Reliability at Vishay Siliconix

This document provides a general description of Vishay Siliconix's reliability program. The reliability data for specific products is available from the information page associated with each part. The general reliability description provided below and the reliability information provided for each part may be revised without prior notice.

CONTENTS

Introduction to Reliability

DEFINITION OF RELIABILITY

There are many popular notions of what constitutes "reliability," or what characterizes a "reliable product." A suitable definition of reliability must be both precise and capable of expression and measurement in mathematical terms. One widely quoted and accepted definition of reliability is "the probability that an item will perform a required function under stated conditions for a stated period of time."

The "required function" implies standards or definitions of satisfactory performance and acceptable rates of failure. The required function is most often defined and measured by an automatic test procedure. However, the required function may also be determined by the customer's expectations in system use. Discrepancies between the two sometimes result in the identification of new failure modes, leading in turn to the inclusion of appropriate tests in future generations of test programs. Sometimes, especially in complex systems, unsatisfactory performance is not the same as failure.

The "stated conditions" are the total physical environment of the system or device. They include the mechanical, thermal, and electrical conditions of use or storage.

The "stated period of time" is the time during which satisfactory performance is desired. This can be relatively short, as in the case of a missile flight, where the probability that no failure will occur during the flight is a good measure of reliability. Other possibilities are periods of disuse followed by use, or continuous use (such as in maintained systems like telephone switches where there is no well-defined mission time).

Reliability is the probability of survival as a function of time and stress and can be expressed as follows:

$$F(t) + R(t) = 1; \text{ or}$$

$$R(t) = 1 - F(t)$$

where F(t) is a cumulative density function, representing the probability of failure up to time t and R(t) is the reliability function, a complement of F(t), representing the probability of survival at time t.

Note that at time zero, the survival is presumed, hence

$$R(0) = 1$$

while at time infinity, the certainty of failure is also to be expected, hence

$$R(\infty) = 1$$

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$$\frac{dF(t)}{dt} = \lambda$$

From the above, it can be proved that

$$F(t) = 1 - \exp(-\lambda t)$$

and

$$R(t) = \exp(-\lambda t)$$

From these equations, once the failure rate is determined, one can predict the probability of survival at any given time. For example, if the failure rate is 100 FITs (see definition below) the reliability of a component after 100,000 hours of operation can be calculated as

$$R(100,000 \text{ hrs}) = 0.99$$

meaning that there is a 99 % probability of survival up to 100,000 hours of use.

"Bathtub" Failure Rate Curve

A constant failure rate assumed in the above example is obviously an oversimplification of the reliability picture. A typical failure (or "hazard") rate curve is shown in Figure 1. This curve depicts the general trend of failure (hazard) rate, X(t), for electronic components along the time of use.
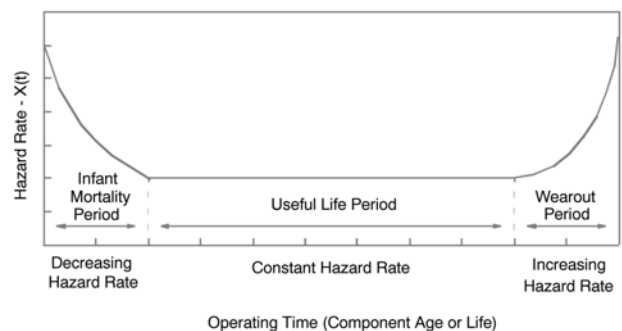
Figure 1. Typical Hazard Rate Curve

The decreasing portion of the curve represents the early failures and is sometimes called the infant mortality period. Occurrence of failures during this period is normally attributed to manufacturing defects. Failures in this period can be screened effectively if the failure mechanisms are well understood. The screening can be done during manufacturing or production testing, or by using a short accelerated reliability stress test.

The constant part of the bathtub failure rate curve, called the "useful life period," lies in between the infant mortality period and the wear-out period. Typically, the failure rate during this period is relatively stable and much lower than that of the other periods. Failures during the useful life period are generally called "random failures" because they appear to occur unpredictably. Good process control can reduce the probability of random failures.

