Telcordia®

Reliability Prediction Procedure for Electronic Equipment

Special Report
SR-332
Issue 4, March 2016

Reliability Prediction Procedure for Electronic Equipment

This document is prepared by Telcordia Network Infrastructure Solutions “NIS”, a division of Ericsson Inc. (“Telcordia”).

Target audience:

This document replaces: SR-332, *Reliability Prediction Procedure for Electronic Equipment*, Issue 3, January 2011, plus February 2011 update.

Technical contact:

Richard Kluge, **NEBS™ Director**
Telcordia — SR-332
One Ericsson Drive
Piscataway, NJ 08854
Phone: +1.732.735.9929
E-mail: richard.kluge@ericsson.com

For more information, call +1.844.251.0201 (Worldwide), email buss.document-info@ericsson.com, or visit the Telcordia GR Web site.

Ericsson Licensing Agreements

Ericsson licensing agreements are designed to fit specific business needs. Ericsson offers an Enterprise License (EL) for select technical documents, including Generic Requirements (GRs). Under the EL agreement, Ericsson grants the licensee a non-exclusive, non-transferable, limited license for the purchased document(s). The purchased document(s) are to be used by employees of the licensee for internal business purposes only.

For more information on the Ericsson Enterprise License, **click here**.

Trademark Acknowledgments

All brand or product names are trademarks or registered trademarks of their respective companies or organizations.

Special Report Notice of Disclaimer

This Special Report is published by Telcordia Network Infrastructure Solutions, "NIS", a division of Ericsson Inc., to inform the industry of the Telcordia view of *Reliability Prediction Procedure for Electronic Equipment*.

Telcordia reserves the right to revise this document for any reason, including but not limited to, conformity with standards promulgated by various agencies; utilization of advances in the state of the technical arts; or the reflection of changes in the design of any equipment, techniques, or procedures described or referred to herein.

TELCORDIA AND ANY OTHER PARTICIPANTS IDENTIFIED IN SECTION 1 MAKE NO REPRESENTATION OR WARRANTY, EXPRESS OR IMPLIED, WITH RESPECT TO THE SUFFICIENCY, ACCURACY, OR UTILITY OF ANY INFORMATION OR OPINION CONTAINED HEREIN.

TELCORDIA AND ANY OTHER PARTICIPANTS IDENTIFIED IN SECTION 1 EXPRESSLY ADVISE THAT ANY USE OF OR RELIANCE UPON SAID INFORMATION OR OPINION IS AT THE RISK OF THE USER AND THAT NEITHER TELCORDIA, NOR ANY OTHER PARTICIPANTS, SHALL BE LIABLE FOR ANY DAMAGE OR INJURY INCURRED BY ANY PERSON ARISING OUT OF THE SUFFICIENCY, ACCURACY, OR UTILITY OF ANY INFORMATION OR OPINION CONTAINED HEREIN.

LOCAL CONDITIONS MAY GIVE RISE TO A NEED FOR ADDITIONAL PROFESSIONAL INVESTIGATIONS, MODIFICATIONS, OR SAFEGUARDS TO MEET SITE, EQUIPMENT, ENVIRONMENTAL SAFETY OR COMPANY-SPECIFIC REQUIREMENTS. IN NO EVENT IS THIS INFORMATION INTENDED TO REPLACE FEDERAL, STATE, LOCAL, OR OTHER APPLICABLE CODES, LAWS, OR REGULATIONS. SPECIFIC APPLICATIONS WILL CONTAIN VARIABLES UNKNOWN TO OR BEYOND THE CONTROL OF TELCORDIA. AS A RESULT, TELCORDIA CANNOT WARRANT THAT THE APPLICATION OF THIS INFORMATION WILL PRODUCE THE TECHNICAL RESULT OR SAFETY ORIGINALLY INTENDED.

This Special Report is not to be construed as a suggestion to anyone to modify or change any product or service, nor does this Special Report represent any commitment by anyone, including but not limited to Telcordia or any participants in the development of this Telcordia Special Report, to purchase, manufacture, or sell any product or service with the described characteristics.

Readers are specifically advised that any entity may have needs, specifications, or requirements different from the generic descriptions herein. Therefore, anyone wishing to know any entity's needs, specifications, or requirements should communicate directly with that entity.

Nothing contained herein shall be construed as conferring by implication, estoppel, or otherwise any license or right under any patent, whether or not the use of any information herein necessarily employs an invention of any existing or later issued patent.

TELCORDIA DOES NOT HEREBY RECOMMEND, APPROVE, CERTIFY, WARRANT, GUARANTEE, OR ENDORSE ANY PRODUCTS, PROCESSES, OR SERVICES, AND NOTHING CONTAINED HEREIN IS INTENDED OR SHOULD BE UNDERSTOOD AS ANY SUCH RECOMMENDATION, APPROVAL, CERTIFICATION, WARRANTY, GUARANTY, OR ENDORSEMENT TO ANYONE.

If further information regarding technical content is required, please contact:

Richard Kluge, NEBS™ Director
Telcordia – SR-332
One Ericsson Drive
Piscataway, NJ 08854
Phone: +1.732.735.9929
E-mail: richard.kluge@ericsson.com

For general information about this or any other Telcordia documents, please contact:

Customer Service
One Ericsson Drive
Piscataway, NJ 08854
+1.844.251.0201 (Worldwide)
E-mail: buss.document-info@ericsson.com
Web site: Telcordia SuperStore

Table of Contents

1 Introduction

1.1 Purpose and Scope . . . 1–1
1.2 Changes . . . 1–2
1.3 Structure of this Report . . . 1–2
1.4 Participants in the Development of SR-332, Issue 4 . . . 1–3
1.5 Automated Reliability Prediction Procedure (ARPP) . . . 1–3

2 Reliability Predictions for Electronic Equipment

2.1 Purposes of Reliability Predictions . . . 2–1
2.2 Definitions . . . 2–2
2.2.1 Equipment Definitions . . . 2–2
2.2.2 Definition of a Failure . . . 2–2
2.2.3 Definition of Failure Rate . . . 2–3
2.2.3.1 Life Cycle of Electronic Equipment . . . 2–3
2.2.3.2 RPP Failure Rate Predictions . . . 2–4
2.2.3.3 Factors Affecting Failure Rates . . . 2–4
2.3 Outline of Methods . . . 2–7
2.3.1 Flow of Early Life Failure Rate Calculations . . . 2–7
2.3.2 Flow of Steady-State Failure Rate Calculations . . . 2–7
2.3.3 Items and Factors Excluded from Failure Rate Calculations . . . 2–8
2.3.4 Guidance for Device Types/Technologies Not in Section 8 . . . 2–9
2.3.5 Statistical Considerations . . . 2–9
2.3.5.1 Upper Confidence Levels . . . 2–9
2.3.5.2 Alternate and Supplementary Methods . . . 2–10
2.3.6 Automated Reliability Prediction Procedure (ARPP) . . . 2–10

3 Steady State Failure Rate Prediction for Devices

3.1 Method I-D: Black Box Technique . . . 3–1
3.2 Method II-D: Techniques Integrating Laboratory Data . . . 3–2
3.2.1 When Laboratory Test Devices Had No Previous Burn-in . . . 3–2
3.2.2 When Laboratory Test Devices Had Previous Burn-in . . . 3–3
3.3 Method III-D: Techniques Integrating Field Data . . . 3–4
3.3.1 Total Operating Hours . . . 3–5
3.3.2 Adjustment Factor (V) . . . 3–5
3.4 Examples . . . 3–6
3.4.1 Example 1: Method I-D, Black Box Technique . . . 3–6
3.4.2 Example 2: Method II-D, Integrating Laboratory Test Data . . . 3–7
3.4.2.1 Example 2a: No Burn-In of Laboratory Test Devices . . . 3–7
3.4.2.2 Example 2b: Previous Burn-In of Laboratory Test Devices . . . 3–7
3.4.3 Example 3: Method III-D, Integrating Field Data . . . 3–8
3.4.3.1 Example 3a: Subject Device is in Test Unit and Operated at the Same Temperature and Electrical Stress . . . 3–9
3.4.3.2 Example 3b: Subject Device is in Test Unit but Operated at Different Temperature . . . 3–9

4 Early Life Factor Prediction for Devices

4.1 Early Life Factor for Device with Limited or No Burn-In 4–1
4.2 Early Life Factor for Device with Extensive Burn-In 4–1
4.2.1 Equivalent Operating Time for Burn-in 4–1
4.2.2 Early Life Factor 4–2
4.3 Examples 4–2
4.3.1 Example 1: Limited or No Burn-In 4–2
4.3.2 Example 2: Extensive Burn-In 4–3

5 Failure Rate Prediction for Units

5.1 Method I: Unit Steady-State Failure Rate Using the Parts Count Method 5–1
5.2 Method II: Integrating Laboratory Test Data on Units 5–3
5.2.1 When Laboratory Test Units Have No Previous Unit/Device Burn-In . . . 5–3
5.2.2 When Laboratory Test Units Had Previous Burn-in 5–4
5.3 Method III: Integrating Field Data on Units 5–5
5.3.1 Total Operating Hours 5–6
5.3.2 Adjustment Factor (V) 5–6
5.4 Unit Early Life Factor 5–7
5.5 Sampling Method - Using Default Temperature and Stress Factors on a Sample of Units 5–7
5.6 Examples 5–8
5.6.1 Example 1: Method I, Parts Count Prediction 5–9
5.6.2 Example 2: Early Life Factor 5–9
5.6.3 Example 3: Method II, Integrating Laboratory Test Data 5–10
5.6.3.1 Example 3a: No Previous Burn-In of Laboratory Test Units 5–10
5.6.3.2 Example 3b: Previous Burn-In of Laboratory Test Units 5–10
5.6.4 Example 4: Method III, Integrating Field Test Data 5–11
5.6.4.1 Example 4a: Subject Unit and Test Unit are Identical and Operated Under the Same Conditions 5–11
5.6.4.2 Example 4b: Subject Unit and Test Unit are Identical but Operated in Different Environments 5–12
5.6.4.3 Example 4c: Test Unit Is Similar but Not Identical to Subject Unit 5–12
5.6.5 Example 5: Method I, Parts Count Prediction, Devices Within a Device Type Have Different Operating Temperatures 5–12

6 System Reliability (Service Affecting Reliability Data)

6.1 Serial System Reliability 6–1
6.1.1 Steady-State Failure Rate 6–1
6.1.2 Early Life Factor 6–1
6.2 Non-Serial Systems 6–2

7 Upper Confidence Levels for Failure Rates

7.1 Upper Confidence Level Calculation 7–1
7.2 Examples 7–2
7.2.1 Example 1: 90% Upper Confidence Level of the Steady-State Failure Rate 7–2
7.2.2 Example 2: 90% Upper Confidence Level of the Early Life Failure Rate 7–2

8 Device Parameter Values

8.1 Capacitor Parameter Values 8–2
8.2 Connector Parameter Values 8–3
8.3 Diode Parameter Values 8–4
8.4 Inductor Parameter Values 8–5
8.5 Integrated Circuit Parameter Values 8–6
8.5.1 Analog Integrated Circuit Devices 8–7
8.5.2 Digital Integrated Circuit Devices 8–8
8.5.3 Random Access Memory (RAM) 8–10
8.5.4 Read Only Memory (ROMS, PROMS, EPROMS) 8–12
8.5.5 Microprocessor 8–14
8.5.6 Microcontroller 8–15
8.5.7 Hybrid Microcircuits 8–15
8.5.8 Combined Analog-Digital Integrated Circuit (Gate Array and Program Array Logic) 8–16
8.6 Microwave Element Devices 8–17
8.7 Opto-Electronic Device Parameter Values 8–18
8.7.1 Fiber Optic Communication Devices and Modules 8–18
8.7.2 Other Opto-Electronic Devices 8–20
8.8 Relay Parameter Values 8–21
8.9 Resistor Parameter Values 8–22
8.9.1 Fixed Resistor 8–22
8.9.2 Variable Resistor 8–23
8.9.3 Resistor Networks 8–24
8.10 Switch Parameter Values 8–25
8.11 Thermistor Parameter Values 8–26
8.12 Transistor Failure Rates 8–27
8.13 Rotating and Miscellaneous Device Parameter Values 8–29

9 Failure Rate Factors

9.1 Temperature Factor 9–1
9.2 Electrical Stress Factor 9–3
9.2.1 Electrical Stress Curves 9–3
9.2.2 Electrical Stress Percentage 9–4
9.3 Quality Factor 9–6
9.4 Environment Factor 9–8

Appendix A: Failure Rate Units

Appendix B: References

B.1 Telcordia Documents B–1
B.2 Non-Telcordia Documents B–1
B.3 Documents on Derating B–1
B.4 Telcordia Documents Referencing SR-332 or a Predecessor B–2
B.5 Reference Notes B–6
B.6 Contact Customer Service B–6
B.7 Order Documents Online From the Telcordia SuperStore B–6
B.8 Web Sites for Generic Requirements Information B–7
B.9 Licensing Agreements for Telcordia Documents B–7

Appendix C: Glossary

C.1 Acronyms C–1
C.2 Definition of Terms C–3

List of Figures

Figure 2-1 Bathtub Curve 2–4

List of Tables

Table 1-1	Participants in the Development of SR-332, Issue 4	1–3
Table 8-1	Capacitor Failure Rate Parameters	8–2
Table 8-2	Connector Failure Rate Parameters	8–3
Table 8-3	Diode Failure Rate Parameters*	8–4
Table 8-4	Inductor Failure Rate Parameters	8–5
Table 8-5	Analog Integrated Circuit Failure Rates	8–7
Table 8-6	Digital Integrated Circuit Failure Rate Parameters	8–8
Table 8-7	Digital Integrated Circuit Failure Rates	8–9
Table 8-8	Random Access Memory Failure Rate Parameters	8–10
Table 8-9	Static Random Access Memory (SRAM) Failure Rates	8–11
Table 8-10	Dynamic Random Access Memory (DRAM) Failure Rates	8–12
Table 8-11	Read Only Memory Failure Rate Parameters	8–13
Table 8-12	Read Only Memory Failure Rates	8–13
Table 8-13	Microprocessor Failure Rate Parameters	8–14
Table 8-14	Bipolar and NMOS Microprocessor Failure Rates	8–14
Table 8-15	CMOS Microprocessor Failure Rates	8–15
Table 8-16	Microwave Element Device Failure Rate Parameters	8–17
Table 8-17	Fiber Optic Communication Device/Module Failure Rate Parameters	8–18
Table 8-18	Opto-Electronic Device Failure Rate Parameters	8–20
Table 8-19	Relay Failure Rate Parameters	8–21
Table 8-20	Fixed Resistor Failure Rate Parameters	8–22
Table 8-21	Variable Resistor Failure Rate Parameters	8–23
Table 8-22	Resistor Network Failure Rate Parameters	8–24
Table 8-23	Switch Failure Rate Parameters	8–25
Table 8-24	Thermistor Failure Rate Parameters	8–26
Table 8-25	Transistor Failure Rate Parameters	8–27
Table 8-26	Miscellaneous Device Failure Rate Parameters	8–29
Table 8-27	Rotating and Miscellaneous Device Failure Rate Parameters	8–30
Table 9-1	Temperature Factors πT	9–2
Table 9-2	Electrical Stress Factors π_S	9–4
Table 9-3	Guidelines for Determination of Electrical Stress Percentage	9–5
Table 9-4	Device Quality Level Description and Factor π_Q	9–7
Table 9-5	Environmental Conditions and Multiplier Factors (π_E)	9–8
Table A-1	Reliability Conversion Factor	A–1

1 Introduction

This section details the purpose and scope of the Reliability Prediction Procedure (RPP) and indicates changes from the previous issue (SR-332, Issue 3, January 2011).

1.1 Purpose and Scope

A prediction of reliability is an important element in the process of selecting equipment for use by telecommunications service providers and other buyers of electronic equipment. As used here, reliability is a measure of the frequency of equipment failures as a function of time. Reliability has a major impact on maintenance and repair costs and on the continuity of service.

The purpose of this RPP is to document recommended methods for predicting device and unit hardware reliability. This procedure also documents a recommended method for predicting serial system hardware reliability. It contains instructions for suppliers to follow when providing predictions of their device, unit, or serial system reliability (hereinafter called “product” reliability). It also can be used directly by telecommunications service providers for product reliability evaluation.

Device and unit failure rate predictions generated using this procedure are applicable for commercial electronic products whose physical design, manufacture, installation, and reliability assurance practices meet the appropriate Telcordia (or equivalent) generic and product-specific requirements.

This procedure cannot be used directly to predict the reliability of a non-serial system. However, the unit reliability predictions resulting from the application of this procedure can be input into system reliability models for prediction of system-level hardware reliability parameters. Troubles caused by transient faults, software problems, procedural errors, or unexpected operating environments can have a significant impact on system-level reliability. Therefore, system hardware failures represent only a portion of the total system trouble rate.

Currently, this procedure also includes some discussion of system-level operating and configuration information that may affect overall system reliability. The procedure directs the requesting organization to compile this information in cases where the unit-level reliability predictions are computed for input to a specific system reliability model. This system-level information is not directly necessary for computation of the unit-level reliability predictions, but these information requirements are not currently addressed in other Telcordia requirements documents (GRs) and, therefore, are included in this Special Report (SR).

For publishing Mean Time Between Failure (MTBF) or Failures per billion device hours (FIT) numbers, Telcordia recommends that the methodology and assumptions should be clearly stated (i.e., the referenced document and issue number, plus environmental and temperature assumptions, should be given). For example: Telcordia SR-332, Issue 4, operating temperature (40°C), electrical stress (50%), environmental factor (1.0), quality factor (1.0), and Upper Confidence Level (60%).

1.2 Changes

The initial issues of SR-332 (and TR-332) were developed from Military Specification MIL-HDBK-217, *Reliability Prediction of Electronic Equipment*, with customizations included to better harmonize with communications applications and equipment. The subsequent issues of SR-332 were revised to incorporate (a) field return data for failed equipment, (b) life-testing data from participants (users and manufacturers) for components and assemblies, (c) new equipment components and design combinations of devices, and (d) feedback from reliability calculations and use of the software tool for network equipment reviews. The overall goal of SR-332 has remained to provide a consistent means to quantitatively compare the intrinsic reliability of different assemblies and combinations of communications components and units.

This issue of the RPP includes the following changes:

- The generic device failure rates in Section 8 have been revised based on new data for many components. For a few devices, the range of complexity covered by the procedures has been extended. In addition, new devices have been added.
- The Environmental Factors in Section 9 have been revised based on field data and collective experience of the forum members.
- Clarification and guidance have been added based on items raised by the forum participants as well as frequently asked questions raised by users of the document.

1.3 Structure of this Report

This report is structured as follows to facilitate the application of the recommended reliability prediction methods:

- Section 1 provides an introduction, describes the changes made to this issue from the previous issue, and lists the participants in the development of SR-332.
- Section 2 describes the purpose of reliability prediction and the Telcordia approach; defines equipment, failures, and failure rates; and gives an overview of the methods used for estimating the failure rates of electronic equipment.
- Section 3 describes techniques for Steady State Failure Rate prediction for devices.
- Section 4 describes Early Life Factor prediction for devices.
- Section 5 describes recommended methods for Failure Rate Prediction for units.
- Section 6 describes the computation of reliability predictions for serial systems.
- Section 7 presents techniques for estimating Upper Confidence Levels (UCLs) for reliability predictions for units and devices.
- Section 8 describes the generic parameter values for devices.
- Section 9 describes the factors that influence failure rates.

- Appendix A describes the relationships of various reliability metrics to the failure rates estimated in this document.
- Appendix B lists the documents referenced in this SR.
- Appendix C lists and defines the acronyms and terms used in this SR.

