
f. Changes in package body flatness caused by warpage, swelling or bulging visible to the naked eye. If parts still meet co-planarity and standoff dimensions they shall be considered passing.

Note 1: If internal cracks are indicated by acoustic microscopy, they must be considered a failure or verified good using polished cross sections through the identified site.
Note 2: For packages known to be sensitive to vertical cracks it is recommended that polished cross sections be used to confirm the nonexistence of near vertical cracks within the mold compound or encapsulant.
Note 3: Failing SMD packages must be evaluated to a higher numeric level of moisture sensitivity using a new set of samples.
Note 4: If the components pass these requirements, and there is no evidence of delamination or cracks observed by acoustic microscopy or other means, the component is considered to pass that level of moisture sensitivity.

Delamination The following delamination changes are measured from pre-moisture soak to post reflow. A delamination change is the change between pre- and post-reflow. The percent (%) delamination change is calculated in relation to the total area being evaluated.

If the SMD Packages pass electrical tests and there is delamination on the back side of the die paddle, heat spreader, die back side (lead on chip only) but there is no evidence of cracking, or other delamination, and they still meet specified dimensional criteria, the SMD Packages are considered to pass that level of moisture sensitivity.

Metal Leadframe Packages:

a. No delamination on the active side of the die.
b. No delamination change >10% on any wire bonding surface of the die paddle (downbond area) or the leadframe of LOC (Lead On Chip) devices.
c. No delamination change >10% along any polymeric film bridging any metallic features that is designed to be isolated (verifiable by through transmission acoustic microscopy).
d. No delamination/cracking change >10% through the die attach region in thermally enhanced packages or devices that require electrical contact to the backside of the die.
e. No surface-breaking feature delaminated over its entire length. A surface-breaking feature includes: lead fingers, tie bars, heat spreader alignment features, heat slugs, etc.