It should be noted that the FIT rate provided for each Vishay Siliconix product is meant for this period. The FIT rate is calculated from high-temperature operating life test data.

The wear-out period begins when an electronic component has aged, degraded, or outlived its useful operating life. The materials used to construct the electronic component start to undergo a fundamental breakdown process and deteriorate rapidly in this period. Consequently, the number of failures during this period increases with time. Electromigration, hot-carrier induced device degradation, and time-dependent dielectric breakdown are some wear-out mechanisms frequently discussed in the reliability literature.

A good reliability program should aim to

- eliminate, or at least minimize, early failures in the infant mortality period by robust product and process design or an effective screening methodology

- minimize random failures by good process control, and

- push out the onset of all wear-out mechanisms beyond the expected lifetime of the components by building-in sufficient margins in both the design and manufacturing of the electronic component.

For example, Vishay Siliconix's Product Reliability Programs are designed to ensure that early and random failures are minimized at time of release (qualification) and continue to decrease as the product matures through a continuous improvement program. In addition, Vishay Siliconix's Process Reliability Test Program is designed to ensure that wear-out mechanisms are pushed well beyond the expected lifetime of the customer's system.

Calculation of Failure Rate at Test Temperature

As stated earlier, the failure rate during the useful life period is constant. Testing components operating in this period allows one to determine the product-specific failure rate. Data from a component sample is obtained using an accelerated life test, and the observed failure rate (FR) is expressed as

$$FR = \frac{F}{SS \times t}$$

where F is the number of failures observed, SS is sample size, and t is time duration of the test in hours

Note that the observed FR is given in the unit of "failures per one component-hour." Because this is normally a very small number, FR is usually expressed in "% per 1000 component-hours," in "ppm" (parts per million component-hours), or in "FITs" ("failure in time" or failures per billion component-hours). Failure rates can be expressed in these units by multiplying the right-hand side of the above equation by 100,000, 1,000,000, or 1,000,000,000, respectively. Hence,

$$FIT = \frac{10^9 \times F}{SS \times t}$$

Because of its widespread use in the reliability community, we will use FIT to denote failure rate in the subsequent discussion.

Observed and Predicted FIT Rates

The observed FIT is obtained from observation of failures in a specific lot sample tested for a given time. Such a FIT is valid only for the sample that was tested. To obtain a FIT that is applicable to an entire component population, statistical confidence factors should be included, and the FIT becomes

$$FIT = \frac{\chi^2}{2} \times \frac{10^9}{SS \times t}$$

where $\chi^2/2$ is the statistical confidence factor and is a function of F and confidence level based on a chi-square distribution.

TABLE 1. Values of $\chi^2/2$ Different Numbers of Failures (F) and Confidence Levels (CL)					
F	CL = 60 %	CL = 80 %	CL = 90 %	CL = 95 %	CL = 99 %
0	0.91	1.6	2.3	3.0	4.6
1	2.0	3.0	3.9	4.8	6.6
2	3.1	4.1	5.3	6.3	8.5
3	4.2	5.5	6.7	7.8	10.0
4	5.2	6.7	8.0	9.2	11.7
5	6.3	7.9	9.3	10.5	13.2
6	7.4	9.1	10.5	11.8	14.5
7	8.4	10.25	11.8	13.2	16.0
8	9.4	11.4	13.0	14.4	17.5
9	10.5	12.5	14.2	15.7	18.8
10	11.5	13.7	15.4	17.0	20.2

The significance of the statistical confidence factor is that it allows prediction of results with a given level of "confidence" from future sample tests. For example, if the FIT (say, 1, meaning one failure per 10^9 component-hours) with a specified CL (say, 60 %) is calculated from the data obtained during accelerated tests for a given component population, then 60 % (CL) of all tested lots from the same component population in the future will have lower FITs.