1.4 Participants in the Development of SR-332, Issue 4

Issue 4 of SR-332 was developed jointly by Telcordia and equipment manufacturers. The participants in this endeavor are listed in Table 1-1.

Table 1-1 Participants in the Development of SR-332, Issue 4

Company Participants	Company Representatives	Company Web Sites
Nokia including Alcatel-Lucent Submarine Networks	Donald S. Jackson Kenneth K. Ng Canan Yaras	www.nokia.com www.alcatel-lucent.com/solutions/submarine-networks
Cisco Systems	John Sohn Henry Zhu	www.cisco.com
VT iDirect	William Birkas Benjamin DeVore	www.idirect.net
Telcordia	Frederick Hawley Richard Kluge Helmut Knehr Randy Schubert	http://telecom-info.telcordia.com/site-cgi/ido/docs2.pl?ID=&page=gr_process

Recent prior issues of SR-332 included participation by the following companies: Alcatel USA, Cisco Systems, Extreme Networks, Intel, JDS Uniphase, Lucent Technologies, and Motorola.

1.5 Automated Reliability Prediction Procedure (ARPP)

FD-ARPP-01, *Automated Reliability Prediction Procedure (ARPP)*, Version 12.0, is a Microsoft® Excel® spreadsheet software tool that automates the reliability prediction procedures in SR-332, Issue 4. It provides suppliers and manufacturers with a simple tool for making RPP calculations. It also provides a means for understanding RPP calculations through the capability of interactive examples provided by the user.

ARPP, Version 12.0:

- Uses SR-332, Issue 4, methodologies: Incorporates the changes developed from the input of several major industrial companies.

- Is less expensive than other industry reliability calculation software: It provides an alternative to expensive, complex software systems, which have the RPP embedded as one of several prediction models.
- Has a format that is portable and easy to use: The portability and relatively small size of the Excel spreadsheet on an individual CD-ROM permits greater flexibility of use than more complex systems.
- Has a parts database capability: This includes the capability to apply a user's internal database that assigns SR-332, Issue 4, device types to specific device products as well as an aid to producing such a database.
- Uses drop-down menus to ease this process.
- Eliminates the cumbersome task of replicating formulas and tables, and the need for SR-332 purchasers to replicate formulas and tables from the SR-332 document into their own tools.
- Ensures the accuracy of calculations: Provides a way for suppliers and manufacturers to double-check calculations made on internal systems.
- Includes a table of generic complexity assumptions: This table has been added to provide guidelines for the complexity of digital and analog Integrated Circuits (ICs) when device complexity information is not available from the device manufacturer.

2 Reliability Predictions for Electronic Equipment

2.1 Purposes of Reliability Predictions

Reliability predictions derived in accordance with this procedure serve the following purposes:

- They help assess the effect of product reliability on the maintenance activity and on the quantity of spare units required for acceptable field performance of any particular system. For example, predictions of the frequency of unit level maintenance actions can be obtained. Reliability prediction can be used to size spare populations.
- They provide necessary input to system-level reliability models. System-level reliability models can subsequently be used to predict, for example, the frequency of system outages in steady-state, the frequency of system outages during early life, expected downtime per year, and system availability.
- They provide necessary input to unit and system-level Life Cycle Cost Analyses. Life cycle cost studies determine the cost of a product over its entire life. Therefore, it is necessary to know how often a unit will need to be replaced. Inputs to this process include unit and system failure rates. This input includes how often units and systems fail during the first year of operation as well as in later years.
- They assist in deciding which product to purchase from a list of competing products. As a result, it is essential that reliability predictions be based on a common procedure.
- They can be used to set factory test standards for products requiring a reliability test. Reliability predictions help determine how often the system should fail.
- They are needed as input to the analysis of complex systems like switching systems and digital cross-connect systems. It is necessary to know how often different parts of the system are going to fail even for redundant components.
- They can be used in design trade-off studies. For example, a supplier could look at a design with many simple devices and compare it to a design with fewer devices that are newer but more complex. The unit with fewer devices is usually more reliable.
- They can also be used to set achievable in-service performance standards against which to judge actual performance and stimulate action.

2.2 Definitions

2.2.1 Equipment Definitions

The RPP views electronic systems as hierarchical assemblies. Systems are constructed from units which, in turn, are constructed from devices. The methods presented in this report predict reliability at these three hierarchical levels:

1. *Device*: A basic component (or part) as listed in Section 8 of this document.
2. *Unit*: Any assembly of devices. This may include, but is not limited to, circuit packs, modules, plug-in units, racks, power supplies, and ancillary equipment. Unless otherwise dictated by maintenance considerations, a unit will usually be the lowest level of replaceable assemblies/devices. The RPP is aimed primarily at the reliability prediction of units.
3. *Serial System*: Any assembly of units for which the failure of any single unit will cause a failure of the system.

2.2.2 Definition of a Failure

The definition of a failure should be well understood by the user. This is a crucial element in predicting system reliability parameters. For non-complex equipment such as units and devices, the definition of a failure is usually clear.

The RPP is directed toward unit-level failures caused by device hardware failures. The following are not included in failure rate predictions using these techniques:

- Transient failures such as those from soft errors due to alpha particle and cosmic radiation effects
- Manufacturing process-induced errors (e.g., solder joints, Printed Circuit Board [PCB] fabrication, wiring)
- Software failures[1]
- Failures from procedural errors.

Such failures may contribute to hardware returns or downtime. Predictions using the techniques in this document may be adjusted as needed to account for these failures if needed for a prediction of hardware return rates or system/network availability.

Any number of causes, including transient faults, software failures, and procedural errors, can result in returned hardware that has no trouble or fault found during diagnostic testing. This situation may result from insufficient test coverage during manufacturing diagnostics or component vendor test escape that truly is a hardware intermittent failure. The amount of this contribution in excess of the SR-332 prediction that should be included in system availability and maintenance estimates

1. Failures due to software/firmware errors on programmable devices are not considered. However, the hardware failure rates of programmable devices are considered.

is left for the reliability analyst to consider based on historical comparisons of predicted failure rates versus actual field return rates.

However, failures in systems with multiple functions may be harder to define. In complex equipment, it may be useful to distinguish between failures affecting maintenance or repair and those affecting service. For example, the failure of an LED is likely to cause a return, but may not cause a service outage. Consequently, LEDs should be included in the failure rate estimate when the estimate is used to determine return rates, but they could likely be disregarded if the estimate is used to determine service availability.

Some complex, multi-function systems may have reliability objectives for individual functions or for various states of reduced service capability. For example, it is often desirable for multichannel systems to define the maximum number of channels that can be out before the system is considered failed, i.e., no longer providing acceptable service. For such systems, it may be necessary to develop reliability and availability models to address these additional objectives. Detailed guidelines for developing these models are outside the scope of this document. Please read Section 6 about System Reliability prediction.

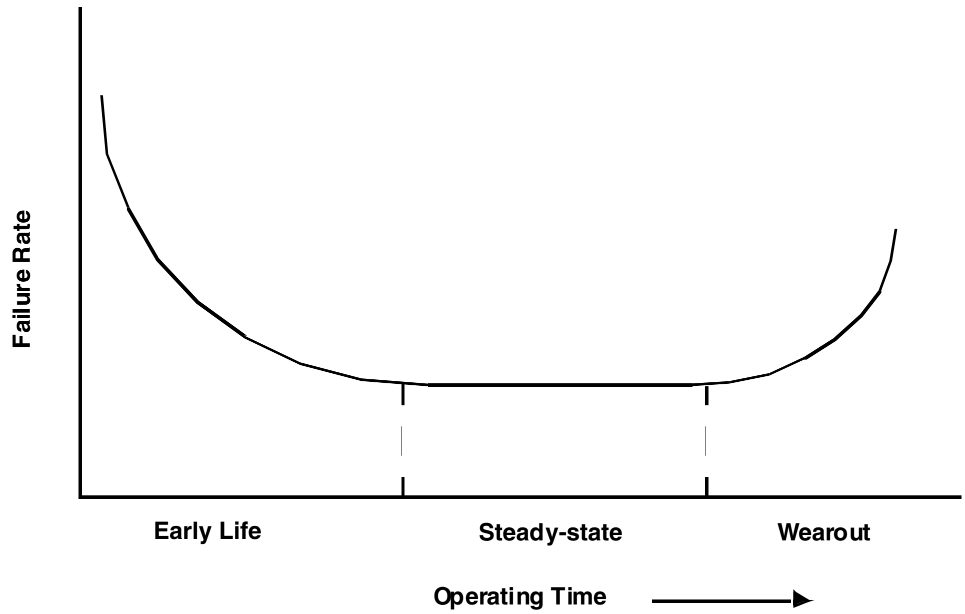
2.2.3 Definition of Failure Rate

2.2.3.1 Life Cycle of Electronic Equipment

The RPP focuses on predicting failure rates for electronic equipment. The RPP does not address other aspects of reliability such as downtime, availability, and impacts of failures. Failure rates are not constant throughout the life cycle of electronic equipment. Failure rates of electronic equipment follow a bathtub curve. As shown in Figure 2-1, a bathtub curve is divided into three time periods:

1. *Early Life (or Infant Mortality)*: The failure rate is high, but decreases rapidly. Time to failure is modeled as a Weibull distribution. The methods assume that this period is the first 10,000 hours of operation (slightly more than a year).
2. *Steady-State*: This period begins after Infant Mortality. Failures occur at a constant rate, referred to as the *steady-state failure rate*. That is, the time to failure follows an exponential distribution. The RPP assumes that electronic equipment is in this period approximately after its first year of operation.
3. *Wear-Out*: The failure rate increases rapidly. Usually, Wear-Out does not occur for electronic devices during the service life, which may be as many as 20 years. For this reason, the Wear-Out period is not considered in the RPP. Certain device types such as batteries, electrolytic capacitors, crystal oscillators, flash memory, fans and motors, hard disk drives, lasers, and other optical devices may have a limited lifetime. These devices are more likely to have their service lives constrained by Wear-Out. For these devices with a limited lifetime, the failure rate applies to the "steady-state" or useful life of the devices before the point in time where Wear-Out occurs. Special consideration should be given to such devices in the proper interpretation of their steady-state failure rates.

Figure 2-1 Bathtub Curve



2.2.3.2 RPP Failure Rate Predictions

With reference to these time periods, the RPP provides predictions of the following:

- *The Steady-State Failure Rate*. The constant failure rate in the Steady-State Period. The Steady-State Failure Rate provides the information needed for long-term product performance.
- *The Early Life Factor*[2]. The average failure rate during the early life (10,000 hours) can be expressed as a multiple of the Steady-State Failure Rate. This multiple (called the *Early Life Factor)*, together with the Steady-State Failure Rate, provides a measure of the number of failures expected in approximately the first year of operation.

2.2.3.3 Factors Affecting Failure Rates

Device failure rates vary as a function of operating conditions and production quality. The operating conditions modeled in the RPP are as follows:

- *Operating Temperature*. The RPP uses a Temperature Factor to model the effect of temperature on failure rate. The value of this Factor is found in Section 9.1 and is based on the device operating temperature and the type of device. The value is normalized to a temperature of 40°C, which produces a Temperature Factor of 1.0 for all device types. When the actual device operating temperature differs significantly from the normalized temperature, the actual

2. Formerly First Year Multiplier.

device operating temperature (as defined below) may be used. The following are temperature definitions as related to the device operating temperature used to determine Temperature Factor.

— ***Ambient Temperature (Ta)***. Ambient temperature is the room temperature or outside air temperature when the unit is operating under normal conditions[3]. GR-63-CORE, *NEBS™ Requirements: Physical Protection*, specifies a room ambient air temperature of 23°C (73°F) measured 1.5 m (59 in) above the floor and 400 mm (15.8 in) in front of the equipment. A 25°C ambient temperature may be used as the air intake to the equipment containing the unit. For outdoor natural convection cooled equipment, ambient temperature is defined as the outside air temperature (including the effects of solar loading) outside the unit based on the specific application.

— ***Device Operating Temperature***. Operating temperature for a device is the temperature inside the unit in which the device resides. This temperature is defined as the temperature 0.5 inch above the surface of the device. When temperature variations across the board are relatively constant (as in forced air cooled systems), the average board temperature may be used. Board temperature may be determined by temperature sensors, thermocouple measurements, computer simulations, or Infrared (IR) imaging. When temperatures across the board vary significantly (as in convection cooled equipment), device case temperatures should be used for the major high heat dissipating devices and the average board temperature for all other devices.

- Usage Example: The normalized device operating temperature of 40°C assumes a 25°C ambient temperature plus a 15°C average board temperature rise due to local heat generation.

— ***Case Temperatures (Tc)***. Case temperature is the external device temperature measured outside the device's case. The case temperature of major heat dissipating devices should be used to determine the operating temperature for these devices.

- Usage Example: Thermal mapping of a power transistor shows an average case temperature of 70°C, with an average board temperature of 50°C for all other devices.

— ***Junction Temperatures (Tj)***. Junction Temperatures cannot be used directly with Table 9-1 to determine a Temperature Factor, since Table 9-1 is calibrated to device operating temperature or case temperature as defined above. Tj can only be used to determine failure rate when a device manufacturer provides a proven Junction Temperature-Failure Rate Model.

- *Electrical Stress*. In the RPP, stress is the ratio of applied voltage (or power) to rated voltage (or power) expressed as a percentage. The RPP uses an Electrical Stress Factor as a quantitative expression for the effect of stress on failure rate. The values for this factor are found in Section 9.2 based on stress and the type of

3. "Normal conditions" refer to the operating conditions for which the reliability prediction is to apply. If the reliability predictions are used as input in a system-level reliability model, these will be the operating conditions for the product in that particular system.

device. The values in the table range from 0.1 to 10.6 when stress goes from 10% to 90% on the most sensitive devices. If the stress is unknown, the RPP assumes stress is 50%, which produces a factor value of 1 for all device types.

- *Quality*. Device failure rates are improved by supplier efforts to ensure the quality of their devices. For predicting failure rates, the RPP uses four Quality Levels for suppliers. Section 9.3 provides descriptions of these Quality Levels as an aid in classifying supplier quality efforts. Each level is assigned a Quality Factor value π_Q, which is used as a multiplier of the basic failure rate. Table 9-4 provides these Quality Factor values, which range from 0.8 (for Quality Level III, the highest level) to 6.0 (for Quality Level 0, the lowest level).
- *Environmental Condition*. The RPP defines six environmental conditions in Section 9.4. A separate prediction should be made for each environmental condition to which the equipment may be exposed. The RPP uses an Environment Factor as a quantitative expression for a condition's effect on failure rate. The defined factors goes from 1 for a ground-based, fixed, controlled environment such as a central office, to 3 for airborne commercial. For a space-based commercial environment such as a commercial communication satellite, refer to MIL-STD-217 or other applicable standards.

The factors considered so far all influence the steady-state failure rate for devices. Suppliers also use various screening procedures to reduce the first-year failure rate. Such procedures as temperature cycling, voltage stressing, and vibration are used to eliminate devices susceptible to failure in the first year before they are shipped and go in service. Of all such procedures, Telcordia has received sufficient documentation for inclusion in the RPP only for burn-in. In this report, "burn-in" is defined as any powered operation that fully simulates (with or without acceleration) normal use conditions. The RPP uses the temperature and the duration of burn-in for a device (as well as for its unit and system, if applicable) in the prediction of the Early Life Factor for the device's failure rate. Accounting for burn-in reduces the estimated value of the Early Life Factor. The longer the burn-in and the higher the burn-in temperature, the more the Early Life Factor is reduced.

Some suppliers have questioned the value of burn-in for mature product designs. Telcordia investigated the relevance of burn-in for mature product designs through a study that included three types of burn-in, as well as no burn-in. This study examined the trade-off of time saved in the manufacturing cycle versus the cost of any additional failure if burn-in is eliminated. This study concluded that for mature product designs it is not necessary to do a burn-in, and the savings of time and material without burn-in would reduce the cost of the mature product. For such mature product designs, an appropriate Early Life Factor may be determined from analysis of field data.

2.3 Outline of Methods

The RPP provides methods for estimating the failure rates of electronic equipment in the Early Life and Steady-State periods of the equipment life cycle. The methods do not cover the Wear-Out period of the life cycle; it is assumed that the equipment has not entered the Wear-Out phase of its life cycle.

2.3.1 Flow of Early Life Failure Rate Calculations

The RPP estimates the Early Life failure rate as the product of the Steady-State failure rate and the Early Life Factor for the equipment in question. Calculation of the Steady-State failure rate is reviewed in Section 2.3.2. The calculation of the Early Life Factor for a device is described in Section 4. As described in Section 5.4, the Early Life Factor for a unit is a weighted average of the Early Life Factors for the devices that compose it.

2.3.2 Flow of Steady-State Failure Rate Calculations

The RPP calculation of failure rate predictions flows up the hierarchy of equipment from device to unit to serial system. The failure rate estimate for a unit is based on the failure rate estimates of the devices that compose that unit. Similarly, the failure rate estimate for a serial system is based on the failure rate estimates of the units that compose that system. Thus, the predictions at the lower equipment level are used to feed predictions at the higher equipment level.

At each level, a failure rate estimate is made using one of three methods:

- *Method I: The Black Box or Parts Count Method*

  This method is the foundation of RPP estimates. It was originally modeled on the methods from MIL-HDBK-217F, *Reliability Prediction of Electronic Equipment*. At the device level, the method assumes that no reliability data is available on the device for which a prediction is to be made; the prediction is based on generic reliability parameters as presented in Section 8. At the unit level, the method assumes that the prediction is based only on the estimates of the failure rates of the individual devices that compose it. This is the simplest and most commonly used method. These techniques are also needed to complete the calculations in the more complex methods incorporating laboratory data or field data.

- *Method II: The integration of laboratory data with the Black Box/Parts Count Method*

  Laboratory data such as results from High Temperature Operating Life (HTOL) tests as per the Joint Electron Device Engineering Council (JEDEC) and Reliability Demonstration Tests (RDTs) may be used to supplement the Black Box and Parts Count procedures. At the device level, these techniques allow the laboratory data to be integrated with the generic data presented in Section 8. At the unit level, these techniques allow the laboratory data to be integrated with the failure rate estimates for the composing devices. The result is a prediction that lies between one generated from Method I and one based only on the laboratory data.

- *Method III: The integration of field data with the Black Box/Parts Count Method*

  If field tracking data on the units or devices are available, the Black Box and Parts Count procedures may be supplemented. At the device level, these techniques allow the field tracking data to be integrated with the generic data presented in Section 8. At the unit level, these techniques allow the field tracking data to be integrated with the failure rate estimates for the composing devices. The result is a prediction that lies between one generated from Method I and one based only on the field tracking data.

In order to distinguish the methods as they apply to different levels, Methods I, II, and III refer to those methods at the unit level, while Methods I-D, II-D, and III-D refer to those methods at the device level.

Section 3 describes Methods I-D, II-D, and III-D for application to estimating failure rates of devices. Method II-D for devices is used when laboratory data for the device in question is available. Method III-D for devices is used when field data for the device in question is available. Method I-D for devices is used when neither field nor laboratory data is available for the device in question.

Section 5 describes Methods I, II, and III for application to estimating failure rates of units. Method II for units is used when laboratory data for the unit in question is available. Method III for units is used when field data for the unit in question is available. Method I for units is used when neither field nor laboratory data is available for the unit in question.

