



AEROSPACE RECOMMENDED PRACTICE

ARP6338™**REV. A**Issued 2015-12
Revised 2019-02

Superseding ARP6338

(R) Process for Assessment and Mitigation of Early Wearout of Life-Limited Microcircuits

RATIONALE

As microcircuit technology progresses, the risk of early wearout increases for users in the aerospace, automotive, defense, and other high performance (AADHP) industries. There is a need for these industries to have a standardized approach to analysis and testing for wearout, to ensure reliability and durability of future products, and to assess likelihood of early wearout in safety and certification analyses. The standardized approach also is intended to avoid introducing competitive disadvantages to those who address the issue pro-actively and effectively.

This revision is being made to (1) revise, correct, and update the wearout acceleration models in Appendix D, (2) remove references to specific wearout analysis software tools in Appendix F (rev original), and revise Appendix F (rev original) to list essential attributes of such tools (and to rename it Appendix E in rev A), (3) to rename Appendix E, mitigation methods in rev original, to Appendix F, mitigation methods, in rev A, and (4) revise and update the language in other clauses to be consistent with subsequent SAE standards work, e.g., ARP6379 and SAE J3168.

FOREWORD

This document describes processes to assess and mitigate the effects of early wearout in life-limited microcircuits (LLM) used in aerospace, automotive, defense, and high-performance (AADHP) applications. As microcircuit technology progresses to smaller and smaller feature sizes, early wearout in AADHP applications becomes an issue for AADHP design, part selection, and reliability assessment.

Wearout failures are defined in this document as intrinsic failures resulting from material degradation in the active regions, dielectrics, and conductors of silicon devices. Typically, such failures occur according to non-random, or non-constant, failure rate distributions, and are thus expressed in terms of "time-to-failure," or "failure fraction." Early wearout occurs when the microcircuit lifetime is shorter than the time it is required to operate in the AADHP equipment.

This document does not address package failures. Neither does it address extrinsic random failures that occur according to constant or decreasing failure rate distributions, which are usually expressed in terms of "mean time between failures."

This document considers the following failure mechanisms: electromigration (EM), time-dependent dielectric breakdown (TDDB), hot carrier injection (HCI), and bias temperature instability (BTI)¹. Depending on the device design, materials, and fabrication technology, one of these mechanisms is likely to dominate in any given AADHP application.

¹ Other life-limiting failure mechanisms also may occur in any given AADHP application, and their effects should be considered where appropriate.

SAE Technical Standards Board Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2019 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER:
Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
http://www.sae.org

SAE WEB ADDRESS:

Full document details: SAE ARP6338A

SAE values your input. To provide feedback on this Technical Report, please visit <http://standards.sae.org/ARP6338A>

Documents
Document Sharing Hub

Many of the microcircuits used in AADHP applications today are commercial-off-the-shelf (COTS) components targeted for markets other than AADHP; and the required lifetimes in the target markets typically are significantly shorter than those of AADHP applications. COTS component manufacturers evaluate their components' expected lifetimes in the target applications, but provide little or no information for AADHP applications. Thus it is the responsibility of the AADHP user to conduct the appropriate analyses and, where necessary, provide mitigations for shorter-than-required lifetimes.

1. SCOPE

This document is intended for use by designers, reliability engineers, and others associated with the design, production, and support of electronic sub-assemblies, assemblies, and equipment used in AADHP applications to conduct lifetime assessments of microcircuits with the potential for early wearout; and to implement mitigations when required; and by the users of the AADHP equipment to assess those designs and mitigations.

This document focuses on the LLM wearout assessment process. It acknowledges that the AADHP system design process also includes related risk mitigation and management; however, this document includes only high-level reference and discussion of those topics, in order to show their relationship to the LLM assessment process.

2. REFERENCES

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

Failure Mechanisms and Models for Semiconductor Devices, JEP122, JEDEC®.

Early Life Failure Rate Calculation Procedure for Electronic Components, JESD74, JEDEC®.

Physics of Failure Reliability Predictions, ANSI/VITA 51.2-2011, VITA.

Customer Notification of Product/Process Changes by Solid-State Suppliers, JESD46, JEDEC®.