FIT at Operating Temperature

Since many reliability aging processes are thermally activated, testing at high temperatures can help "accelerate" the aging of components such that sufficient data can be gathered in a relatively short time as compared to their expected lifetimes. The thermally activated process can be described by

$$FIT \propto \exp\left(-\frac{Ea}{kT}\right)$$

Statistical confidence factors can be found in "Chi square" charts or from "Poisson charts" given in statistics textbooks. Table 1 shows values of ($\chi^2/2$) for different numbers of failures (F) and for different confidence levels (CL).

The FIT at a certain junction temperature may be calculated from the FIT calculated at test temperatures using the Arrhenius equation:

$$\frac{FIT_{T_1}}{FIT_{T_2}} = \exp\left[-\frac{Ea}{K}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

where k is Boltzman constant = 8.63 x 10^{-5} (eV/$^\circ$K), T_1 and T_2 are junction temperatures ($^\circ$K), and Ea is the activation energy.

The Arrhenius equation for different activation energies is presented as a graph in Figure 2. With the FIT known for a specific junction temperature, one can use the Arrhenius plot to determine the FIT for another junction temperature.

At Vishay Siliconix, accelerated tests are typically carried out at 125 $^\circ$C to 175 $^\circ$C. Lifetime is then extrapolated to a 55 $^\circ$C junction temperature. An "apparent" activation energy of 0.7 eV is used based on historical data combining all failure mechanisms. For the upper confidence level (CL), 60 % is used.
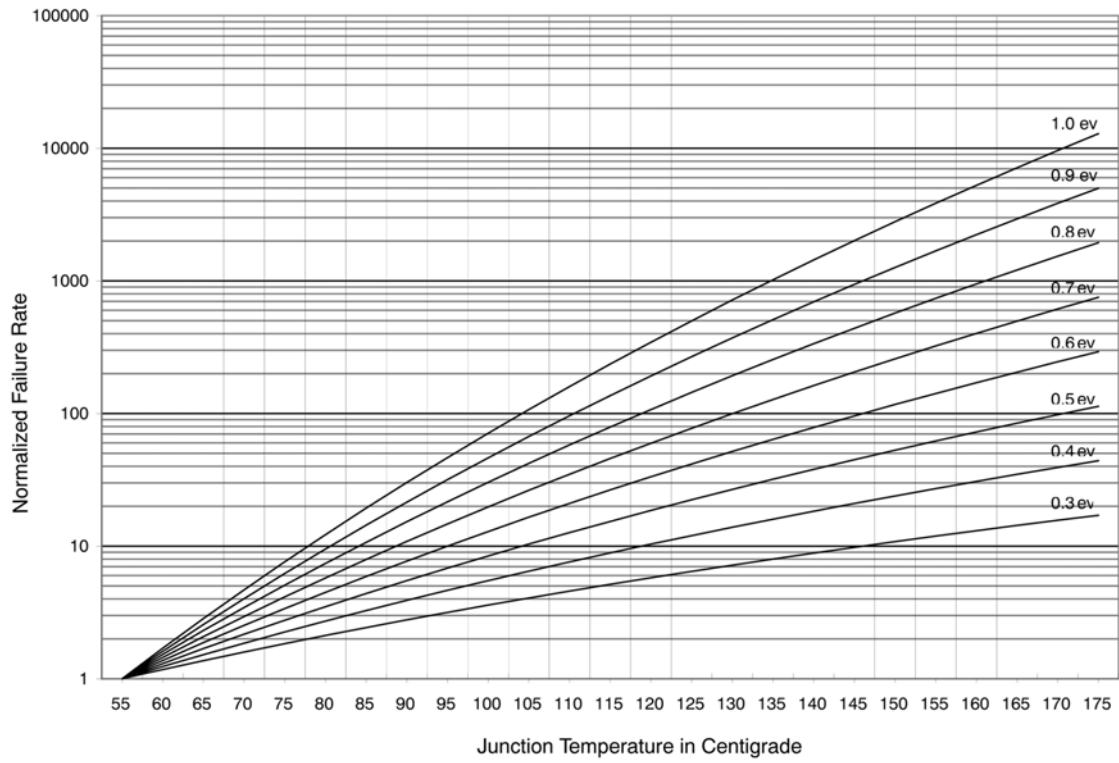
Figure 2. The Arrhenius Plot for Different Activation Energies