It is possible to apply all three methods in a failure rate estimate. For example, a unit may consist of three devices A, B, and C. Laboratory data exists for device A allowing the use of Method II-D in the estimate of device A's failure rate. Field data exists for device B allowing the use of Method III-D in the estimate of device B's failure rate. No laboratory or field data exists for device C, so Method I-D must be employed to estimate device C's failure rate. Therefore, the failure rate estimate for this unit is based on device failure rates utilizing all three methods at the device level. In addition, laboratory or field data for the unit could exist, allowing the use of Methods II and III at the unit level as well. For this reason, an explanation of the various methods employed at each level in a failure rate estimate may be useful.

2.3.3 Items and Factors Excluded from Failure Rate Calculations

Wire, Cable, Solder Connections, Wire Wrap Connections, and Printed Wiring Boards: When unit failure rates are being predicted, wire, cable, solder connections, wire wrap connections, and printed wiring boards (but not attached devices and connector fingers) may be excluded. In the case of solder connections, wiring, and circuit boards, it is assumed that board assembly manufacturers control their manufacturing processes, including soldering, in accordance with requirements that result in negligible contribution to unit failure rates.

Restriction of the Use of Certain Hazardous Substances (RoHS): The generic failure rates provided in Section 8 are based on data obtained from both RoHS-compliant and non-RoHS-compliant devices. The data shows no difference based on RoHS compliance.

Surface Mount Technology: RPP base failure rate predictions for surface mount devices are equal to the RPP predictions for the corresponding conventional versions. At this time, Telcordia has received no evidence indicating a significant difference in failure rates between conventional and surface mount devices, even though several manufacturers have indicated that surface mount devices appear to be more reliable. Separate failure rate predictions for surface mount devices may be included in future RPP issues if equipment suppliers or users contribute valid field reliability data or other evidence that indicates a significant difference.

Non-Service-Affecting Equipment in Availability Analyses: When unit failure rate predictions are to be used as input into system reliability models, the requesting organization may also approve exclusion of devices whose failure will not cause an immediate loss of service, necessitate an immediate maintenance visit, or result in additional service disruption during later system maintenance activities. For example, failure of a particular device may not immediately affect service, but may affect the system recovery time given a subsequent outage. This may include devices provided for monitoring, alarm, or maintenance purposes (e.g., channel busy lamps or failure indicator lamps).

2.3.4 Guidance for Device Types/Technologies Not in Section 8

If a prediction requires failure rates for devices not addressed adequately in Section 8, the use of other data sources (e.g., test data or field data from suppliers or manufacturers) is encouraged. The Telcordia technical contact listed on page ii may be contacted about the need for including new devices in Section 8.

In determining whether a device from a laboratory test or from the field is a suitable counterpart for the subject device, the similarity of the wafer process, device materials, assembly process, transistor structure, and external packaging should be considered.

2.3.5 Statistical Considerations

2.3.5.1 Upper Confidence Levels

The failure rate estimates for devices and units described in Section 3 and Section 5, respectively, are *mean* estimates. These estimates do not account for the uncertainty and variability in the data used to generate the generic device failure rates in Section 8. If a more conservative estimate of failure rates is desired, such as between 60% and 90% Upper Confidence Levels (UCLs), then the procedure can be used. Such an estimate means that there is only a 100% - 60% = 40% chance, or a 100% - 90% = 10% chance, that the predicted failure rate underestimates the true failure rate. The higher the UCL level is, the more conservative the estimate and the greater the protection against underestimating the true failure rate.

Section 7 provides techniques to estimate the UCLs of failure rates based on the mean and standard deviation estimates produced by the techniques in Section 3 and Section 5.

2.3.5.2 Alternate and Supplementary Methods

Information provided in Section 8 is primarily based on field data. Field data is believed to be the most accurate source for failure rates. This does not preclude the use of additional sources of data that are technically sound. A key consideration to determine if the data source is technically sound is that the devices are operated in a similar manner as in the unit undergoing prediction.

These sources could include a device manufacturer's test data, or field data from a supplier or other source. Telcordia provides methods to incorporate this type of data into the SR-332 prediction. When incorporating vendor or laboratory test data, users must follow the Method II-D technique specified in Section 3.2. When incorporating field data, a user must follow the Method III-D techniques specified in Section 3.3. Both methods provide a blended value of the mean and standard deviation that weighs the strength of the supplemental data against the existing failure rate estimate given in Section 8.

The use of these methods (Method II-D or III-D) in a prediction should be explicitly described when applied in making predictions.

2.3.6 Automated Reliability Prediction Procedure (ARPP)

Telcordia supports a Microsoft Excel-based software tool called FD-ARPP-01, *Automated Reliability Prediction Procedure (ARPP)*, that performs the various calculations described in this document. Using the drop-down menu feature, the device category, subcategory, quality level, environment, and prediction method are selected. Operating temperature and electrical stress are entered at the unit level (which applies the same parameter to all devices), or may be entered at the device level for each individual device. Environmental factor and desired confidence level are entered at the unit level.

Laboratory and field data may also be integrated into the prediction calculation for the entire unit or for each individual device. Output parameters include total unit failure rate (FITs) and Mean-Time-Between-Failure (MTBF) with both mean and Upper Confidence Level (UCL) values provided.

The ARPP software tool is available as a companion to the SR-332 document when purchased.

3 Steady State Failure Rate Prediction for Devices

Depending on the amount of data available, the steady-state failure rate λ_{SS_i} for device i can be predicted using one of three techniques:

1. *Method I-D: Black Box*
   This technique assumes that no data is available from the laboratory or the field. The prediction is based solely on generic data available in this document.
2. *Method II-D: Black Box Integrated with Laboratory Data*
   This technique assumes that relevant laboratory data on the device is available. The technique weights the laboratory data against the generic data to produce a refined prediction of the failure rate.
3. *Method III-D: Black Box Integrated with Field Data*
   This technique assumes that relevant field data on the device is available. The technique weights the field data against the generic data to produce a refined prediction of the failure rate.

Note that all three techniques require a black box prediction of the failure rate. The additional data in the other two techniques are used to improve the accuracy of the prediction for a particular device.

The techniques are used to calculate the mean and standard deviation of the device steady-state failure rate, λ_{SS_i} and σ_{SS_i}, respectively. Note that the standard deviation of the device steady-state failure rate needs to be calculated only if an Upper Confidence Level (UCL) of the failure rate is to be calculated for a device or unit; otherwise, its calculation may be skipped.

3.1 Method I-D: Black Box Technique

The prediction of the steady-state failure rate for a device is based on a generic steady-state failure rate for the type of device. This generic value is then modified for quality, stress, and temperature. The mean black box steady-state failure rate, λ_{BB_i}, is:

$$\lambda_{BB_i} = \lambda_{G_i}\pi_{Q_i}\pi_{S_i}\pi_{T_i} \tag{3-1}$$

and the standard deviation of the black box steady-state failure rate is

$$\sigma_{BB_i} = \sigma_{G_i}\pi_{Q_i}\pi_{S_i}\pi_{T_i} \tag{3-2}$$

where

λ_{G_i} = *mean generic steady-state failure rate* for device i (Section 8).

σ_{G_i} = *standard deviation of the generic steady-state failure rate* for device i (Section 8).

π_{Q_i} = *Quality Factor* for device i (Section 9.3).

π_{S_i} = *Electrical Stress Factor* for device i (Section 9.2) based on the percent electrical stress. If stress is unknown, use 1, which assumes 50% electrical stress.

π_{T_i} = *Temperature Factor* for device *i* (Section 9.1) based on normal operating temperature during the steady state. If the temperature is unknown, use 1, which assumes 40°C.

When there is no laboratory data or field data for the device available, the mean and standard deviation of the device steady-state failure rate, λ_{SS_i} and σ_{SS_i}, respectively, are equal to the mean and standard deviation of the black box steady-state failure rate:

$$\lambda_{SS_i} = \lambda_{BB_i} \text{ and } \sigma_{SS_i} = \sigma_{BB_i} \quad \textbf{(3-3)}$$

3.2 Method II-D: Techniques Integrating Laboratory Data

Two techniques are available for using laboratory data to predict steady-state device failure rate. The technique to use depends on whether the devices in the laboratory test were burned-in or not. In either case, the mean and standard deviation of the device steady-state failure rate are, respectively,

$$\lambda_{SS_i} = \frac{\lambda_{BB_i}(2+n)}{A} \text{ and } \sigma_{SS_i} = \frac{\lambda_{BB_i}\sqrt{2+n}}{A} \quad \textbf{(3-4)}$$

where n is the number of device failures in the laboratory test, and λ_{BB_i} is the black box steady-state failure rate described in Section 3.1. The techniques differ only in the calculation of A. This prediction technique is based on "A Bayes Procedure for Combining Black Box Estimates and Laboratory Tests."

This method may be applied using laboratory data for a similar counterpart to the subject device of the prediction. In determining whether a device from a laboratory test is a suitable counterpart for the subject device, the similarity of the wafer process, device materials, assembly process, transistor structure, and external packaging should be considered.

3.2.1 When Laboratory Test Devices Had No Previous Burn-in

- If $T_1 \leq 10{,}000$ hours, then use the following value for A in Equation 3-4:

$$A = 2 + 4 \times 10^{-6} \times N_0 T_1^{0.25} \lambda_{G_i} \pi_{Q_i} \quad \textbf{(3-5)}$$

- If $T_1 > 10{,}000$ hours, then use the following value for A in Equation 3-4:

$$A = 2 + 10^{-9} \times N_0 (T_1 + 30{,}000) \lambda_{G_i} \pi_{Q_i} \quad \textbf{(3-6)}$$

where

λ_{G_i} = the device generic failure rate in FITs. If no generic failure rate is listed in Section 8, then a failure rate from another source may be used (see Section 2.3.4).

N_0	=	number of devices on test.
T_1	=	effective time on test in hours is $T_a \times A_L$ given the actual time on test (T_a) and the laboratory test temperature acceleration factor (A_L) from Curve 7, Table 9-1.
π_{Q_i}	=	laboratory test device Quality Factor from Table 9-4.

3.2.2 When Laboratory Test Devices Had Previous Burn-in

When there is burn-in, prediction is more complicated. Use the following value for A in Equation 3-4:

$$A = 2 + 4 \times 10^{-6} \times N_0 W \lambda_{G_i} \pi_{Q_i} \quad \textbf{(3-7)}$$

where π_{Q_i}, λ_{G_i}, and N_0 are defined as in the previous subsection.

The time factor W is based on the effective time on test (T_1 as described in the previous subsection) and on the total effective burn-in time for devices (T_e):

- If $T_e > 10{,}000$, then

$$W = T_1 / 4{,}000$$

- If $T_1 + T_e \leq 10{,}000$, then

$$W = (T_1 + T_e)^{0.25} - T_e^{0.25}$$

- Otherwise,

$$W = ((T_1 + T_e)/4{,}000) + 7.5 - T_e^{0.25}$$

The total effective burn-in time for devices (T_e) is

$$T_e = A_{b,d}\, t_{b,d}$$

where

$A_{b,d}$	=	temperature acceleration factor (from Curve 7, Table 9-1) due to device burn-in
$t_{b,d}$	=	device burn-in time (hours)

3.3 Method III-D: Techniques Integrating Field Data

Here the steady-state failure rate for device i is obtained as a weighted average of the black box steady-state failure rate and the field failure rate. The technique assumes that the black box steady-state failure rate is based on data that includes two failures.

The *subject* is the device for which a failure rate prediction is being made. The *tracked system* is the hardware system for which field failure data exists. In order for this data to be applicable to a prediction of the subject failure rate, the tracked system must contain a counterpart device identical or similar to the subject. In determining whether such a device is a suitable counterpart for the subject device, the similarity of the wafer process, assembly process, transistor structure, and external packaging should be considered.

The user of this method must ensure that the necessary processes and controls are in place to accurately account for all field failures. Field data from device vendors may be inadequate because they usually have limited visibility on how their devices are used and what processes are in place for return and repair. In addition:

- The quality level (see Table 9-4) of the subject must be equal to or better than the quality levels of the devices in the tracked systems.
- The environmental level of the subject must be the same or less severe than the environmental level of the tracked system.
- The field tracking study must cover an elapsed clock time of at least 3,000 hours.

The mean and standard deviation of the subject device steady-state failure rate are, respectively,

$$\lambda_{SS_i} = \frac{2+f}{B} \quad \text{and} \quad \sigma_{SS_i} = \frac{\sqrt{2+f}}{B} \qquad \textbf{(3-8)}$$

where

$$B = \frac{2}{\lambda_{BB_i}} + \frac{Vt\pi_{E_C}}{10^9} \qquad \textbf{(3-9)}$$

t	=	Total operating hours of the subject's counterpart in the tracked systems
f	=	Field failure count (number of failures of the subject's counterpart observed in the tracked systems in time t)
V	=	Factor to adjust for differences between the subject and its counterpart in the tracked systems (see Section 3.3.2)
π_{E_C}	=	*Environment Factor* for the tracked systems (Table 9-5)
λ_{BB_i}	=	the black box failure rate prediction for the subject device i.

These elements of the equation are described in more detail in the following subsections.

3.3.1 Total Operating Hours

Total operating hours is the total exposure of the subject's counterpart as tracked in the field. Suppose these systems have been tracked for T system-hours. If each system contains N_U units, each containing N_D counterpart devices comparable to the subject device, then $t = N_D \times N_U \times T$.

To use this technique, the total operating hours must be sufficiently long to provide a reasonable opportunity for at least two failures to have occurred. In order to assure this, either

- The number of field failures f must be greater than or equal to two

  OR

- The following inequality must be satisfied:

$$t \geq \frac{2 \times 10^9}{\lambda_{BB_C} \times \pi_{E_C}}$$

where λ_{BB_C} is the black box failure rate prediction and π_{E_C} is the Environment Factor for the subject's counterpart in the tracked system. Note that if the subject and its counterpart are identical, then $\lambda_{BB_C} = \lambda_{BB_i}$.

3.3.2 Adjustment Factor (V)

If the subject and its counterpart in the tracked system are identical and used under the same temperature and electrical stress conditions, then no adjustment is needed ($V = 1$).

If the subject and its counterpart in the tracked systems are similar, but

- have different quality levels, or
- are used under different temperature and/or electrical stress conditions, then

$$V = \frac{\lambda_{BB_C}}{\lambda_{BB_i}}$$

where λ_{BB_C} is the black box failure rate prediction for the counterpart in the tracked system.

3.4 Examples

This section contains an example calculation for each of the three cases. All of the examples assume that a reliability prediction is needed for device A65BC, a digital bipolar non-hermetic integrated circuit with 30 gates. Quality Level II is assumed. The device will operate at 45°C at 50% electrical stress.

3.4.1 Example 1: Method I-D, Black Box Technique

The technique requires the following elements:

- λ_{G_i} = *generic mean steady-state failure rate*. Table 8-7 shows that a digital bipolar integrated circuit with 30 gates has a generic mean failure rate of 1.2 FITs.
- σ_{G_i} = *standard deviation of generic steady-state failure rate*. Table 8-7 shows that the standard deviation of the generic mean failure rate of this device is 0.5 FITs.
- π_{Q_i} = *Quality Factor*. Table 9-4 indicates that Quality Level II has a Quality Factor of 1.
- π_{S_i} = *Electrical Stress Factor*. Section 8.5 specifies that the Electrical Stress Factor equals 1 for integrated circuits.
- π_{T_i} = *Temperature Factor*. Table 8-6 specifies that Curve 6 in Table 9-1 should be used to determine temperature stress for digital bipolar integrated circuits with 30 gates. Based on the operating temperature of 45°C, this curve gives a Temperature Factor of 1.2.

To estimate the mean failure rate, the basic equation used is Equation 3-1 in Section 3.1:

$$\lambda_{BB_i} = \lambda_{G_i}\pi_{Q_i}\pi_{S_i}\pi_{T_i} = 1.2 \times 1 \times 1 \times 1.2 = 1.44 \text{ FITS.}$$

The estimate of the standard deviation of the failure rate is based on Equation 3-2 in Section 3.1:

$$\sigma_{BB_i} = \sigma_{G_i}\pi_{Q_i}\pi_{S_i}\pi_{T_i} = 0.5 \times 1 \times 1 \times 1.2 = 0.6 \text{ FITS.}$$

This technique assumes that no data from laboratory testing or field tracking studies is available. The prediction of the device's failure rate is based entirely on generic data contained in this report. So,

$$\lambda_{SS_i} = \lambda_{BB_i} = 1.44 \text{ FITS and } \sigma_{SS_i} = \sigma_{BB_i} = 0.6 \text{ FITS.}$$

3.4.2 Example 2: Method II-D, Integrating Laboratory Test Data

Assume that N_0 = 2,000 A65BC devices are tested at 100°C for T_a = 1,000 hours, resulting in n = 4 failures of device A65BC.

The effective time on test is:

$$T_1 = T_a \times A_L = 1{,}000 \times 11 = 11{,}000 \text{ hours,}$$

where the acceleration factor (A_L) comes from Table 9-1, Curve 7, based on the 100°C test temperature.

3.4.2.1 Example 2a: No Burn-In of Laboratory Test Devices

Since T_1 > 10,000 hours, then Equation 3-6 is used for A:

$$\begin{aligned} A &= 2 + 10^{-9} \times N_0(T_1 + 30{,}000)\lambda_{G_i}\pi_{Q_i} \\ &= 2 + 10^{-9} \times 2{,}000 \times (11{,}000 + 30{,}000) \times 1.2 \times 1 \\ &= 2.10 \end{aligned}$$

Using Equation 3-4,

$$\lambda_{SS_i} = \frac{\lambda_{BB_i}(2+n)}{A} = \frac{1.44 \times (2+4)}{2.10} = 4.11 \text{ FITs}$$

and

$$\sigma_{SS_i} = \frac{\lambda_{BB_i}\sqrt{2+n}}{A} = \frac{1.44 \times \sqrt{2+4}}{2.10} = 1.68 \text{ FITs}.$$

Note that the laboratory test data has increased the predicted unit failure rate compared to the black box prediction based solely on industry-wide data in this report.

3.4.2.2 Example 2b: Previous Burn-In of Laboratory Test Devices

Using Equation 3-7:

$$\begin{aligned} A &= 2 + 4 \times 10^{-6} \times N_0 W \lambda_{G_i}\pi_{Q_i} \\ &= 2 + 4 \times 10^{-6} \times 2{,}000 \times W \times 1.2 \times 1 \\ &= 2 + 0.0096 \times W \end{aligned}$$

Only W is needed to complete the calculation of A. The value of W reflects the burn-in of the laboratory test devices. Assume that laboratory test devices have $t_{b,d}$ = 168 hours of device burn-in at 150°C. Based on this temperature, $A_{b,d}$ = 47 using Curve 7 of Table 9-1. To calculate W, first calculate total effective burn-in time for laboratory test devices:

$$T_e = A_{b,d}\, t_{b,d} = 47 \times 168 = 7{,}896 \text{ hours.}$$

Adding this to T_1 = 11,000 hours, we get $T_1 + T_e$ = 18,896 hours.

Since $T_1 + T_e > 10{,}000 \geq T_e$, then

$$W = ((T_1 + T_e)/4{,}000) + 7.5 - T_e^{0.25} = (18{,}896/4{,}000) + 7.5 - 7{,}896^{0.25} = 2.80.$$

Therefore, using Equation 3-4,

$$\lambda_{SS_i} = \frac{\lambda_{BB_i}(2+n)}{A} = \frac{1.44 \times (2+4)}{2 + 0.0096 \times 2.80} = 4.26 \text{ FITs}$$

and

$$\sigma_{SS_i} = \frac{\lambda_{BB_i}\sqrt{2+n}}{A} = \frac{1.44 \times \sqrt{2+4}}{2 + 0.0096 \times 2.80} = 2.45 \text{ FITs}.$$

Note that the prediction of the steady-state failure rate is higher if laboratory test devices had burn-in prior to testing. Devices with burn-in are not expected to fail as often as the same devices with no burn-in.