Information Requirements for the Qualification of Silicon Devices, JESD69, JEDEC®.

Method for Developing Acceleration Models for Electronic Component Failure Mechanisms, JESD91, JEDEC®.

Solid-State Reliability Assessment and Qualification Methodologies, JEP143, JEDEC®.

3. TERMS, DEFINITIONS, ABBREVIATIONS, AND ACRONYMS

3.1 AADHP

Aerospace, automotive, defense, and high performance; used to define a class of electronic equipment characterized by long service lifetime, rugged operating conditions, and high consequences of failure.

3.2 BIAS TEMPERATURE INSTABILITY (BTI)

A semiconductor device failure mechanism in which interface traps and electrical charges are generated in CMOS devices. Negative bias temperature instability (NBTI) is generated under negative gate bias, and positive bias temperature instability is generated in positive gate bias.

3.3 CMOS

Complementary metal oxide semiconductor.

3.4 COTS

Commercial-off-the-shelf.

3.5 EARLY WEAROUT

Wearout of a semiconductor device prior to the time it is required to operate in the application.

3.6 ELECTROMIGRATION (EM)

Transport of material caused by the gradual movement of the ions in a conductor due to the momentum transfer between conducting electrons and diffusing metal atoms.

3.7 FIT

Failure unIT, a failure rate of 1 failure per 10⁹ device hours; also called Failure in Time. *(This term was originally defined as a Failure unIT by Stewart Peck and Conrad Zierdt of Bell Telephone Laboratories in the 1970s. Refer to, for example, "Accelerated Testing Handbook, fifth edition," by D.S. Peck and O.D. Trapp, Technology Associates, 1987.)*

3.8 GENERIC DATA

Data from sources other than the LLM manufacturer or user.

3.9 GENERIC MODELS

Models from sources other than the LLM manufacturer or user.

3.10 HIGH TEMPERATURE OPERATING LIFE (HTOL)

A test, typically performed by the part manufacturer, to demonstrate reliability.

3.11 HOT CARRIER INJECTION (HCI)

A failure mechanism in which an electron or hole gains sufficient kinetic energy to be injected into a normally forbidden region of the device, cause an interface state to be generated.

3.12 KEY PERFORMANCE FUNCTIONAL GROUP (KPFG)

A functional group within a microcircuit that can, with sufficient knowledge of its structure and potential wearout mechanisms, be assessed for limited life separately from the remainder of the microcircuit.

3.13 LIFE-LIMITED MICROCIRCUIT (LLM)

A microcircuit that could, potentially, have a limited lifetime in the application, due to one of the wearout mechanisms described in this document.

3.14 MICROCIRCUIT (μ c)

A semiconductor device containing a number of permanently connected components on single substrate of semiconducting material.

3.15 MICROCIRCUIT FAMILY

A set of microcircuits manufactured using the same materials and technology, and performing a similar function.

3.16 RELIABILITY PHYSICS ANALYSIS (RPA)

An approach to the design and development of reliable product to prevent failure, based on the knowledge of root cause failure mechanisms. RPA, which may also be called Physics of Failure (PoF), is based on understanding the relationships between requirements and the physical characteristics of the product and their variation in the manufacturing processes, and the reaction of product elements and materials to loads (stressors) and interaction under loads and their influence on the fitness for use with respect to the use conditions and time. (Refer to JEDEC JEP148, April 2004, "Reliability Mechanisms of Semiconductor Devices Based on Physics of Failure Risk and Opportunity Assessment.")

3.17 SUBSTANTIALLY SIMILAR

Having the same materials, manufacturing technology, and feature sizes, within a small range of limits.

3.18 TIME-DEPENDENT DIELECTRIC BREAKDOWN (TDDDB)

Failure mechanism in which the gate oxide breaks down as a result of long exposure to relatively low electrical stresses; the breakdown is caused by the formation of a conductive path through the oxide to the substrate due to electron tunneling current, when the device is operated close to its specified operating voltage.

3.19 TTF

Time to failure; usually indicates the time to a specific percentage of failures.

3.20 WEAROUT FAILURE

An intrinsic failure resulting from material degradation in the gates or conductors of a microcircuit.