Product Reliability Programs

Product reliability at Vishay Siliconix is assured by two primary reliability programs: the Qualification Program and the Reliability Monitor Program. Like most other U.S. semiconductor manufacturers, assembly, test, and reliability stress testing are done overseas on many products at Vishay Siliconix. Results from the qualification and reliability monitor programs are entered via a worldwide computer network into the reliability database that is located at the company's Santa Clara facility.

QUALIFICATION PROGRAM

Purpose

Qualification is a means for verifying newly introduced and modified circuit designs, fabrication processes, package materials and types, and assembly methods and locations, result in products meeting specified reliability requirements. In addition, the qualification process is a source of much information on the major characteristics of a new product or process technology.

Qualification Categories

All significant changes require qualification, but the degree of qualification depends on the nature of the changes. Vishay Siliconix has grouped these changes into three categories, with Category A events requiring the largest sample sizes and longest stress periods of life tests, and Category C events requiring the smallest sample sizes and shorter life test periods. Table 2 illustrates the kind of changes that constitute each qualification category.

Qualification Test Plan (QTP)

Vishay Siliconix has adopted the Stress-Test-Driven Qualification methodology described in JEDEC Standard JESD47. Guidelines for items undergoing stress tests and evaluations and their corresponding sample sizes required for each change are provided in a controlled qualification specification, 1910: Reliability Test Program. The stress tests and evaluations employed in a specific qualification are selected from the following list based on the nature of the change and the device and package type to be qualified.

- High-Temperature Operating Life (HTOL)
- High-Temperature Reverse Bias (HTRB)
- High-Temperature Gate Bias (HTGB)
- HAST (Highly Accelerated Stress Test)
- Pressure Pot (Autoclave)

- Temperature Cycling
- Power Cycling
- High-Temperature Storage
- Resistance fo Solder Heat
- Preconditioning
- Moisture Sensitivity Level (MSL) Classification
- Gate Oxide Integrity
- Metal Electromigration
- Hot Electron Effects Immunity
- Metal Step Coverage
- Passivation Integrity
- Latch-Up Characterization
- ESD Characterization
- DPA (Destructive Physical Analysis)
- Die Shear
- Bond Integrity
- Lead Fatigue
- Solderability
- Solder Dunk
- Bond Strength
- C-SAM
- X-Ray
- SIMS
- Mark Permanency
- Salt Atmosphere
- Mechanical Shock
- Whisker Check (for pure tin plated parts)

TABLE 2. Qualification Categories	
Category A	New Process
	New Fab Facility
	New Design on New Process
Category B	New Product on Qualified Process
	Redesign on Qualified Process/Design Rules
	New Package/Assembly Location/Piece Parts
Category C	Minor Design Revision
	Minor Package/Assembly Change
	Minor Process/Fab Equipment Change

Qualification and Release Process

A typical qualification starts with the review of changes involved, from which a qualification test plan (QTP) is generated. The QTP is then submitted for Engineering Change Notice (ECN) approval. Once the QTP is approved, samples are built and stress tests and evaluations are performed accordingly. When the stress tests and evaluations are completed and the results are satisfactory, then a release document is written and submitted for ECN approval.

If any failure is encountered in any of the specified stress tests and evaluations, then an engineering investigation, including failure analysis (FA) to determine failure modes, is conducted. When corrective actions are completed, the qualification can restart. This process reiterates until all stress tests and evaluations pass with satisfactory results.

RELIABILITY MONITOR PROGRAM

Purpose/Description

The Reliability Monitor Program, which includes accelerated life, environmental, and packaging related tests, provides a continuous monitor of product reliability performance. The program furnishes up-to-date information about the failure rate and failure mechanisms of a given technology family or package type that can be used to predict and improve long-term reliability. The monitor program alerts management to changes in reliability performance and activates engineering intervention when required.