3.4.3 Example 3: Method III-D, Integrating Field Data

Assume that field data exists for the unit for $t = 10^8$ total operating hours in a ground fixed, uncontrolled environment ($\pi_{E_C} = 2$). During the study, $f = 8$ failures were observed. Using Equation 3-9,

$$B = \frac{2}{\lambda_{BB_i}} + \frac{Vt\pi_{E_C}}{10^9} = \frac{2}{1.44} + \frac{V \times 10^8 \times 2}{10^9} = 1.39 + 0.2 \times V.$$

Using Equation 3-8,

$$\lambda_{SS_i} = \frac{2+f}{B} = \frac{2+8}{1.39 + 0.2 \times V} = \frac{10}{1.39 + 0.2 \times V}$$

and

$$\sigma_{SS_i} = \frac{\sqrt{2+f}}{B} = \frac{\sqrt{2+8}}{1.39 + 0.2 \times V} = \frac{3.16}{1.39 + 0.2 \times V}.$$

The steady-state failure rate prediction depends on the similarities between the subject and its counterpart in the field systems as reflected by the adjustment factor *V*.

3.4.3.1 Example 3a: Subject Device is in Test Unit and Operated at the Same Temperature and Electrical Stress

In this case, $V = 1$, so

$$\lambda_{SS_i} = \frac{10}{1.39 + 0.2 \times 1} = 5.59 \text{ FITs} \text{ and } \sigma_{SS_i} = \frac{3.16}{1.39 + 0.2 \times 1} = 1.25 \text{ FITs}.$$

3.4.3.2 Example 3b: Subject Device is in Test Unit but Operated at Different Temperature

Assume that the test unit was operated at a temperature of 50°C. Recall that the subject device is operated at 45°C. The Temperature Factors for the test system and subject are obtained from Table 9-1, Curve 6: $\pi_{T_C} = 1.5$ and $\pi_{T_i} = 1.2$.

In this case,

$$V = \frac{\lambda_{BB_C}}{\lambda_{BB_i}} = \frac{\lambda_{G_C}\pi_{Q_C}\pi_{S_C}\pi_{T_C}}{\lambda_{G_i}\pi_{Q_i}\pi_{S_i}\pi_{T_i}} = \frac{\lambda_{G_i}\pi_{Q_i}\pi_{S_i}\pi_{T_C}}{\lambda_{G_i}\pi_{Q_i}\pi_{S_i}\pi_{T_i}} = \frac{\pi_{T_C}}{\pi_{T_i}} = \frac{1.5}{1.2} = 1.25$$

since the subject device and its counterpart in the tracked system are similar devices of the same quality and are used with the same electrical stress.

So,

$$\lambda_{SS_i} = \frac{10}{1.39 + 0.2 \times 1.25} = 6.10 \text{ FITs} \text{ and } \sigma_{SS_i} = \frac{3.16}{1.39 + 0.2 \times 1.25} = 1.93 \text{ FITs}.$$

Note that the predicted failure rate is lower since the field units were operated at a greater degree of temperature stress.

4 Early Life Factor Prediction for Devices

The Early Life Factor for a device $\pi_{\mathrm{EL_i}}$ is the ratio of its early life failure rate to its steady-state failure rate. Two techniques are used to estimate the Early Life Factor for a device, depending on the amount of burn-in. Burn-in may be performed on the device alone, a unit containing the device, and a system containing the device.

4.1 Early Life Factor for Device with Limited or No Burn-In

When burn-in is less than or equal to 1 hour, the Early Life Factor is determined by the Temperature Factor (π_{T_i} from Table 9-1) and Electrical Stress Factor (π_{S_i} from Table 9-2) under normal operating conditions:

- If $1.14 \geq \pi_{T_i}\pi_{S_i}$, then

$$\pi_{\mathrm{EL_i}} = \frac{4}{(\pi_{T_i}\pi_{S_i})^{0.75}} . \quad \textbf{(4-1)}$$

- Otherwise,

$$\pi_{\mathrm{EL_i}} = 1 + \frac{3}{\pi_{T_i}\pi_{S_i}} . \quad \textbf{(4-2)}$$

4.2 Early Life Factor for Device with Extensive Burn-In

The computation of the device Early Life Factor is a two-step process:

- *Step 1*: Calculate the device *equivalent operating time from burn-in* t_{e_i}.
- *Step 2*: Calculate the device Early Life Factor based on the equivalent operating time, the electrical stress, and the normal operating temperature.

4.2.1 Equivalent Operating Time for Burn-in

This quantity is the sum of the device, unit, and system burn-in times weighted by burn-in acceleration factors[1]:

(4-3)

$$t_{e_i} = \frac{A_{b,d}t_{b,d} + A_{b,u}t_{b,u} + A_{b,s}t_{b,s}}{A_{op}\ \pi_{S_i}}$$

1. This equation assumes that electrical stress is 50% during burn-in.

where

$A_{b,d}$	=	Arrhenius acceleration factor (Table 9-1, Curve 7) corresponding to the device burn-in temperature
$t_{b,d}$	=	device burn-in time (hours)
$A_{b,u}$	=	Arrhenius acceleration factor (Table 9-1, Curve 7) corresponding to the unit burn-in temperature
$t_{b,u}$	=	unit burn-in time (hours)
$A_{b,s}$	=	Arrhenius acceleration factor (Table 9-1, Curve 7) corresponding to the system burn-in temperature
$t_{b,s}$	=	system burn-in time (hours)
A_{op}	=	temperature acceleration factor (Table 9-1, Curve 7) corresponding to normal operating temperature. If the temperature is unknown, use 1, which assumes 40°C.

4.2.2 Early Life Factor

Let $X = t_{e_i}\pi_{T_i}\pi_{S_i}$ and $Y = X + 8760 \times \pi_{T_i}\pi_{S_i}$.

- If $X \geq 10{,}000$, then $\pi_{EL_i} = 1$.
- If $Y \leq 10{,}000$, then

$$\pi_{EL_i} = \frac{0.46 \times [Y^{0.25} - X^{0.25}]}{\pi_{T_i}\pi_{S_i}}. \qquad \textbf{(4-4)}$$

- Otherwise,

$$\pi_{EL_i} = \frac{1.14}{\pi_{T_i}\pi_{S_i}}\left[\frac{X}{10{,}000} - 4\left[\frac{X}{10{,}000}\right]^{0.25} + 3\right] + 1. \qquad \textbf{(4-5)}$$

4.3 Examples

This section contains an example calculation for each of the two cases. As in the examples in Section 3.4, both examples assume that a reliability prediction is needed for device A65BC, a digital bipolar non-hermetic integrated circuit with 30 gates. Quality Level II is assumed. The device will operate at 45°C at 50% electrical stress, as established in Section 3.4, $\pi_{T_i} = 1.2$ and $\pi_{S_i} = 1$.

4.3.1 Example 1: Limited or No Burn-In

Since $\pi_{T_i}\pi_{S_i} = 1.2 \times 1 = 1.2 > 1.14$, then, using Equation 4-2, the Early Life Factor is:

$$\pi_{EL_i} = 1 + \frac{3}{\pi_{T_i}\pi_{S_i}} = 1 + \frac{3}{1.2} = 3.5.$$

4.3.2 Example 2: Extensive Burn-In

Assume that the device has had 168 hours of device burn-in at 150°C, 72 hours of unit burn-in at 70°C, and no system burn-in. According to these assumptions, the following are the values for the burn-in parameters:

- Device burn-in time $t_{b,d}$ = 168
- Device Arrhenius acceleration factor $A_{b,d}$ = 47 (corresponding to the device burn-in temperature of 150°C in Table 9-1, Curve 7)
- Unit burn-in time $t_{b,u}$ = 72
- Unit Arrhenius acceleration factor $A_{b,u}$ = 3.7 (corresponding to the unit burn-in temperature of 70°C in Table 9-1, Curve 7)
- System burn-in time $t_{b,s}$ = 0
- Temperature acceleration factor A_{op} = 1.3 (corresponding to the operating temperature of 45°C in Table 9-1, Curve 7).

The first step is to calculate the equivalent operating time for burn-in:

$$t_{e_i} = \frac{A_{b,d}t_{b,d} + A_{b,u}t_{b,u} + A_{b,s}t_{b,s}}{A_{op}\ \pi_{S_i}} = \frac{47 \times 168 + 3.7 \times 72 + 0}{1.3 \times 1} = 6{,}279$$

Since

$$X = t_{e_i}\pi_{T_i}\pi_{S_i} = 6{,}279 \times 1.2 \times 1 = 7{,}535 < 10{,}000$$

and

$$Y = X + 8760 \times \pi_{T_i}\pi_{S_i} = 7{,}535 + 8{,}760 \times 1.2 \times 1 = 18{,}047 > 10{,}000$$

then, using Equation 4-5,

$$\begin{aligned}
\pi_{EL_i} &= \frac{1.14}{\pi_{T_i}\pi_{S_i}}\left[\frac{X}{10{,}000} - 4\left[\frac{X}{10{,}000}\right]^{0.25} + 3\right] + 1 \\
&= \frac{1.14}{1.2 \times 1}\left[\frac{7535}{10{,}000} - 4\left[\frac{7535}{10{,}000}\right]^{0.25} + 3\right] + 1 \\
&= 1.025
\end{aligned}$$

Note that the burn-in reduced the Early Life Factor so that the early life failure rate is only slightly higher than the steady-state failure rate.

5 Failure Rate Prediction for Units

The failure rate prediction for a unit is based on the failure rates predicted for its device components. This prediction technique is commonly known as the “Parts Count” method in which the mean unit failure rate λ_{SS} is assumed to be equal to the sum of the device failure rates. If data from laboratory tests or field studies of units are available, they can be used to modify the Parts Count prediction.

The techniques are used to calculate the mean and standard deviation of the unit steady-state failure rate, λ_{SS} and σ_{SS}, respectively. Note that the standard deviation of the unit steady-state failure rate needs to be calculated only if an Upper Confidence Level of the failure rate is to be calculated for the unit; otherwise, its calculation may be skipped.

5.1 Method I: Unit Steady-State Failure Rate Using the Parts Count Method

The *Parts Count prediction* for a unit computes the mean steady-state failure rate λ_{PC} as the sum of the mean device steady-state failure rate predictions λ_{SS_i} for all n device types in the unit[1], weighted by the quantity of each device type (N_i) and by the unit Environment Factor π_E.

Specifically, the mean steady-state failure rate is

$$\lambda_{PC} = \pi_E \sum_{i=1}^{n} L_i \tag{5-1}$$

and the standard deviation[2] of the steady-state failure rate of the unit is

$$\sigma_{PC} = \pi_E \sqrt{\sum_{i=1}^{n} C_i^2} \ . \tag{5-2}$$

1. For this calculation, a device type is a particular product. So, if Unit A consists of N_1 devices of a product with Part Number X, N_2 devices of a product with Part Number Y, and N_3 devices of a product with Part Number Z, then n= 3.

2. This calculation assumes that the failure rate estimates for the various device types that make up the unit are statistically independent. In actuality, these estimates are likely to be correlated to some degree. Thus, the application of Equation 5-2 as described provides a lower bound for the actual standard deviation. In most situations, the difference between this lower bound and accounting for the correlation should be relatively small. However, the application of Equation 5-5 can be generalized to account for this correlation; if a more conservative standard deviation estimate is desired, the definition of a device type in the footnote above can be expanded to all devices in the unit using the same failure rate data from Section 8.

For a given device type i:

- If all N_i devices of type i in the unit have the same quality and are used under the same temperature and electrical stress conditions in the unit, then

$$L_i = N_i \lambda_{SS_i} \text{ and } C_i = N_i \sigma_{SS_i} \quad \textbf{(5-3)}$$

The default standard deviation associated with the group of like devices uses the multiplier of N_i rather than the square root of N_i because the devices have nearly identical characteristics and are expected to behave in the same manner, thus exhibiting a strong correlation. If the user strongly believes that individual devices are independent, then the value square root of N_i may be used in Equation 5-3 for the standard deviation (σ_{SS_i}).

- Otherwise,

$$L_i = \lambda_{G_i} \times \sum_{k=1}^{K} N_{i(k)} \pi_{T_{i(k)}} \pi_{S_{i(k)}} \pi_{Q_{i(k)}} \quad \textbf{(5-4)}$$

and

$$C_i = L_i \text{ x } \sigma_{G_i} / \lambda_{G_i} \quad \textbf{(5-5)}$$

where the N_i devices of type i in the unit can be divided into K groups such that

$$N_i = \sum_{k=1}^{K} N_{i(k)}$$

and within each group k, all $N_{i(k)}$ devices have the same quality ($\pi_{Q_{i(k)}}$) and are used under the same temperature ($\pi_{T_{i(k)}}$) and electrical stress ($\pi_{S_{i(k)}}$) conditions in the unit. λ_{G_i} and σ_{G_i} are the mean generic steady-state failure rate for device type i and its standard deviation, respectively (as found in Section 8).

If no data from laboratory tests or field studies of this unit are available, the mean and standard deviation of the unit steady-state failure rate, λ_{SS} and σ_{SS} , respectively, are equal to the mean and standard deviation of the Parts Count steady-state failure rate prediction:

$$\lambda_{SS} = \lambda_{PC} \text{ and } \sigma_{SS} = \sigma_{PC} \; . \quad \textbf{(5-6)}$$

5.2 Method II: Integrating Laboratory Test Data on Units

Prediction of unit steady-state failure rate may be improved if data from units tested in the laboratory are available. Two techniques are available for using laboratory data to predict steady-state device failure rate. The technique to use depends on whether the units in the laboratory test were burned-in or not. In either case, the mean and standard deviation of the unit steady-state failure rate are, respectively,

$$\lambda_{SS} = \frac{2+n}{A} \text{ and } \sigma_{SS} = \frac{\sqrt{2+n}}{A} \quad \textbf{(5-7)}$$

where n is the number of unit failures in the laboratory test. The techniques differ only in the calculation of A.

This method may be applied using laboratory data for a similar counterpart to the subject unit of the prediction. In determining whether a unit from a laboratory test is a suitable counterpart for the subject unit, the similarity of the cooling design, assembly process, product functions, and potential failure modes/mechanisms should be considered.

5.2.1 When Laboratory Test Units Have No Previous Unit/Device Burn-In

When units are tested in the laboratory, the following formulas describe the calculation of the unit steady-state failure rate:

- If $T_1 \leq 10{,}000$, then use the following value for A in Equation 5-7:

$$A = \frac{2}{\lambda_{PC}} + \frac{4 \times N_0 T_1^{0.25}}{\pi_E \pi_T \times 10^6} \quad \textbf{(5-8)}$$

- If $T_1 >$ 10,000 hours, then use the following value for A in Equation 5-7:

$$A = \frac{2}{\lambda_{PC}} + \frac{N_0(T_1 + 30{,}000)}{\pi_E \pi_T \times 10^9} \quad \textbf{(5-9)}$$

where

λ_{PC}	=	the unit parts count failure rate in FITs as described in Section 5.1.
π_E	=	unit *Environment Factor* (Table 9-5).
π_T	=	*Temperature Factor* for unit (Table 9-1, Curve 7) based on normal operating temperature during the steady state. If the temperature is unknown, use 1, which assumes 40°C.
N_0	=	number of units on test.
T_1	=	effective time on test in hours. The effective time on test is the product of the actual time on test (T_a) and the laboratory test temperature acceleration factor (A_L) from Table 9-1, Curve 7.

5.2.2 When Laboratory Test Units Had Previous Burn-in

When there is burn-in, prediction is more complicated. Use the following value for A in Equation 5-7:

$$A = \frac{2}{\lambda_{PC}} + \frac{4 \times N_0 W}{\pi_E \pi_T \times 10^6} \quad \textbf{(5-10)}$$

where λ_{PC}, π_E, π_T, and N_0 are defined as in the previous subsection.

The time factor W is based on the effective time on test (T_1 as described in the previous subsection) and on the total effective burn-in time for units (T_e):

- If $T_e > 10{,}000$, then

$$W = T_1 / 4{,}000$$

- If $T_1 + T_e \le 10{,}000$, then

$$W = (T_1 + T_e)^{0.25} - T_e^{0.25}$$

- Otherwise,

$$W = ((T_1 + T_e)/4{,}000) + 7.5 - T_e^{0.25}$$

The total effective burn-in time for units tested in the laboratory (T_e) is

$$T_e = T^*_{b,d} + A_{b,u}\, t_{b,u}$$

where

$T^*_{b,d}$	=	average test device effective burn-in time.
$A_{b,u}$	=	temperature acceleration factor (from Table 9-1, Curve 7) corresponding to the test unit burn-in temperature.
$t_{b,u}$	=	test unit burn-in time (hours).

5.3 Method III: Integrating Field Data on Units

Here the steady-state failure rate for a unit is obtained as a weighted average of the Parts Count steady-state failure rate and the field failure rate. The technique assumes that the Parts Count steady-state failure rate is based on data that includes two failures.

The *subject* is the unit for which a failure rate prediction is being made. The *tracked system* is the hardware system for which field failure data exists. For this data to be applicable to a prediction of the subject failure rate, the tracked system must contain a counterpart unit identical or similar to the subject. In determining whether such a unit is a suitable counterpart for the subject unit, the similarity of the cooling design, assembly process, product functions and potential failure modes/ mechanisms should be considered. The user must ensure that the necessary processes and controls are in place to accurately account for all field failures. Failed units from the field may be discarded without notifying the vendor, which could significantly overestimate the unit reliability. In addition:

- The quality level (see Table 9-4) of the subject must be equal to or better than the quality levels of the units in the tracked systems.
- The environmental level of the subject must be the same or less severe than the environmental level of the tracked system.
- The field tracking study must cover an elapsed clock time of at least 3,000 hours.

The mean and standard deviation of the subject unit steady-state failure rate are, respectively,

$$\lambda_{SS} = \frac{2+f}{B} \quad \text{and} \quad \sigma_{SS} = \frac{\sqrt{2+f}}{B} \qquad \textbf{(5-11)}$$

where

$$B = \frac{2}{\lambda_{PC}} + \frac{Vt}{10^9} \qquad \textbf{(5-12)}$$

and

t	=	Total operating hours of the subject's counterpart in the tracked systems
f	=	Field failure count (number of failures of the subject's counterpart observed in the tracked systems during the field tracking study)
V	=	Factor to adjust for differences between the subject and its counterpart in the tracked systems
λ_{PC}	=	The Parts Count failure rate prediction for the subject unit.

These elements of the equation are described in more detail in the following subsections.

5.3.1 Total Operating Hours

Total operating hours is the total exposure of the subject's counterpart as tracked in the field. Suppose that these systems have been tracked for T system-hours. If each system contains N_U units, then $t = N_U \times T$.

To use this technique, the total operating hours must be long enough to provide a reasonable opportunity for at least two failures to have occurred. In order to assure this, either

- The number of field failures f must be greater than or equal to two

  OR

- The following inequality must be satisfied:

$$t \geq \frac{2 \times 10^9}{\lambda_{PC_C}}$$

where λ_{PC_C} is the Parts Count failure rate prediction for the subject's counterpart in the tracked system. Note that if the subject and its counterpart are identical, then $\lambda_{PC_C} = \lambda_{PC}$.

5.3.2 Adjustment Factor (V)

If the subject and its counterpart in the tracked system are identical, and the subject and tracked system are used under the same environment conditions (see Section 9.4), then no adjustment is needed ($V = 1$).

If the subject and its counterpart in the tracked system are identical, but the subject is used under environment conditions different than those for the tracked system, then $V = \pi_{E_C} \S \pi_{E_i}$, where π_{E_i} and π_{E_C} are the Environment Factors for the subject and its counterpart in the tracked system, respectively.

