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METHODS FOR CALCULATING FAILURE RATES IN UNITS OF FITS

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Introduction

The calculation of failure rates is an important metric in assessing the reliability performance of a product or process. This data can be used as a benchmark for future performance or an assessment of past performance, which might signal a need for product or process improvement. Reliability data are expressed in numerous units of measurement. This document uses the units of FITs (Failures-In-Time), where one FIT is equal to one failure occurring in 10^9 device-hours. These methods are assembled here to provide a reference to the way failure rates are calculated in FITs.

Most of these methods only apply to constant failure rates. They assume that a χ^2 distribution is a reasonable approximation of the failure distribution over time. The examples given use failures that exhibit an Arrhenius behavior. Other failure models can also be applied to these methods, but care must be used for those models that do not simulate a constant failure rate.

Please note that the methods described in this document represent simplified ways of calculating failure rates using various forms of data. More detailed methods exist in other publications, such as EIA/JESD63 Standard Method for Calculating the Electromigration Model Parameters for Current Density and Temperature and JESD37 Standard for Lognormal Analysis of Uncensored Data and of Singly Right-Censored Data Using the Persson and Rootzen Method.

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METHODS FOR CALCULATING FAILURE RATES IN UNITS OF FITs

(From JEDEC Board Ballot JCB-20-35, formulated under the cognizance of the JC-14.3 Subcommittee on Silicon Devices Reliability Qualification and Monitoring.)

1 Scope

The methods described in this document apply to failure modes and mechanisms whose failures exhibit a constant failure rate, e.g., an Arrhenius behavior characterized by an activation energy for failure. If data on the distributions of failure with time exist, these activation energies can be assumed from prior knowledge or failure analysis signatures. If the default activation energies are not known or can't be determined, an activation energy can be used as a default. Refer to JEP122 Activation Energies for Failure Mechanisms to obtain initial estimates.

The purpose of this method is to provide a reference to the way failure rates are calculated in FITs.

2 Terms and definitions

probability density function of the time-to-failure; mortality function $[f(t)]$: The probability of failure at a given instant of time t . $F(t)dt$ is the probability of failure in the interval t to $t + dt$.

cumulative distribution function of the time-to-failure; cumulative mortality function $[F(t)]$: The probability that a device will have failed by time t or the fraction of units that have failed by time t . It is the integral of $f(t)$.

cumulative reliability function $[R(t)]$: The probability that a device will function at time t or the fraction of units surviving to time t . $R(t) = 1 - F(t)$

instantaneous (or hazard) failure rate $[h(t)]$: The rate at which devices are failing referenced to the survivors. $h(t) = f(t) / R(t)$

cumulative hazard function $[H(t)]$: The integral of $h(t)$.

FIT (failure in time): The number of failures per 10^9 device-hours. Typically used to express the failure rate. Similarly, it can be defined as 1 PPM per 1000 hours of operation or one failure per 1000 devices run for one million hours of operation.

population failure distributions: The frequency of occurrence of failures over segments of time. Typically seen failure distributions are Normal, Lognormal (wearout), Weibull and Exponential.

2 Terms and definitions (cont'd)

bathtub curve: A plot of hazard rate versus time that exhibits three phases of life: infant mortality (initially decreasing failure rate with time), intrinsic or useful life (relatively constant failure rate) and wearout (increasing failure rate with time).

acceleration factor (AF): A multiplier relating failure times during an accelerated life test versus those during useful life application conditions, assuming the same cumulative percent failures and sigma for the two different stress conditions.

activation energy (EA): The excess free energy over the ground state that must be acquired by an atomic or molecular system in order that a particular process can occur. Examples are the energy needed by the molecule to take part in a chemical reaction, by an electron to reach the conduction band in a semiconductor, or by a lattice defect to move to a neighboring site.

apparent activation energy (EA'): Activation energy that is calculated using the principles of the physical relationship between stress and failure rate but is not directly related to a basic change in physical processes. It may be based on too many possible physical "effects" that, when stressed as a unit, produce a cumulative effect. It is similar to the concept of activation energy but measures the probability of not exceeding some measurable attribute. A plot of the reciprocal or absolute temperature ($1/T(K)$) versus the log of percent failed is linear.