The monitor program covers the entire range of technologies and product lines manufactured by Vishay Siliconix. To accomplish this, a generic approach is used. Components built in the same wafer fab, using the same manufacturing process, and having similar complexity and functionality, are grouped into a "technology family." One or more components, on a rotational basis, and representing each technology family, are monitored according to a monthly (short-term) or quarterly (long-term) schedule.

The monitoring program also includes different package types in order to monitor the broad range of packages offered by Vishay Siliconix. Devices in surface-mount packages are subjected to pre-conditioning, simulating the stress of board mounting, according to the moisture sensitivity level (MSL) for which they are qualified, before beginning the monitoring flow. Monitoring is performed from the customer's point of view: customer-ready parts are used and are electrically tested to data sheet standards before and after each specified test point.

Vishay Siliconix has two basic reliability monitor flows, each designed for a specific purpose. These are the Short-term and Long-term monitors.

Short-Term Monitor

The short-term monitor runs on a monthly basis, and each test is typically completed within one week after preconditioning. It is intended to provide a fast alert in case of changes in reliability performance.

The short-term monitor consists of life tests at high temperature (HTOL, or HTRB and HTGB, depending on the device type), pressure pot, temperature cycling, and certain package tests (see Table 3). Some of the life tests may be extended to provide data for the long-term monitors.

TABLE 3. Short-Term Reliability Monitor		
Test	**Condition**	**Test Point(s)**
High Temperature Operating Life	125 °C or 150 °C	0, 168 Hours
High Temperature Reverse Bias	150 °C or 175 °C	0, 168 Hours
High Temperature Gate Bias	150 °C or 175 °C	0, 168 Hours
Pressure Pot (Plastic Only)	121 °C, 15 PSIG	0, 96 Hours
Temperature Cycling	Air-to-Air –65 °C to 150 °C	0, 100 Cycles
Solderability	Mil-Std-883D, M2003	
Lead Fatigue (Through-Hole Only)	Mil-Std-883D, M2004	0 Hour
Solder Dunk (SMDs Only)	260 °C, 10 sec.	3 Cycles
C-SAM (SMDs Only)	(Follow Industry Standard)	0 Hour

TABLE 4. Long-Term Reliability Monitor		
Test	**Condition**	**Test Point(s)**
High Temperature Operating Life	125 °C or 150 °C	0, 168, 1000 Hours
High Temperature Reverse Bias	150 °C or 175 °C	0, 168, 1000 Hours
High Temperature Gate Bias	150 °C or 175 °C	0, 168, 1000 Hours
Biased Temperature/Humidity (Plastic Only)	85 °C, 85 % RH; or	0, 500, 1000 Hours
	130 °C, 85 % RH (HAST)	0, 100 Hours
Temperature Cycling	Air-to-Air –65 °C to 150 °C	0, 100, 500 Cycles
Power Cycling (High Power Automotive Products Only)	ΔT_J = 100 °C	0, 2000, 4000, 8752 Cycles (for TO-220, TO-263, and TO-263T) 0, 4000, 8000, 15000 Cycles (for TO-251 and TO-252)

Long-Term Monitor

The long-term monitor provides life stresses for periods long enough to provide the data necessary to calculate steady-state failure rates (FITs). It also includes stresses such as biased temperature/humidity (HAST) and temperature cycling (see Table 4).

Alert Levels

As part of its Reliability Monitoring Program, Vishay Siliconix has established an internal standard for the failure rate of monitored lots which, when exceeded, requires written cautions or alerts to management. An alert may be removed only after corrective action has been executed and verified. Even if observed failure rates do not exceed alert levels, reliability managers of a monitoring plant site are required to report any unusual performance and must initiate appropriate corrective action.