If a) the subject and its counterpart in the tracked system are similar but not identical, and/or b) they are used in different temperature or electrical stress conditions, then

$$V = \lambda_{PC_C} / \lambda_{PC}$$

where λ_{PC} and λ_{PC_C} are the Parts Count failure rates for the subject and its counterpart in the tracked system, respectively (see Section 5.1).

5.4 Unit Early Life Factor

A unit's Early Life Factor π_{EL} is a weighted average of the Early Life Factors for its devices π_{EL_i}:

$$\pi_{EL} = \frac{\sum_{i=1}^{n} L_i \pi_{EL_i}}{\lambda_{PC} / \pi_E} \quad \textbf{(5-13)}$$

5.5 Sampling Method - Using Default Temperature and Stress Factors on a Sample of Units

In cases where a large number of unit level predictions for a system are to be computed, providing Electrical Stress and Temperature Factors for each device in every unit level prediction may not be necessary. The question becomes on which units and for which devices can one assume the default Temperature and Electrical Stress factors. The following approach may be used:

1. Select a sample of ten unit designs that are representative of the system. Care must be used to avoid bias in the sample selection. This is particularly important when system-level parameters computed in a system reliability model are to be compared with the system-level parameters for a competing system. Use the following criteria:
   A. If any devices are burned-in, select ten unit designs that, on the whole, contain a proportion of these devices consistent with the proportion of burned-in devices in the system.
   B. Do not select unit designs for units that are subjected to unit-level burn-in. Predictions for these designs should be computed using the complete reliability prediction technique.
   C. Include unit designs that are used in large quantities in the system.
   D. Include unit designs that perform different functions, for example, power supplies and digital, analog, and memory units.
2. Perform a complete reliability prediction and calculate the Early Life Factor (π_{EL}) for each selected unit design.
3. Perform a *default* steady-state black box reliability prediction on *all* units using all default stress and Temperature Factors (excluding those in item 1B, above) and assuming no burn-in. That is, assume 50% stress and 40°C for all devices in the unit.
4. The average π_{EL} value determined from the sample in item 2 is applied to all non-sampled unit designs (excluding those in item 1B, above).
5. The average ratio between the selected steady-state black box predictions and the *default* steady-state black box prediction should be applied to all non-sampled designs (excluding those in item 1B, above).

If the sample adequately represents the total system, this approach will provide a reasonably accurate prediction of early life and steady-state unit failure rates with less effort than performing a complete reliability prediction on every unit design.

5.6 Examples

This section contains an example calculation for each of the three cases for steady-state failure rate and for Early Life Factor. All of the examples assume that a reliability prediction has been requested for a product called APPARATUS. This product consists of a single unit (called EXAMPLE) having the following devices with mean failure rate predictions λ_{SS_i} having standard deviations σ_{SS_i} and Early Life Factors π_{EL_i}:

Device Type	Quantity	λ_{SS_i} (FITs)	σ_{SS_i} (FITs)	π_{EL_i}
IC, Digital, Bipolar, Non-hermetic, 30 gates	17	1.2	0.5	1
IC, Digital, NMOS, Non-hermetic, 200 gates	14	20	14	1
Transistor, Silicon, PNP, ≤ 0.6 W	5	0.69	0.31	2.6
Capacitor, Discrete, Fixed, Ceramic	5	0.1	0.01	2.8
Single LED Segment	10	0.25	0.18	2.0

Note: The devices in this example have different Early Life Factors π_{EL_i} as a result of different degrees of device burn-in.

Device Quality Level I is assumed for the capacitors and the LED, and Device Quality Level II is assumed for all other devices on the unit. All devices are assumed to be operating at 40°C and 50% electrical stress. A prediction is needed assuming a Ground, Fixed, Uncontrolled environment ($\pi_E = 2$) (see Table 9-5).

All examples that follow (except Example 5) assume that all devices within a type have the same quality and are used under the same temperature and electrical stress conditions in the unit. Example 5 makes this assumption for all device types except Digital N-type Metal-Oxide Semiconductor (NMOS) Integrated Circuits (ICs) which have different operating temperatures.

5.6.1 Example 1: Method I, Parts Count Prediction

Using Equation 5-1 in Section 5.1, the mean steady-state failure rate prediction is

$$\begin{aligned}\lambda_{PC} &= \pi_E \sum_{i=1}^{n} L_i \\ &= \pi_E \sum_{i=1}^{n} N_i \lambda_{SS_i} \\ &= 2 \times [(17 \times 1.2) + (14 \times 20) + (5 \times 0.69) + (5 \times 0.1) + (10 \times 0.25)] \\ &= 614 \text{ FITs}\end{aligned}$$

and using Equation 5-2, the standard deviation of the steady-state failure rate prediction is

$$\begin{aligned}\sigma_{PC} &= \pi_E \sqrt{\sum_{i=1}^{n} C_i^2} \\ &= \pi_E \sqrt{\sum_{i=1}^{n} (N_i \sigma_{SS_i})^2} \\ &= 2 \times \sqrt{[(17 \times 0.5)^2 + (14 \times 14)^2 + (5 \times 0.31)^2 + (5 \times 0.01)^2 + (10 \times 0.18)^2]} \\ &= 392 \text{ FITs}\end{aligned}$$

5.6.2 Example 2: Early Life Factor

Using Equation 5-13 in Section 5.4

$$\begin{aligned}\pi_{EL} &= \frac{\sum_{i=1}^{n} L_i \pi_{EL_i}}{\lambda_{PC} / \pi_E} \\ &= \frac{\sum_{i=1}^{n} N_i \lambda_{SS_i} \pi_{EL_i}}{\lambda_{PC} / \pi_E} \\ &= \frac{(17 \times 1.2 \times 1) + (14 \times 20 \times 1) + (5 \times 0.69 \times 2.6) + (5 \times 0.1 \times 2.8) + (10 \times 0.25 \times 2)}{614 / 2} \\ &= 1.03\end{aligned}$$

Since the Early Life Factor is 1.03, then the mean failure rate for the early life period is

$$614 \times 1.03 = 632 \text{ FITs.}$$

5.6.3 Example 3: Method II, Integrating Laboratory Test Data

Assume that the unit will be normally operated at 40°C; using Table 9-1 (Curve 7), this gives $\pi_T = 1$. Recall from Example 1 that the Parts Count prediction was $\lambda_{PC} = 614$ FITs.

Assume 500 units are tested at 65°C for 1,000 hours, resulting in 3 failures. So, $N_0 = 500$, $n = 3$, and $T_a = 1{,}000$. Based on a laboratory test temperature of 65°C, Table 9-1 (Curve 7) gives acceleration factor $A_L = 3.0$. The effective time on test is:

$$T_1 = T_a \times A_L = 1{,}000 \times 3.0 = 3{,}000 \text{ hours}$$

5.6.3.1 Example 3a: No Previous Burn-In of Laboratory Test Units

Since $T_1 \leq 10{,}000$, then Equation 5-8 is used to calculate A:

$$A = \frac{2}{\lambda_{PC}} + \frac{4 \times N_0 T_1^{0.25}}{\pi_E \pi_T \times 10^6} = \frac{2}{614} + \frac{4 \times 500 \times 3000^{0.25}}{2 \times 1 \times 10^6} = 0.0107 .$$

Using Equation 5-7

$$\lambda_{SS} = \frac{2+n}{A} = \frac{2+3}{0.0107} = 469 \text{ FITs} \quad \text{and} \quad \sigma_{SS} = \frac{\sqrt{2+n}}{A} = \frac{\sqrt{2+3}}{0.0107} = 210 \text{ FITs} .$$

Note that the laboratory test data has reduced the predicted unit failure rate to about 60% of the Parts Count prediction based solely on industry-wide data in this report.

5.6.3.2 Example 3b: Previous Burn-In of Laboratory Test Units

Equation 5-10 is used to calculate A:

$$A = \frac{2}{\lambda_{PC}} + \frac{4 \times N_0 W}{\pi_E \pi_T \times 10^6} = \frac{2}{614} + \frac{4 \times 500 \times W}{2 \times 1 \times 10^6} = 0.00326 + W / 1000.$$

Only W is needed to complete the calculation of A. The value of W reflects the burn-in of the laboratory test units. Assume that laboratory test units have no device burn-in ($T^*_{b,d} = 0$), but do have $t_{b,u} = 1000$ hours of unit burn-in at 70°C. Based on this temperature, we find that $A_{b,u} = 3.7$ using Curve 7 of Table 9-1. To calculate W, first calculate total effective burn-in time for laboratory test units:

$$T_e = T^*_{b,d} + A_{b,u}\, t_{b,u} = 0 + (3.7 \times 1000) = 3{,}700 \text{ hours.}$$

Adding this to $T_1 = 3{,}000$ hours, we get $T_1 + T_e = 6{,}700$ hours. Since $T_1 + T_e \leq 10{,}000$, then

$$W = 6700^{0.25} - 3700^{0.25} = 1.25.$$

So,

$$A = 0.00326 + W/1000 = 0.00326 + 1.25/1000 = 0.00451.$$

Using Equation 5-7

$$\lambda_{SS} = \frac{2 + n}{A} = \frac{2 + 3}{0.00451} = 1109 \text{ FITs} \quad \text{and} \quad \sigma_{SS} = \frac{\sqrt{2 + n}}{A} = \frac{\sqrt{2 + 3}}{0.00451} = 496 \text{ FITs}.$$

Note that this mean estimate is more than two times greater than the prediction based on laboratory test units with no burn-in.

5.6.4 Example 4: Method III, Integrating Field Test Data

Field data exists for the unit for $t = 10^8$ hours. During the study, $f = 140$ failures were observed. Using Equation 5-12,

$$B = \frac{2}{\lambda_{PC}} + \frac{Vt}{10^9} = \frac{2}{614} + \frac{V \times 10^8}{10^9} = 0.00326 + V / 10.$$

Using Equation 5-11,

$$\lambda_{SS} = \frac{2 + f}{B} = \frac{2 + 140}{0.00326 + V/10} = \frac{1420}{0.0326 + V} \text{ FITs}$$

and

$$\sigma_{SS} = \frac{\sqrt{2 + f}}{B} = \frac{\sqrt{2 + 140}}{0.00326 + V/10} = \frac{119.2}{0.0326 + V} \text{ FITs}.$$

5.6.4.1 Example 4a: Subject Unit and Test Unit are Identical and Operated Under the Same Conditions

In this case, $V = 1$ so

$$\lambda_{SS} = \frac{1420}{0.0326 + V} = \frac{1420}{0.0326 + 1} = 1375 \text{ FITs}$$

and

$$\sigma_{SS} = \frac{119.2}{0.0326 + V} = \frac{119.2}{0.0326 + 1} = 115 \text{ FITs}.$$

5.6.4.2 Example 4b: Subject Unit and Test Unit are Identical but Operated in Different Environments

Assume that the test unit was operated in a Ground, Mobile environment ($\pi_{E_C} = 6$). In this case, $V = \pi_{E_C} / \pi_E = 6/2 = 3$.

So,

$$\lambda_{SS} = \frac{1420}{0.0326 + V} = \frac{1420}{0.0326 + 3} = 468 \text{ FITs}$$

and

$$\sigma_{SS} = \frac{119.2}{0.0326 + V} = \frac{119.2}{0.0326 + 3} = 39 \text{ FITs} .$$

5.6.4.3 Example 4c: Test Unit Is Similar but Not Identical to Subject Unit

Assume that the Parts Count prediction for the failure rate of the test unit is $\lambda_{PC_C} = 1200$ FITs. In this case, $V = \lambda_{PC_C} / \lambda_{PC} = 1200/614 = 1.954$.

So,

$$\lambda_{SS} = \frac{1420}{0.0326 + V} = \frac{1420}{0.0326 + 1.954} = 715 \text{ FITs}$$

and

$$\sigma_{SS} = \frac{119.2}{0.0326 + V} = \frac{119.2}{0.0326 + 1.954} = 60 \text{ FITs} .$$

5.6.5 Example 5: Method I, Parts Count Prediction, Devices Within a Device Type Have Different Operating Temperatures

Example 5 assumes that all devices within a type have the same quality and are used under the same temperature and electrical stress conditions in the unit except for device type 2 (Digital NMOS ICs), where eight of the devices are used at operating temperatures of 40°C while the other six are used at 50°C.

The N_2=14 Digital NMOS ICs are divided into

- Group 1 of $N_{2(1)}$ = eight devices at operating temperature 40°C, and
- Group 2 of $N_{2(2)}$ = six devices at operating temperature 50°C.

Using Temperature Stress Curve 8 (see Table 8-6) in conjunction with Table 9-1, $\pi_{T_{2(1)}} = 1$ and $\pi_{T_{2(2)}} = 1.7$.

The example assumes that $\pi_{S_{2(1)}} = \pi_{S_{2(2)}} = 1$ and $\pi_{Q_{2(1)}} = \pi_{Q_{2(2)}} = 1$.

Digital NMOS ICs with 200 gates have a mean generic failure rate $\lambda_{G_2} = 20$ FITs with standard deviation $\sigma_{G_2} = 14$ FITs (see Table 8-7).

Using Equation 5-4:

$$\begin{aligned} L_2 &= \lambda_{G_2} \times \sum_{k=1}^{K} N_{2(k)} \pi_{T_{2(k)}} \pi_{S_{2(k)}} \pi_{Q_{2(k)}} \\ &= \lambda_{G_2} \times [N_{2(1)} \pi_{T_{2(1)}} \pi_{S_{2(1)}} \pi_{Q_{2(1)}} + N_{2(2)} \pi_{T_{2(2)}} \pi_{S_{2(2)}} \pi_{Q_{2(2)}}] \\ &= 20 \times [(8 \times 1 \times 1 \times 1) + (6 \times 1.7 \times 1 \times 1)] \\ &= 364 \text{ FITs} \end{aligned}$$

and Equation 5-5:

$$C_2 = L_2 \times \sigma_{G_2} / \lambda_{G_2} = 364 \times 14 / 20 = 255 \text{ FIT.}$$

Using Equation 5-1, the mean unit steady-state failure rate prediction is

$$\begin{aligned} \lambda_{PC} &= \pi_E \sum_{i=1}^{n} L_i \\ &= 2 \times [(17 \times 1.2) + 364 + (5 \times 0.69) + (5 \times 0.1) + (10 \times 0.25)] \\ &= 782 \text{ FITs.} \end{aligned}$$

Using Equation 5-2, the standard deviation of the steady-state failure rate prediction is

$$\begin{aligned} \sigma_{PC} &= \pi_E \sqrt{\sum_{i=1}^{n} C_i^2} \\ &= 2 \times \sqrt{[(17 \times 0.5)^2 + (255)^2 + (5 \times 0.31)^2 + (5 \times 0.01)^2 + (10 \times 0.13)^2]} \\ &= 510 \text{ FITs.} \end{aligned}$$

6 System Reliability (Service Affecting Reliability Data)

This section describes the computation of reliability predictions for serial systems. A serial system is a system for which the failure of any unit results in the failure of the entire system. This section also provides an introduction to what is needed for non-serial systems.

6.1 Serial System Reliability

This section describes the computation of reliability predictions for serial systems.

6.1.1 Steady-State Failure Rate

If the specified reliability parameters, failure criteria, equipment configuration, and operating conditions indicate that a serial reliability model is appropriate, the total system failure rate, λ_{SYS}, will be the sum of all the unit steady-state failure rates, λ_{SS}. That is,

$$\lambda_{SYS} = \sum_{j=1}^{M} \lambda_{SS_{(j)}} \tag{6-1}$$

where $\lambda_{SS(j)}$ is the unit steady-state failure rate for unit *j*, and *M* is the number of units. The discussion in early subsections of Section 5 omitted the subscript *j* for simplicity because there was only one unit. Note that the unit steady-state failure rates are assumed to reflect only service-affecting failures. The standard deviation σ_{SYS} of the total system failure rate is

$$\sigma_{SYS} = \sqrt{\sum_{j=1}^{M} \sigma_{SS_{(j)}}^{2}} \ . \tag{6-2}$$

6.1.2 Early Life Factor

The Early Life Factor $\pi_{EL_{SYS}}$ for a serial system is given by the following:

$$\pi_{EL_{SYS}} = \frac{\sum_{j=1}^{M} \lambda_{SS_{(j)}} \pi_{EL_{(j)}}}{\lambda_{SYS}} \tag{6-3}$$

where $\pi_{EL_{(j)}}$ is the Early Life Factor for the j^{th} unit.

6.2 Non-Serial Systems

Most complex communications systems do not conform to a serial reliability model. A serial system is one in which the failure of any unit results in the failure of the entire system. Typically, there may be some redundancy in the equipment so that the failure of some unit may not result in the loss of service for any customers. In addition, some failures may not affect all customers so that different levels of failures have to be considered. Finally, the requesting organization may be interested in items like system downtime or system availability. In these cases, a simple serial model is generally not appropriate. In these cases, a suitable reliability/availability model must be developed.

To develop a reliability/availability model, the following information is needed:

- Steady-state failure rates for each of the units
- Repair rates (or distribution of repair times) of each of the units
- Description of the redundancy of each of the units
- Number of repair people available
- Any repair priorities
- Travel time distributions to repair sites
- Restoration times (including rebooting times)
- Number and availability of spares
- Alarms/failure detection capabilities
- Probability of successfully switching over to the standby unit when the active unit fails
- Description of manual and automatic diagnostic aids.

This information should be provided along with the source of the information. For example, if there is data on the repair times for some piece of equipment, this information should be provided. Anyone developing a reliability model needs to prepare drawings, diagrams, or specifications to substantiate the reliability model. Since most reliability models require the use of some software, the person developing the model needs to provide the name of the software used in the development of the reliability model.

To develop a representative reliability model requires the knowledge of a reliability engineer. A good reference on developing system reliability models is SR-1171, *Methods and Procedures for System Reliability Analysis*. Another reliability engineering reference is *Probabilistic Reliability: An Engineering Approach*.

More detail on the specification of reliability modeling techniques for complex systems is beyond the scope of this procedure.

7 Upper Confidence Levels for Failure Rates

The failure rate estimates for devices and units described in Section 3 and Section 5, respectively, are *mean* estimates. These estimates do not account for the uncertainty and variability in the data used to generate the generic device failure rates in Section 8. If a more conservative estimate of failure rates is desired, such as between 60% and 90% Upper Confidence Levels (UCLs), then the procedure can be used. Such an estimate means that there is only a 100% - 60% = 40% chance, or a 100% - 90% = 10% chance, that the predicted failure rate underestimates the true failure rate. The higher the UCL level, the more conservative the estimate and the greater the protection against underestimating the true failure rate.

This section presents techniques for estimating a UCL for a failure rate given the mean and standard deviation of the estimate as calculated using the techniques in Section 3 and Section 5. The techniques are described here for failure rate estimates of units; UCLs for device failure rates can also be calculated using these techniques by treating the device as a unit with one device.

7.1 Upper Confidence Level Calculation

The technique assumes that the failure rate follows a gamma distribution. Given the mean λ and standard deviation σ of the failure rate for the unit, the shape and scale parameters of the gamma distribution are:

$$\text{shape } \kappa = (\lambda / \sigma)^2 \qquad \textbf{(7-1)}$$

$$\text{scale } \theta = \sigma^2 / \lambda \qquad \textbf{(7-2)}$$

The P% Upper Confidence Level for the failure rate is the P% quantile of the gamma distribution with shape κ and scale θ. That is,

$$\lambda_{P\%UCL} = G^{-1}(P/100, \kappa, \theta) \qquad \textbf{(7-3)}$$

where the function G^{-1} is the inverse cumulative distribution function of the gamma distribution with the given shape and scale.