3 Methods for calculating failure rates

The methods detailed below are arranged in an order such that an increasing amount of detail regarding the failure data is available for each successive model

3.1 Case I: Single activation energy procedure for constant failure rate distributions

Assumptions:

- NO TEST INTERVALS (single read point of 2000 hours)
- UNKNOWN FAILURE MECHANISMS
- NOMINAL VOLTAGES DURING STRESS TEST

This method assumes knowledge of the number of failures in a known sample size from a life test with a single stress temperature and single end point test. The failures have not been segregated or analyzed to determine the applicable failure mechanism, so an apparent activation energy is assumed for all failures.

3.1 Case I: Single activation energy procedure for constant failure rate distributions (cont'd)

3.1.1 Summarize the data

- $f = \# \text{ of failures} = 15$
- $ss = \text{sample size} = 500$
- $T_{\text{STRESS}} = \text{stress temperature} = 125\text{ }^{\circ}\text{C}$
- $T_{\text{USE}} = \text{use temperature} = 55\text{ }^{\circ}\text{C}$
- $E_A(\text{avg}) = \text{apparent activation energy} = 0.7\text{ eV}$
- Very low power consumption during life test (negligible self heating)
- Apparent activation energy may or may not be an average.

3.1.2 Calculate the acceleration factor

Using the Arrhenius equation (1), calculate the acceleration factor for the failures at the given stress and use temperatures.

$$\begin{aligned}
 AF &= \exp \left[\left(\frac{E_A}{k} \right) \cdot \left(\left(\frac{1}{T_{\text{USE}}} \right) - \left(\frac{1}{T_{\text{STRESS}}} \right) \right) \right] \\
 &= \exp \left[(8.6 \cdot 10^{-5} \text{ eV/K}) \cdot \left(\left(\frac{1}{(55+273)^{\circ}\text{K}} \right) - \left(\frac{1}{(125+273)^{\circ}\text{K}} \right) \right) \right] \quad (1) \\
 &= 78.6
 \end{aligned}$$

Usually devices draw power during life test. Junction temperature can be derived from the ambient temperature, power dissipation and the thermal impedance, and should be used for accurate estimation of the acceleration factor. The self-heating in a device is package-dependent. The thermal dissipation property of a package (θ_{ja}) determines the amount of self-heating for the package. θ_{ja} is a function of the air velocity around the package body. A good rule of thumb is that θ_{ja} is reduced by as much as 30% for moving air compared to still air. As an example, if we were to assume that θ_{ja} were $60\text{ }^{\circ}\text{C/W}$, the power dissipation were 0.1 watt at $125\text{ }^{\circ}\text{C}$, and 0.12W at $55\text{ }^{\circ}\text{C}$, then there would be $7.2\text{ }^{\circ}\text{C}$ ($60 \cdot 0.12$) difference between junction temperature and ambient at $55\text{ }^{\circ}\text{C}$ and $6\text{ }^{\circ}\text{C}$ ($60 \cdot 0.1$) difference at $125\text{ }^{\circ}\text{C}$. Thus, the acceleration factor would be calculated based on $131\text{ }^{\circ}\text{C}$ as stress temperature vs. $62.2\text{ }^{\circ}\text{C}$ as the actual use temperature. The net effect of the self-heating would reduce acceleration factor to 62.5 , compared to 78.6 calculated earlier without a self-heating consideration.

Some mechanisms such as oxide and inter-layer dielectrics may also be accelerated due to the applied electric fields. Appropriate models may be used to calculate acceleration due to voltage applied. Refer to JEP122 for the most commonly used models.