The Product Reliability Monitor program is summarized in a general outline form as a flow chart in Figure 3.
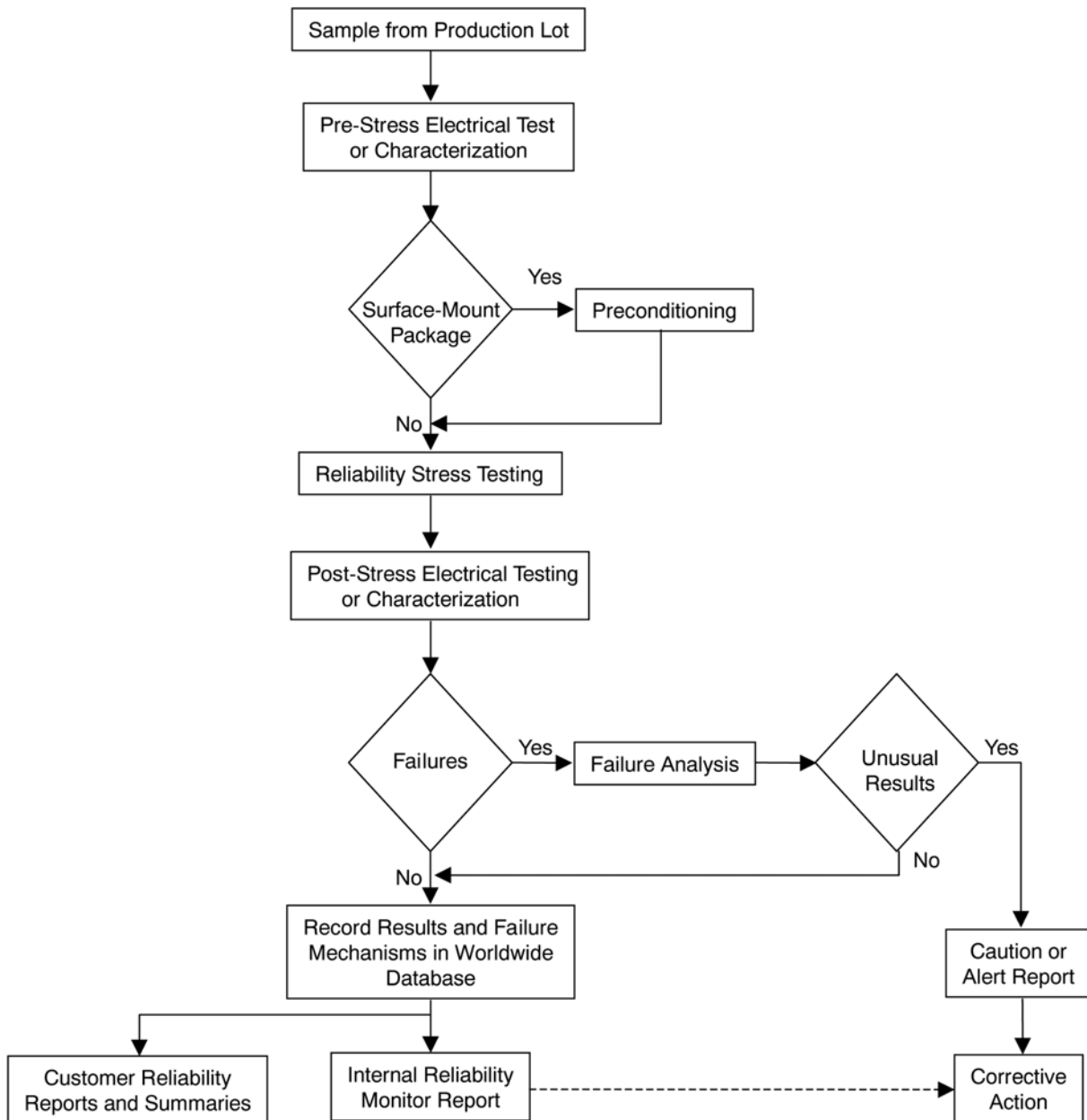
Figure 3. Reliability Monitor Flow (Short- and Long-Term Monitors)

Moisture Sensitivity Level (MSL)
For Plastic Surface Mount Devices

**Test Method: IPC/JEDEC J-STD-020C
(for reference)**

The purpose of the MSL testing is to identify the classification level of nonhermetic solid state surface-mount devices (SMDs) that are sensitive to moisture-induced stress. This allows them to be properly packaged, stored, and handled to avoid damage during assembly solder reflow attachment and/or repair operations.