If the shape parameter is large (i.e., greater than 100), the UCL can also be calculated as the P% quantile of the normal distribution with mean λ and standard deviation σ. That is,

$$\lambda_{P\%UCL} = N^{-1}(P/100, \lambda, \sigma) \qquad \textbf{(7-4)}$$

where the function N^{-1} is the inverse cumulative distribution function of the normal distribution with mean λ and standard deviation σ

The inverse cumulative distribution functions of the gamma and normal distributions are standard functions in spreadsheet applications such as Microsoft® Excel®.

7.2 Examples

7.2.1 Example 1: 90% Upper Confidence Level of the Steady-State Failure Rate

The EXAMPLE unit described in Section 5.6.1 has the following parameter estimates:

- Mean steady-state failure rate λ_{SS} = 614 FITs
- Standard deviation of steady-state failure rate σ_{SS} = 392 FITs.

Using Equation 7-1, the shape κ of the gamma distribution for failure rate of the EXAMPLE unit is

$$\text{shape } \kappa = (614 / 392)^2 = 2.45$$

and, using Equation 7-2, the scale θ of the gamma distribution for failure rate of the EXAMPLE unit is

$$\text{scale } \theta = 392^2 / 614 = 250 \text{ FITs.}$$

The 90% Upper Confidence Level for the steady-state failure rate is

$$\lambda_{90\%UCL} = G^{-1}\,(90/100, 2.45, 250) = 1137 \text{ FITs.}$$

7.2.2 Example 2: 90% Upper Confidence Level of the Early Life Failure Rate

The Early Life Factor for the EXAMPLE unit is 1.11 as calculated in Section 5.6.2. Then the 90% Upper Confidence Level for the failure rate in the early life period is

$$1137 \times 1.11 = 1262 \text{ FITs.}$$

8 Device Parameter Values

This section presents generic parameter values for a variety of devices that can be used in the estimation of failure rates. The tables used in this presentation may be copied and used as needed. The parameters describe generic failure rates plus the temperature and electrical stress curves that influence the estimation.

The tables in this section give the mean point estimates λ_G of generic steady-state failure rates in FITs for a variety of devices. The tables also provide standard deviations σ_G in FITs for each device failure rate. The standard deviation is a reflection of the strength of the data supporting the mean failure rate estimate; the smaller the standard deviation is in proportion to the mean, the more accurate the estimate. The standard deviation values are only used if an upper confidence level for a failure rate is to be estimated. The failure rate means and standard deviations are rounded to two significant digits.

The steady-state failure rates represent the device reliability before Wear-Out occurs (typically > 20 years). However, some devices such as electrolytic capacitors, crystal oscillators, flash memory, fans and motors, hard disk drives, lasers, and other optical devices may have a limited lifetime. For these devices with a limited lifetime, the failure rate applies to the “steady-state” or useful life of the devices before the point in time where Wear-Out occurs.

The mean and standard deviation values given in this section represent failure rates assuming for the default conditions of 40°C operating temperature, 50% electrical stress, Quality Level II, and G_B environmental factor 1 (i.e., $\pi_T = 1.0$, $\pi_S = 1.0$, $\pi_Q = 1.0$, and $\pi_E = 1.0$). Parameters are provided to adjust these values to the actual stress conditions used in the design. These parameters cannot be used to determine the reliability of a component operating outside of the vendor’s rated specifications limits. In fact, the formulas may not fully account for the impact to reliability when components are used at or near the specification limits. Under these conditions, the component becomes more susceptible to the normal variations occurring during manufacturing and use. Therefore, the component failure rates provided in this section assume that designs will employ adequate derating of key stress parameters. Section 9 describes these factors and their impact on failure rates.

Note that it is typically recommended that IC temperatures be derated from their maximum rated value. See ANSI/GEIA STD-0008, *TechAmerica Standard Derating of Electronic Components*, and other documents in Appendix B for further information on derating. For ICs with quality level less than QL II, additional derating may be required to account for the lower quality level of these devices.

Devices with no temperature or electrical stress curves listed either have no impact from these effects, or the impact on their failure rates is not well understood. Users are invited to contact the Telcordia technical contact given on page ii with any references or sources to non-proprietary industry sources that can be used in a future update.

The failure rates are based on data provided by several suppliers. New devices added and listed in the tables in this issue are in *italics*. Values in the tables and equations in Section 8 that have changed from Issue 3 are in **bold**. The remaining failure rates were not modified because no new data was available.

The tables do not include any failure rates for solder joints or bare circuit packs. The procedure assumes that board assembly manufacturers control their manufacturing processes (including soldering) in accordance with GR-357-CORE, *Generic Requirements for Assuring the Reliability of Components Used in Telecommunications Equipment*. Properly controlled soldering processes will result in negligible contribution to the board failure rate due to solder joint defects (see Section 2.3.3).

8.1 Capacitor Parameter Values

Table 8-1 lists parameter values for capacitor devices. The failure rate for a capacitor network should be calculated as a unit consisting of its individual capacitor devices.

Table 8-1 Capacitor Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)	ELEC. STRESS (Table 9-2)
FIXED				
Paper	5.1	3.6	2	J
Paper/Plastic	0.76	0.24	2	J
Plastic	0.46	0.13	3	J
Mica	0.44	0.30	7	G
Glass	0.55	0.33	7	G
Ceramic	0.10	0.01	1	H
Tantalum, Solid, Hermetic	0.95	0.23	3	J
Tantalum, Solid, Non-Hermetic	0.19	0.13	3	J
Tantalum, Nonsolid	3.6	2.5	3	G
Aluminum, Electrolytic				
$<$ 400 µF	0.73	0.17	7	E
$\geq$ 400 µF	**1.5**	**0.5**	7	E
Aluminum, Chassis Mounted				
$<$ 400 µF	21	15	7	E
$\geq$ 400 and $\leq$ 1200 µF	39	27	7	E
$>$ 1200 µF	54	38	7	E
Silicon Chip	1.0	4.4	7	G
MOS or Chip	0.41	0.19	7	G
VARIABLE				
Air, Trimmer	8.0	3.8	5	H
Ceramic	4.0	1.9	3	J
Piston, Glass	1.5	1.1	5	H
Vacuum	13	9.1	2	I

For capacitors, electrical stress percentage is based on voltage, specifically

$$\text{electrical stress percentage} = \frac{\text{Applied DC Voltage + AC Peak Voltage}}{\text{Rated Voltage}} .$$

8.2 Connector Parameter Values

Table 8-2 lists parameter values for connector devices. For all connector devices (except Electric Coaxial), the mean and standard deviation of failure rates are given as P x v, where P is the number of pins in the connector, and v is the FITs per pin.

The Electrical Stress Factor π_S equals 1 for connectors.

All connectors use temperature stress curve 7.

Table 8-2 Connector Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)[a]	σ_G (FITs)[a]	TEMP. STRESS (Table 9-1)
General Purpose, Power[b c]	P x 2.2	P x 1.2	7
Coaxial, Electric	**0.29**	**0.10**	7
Optical	P x 30	P x 9.5	7
Multi-Pin[b]	**P x 0.040**	**P x 0.010**	7
Printed Board, Edge	P x 0.13	P x 0.088	7
Ribbon Cable[b]	P x 0.10	P x 0.073	7
IC Socket[b]	P x 0.10	P x 0.047	7

a. Failure rates are derived from connectors that meet GR-1217-CORE, *Generic Requirements for Separable Electrical Connectors Used in Telecommunications Hardware*, Service Level II requirements or greater, and are used within the durability limits (number of mating cycles) specified. Operation beyond the durability limits may result in Wear-Out, where these failure rates do not apply. See GR-1217 for more information.

b. Failure rates are per contact pair. Pins that are "no connects" can be discounted from the total number of pins in the connector for a more refined prediction.

c. Power connectors distribute AC or DC power throughout the system; typically, -48V DC in telecom equipment. Power connectors are typically larger than other circuit connectors in order to handle higher current.

8.3 Diode Parameter Values

Table 8-3 lists parameter values for diode devices.

Table 8-3 Diode Failure Rate Parameters*

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)	ELEC. STRESS (Table 9-2)
SILICON				
General Purpose				
≤ 20 AMP	0.33	0.23	4	F, K
> 20 AMP	4.6	3.3	4	F, K
Microwave Detector	51	36	3	F
Microwave Mixer	1.42	0.71	3	F
GERMANIUM				
General Purpose				
< 1 AMP	6.2	4.4	8	F, K
≥ 1 and ≤ 20 AMP	15	11	8	F, K
> 20 AMP	62	44	8	F, K
Microwave Detector	140	98	8	F
Microwave Mixer	260	180	8	F
VOLTAGE REGULATOR				
≤1.5 W	0.90	0.64	3	E
> 1.5 W	9.3	2.8	3	E
THYRISTOR				
≤ 1 AMP	13	5.2	4	F
> 1 AMP	72	23	4	F
TVS SURGE SUPPRESSOR	*2.55*	*0.81*	*4*	*F*
VARACTOR, STEP RECOVERY, TUNNEL	13	8.3	3	H
VARISTOR, SILICON CARBIDE	7.8	2.6	3	C
VARISTOR, METAL OXIDE	5.1	3.6	3	C

***Note**: For rectifiers and diode networks, count individual diodes and use the table for the appropriate failure rate to multiply by the number of diodes.

Electrical Stress for Devices with One Stress Curve

For varactor, step recovery, and tunnel diodes, electrical stress percentage is based on power, specifically

$$\text{electrical stress percentage} = \frac{\text{Actual Dissipated Power}}{\text{Rated Power}} .$$

For zener diodes, electrical stress percentage is based on current or power, specifically

$$\text{electrical stress percentage} = \frac{\text{Actual Zener Current or Power}}{\text{Rated Zener Current or Power}}.$$

For other diodes, electrical stress percentage is based on current or power, specifically

$$\text{electrical stress percentage} = \frac{\text{Average Forward Current}}{\text{Rated Forward Current}}.$$

Electrical Stress for Devices with Two Stress Curves

The Electrical Stress Factor $\pi_S = \pi_{S_C}\pi_{S_V}$

where

π_{S_C} is the Electrical Stress Factor determined using the first curve with electrical stress determined by the ratio of operating current to rated current and

π_{S_V} is the Electrical Stress Factor determined using the second curve with electrical stress determined by the ratio of operating voltage to rated voltage.

8.4 Inductor Parameter Values

Table 8-4 lists parameter values for inductive devices.

The Electrical Stress Factor π_S equals 1 for inductors.

All inductors use temperature stress curve 3.

Table 8-4 Inductor Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)
TRANSFORMER			
Pulse Low Level (< 5V)	3.0	0.90	3
Pulse High Level (≥ 5V)	9.8	6.9	3
Audio	2.1	0.78	3
Power (> 1W)	**5.0**	**2.0**	3
Radio Frequency	4.6	1.74	3
COIL			
Load Coil	0.90	0.30	3
Power Filter	0.24	0.07	3
Radio Frequency, Fixed	0.11	0.02	3
Radio Frequency, Variable	1.7	0.58	3
Ferrite Beads	0.1	0.07	3
Chip/Ceramic Filter	0.1	0.07	3

8.5 Integrated Circuit Parameter Values

This subsection describes failure rate parameter values for

- Analog Integrated Circuits
- Digital Integrated Circuits
- Random Access Memory
- Read Only Memory
- Microprocessors
- Microcontrollers
- Hybrid Microcircuits
- Gate Array and Program Array Logic.

The generic failure rates apply to both conventional (through-hole) and surface mount technology (see Section 2.3.3).

This section gives the generic steady-state failure rates of integrated circuit devices irrespective of whether the integrated circuits are packaged (i.e., encapsulated) or are bare chips (i.e., unencapsulated).

The Electrical Stress Factor π_S equals 1 for integrated circuits.

Formulas in this section use "ln" for the natural logarithm function and "Exp" for the exponential function with base *e*.

Failure rates are shown in the following tables as a function of device complexity (transistors, gates, bits, or bus width). For many devices, such as memory and microprocessor devices, the complexity value is provided on the device data sheet. However, data sheets for many analog and digital integrated circuits do not provide this information. Therefore, for the most accurate failure rate estimate, it is recommended that this information be obtained from the device manufacturer. The user should note that the failure rates are generally provided for a range of complexity values so that an exact gate or transistor count is rarely necessary. In addition, the error associated with being slightly off is typically small, especially as the device complexity increases. If the user is still unable to determine the correct complexity range, the notes section of the ARPP software tool provides generic complexity values for a number of common component families. However, the use of these generic complexity values may result in additional uncertainty with the resulting prediction.

8.5.1 Analog Integrated Circuit Devices

The failure rates for analog integrated circuit devices are a function of the number of transistors in the device. The mean and standard deviation of the failure rate given the number of transistors T are calculated from the following equations[1]:

$$\lambda_G = 0.33T^{0.440} \tag{8-1}$$

and

$$\sigma_G = 0.707\lambda_G \; . \tag{8-2}$$

Table 8-5 lists failure rates for analog integrated circuit devices based on these equations.

The Temperature Curve for this device type is curve 9.

Table 8-5 Analog Integrated Circuit Failure Rates

DEVICE COMPLEXITY (Transistors)		λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)
Range	**Nominal**			
1-32	20	1.2	0.87	9
33-90	70	2.1	1.51	9
91-170	150	3.0	2.12	9
171-260	200	3.4	2.40	9
261-360	300	4.1	2.87	9
361-470	450	4.9	3.43	9
471-590	550	5.3	3.75	9
591-720	700	5.9	4.17	9
721-860	800	6.2	4.42	9
> 860		$0.33\ T^{0.440}$	$0.707\ \lambda_G$	9

1. Anecdotal information suggests that the mean failure rate for analog ICs should not exceed 50 FITs; however, since no data was provided, the analog IC failure rates were not updated.

8.5.2 Digital Integrated Circuit Devices

Table 8-6 provides the failure rate parameters for digital integrated circuit devices. The failure rates for digital integrated circuit devices are a function of technology (Bipolar, NMOS, and Complementary Metal-Oxide Semiconductor [CMOS]) and the number of gates in the device. The number of gates is equal to the number of logical gates on the device schematic. The mean and standard deviation of the failure rate (given the technology and the number of gates) are calculated from the equations given in Table 8-6.

Table 8-6 Digital Integrated Circuit Failure Rate Parameters

Technology	Failure Rate (FITs) as a function of the number of logical gates (G)	Temperature Curve
Bipolar	$\lambda_G = \mathrm{Exp}[-0.0445\ln G + 0.0268(\ln G)^2]$ $\sigma_G = \lambda_G[0.690 - 0.126\ln G + 0.0118(\ln G)^2]$	6
NMOS	$\lambda_G = 4.40(G + 100)^{0.243}$ $\sigma_G = 0.707\lambda_G$	8
CMOS	$\lambda_G = \mathrm{Exp}[0.55 + 0.0549\ln G + 0.00227(\ln G)^2]$ $\sigma_G = \lambda_G[0.513 - 0.0383\ln G + 0.00187(\ln G)^2]$	8

Table 8-7 lists failure rates for digital integrated circuit devices based on the above equations.

Table 8-7 Digital Integrated Circuit Failure Rates

DEVICE COMPLEXITY (Gates)		BIPOLAR		NMOS		CMOS	
		λ_G (FITs)	σ_G (FITs)	λ_G (FITs)	σ_G (FITs)	λ_G (FITs)	σ_G (FITs)
Range	**Nominal**						
1-20	15	1.1	0.5	14	9.9	2.04	0.86
21-50	40	1.2	0.5	15	10	2.19	0.87
51-100	80	1.4	0.5	16	11	2.30	0.88
101-500	400	2.0	0.7	20	14	2.61	0.92
501-1000	800	2.5	0.9	23	16	2.77	0.94
1001-2000	1600	3.1	1.2	27	19	2.94	0.98
2001-3000	2500	3.6	1.6	30	21	3.06	1.00
3001-5000	4000	4.4	2.0	33	23	3.19	1.04
5001-7500	6500	5.3	2.6	37	26	3.34	1.07
7501-10000	9000	6.2	3.2	40	29	3.45	1.10
10001-15000	13000	7.3	4.0	44	31	3.57	1.14
15001-20000	18000	8.5	5.0	48	34	3.69	1.17
20001-30000	25000	10.0	6.2	52	36	3.81	1.21
30001-50000	40000	12.7	8.6	58	41	4.00	1.27
50001-100000	80000	18.4	14.2			4.30	1.37
100001-1000000	550000					5.32	1.78
1000001-10000000	5500000					7.02	2.59
10000001-100000000	55000000					9.48	4.02
100000001-1000000000	550000000					13.12	6.56

8.5.3 Random Access Memory (RAM)

Table 8-8 provides the failure rate parameters for RAM devices. The parameters for RAM devices are a function of device type and technology (Static versus Dynamic and Bipolar, NMOS, or CMOS) and the number of bits in the device. The mean and standard deviation of the failure rate given the technology and the number of bits are calculated from the equations given in Table 8-8.

Table 8-8 Random Access Memory Failure Rate Parameters

Technology	Failure Rate (FITs) as a function of the number of Megabits (B)	Temperature Curve
Static Bipolar	$\lambda_G = 12.69(1024B + 0.25)^{0.378}$ $\sigma_G = 0.707\lambda_G$	6 if B > 0.00224 7 otherwise
Static NMOS	$\lambda_G = 2.0(1024B + 0.25)^{0.321}$ $\sigma_G = 0.707\lambda_G$	8 if B > 0.038 9 otherwise
Static CMOS	$\lambda_G = \mathrm{Exp}[2.2 + 0.141\ln B + 0.00442(\ln B)^2]$ $\sigma_G = \lambda_G[0.284 + 0.00441\ln B + 0.0112(\ln B)^2]$	8 if B > 0.038 9 otherwise
Dynamic NMOS/CMOS	$\lambda_G = \mathrm{Exp}[1.56 + 0.151\ln B + 0.00287(\ln B)^2]$ $\sigma_G = \lambda_G[0.371 - 0.0186\ln B + 0.00652(\ln B)^2]$	8 if B > 0.038 9 otherwise

Table 8-9 lists failure rates for Static RAM devices based on the above equations.

Table 8-9 Static Random Access Memory (SRAM) Failure Rates

DEVICE COMPLEXITY		BIPOLAR		NMOS		CMOS	
		λ_G (FITs)	σ_G (FITs)	λ_G (FITs)	σ_G (FITs)	λ_G (FITs)	σ_G (FITs)
Range	**Nominal**						
1-320 BITS	256 BITS	9.8	6.9	1.61	1.1	3.80	3.9
321-576	512 BITS	11	8.0	1.83	1.3	3.99	3.6
577-1120	1K[a]	14	9.8	2.16	1.5	4.21	3.3
1121-2240	2K	17	12	2.61	1.8	4.46	3.1
2241-5000	4K	22	16	3.21	2.3	4.74	2.8
5001-11000	8K	28	20	3.97	2.8	5.06	2.7
11001-17000	16K	36	26	4.93	3.5	5.43	2.5
17001-38000	32K	47	33	6.15	4.3	5.85	2.4
38001-74000	64K	61	43	7.67	5.4	6.33	2.3
74001-150,000	128K	79	56	9.57	6.8	6.88	2.2
150,001-300,000	256K	100	73	11.95	8.5	7.51	2.2
300,001-600,000	512K	130	95	14.93	10.6	8.23	2.4
600,001-1,200,000	1M[b]	170	120	18.51	13.1	9.03	2.6
1,200,001-2,400,000	2M	230	160	23.12	16.3	9.97	2.9
2,400.001-4,800,000	4M	290	210	28.88	20.4	11.07	3.4
4,800,001-9,600,000	8M	380	270	36.08	25.5	12.33	4.2
9,600,001-19,200,000	16M	500	350	45.07	31.9	13.80	5.3
19,200,001-38,400,000	32M	650	460	56.30	39.8	15.51	6.7
38,400,001-76,800,000	64M	840	590	70.33	49.7	17.51	8.7
76,800,001-153,600,000	128M	1100	770	87.41	61.8	19.79	11.2
153,600,001-307,200,000	256M	1400	1000	109.74	77.6	22.60	14.8

a. K equals 1024 BITS.

b. M equals 1024 K.