4. LIFE-LIMITED MICROCIRCUIT IDENTIFICATION, ASSESSMENT, AND MITIGATION PROCESS

This clause describes the process for lifetime assessment of microcircuits. It also includes brief descriptions of risk analysis and mitigation methods for early wearout. The process is illustrated by the flow diagram in Appendix A².

4.1 Application Requirements

Identify and document the required environmental and operating conditions that have the potential to impact the lifetime of microcircuits. Examples are: ambient temperature, junction temperature, operating voltage, duty cycle, etc.

4.2 Identification

Identify all potential LLM in the sub-assembly, assembly, and equipment that are subject to early wearout in the AADHP application due to the combined effects of the following failure mechanisms: electromigration (EM), time-dependent dielectric breakdown (TDDDB), hot carrier injection (HCI), and bias temperature instability (BTI).

Include all microcircuits on the parts list of the AADHP equipment for which the component lifetime in the application cannot be assured by the component data sheet or other device manufacturer information. Typically, the list includes, as a minimum, COTS microcircuits with feature sizes less than 50 nanometers (nm).

Appendix B illustrates a format that can be used to list the identified microcircuits, and describe their application requirements.

4.3 Application-Specific Assessment by the LLM Manufacturer

The most credible assessment, and the one most preferred³, is an estimate of the expected lifetime of the LLM in the AADHP application, provided by the manufacturer of LLM, based on the manufacturer's test data, acceleration models, design information, materials, and production technology for the specific microcircuit or microcircuit family, and also on the use conditions of the application.

4.4 Application-Specific Assessment by the LLM User with Applicable In-Service Data

In cases where the LLM user has in-service (also called field) data from similar LLM in similar applications, the assessment includes a comparison of the in-service data with the proposed use, with modifications made to account for differences, within limits described in detail by the LLM user.

² The processes described in this clause are intended for use at the microcircuit level; however, they are equally applicable to key performance functional groups (KPFs) within microcircuits. If sufficient knowledge exists, the user is encouraged to perform the assessment(s) at the KPF level.

³ Although this is typically the case, it is not always so. For example, there may be in-service data available for the specific microcircuit in nearly-identical operating environments that are more credible than estimates from the microcircuit manufacturer.

4.5 Analysis by the LLM User

The analysis process includes two major elements:

1. Relevant test data, as described in order of preference in 4.5.1.1, 4.5.1.2, and 4.5.1.3; and
2. Credible acceleration models, as described in order of preference in 3.5.2.1, 3.5.2.2, and 3.5.5.3.

Appendix C contains guidance regarding the use of data and acceleration models from various sources.

4.5.1 Test Data

The three major categories of relevant data are listed below, in order of preference. Where appropriate, it may be realistic to use data from more than one of the sources.

4.5.1.1 LLM Manufacturer Data

Examples are:

- Data from accelerated stress tests, e.g., HTOL designed and conducted by the LLM manufacturer;
- Data from tests conducted on primitive structures during development by the LLM manufacturer; and
- Data obtained by the LLM manufacturer regarding performance of their products in service.

Relevant data could be from tests conducted on the specific microcircuit, or microcircuits with similar technology, size, etc., or from data conducted on primitive test structures representing the structures of the specific microcircuit.

Relevant data could be a subset of qualification tests or periodic product or process monitoring.

4.5.1.2 LLM User Data

Credible data from tests designed and conducted by the LLM user are based on a reliability physics analysis (RPA) based understanding of the susceptibility of the device to the four major failure mechanisms. Typically, such tests are similar to those defined and conducted by the LLM manufacturer.

Some third-party test and analysis organizations have developed their own databases, based on experience with LLM users. Such data may be considered acceptable, and maybe even preferable, to LLM user data.

4.5.1.3 Generic Data

Generic data are obtained from tests of the specific microcircuit, performed by a party other than the LLM manufacturer or user. Examples include:

- Test data from the LLM manufacturer or the user on a device that is substantially similar to the device used in the AADHP application;
- Test data reported in the literature, for the LLM used in the AADHP application, or one substantially similar to it;
- In-service (or field) failure or reliability data from the LLM used in the application, or one substantially similar to it;
- Other data that can be demonstrated as relevant.