Vishay Siliconix plastic surface-mount devices (SMDs) pass MSL Level 1 for the Sn-Pb eutectic assembly process. They are classified as non-moisture sensitive and do not require dry pack. The floor lifetime is unlimited under conditions of 85 % maximum relative humidity at temperatures not higher than 30 °C.

Vishay Siliconix products are available with lead (Pb)-free exterior plating. The lead-free parts tested thus far pass MSL 1 for the lead-free assembly process. Updated availability and schedule information is provided on the Vishay web site. For additional information see *How to Get Lead-Free Status* (*http://www.vishay.com/how/leadfree*). For Vishay Siliconix active lead-free products see the *Vishay Lead (Pb)-Free Family Summary Sheet—Active Components (http://www.vishay.com/doc?49321).*

Surface Mount Solder Reflow Preconditioning

Vishay Siliconix performs solder reflow preconditioning on SMDs prior to environmental testing. The purpose of the preconditioning prior to reliability testing is to simulate the assembly solder reflow attachment process prior to the operation of the device. All Vishay Siliconix manufacturing facilities have convection solder reflow equipment capable of reproducing the reflow profile (see Appendix A).

For Vishay Siliconix SMDs, the solder reflow profile outlined in IPC/JEDEC J-STD-020C is recommended (see Appendix A) unless otherwise noted in the document, *Vishay Lead (Pb)-Free Family Summary Sheet—Active Components (http://www.vishay.com/doc?49321).*

The preconditioning procedures are outlined as follows:

1. Perform a room temperature electrical dc and functional test to verify that the devices meet the room temperature data sheet specification.

2. Store the devices in a temperature/humidity chamber for moisture absorption under conditions of 85 % R.H. at 85 °C for 168 hours.

3. Remove the devices from the temperature/humidity chamber and allow them to dry in the air for a minimum of fifteen (15) minutes.

4. No sooner than fifteen (15) minutes and for no longer than four (4) hours after removal from the temperature/humidity chamber, submit the devices to three (3) cycles of convection solder reflow as defined in Appendix A. The devices shall be allowed to cool down for five (5) minutes minimum and 60 minutes maximum between convection cycles.

5. Perform electrical room temperature dc and functional tests on all devices.

Submit preconditioned devices to reliability testing such as Temperature Cycle, HAST (130 °C/85 % R.H.), and Pressure Pot (Autoclave).

Molding Compound Flammability and Environmental

Vishay Siliconix molding compounds are carefully selected to ensure that they meet the customer's requirements. The epoxy molding compounds are not formulated with Polybrominated Biphenyls (PBBs) and Polybrominated Diphentl Ethers (PBDEs) as a fire retardant agent. Flammability meets the following standards:

FLAMMABILITY STANDARDS	
Flammability:	UL-94 (V-O)
Oxygen Index:	ASTM D2863 OI28 minimum