Table 8-10 lists failure rates for Dynamic Random Access Memory (DRAM) devices based on the equations in Table 8-8. DRAM includes:

- Flash Memory Cards,
- Solid State Drive/Disk (SSD), and
- Any other form of dynamic memory devices.

These failure rates are applicable to NMOS and CMOS DRAM devices, with or without an Error Correcting Code (ECC). The error-correcting effect of ECC should be modeled separately (e.g., for availability analysis).

Table 8-10 Dynamic Random Access Memory (DRAM) Failure Rates

DEVICE COMPLEXITY		λ_G (FITs)	σ_G (FITs)
Range	**Nominal**		
1-320 BITS	256 BITS	1.7	1.6
321-576	512 BITS	1.8	1.6
577-1120	1K[a]	1.9	1.6
1121-2240	2K	2.1	1.5
2241-5000	4K	2.3	1.5
5001-11000	8K	2.5	1.5
1101-17000	16K	2.7	1.5
17001-38000	32K	2.9	1.5
38001-74000	64K	3.2	1.5
74001-150,000	128K	3.5	1.5
150,001-300,000	256K	3.9	1.6
300,001-600,000	512K	4.3	1.7
600,001-1,200,000	1M[b]	4.8	1.8
1,200,001-2,400,000	2M	5.3	1.9
2,400.001-4,800,000	4M	5.9	2.1
4,800,001-9,600,000	8M	6.6	2.4
9,600,001-19,200,000	16M	7.4	2.7
19,200,001-38,400,000	32M	8.3	3.2
38,400,001-76,800,000	64M	9.4	3.8
76,800,001-153,600,000	128M	10.6	4.6
153,600,001-307,200,000	256M	12.0	5.6
307,200,001-614,400,000	512M	13.6	6.9
614,400,001-1,228,800,000	1024M	15.6	8.6
1,228,800,001-2,457,600,000	2048M	17.8	10.8
2,457,600,001-4,915,200,000	4096M	20.4	13.6

a. K equals 1024 BITS.

b. M equals 1024 K.

NOTE: The effects of Error Correction Code (ECC) and In-Field Repair (IFR) of memory devices is not taken into account in the device FIT rates shown in Table 8-10. The impact of ECC and IFR should be modeled separately.

8.5.4 Read Only Memory (ROMS, PROMS, EPROMS)

Table 8-11 provides the failure rate parameters for read only memory devices including Programmable ROMS (PROMS) and Erasable PROMS (EPROMS) (including electrically erasable and flash versions). Flash memory, based on very limited data, appears to have FIT rates similar to DRAM FIT rates. The parameters for ROM devices are a function of technology (Bipolar, NMOS, and CMOS) and the number of bits in the device. The mean and standard deviation of the failure rate given the technology and the number of bits are calculated from the equations given in Table 8-11.

Table 8-11 Read Only Memory Failure Rate Parameters

Technology	Failure Rate (FITs) as a function of the number of kilobits (B)	Temperature Curve
Bipolar	$\lambda_G = \mathrm{Exp}[1.04 + 0.754\ln B + 0.00288(\ln B)^2]$ $\sigma_G = \lambda_G[0.413 - 0.0364\ln B + 0.00709(\ln B)^2]$	6
NMOS	$\lambda_G = 5.84(B + 0.25)^{0.248}$ $\sigma_G = 0.707\lambda_G$	10 if B > 38 9 otherwise
CMOS	$\lambda_G = 1.60(B + 0.25)^{0.237}$ $\sigma_G = 0.707\lambda_G$	10 if B > 38 9 otherwise

Table 8-12 lists failure rates for ROM devices based on the above equations.

Table 8-12 Read Only Memory Failure Rates

DEVICE COMPLEXITY		BIPOLAR		NMOS		CMOS	
		λ_G (FITs)	σ_G (FITs)	λ_G (FITs)	σ_G (FITs)	λ_G (FITs)	σ_G (FITs)
Range	**Nominal**						
1-320 BITS	256 BITS	1.0	0.48	4.9	3.5	1.4	1.0
321-576	512 BITS	1.7	0.74	5.4	3.8	1.5	1.1
577-1120	1K[a]	2.8	1.2	6.2	4.4	1.7	1.2
1121-2240	2K	4.8	1.9	7.1	5.0	1.9	1.4
2241-5000	4K	8.1	3.0	8.4	5.9	2.3	1.6
5001-11000	8K	14	5.1	9.9	7.0	2.6	1.9
11001-17000	16K	23	8.6	12	8.2	3.1	2.2
17001-38000	32K	40	15	14	9.8	3.6	2.6
38001-74000	64K	68	26	16	12	4.3	3.0
74001-150,000	128K	120	47	19	14	5.1	3.6
150,001-300,000	256K	200	87	23	16	6.0	4.2
300,001-600,000	512K	350	160	27	19	7.0	5.0
600,001-1,200,000	1M[b]	600	300	33	23	8.2	5.8
1,200,001-2,400,000	2M	1000	570	39	27	9.7	6.9
2,400,001-4,800,000	4M	1800	1100	46	32	11.4	8.1
4,800,001-9,600,000	8M	3200	2100	55	39	13.5	9.5
9,600,001-19,200,000	16M	5600	4100	65	46	15.9	11.2

a. K equals 1024 BITS.

b. M equals 1024 K.

8.5.5 Microprocessor

Table 8-13 provides the failure rate parameters for microprocessor devices. The failure rates for microprocessor devices are a function of (a) technology (Bipolar, NMOS, and CMOS) and (b) device complexity (the number of gates for Bipolar and NMOS devices or bus width for CMOS devices). The number of gates is equal to the number of logical gates on the device schematic (including associated peripheral circuits). The mean and standard deviation of the failure rate given the technology and the device complexity are calculated from the equations given in Table 8-13.

The Electrical Stress Factor π_S equals 1 for microprocessors.

Table 8-13 Microprocessor Failure Rate Parameters

Technology	Failure Rate (FITs) as a function of the number of logical gates (G) or the bus width in bits (B)	Temperature Curve
Bipolar	$\lambda_G = 1.71(G+100)^{0.235}$ $\sigma_G = 0.707\lambda_G$	6
NMOS	$\lambda_G = 3.25(G+100)^{0.332}$ $\sigma_G = 0.707\lambda_G$	8
CMOS	$\lambda_G = \mathrm{Exp}[1.20 + 0.0442\ln B + 0.154(\ln B)^2]$ $\sigma_G = \lambda_G[2.88 - 1.89\ln B + 0.374(\ln B)^2]$	8

Table 8-14 lists failure rates for Bipolar and NMOS microprocessor devices, while Table 8-15 lists failure rates for CMOS microprocessor devices based on these equations.

Table 8-14 Bipolar and NMOS Microprocessor Failure Rates

DEVICE COMPLEXITY		BIPOLAR		NMOS	
		λ_G (FITs)	σ_G (FITs)	λ_G (FITs)	σ_G (FITs)
Range	**Nominal**				
1-20 GATES	15	5.2	3.7	16	11
21-50	40	5.5	3.9	17	12
51-100	80	5.8	4.1	18	13
101-500	400	7.4	5.2	26	18
501-1000	800	8.5	6.0	31	22
1001-2000	1600	9.8	6.9	38	27
2001-3000	2500	11	7.7	44	31
3001-5000	4000	12	8.5	51	36
5001-7500	6500	14	9.6	60	43
7501-10000	9000	15	10	67	47
10001-15000	13000	16	11	76	53
15001-20000	18000	17	12	84	60
20001-30000	25000	18	13	94	66
30001-50000	40000	21	15	110	78

Table 8-15 CMOS Microprocessor Failure Rates

BUS WIDTH (Bits)	λ_G (FITs)	σ_G (FITs)
8	7.1	4.0
16	12.3	6.3
32	24.6	20.2
64	57.3	85.2

8.5.6 Microcontroller

The mean failure rate for a microcontroller is:

$$\lambda_G = \lambda_{Microprocessor} + \lambda_{RAM} \tag{8-3}$$

where

$\lambda_{Microprocessor}$ = the generic steady-state failure rate for the microprocessor (see Section 8.5.5), and

λ_{RAM} = the generic steady-state failure rate for the RAM device it contains (see Section 8.5.3).

The standard deviation of the failure rate for a microcontroller is:

$$\sigma_G = \sqrt{\sigma^2_{Microprocessor} + \sigma^2_{RAM}} \tag{8-4}$$

where

$\sigma_{Microprocessor}$ = the standard deviation of the generic steady-state failure rate for the microprocessor (see Section 8.5.5), and

σ_{RAM} = the standard deviation of the generic steady-state failure rate for the RAM device it contains (see Section 8.5.3).

To determine temperature stress, use the Temperature Curve appropriate for the microprocessor (see Table 8-13).

The Electrical Stress Factor π_S equals 1 for microcontrollers.

8.5.7 Hybrid Microcircuits

Hybrid microcircuits are nonstandard, and their complexity cannot be determined from their names or functions. If devices comprising a Hybrid Integrated Circuit (HIC) are burned-in on a device level, the reliability calculations become more complicated. Since this condition is seldom expected to occur, no provision has been made for it in this model. For further assistance in this regard, contact a reliability subject matter expert.

The Hybrid Failure rate model is

$$\lambda_{HIC} = \left(\sum_{i} \lambda_{G_i} \pi_{Q_i} \pi_{S_i} \pi_{T_i}\right) + (N_I \lambda_I + N_C \lambda_C + N_R \lambda_R) \pi_F \quad \textbf{(8-5)}$$

and

$$\sigma_{HIC} = \sqrt{\left\{\sum_{i} (\sigma_{G_i} \pi_{Q_i} \pi_{S_i} \pi_{T_i})^2\right\} + \{(N_I \sigma_I)^2 + (N_C \sigma_C)^2 + (N_R \sigma_R)^2\} \pi_F^2} \quad \textbf{(8-6)}$$

where:

λ_G = device failure rate for each chip or packaged device i used
π_Q = Quality Factor of chip/device i
π_S = Electrical Stress Factor of chip/device i
π_T = Temperature Factor of chip/device i
N_I = number of internal interconnects (i.e., crossovers, excluding any device leads or external HIC package leads). If the HIC includes any type of connector, the connector should be considered as an attached component.
λ_I = 0.41 FITs
σ_I = 0.29 FITs
N_C = number of thin or thick film capacitors
λ_C = 0.26 FITs
σ_C = 0.18 FITs
N_R = number of thin or thick film resistors
λ_R = 0.26 FITs
σ_R = 0.18 FITs
π_F = circuit function factor
1.0 for digital HICs
1.25 for linear or linear-digital HICs

For purposes of calculating the Early Life Factor of the HIC, use $\lambda_{HIC}/\lambda_{HIC_{BB}}$ for the product of $\pi_S \pi_T$ where $\lambda_{HIC_{BB}}$ is the HIC failure rate when π_S and π_T are set equal to 1 for all devices in Equation 8-5. If devices comprising an HIC are burned-in on a device level, the reliability calculations become more complicated. For further assistance in this regard, consult a reliability subject matter expert.

8.5.8 Combined Analog-Digital Integrated Circuit (Gate Array and Program Array Logic)

The mean failure rate for these devices is:

$$\lambda_G = \lambda_{Digital} + \lambda_{Analog} \quad \textbf{(8-7)}$$

where

$\lambda_{Digital}$ = the generic steady-state failure rate for a digital IC based on the number of gates being used for the digital portion of the circuit (see Section 8.5.2), and

λ_{Analog} = the generic steady-state failure rate for an analog IC based on the number of transistors being used for the analog portion of the circuit (see Section 8.5.1).

The standard deviation of the failure rate for these devices is:

$$\sigma_G = \sqrt{\sigma_{Digital}^2 + \sigma_{Analog}^2} \tag{8-8}$$

where

$\sigma_{Digital}$ = the standard deviation of the generic steady-state failure rate for a digital IC based on the number of gates being used for the digital portion of the circuit (see Section 8.5.2), and

σ_{Analog} = the standard deviation of the generic steady-state failure rate for an analog IC based on the number of transistors being used for the analog portion of the circuit (see Section 8.5.1).

The Temperature Stress Curve is based on the digital IC technology (see Table 8-6).

8.6 Microwave Element Devices

Table 8-16 lists parameter values for microwave element devices. Temperature and Electrical Stress have no impact on the failure rates of these devices ($\pi_S = \pi_T = 1$).

Table 8-16 Microwave Element Device Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)
MICROWAVE ELEMENTS		
Coaxial and Waveguide		
Load	7.7	5.5
Attenuator		
Fixed	3.8	2.3
Variable	1.81	0.55
Fixed Elements		
Directional Couplers	1.11	0.78
Fixed Stubs	5.1	3.6
Cavities	5.1	3.6
Variable Elements		
Tuned Stubs	51	36
Tuned Cavities	11	4.1
Ferrite Devices (Transmit)	100	73
Ferrite Devices (Receive)	51	36
RF/MICROWAVE PASSIVES		
Filter	0.48	0.14
Isolator / Circulator (low power - < 25 W)	1.76	1.02
Isolator / Circulator (high power - ≥ 25 W)	**4.38**	**1.66**
Splitter/Combiner	0.60	0.42

8.7 Opto-Electronic Device Parameter Values

8.7.1 Fiber Optic Communication Devices and Modules

In this document, a module is defined as a small packaged assembly that includes a laser diode/LED/detector and easy means for electrical connections and optical couplings.

The failure rates assume that only hermetic fiber optic devices are used for the laser modules, LED modules, and detector modules. The use of non-hermetic or lower quality parts are expected to produce much higher failure rates than those predicted by using the device Quality Factors in Table 9-4.

Unlike other devices, several fiber optic communication modules have separate failure rates for controlled and uncontrolled environments (see Table 9-5). These are in addition to the Environment Factor applied to the unit in which they reside.

If the module contains other electronic devices or hybrids (such as a laser drive in the laser module and amplifiers in the detector module), additional failure rates should be added to the failure rates given here. Also, significant differences in failure rates of these devices are expected among different suppliers; this variability is not captured in the standard deviation of the failure rate.

SR-TSY-001369, *Introduction to Reliability of Laser Diodes and Modules*, discusses reliability issues for laser modules.

Table 8-17 lists parameter values for fiber optic communication devices and modules.

The Electrical Stress Factor π_S equals 1 for fiber optic communication devices and modules.

Table 8-17 Fiber Optic Communication Device/Module Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)
TRANSMIT/RECEIVE ELEMENTS			
DISTRIBUTED FEEDBACK (DFB) LASER	100	81	7
ELECTRO-ABSORPTION MODULATOR LASER			
Uncooled	110	89	7
Cooled	300	240	7
CONTINUOUS WAVE (CW) LASER - IC	150	120	7
PUMP LASER			
$\leq$ 90 mW output	500	400	7
$>$ 90 and $\leq$ 150 mW	900	730	7
$>$ 150 mW	1000	810	7

Table 8-17 Fiber Optic Communication Device/Module Failure Rate Parameters (Continued)

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)
LASER MODULE - CW LASER			
Controlled Environment	180	54	7
Other Environments	270	81	7
FIBER OPTIC LED MODULE			
Controlled Environment	58	22	8
Other Environments	270	100	8
FIBER OPTIC DETECTOR MODULE			
Controlled Environment	330	100	10
Other Environments	920	280	10
RECEIVER MODULE			
PIN Diode	150	120	7
Avalanche Photo Detector	200	160	7
TRANSCEIVER / SFP			
< 10 Gbps (e.g., SFP)	**50**	**20**	7
≥ 10 Gbps and < 40 Gbps	**100**	**35**	7
≥ 40 Gbps and < 100 Gbps	*250*	*170*	*7*
≥ 100 Gbps and < 400 Gbps	*500*	*180*	*7*
MODULATOR - LITHIUM NIOBATE	170	140	7
AMPLIFIERS[a]			
8 & 16 CHANNELS	200	160	7
40 & 80 CHANNELS	500	400	7
TRANSPONDERS[b]			
COOLED	630	510	7
UNCOOLED	470	380	7
WAVELENGTH SPLIT/ADD/DROP			
WAVELENGTH COUPLER/SPLITTER - FUSED FIBER 1310/ 1550 NM			
Controlled Environment	93	65	5
Other Environments	370	260	5
DENSE WAVELENGTH DIVSION MULTIPLEXER (DWDM)			
Optical Add-Drop Multiplexer (OADM), Thin Film			
Controlled Environment	290	170	5
Other Environments	790	460	5
Interleaver, Thin Film	100	81	7
Mux/Demux - AWG			
8 channel	100	81	7
16 channel	200	160	7
20 channel	300	240	7

Table 8-17 Fiber Optic Communication Device/Module Failure Rate Parameters (Continued)

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)
40 channel	500	400	7
40 channel with on-chip VOA	1000	810	7
POWER COUPLER/DIVIDER (TAP)			
1x2	20	16	7
1x4	50	40	7
1x6	100	81	7
OPTICAL SWITCHES			
1x2 or 2x1	50	40	7
1x4 or 4x1	100	81	7
1x8 or 8x1	200	160	7
OPTICAL ISOLATOR - THIN FILM WITH ROTATOR CRYSTAL	21	12	10
DISPERSION COMPENSATING MODULE	20	16	7
OPTICAL WAVELENGTH LOCKER	200	160	7

a. Pump lasers not included
b. Retransmit, Reshape, Retime (3R)

8.7.2 Other Opto-Electronic Devices

Table 8-18 lists parameter values for opto-electronic modules.

The Electrical Stress Factor π_S equals 1 for these devices.

Table 8-18 Opto-Electronic Device Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)
OTHER OPTICAL DEVICES			
Single LED/LCD Segment	0.25	0.18	10
Phototransistor	31	22	10
Photodiode	7.7	5.5	10
SINGLE ISOLATORS / COUPLERS			
Photodiode Detector	5.1	3.6	10
Phototransistor Detector	2.1	0.71	10
Light Sensitive Resistor	10	7.3	10
DUAL ISOLATORS / COUPLERS			
Photodiode Detector	10	7.3	10
Phototransistor Detector	3.7	2.9	10
Light-Sensitive Resistor	21	15	10

8.8 Relay Parameter Values

Table 8-19 lists parameter values for relay devices.

All relay devices use electrical stress curve C and temperature stress curve 3.

Table 8-19 Relay Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)	ELEC. STRESS (Table 9-2)
General Purpose	1.9	1.9	3	C
Contactor	140	98	3	C
Latching	3.9	2.3	3	C
Reed	26	18	3	C
Thermal, Bimetal	26	18	3	C
Mercury	26	18	3	C
Solid State	21	6.9	3	C

For relays, electrical stress percentage is based on current, specifically

$$\text{electrical stress percentage} = \frac{\text{Contact Current}}{\text{Rated Current}}.$$

using the rating appropriate for the type of load (e.g., resistive, inductive, lamp).

8.9 Resistor Parameter Values

8.9.1 Fixed Resistor

Table 8-20 lists parameter values for fixed resistor devices including Surface Mount Technology (SMT).