APPENDIX A

CLASSIFICATION REFLOW PROFILES (IPC/JEDEC J-STD-020C)			
	Sn-Pb Eutectic Assembly		Pb-Free Assembly
Profile Feature	**Large Body**	**Small Body**	**All Packages** See *Vishay Lead (Pb)-Free Family Summary Sheet—Active Components* (*http://www.vishay.com/doc?49321*) for exceptions.
Reflow Conditions	Pkg. Thickness ≥ 2.5 mm or Pkg. Volume ≥ 350 mm^3	Pkg. Thickness < 2.5 mm and Pkg. Volume < 350 mm^3	
Average ramp-up rate (T_L to T_P)	3 °C/second max.		3 °C/second max.
Preheat • Temperature Min. (T_{Smin}) • Temperature Max. (T_{Smax}) • Time (min to max) (t_S)	100 °C 150 °C 60-120 seconds		150 °C 200 °C 60-180 seconds
Time maintained above: • Temperature (T_L) • Time (t_L)	183 °C 60-150 seconds		217 °C 60-150 seconds
Peak Temperature (T_P)	225 +0/ -5 °C	240 +0/ -5 °C	260 +0/ -5 °C
Time within 5 °C of actual Peak Temperature (t_P)	10-30 seconds		20-40 seconds
Ramp-down Rate	6 °C/second max.		6 °C/second max.
Time 25 °C to Peak Temperature (t $_{25 \ °C \ to \ Peak}$)	6 minutes max.		8 minutes max.

NOTE: All temperatures refer to topside of the package, measured on the package body surface.
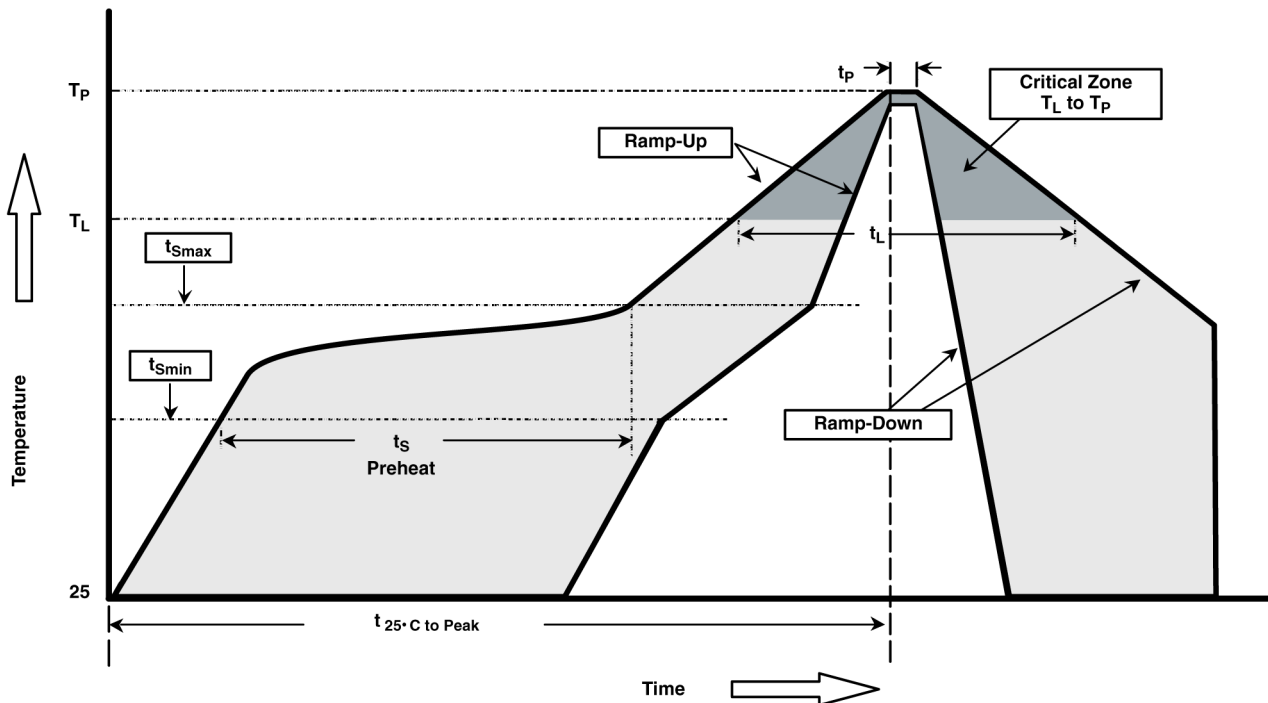
Definitions of Classification Reflow Profiles as Given in the above Table