Table 8-20 Fixed Resistor Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)	ELEC. STRESS (Table 9-2)
COMPOSITION				
≤ 1 MEGOHM	0.18	0.13	6	D
> 1 MEGOHM	2.1	1.5	4	D
FILM (Carbon, Oxide, Metal)				
≤ 1 MEGOHM	0.08	0.02	3	C
> 1 MEGOHM	0.24	0.07	3	C
FILM, POWER (> 1W)				
≤ 1 MEGOHM	0.30	0.22	1	A
> 1 MEGOHM	0.71	0.49	1	A
WIREWOUND, ACCURATE				
≤ 1 MEGOHM	8.2	5.8	2	C
> 1 MEGOHM	21	15	2	C
WIREWOUND, POWER, LEAD MOUNTED	0.80	0.25	3	D
WIREWOUND, POWER, CHASSIS MOUNTED	5.1	3.6	3	D

For fixed resistors, electrical stress percentage is based on power, specifically

$$\text{electrical stress percentage} = \frac{\text{Applied Power}}{\text{Rated Power}}.$$

8.9.2 Variable Resistor

Table 8-21 lists parameter values for variable resistor devices.

Table 8-21 Variable Resistor Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)	ELEC. STRESS (Table 9-2)
NON-WIREWOUND				
Film	7.3	3.1	3	B
Low Precision, Carbon				
≤ 200K OHM	18	13	4	B
> 200K OHM	26	18	4	B
Precision				
≤ 200K OHM	13	9.1	4	A
> 200K OHM	21	15	4	A
Trimmer				
≤ 200K OHM	13	9.1	2	A
> 200K OHM	21	15	2	A
WIREWOUND				
High Power				
≤ 5K OHM	87	62	3	B
> 5K OHM	120	87	3	B
Leadscrew	13	9.1	3	C
Precision				
≤ 100K OHM	100	73	3	A
> 100K OHM	180	130	3	A
Semi-Precision				
≤ 5K OHM	44	31	4	C
> 5K OHM	62	44	4	C

For variable resistors, electrical stress percentage is based on power, specifically

$$\text{electrical stress percentage} = \frac{\text{Input Voltage}^2 / \text{Total Resistance}}{\text{Rated Power}}.$$

8.9.3 Resistor Networks

Table 8-22 lists parameter values for resistor networks. Failure rates are based on the number of resistors *R* in the network.

The Electrical Stress Factor π_S equals 1 for resistor networks.

All resistor networks use temperature stress curve 6.

Table 8-22 Resistor Network Failure Rate Parameters

RESISTOR TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)
DISCRETE ELEMENTS	R x 0.14	R x 0.09	6
THICK OR THIN FILM	R x 0.04	R x 0.03	6

For resistor networks, electrical stress percentage is based on power, specifically

$$\text{electrical stress percentage} = \frac{\text{Applied Power}}{\text{Rated Power}} .$$

8.10 Switch Parameter Values

Table 8-23 lists parameter values for switch devices. The failure rate depends on the number of contact pairs $c = n \times m$, where n equals the number of poles and m equals the number of throws. For example, a Single Pole Double Throw (SPDT) switch has $c = 1 \times 2 = 2$ contact pairs.

All switches use electrical stress curve C and temperature stress curve 7.

Table 8-23 Switch Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)	ELEC. STRESS (Table 9-2)
Pushbutton	1.99	1.40	7	C
Toggle	5.1 + 2.6 c	$\sqrt{13 + 3.2c^2}$	7	C
Rocker or Slide	5.1 + 0.38c	$\sqrt{13 + 0.068c^2}$	7	C
Rotary	7.7 + 2.6c	$\sqrt{30 + 3.2c^2}$	7	C

For switches, electrical stress percentage is based on current, specifically

$$\text{electrical stress percentage} = \frac{\text{Contact Current}}{\text{Rated Current}} \,.$$

using the rating appropriate for the type of load (e.g., resistive, inductive, lamp).

8.11 Thermistor Parameter Values

Table 8-24 lists parameter values for thermistor devices.

The Electrical Stress Factor π_S equals 1 for thermistors.

All thermistors use temperature stress curve 7.

Table 8-24 Thermistor Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)
Bead	2.1	1.5	7
Disk	5.1	3.6	7
Rod	7.7	5.5	7
Polymetric Positive Temperature Coefficient (PPTC) Device	5.1	3.6	7

8.12 Transistor Failure Rates

Table 8-25 lists parameter values for transistor devices.

Table 8-25 Transistor Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)	ELEC. STRESS (Table 9-2)
SILICON				
NPN/PNP				
≤ 0.6 W	0.69	0.31	4	E,E
> 0.6 and ≤ 6.0 W	1.77	1.02	4	E,E
> 6.0 W	7.7	2.3	4	E,E
GERMANIUM				
NPN				
≤ 0.6 W	31	22	4	E,E
> 0.6 and ≤ 6.0 W	46	33	4	E,E
> 6.0 W	77	55	4	E,E
PNP				
≤ 0.6 W	10	7.3	4	E
> 0.6 and ≤ 6.0 W	15	11	4	E
> 6.0 W	28	20	4	E
FIELD EFFECT				
Silicon				
Linear	11	3.9	4	E
Switch	3.44	0.75	4	E
High Frequency/RF	9.3	4.9	4	E
GaAs				
Low Noise (≤ 100 mW)	51	36	4	E
Driver (≤ 100 mW)	360	250	4	E
pHEMT Switch	*2.02*	*0.43*	*10*	*E*
UNIJUNCTION	93	65	4	E
MICROWAVE				
Pulse Amplifier	570	400	7	E
Continuous Wave	1100	800	7	E
POWER AMPLIFIER				
RF InGaP/GaAS/SiGs HBT	3.2	**0.5**	10	E
RF LDMOS	*3.68*	*0.47*	*10*	*E*

Electrical Stress for Devices with One Stress Curve

The electrical stress percentage is based on power, specifically

$$\text{electrical stress percentage} = \frac{\text{Dissipated Power}}{\text{Rated Power}} \times 100.$$

Electrical Stress for Devices with Two Stress Curves

The Electrical Stress Factor $\pi_S = \pi_{S_P}\pi_{S_V}$

where

π_{S_P} is the Electrical Stress Factor determined using the first curve with electrical stress determined by the ratio of operating power to rated power and

π_{S_V} is the Electrical Stress Factor determined using the second curve with electrical stress determined by the ratio of operating voltage to rated voltage.

8.13 Rotating and Miscellaneous Device Parameter Values

Table 8-26 and Table 8-27 list parameter values for rotating and miscellaneous devices. Temperature and Electrical Stress have no impact on the failure rates of many miscellaneous devices ($\pi_S = \pi_T = 1$). Those devices for which Temperature Stress has an impact are shown in Table 8-27. Rotating devices (such as fans and hard disk drives) are limited-life components; the steady-state rates given here apply during the useful life before unacceptable Wear-Out. Blower and fan assemblies should be treated as units composed of a motor plus the various electrical devices in their composition.

Table 8-26 Miscellaneous Device Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)
MISCELLANEOUS DEVICES		
GYROSCOPE	26000	18000
VIBRATOR		
60 Hertz	7700	5500
120 Hertz	10000	7300
400 Hertz	21000	15000
CERAMIC RESONATOR	13	9.1
CIRCUIT BREAKER		
Protection-Only Application (per pole)	50	30
Power On/Off Application (per pole)	870	620
FUSE		
≤ 30A	0.40	0.19
> 30A	0.80	0.38
SURGE ARRESTOR SMD / GAS DISCHARGE TUBE	*0.49*	*0.28*
LAMP		
Neon	100	73
Incandescent		
5V DC	720	510
12V DC	2200	1500
48V DC	2200	1600
METER	150	110
THERMO-ELECTRIC COOLER (< 2W)	4.9	9.7
DELAY LINES	37	21
BATTERY		
Nickel Cadmium / *Nickel Metal Hydride*[a]	51	36
Lithium	25	7.5

a. A reliability based on Nickel Cadmium estimates. More reliability data is sought for Nickel Metal Hydride batteries.

Table 8-27 Rotating and Miscellaneous Device Failure Rate Parameters

DEVICE TYPE	λ_G (FITs)	σ_G (FITs)	TEMP. STRESS (Table 9-1)
MISCELLANEOUS DEVICES			
QUARTZ CRYSTAL	**3.1**	**1.5**	7
CRYSTAL OSCILLATOR			
Quartz Controlled	**3.2**	**1.5**	9
Voltage Controlled or Temperature Compensated	**2.4**	**1.5**	9
Oven Controlled	**202**	**24**	NA
RF SYNTHESIZER / TUNER	*7.6*	*4.6*	*9*
POWER MODULE			
DC-DC, BOARD MOUNTED (POWER BRICK)			
≤ 12W	10	8.1	7
> 12W and ≤ 55W	40	32	7
> 55W and ≤ 105W	60	48	7
> 105W and ≤ 200W	100	81	7
> 200W and ≤ 400W	210	160	7
> 400W[a]	*See Note a*	*See Note a*	*NA*
AC / DC POWER SUPPLY			
≤ 25W	*30*	*10*	*7*
> 25W and ≤ 50W	*50*	*15*	*7*
> 50W and ≤ 100W	*125*	*50*	*7*
> 100W and ≤ 200W	*200*	*75*	*7*
> 200W and ≤ 400W	*350*	*125*	*7*
> 400W[a]	*See Note a*	*See Note a*	*NA*
ROTATING DEVICES[b]			
Blower Motor	260	180	6
Fan Motor < 1/3 HP	26	18	6
Equipment Fan < 80 mm diameter[c]	*150*	*50*	*6*
Equipment Fan < 150 mm diameter[c]	300	100	6
Hard Disk Drive	2500	1000	NA

a. Above 400W, a piece part analysis should be completed.

b. A blower is a rotating drum driven by a motor.

c. An equipment fan consists of a fan motor and fan blades in a single fan assembly that is powered by either AC or DC power. Equipment fans may also include built-in speed control and fan rotation sensors for alarming.

9 Failure Rate Factors

This section defines and provides tables for factors that affect electronic equipment failure rates including Environment, Quality, Electrical Stress, and Temperature Factors. These tables may be copied and used as needed.

9.1 Temperature Factor

The failure rates provided in Section 8 assume an operating temperature of 40°C. If a device is in an environment that produces an operating temperature higher or lower than this base value, then the failure rate must be adjusted using the Temperature Factor as described in Section 3. The Temperature Factor is also used to calculate the effect of burn-in on infant mortality in Section 4.

The Temperature Factor π_T is derived by the following equation:

$$\pi_T = e^{\frac{Ea}{k}\left[\frac{1}{T_0} - \frac{1}{T_1}\right]} \qquad \textbf{(9-1)}$$

where

T_0 = reference temperature in °k = 40 + 273 = 313
T_1 = operating temperature in °k = operating temperature in °C + 273
Ea = activation energy in eV
k = Boltzmann constant = 8.62 x 10^{-5} eV/°k

The activation energy Ea is defined using the following table as a function of the temperature curve for the device type as specified in Section 8. Curve 7 has an additional special purpose. It is used to model temperature effects during Early Life and burn-in; a common curve is used for these purposes because many of the failure mechanisms during Early Life and burn-in are a result of manufacturing defects or weaknesses in devices for which the temperature effect is common across device types.

Curve	1	2	3	4	5	6	7	8	9	10
Ea (eV)	0.05	0.10	0.15	0.22	0.28	0.35	0.40	0.45	0.56	0.70

The ambient temperature for the device is used as the operating temperature. When the ambient temperature above the devices does not vary more than a few degrees, a single temperature reading is considered adequate. In this case, the ambient temperatures of the devices and the unit containing these devices are taken to be the temperature obtained by placing a probe in the air ½ inch above the unit. If there is a wide variation in ambient temperature above the devices, it would be necessary to use special procedures not contained in this document. In such cases, a reliability analyst should be consulted.

Table 9-1 provides Temperature Factors for various operating temperatures for each temperature curve. The table also defines the range of operating temperatures for which Equation 9-1 is considered valid. For temperatures above 65°C and below its operating limit, use Equation 9-1; Curve 7 is extended for temperatures up to 150°C for assistance with burn-in and integration of laboratory test data. For temperatures below 30°C, use the Temperature Factor of 30°C.

Table 9-1 Temperature Factors π_T (Sheet 1 of 2)

Operating Ambient Temperature °C	Temperature Stress Curve									
	1	2	3	4	5	6	7*	8	9	10
30	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.4
31	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5
32	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5
33	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6
34	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6
35	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7
36	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7
37	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8
38	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.8
39	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
40	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
41	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1
42	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.2
43	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.3
44	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.4
45	1.0	1.1	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.5
46	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.5	1.6
47	1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.6	1.8
48	1.0	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.7	1.9
49	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.8	2.1
50	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2.2
51	1.1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	2.0	2.4
52	1.1	1.1	1.2	1.4	1.5	1.6	1.7	1.9	2.2	2.6
53	1.1	1.2	1.2	1.4	1.5	1.7	1.8	1.9	2.3	2.8
54	1.1	1.2	1.3	1.4	1.6	1.7	1.9	2.0	2.4	3.0
55	1.1	1.2	1.3	1.5	1.6	1.8	2.0	2.1	2.6	3.3
56	1.1	1.2	1.3	1.5	1.7	1.9	2.1	2.3	2.7	3.5
57	1.1	1.2	1.3	1.5	1.7	2.0	2.1	2.4	2.9	3.8
58	1.1	1.2	1.4	1.6	1.8	2.0	2.2	2.5	3.1	4.1
59	1.1	1.2	1.4	1.6	1.8	2.1	2.3	2.6	3.3	4.4
60	1.1	1.2	1.4	1.6	1.9	2.2	2.4	2.7	3.5	4.8
61	1.1	1.3	1.4	1.7	1.9	2.3	2.5	2.9	3.7	5.1
62	1.1	1.3	1.4	1.7	2.0	2.3	2.6	3.0	3.9	5.5
63	1.1	1.3	1.5	1.7	2.0	2.4	2.8	3.1	4.1	5.9
64	1.1	1.3	1.5	1.8	2.1	2.5	2.9	3.3	4.4	6.3
65	1.1	1.3	1.5	1.8	2.2	2.6	3.0	3.4	4.6	6.8
70	1.2	1.4	1.6	2.0	2.5	3.1	3.7	4.3	6.1	9.7
75	1.2	1.5	1.8	2.3	2.8	3.7	4.4	5.4	8.0	13.6
80	1.2	1.5	1.9	2.5	3.0	4.4	5.4	6.6	10.5	18.9
85	1.3	1.6	2.0	2.8	3.7	5.1	6.4	8.1	13.6	26.1
90							7.7			
95							9.2			
100							11			

Table 9-1 Temperature Factors π_T (Sheet 2 of 2)

Operating Ambient Temperature °C	Temperature Stress Curve 1	2	3	4	5	6	7*	8	9	10
105							13			
110							15			
115							18			
120							20			
125							24			
130							27			
135							32			
140							36			
145							41			
150							47			

*NOTE: Curve 7 (Ea = 0.40 eV) is extended for temperatures up to 150°C for burn-in calculations.

9.2 Electrical Stress Factor

The failure rates provided in Section 8 assume an electrical stress percentage of 50%. If a device's application produces an electrical stress percentage higher or lower than this base value, then the failure rate must be adjusted using the Electrical Stress Factor as described in Section 3.

9.2.1 Electrical Stress Curves

Electrical Stress Factors vary as a function of the effect of electrical stress on the various types of devices and on the amount of stress encountered in any particular application. Section 8 describes the appropriate Electrical Stress Factor curve to use and how to calculate electrical stress for each type of device. If no curve letter is shown, the Electrical Stress Factor may be considered to be $\pi_S = 1$. If a curve letter is shown, the Electrical Stress Factor π_S is calculated using the following equation

$$\pi_S = e^{m(p_1 - p_0)} \quad \textbf{(9-2)}$$

where the parameter m defines the curve, p_0 is the reference stress (50%), and p_1 is the stress percentage for the equipment in question. Curve K is the same as Curve A, except $\pi_S = 1$ for stress $p_1 < 50\%$. If two Electrical Stress Factors apply to a device, use the product of the two stress factors.

Table 9-2 presents the appropriate parameter value of m for each curve letter and gives π_S values for each curve at various stress levels.

Table 9-2 Electrical Stress Factors π_S

% STRESS	Electrical Stress Curve										
	A	B	C	D	E	F	G	H	I	J	K
10	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.2	0.2	0.1	1.0
20	0.8	0.8	0.7	0.6	0.5	0.4	0.3	0.3	0.3	0.2	1.0
30	0.9	0.8	0.8	0.7	0.6	0.6	0.5	0.4	0.4	0.3	1.0
40	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	1.0
50	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
60	1.1	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.8	1.1
70	1.1	1.2	1.3	1.5	1.6	1.8	2.0	2.3	2.5	3.3	1.1
80	1.2	1.3	1.5	1.8	2.1	2.4	2.9	3.4	4.0	5.9	1.2
90	1.3	1.4	1.7	2.1	2.6	3.2	4.1	5.2	6.3	10.6	1.3

Curve	A	B	C	D	E	F	G	H	I	J	K
m	0.6	0.9	1.3	1.9	2.4	2.9	3.5	4.1	4.6	5.9	0.6

9.2.2 Electrical Stress Percentage

The stress percentage p_1 is calculated by multiplying the ratio of applied voltage (or current or power) to the rated voltage (or current or power) by 100. “Rated” as used here refers to the maximum or minimum value specified by the manufacturer after any derating for temperature, etc. If the amount of stress varies during normal operation of the end product in which the device is used, use the average stress percentage. Section 8 describes how to calculate stress percentage for each applicable device type. The ratios for different types of devices are summarized in Table 9-3.

Table 9-3 Guidelines for Determination of Electrical Stress Percentage

Capacitor -	Sum of applied dc voltage plus ac peak voltage / rated voltage
Resistor, fixed -	applied power / rated power
Resistor, variable -	(V_{in}^{2} / total resistance) / rated power
Relay, Switch -	Contact current / rated current (rating appropriate for type of load, e.g., resistive, inductive, lamp)
Diode, general - purpose, Thyristor	average forward current / rated forward current
Diode, zener -	actual zener current or power / rated zener current or power
Varactor, Step - recovery, Tunnel diode	actual dissipated power / rated power
Transistor -	Power dissipated / rated power.

9.3 Quality Factor

The device failure rates contained in this document reflect the expected field reliability performance of generic device types. The actual reliability of a specific device will vary as a function of the degree of effort and attention paid by an equipment manufacturer to factors such as device selection/application, supplier selection/control, electrical/mechanical design margins, equipment manufacture process control, and quality program requirements.

Table 9-4 describes the four quality levels and presents values for their associated Quality Factors. The quality levels are not intended to characterize or quantify all of the factors that may influence device reliability. They provide an indication of the total effort an equipment manufacturer considers reasonable to expend to control these factors. These quality levels also reflect the scope and depth of the particular equipment manufacturer's component engineering program.

The Quality Level to be used for estimating the reliability of a given system can be determined by an analysis of the equipment manufacturer's component engineering program and of its implementation throughout all stages of the product realization process. The criteria contained in GR-357-CORE can be used to guide such an analysis.

Justification for the use of all quality levels other than Quality Level 0 should be provided. For more information on component reliability assurance practices, see GR-357-CORE and GR-2969-CORE, *Generic Requirements for the Design and Manufacture of Short-Life, Information-Handling Products and Equipment*. GR-357-CORE also includes discussion of alternative types of reliability assurance practices such as reliability monitoring programs for qualification and lot-to-lot controls.

Table 9-4 Device Quality Level Description and Factor π_Q

QUALITY LEVEL 0 — This level shall be assigned to commercial-grade, reengineered, remanufactured, reworked, salvaged, or gray-market components that are procured and used without device qualification, lot-to-lot controls, or an effective feedback and corrective action program by the primary equipment manufacturer or its outsourced lower-level design or manufacturing subcontractors. However, steps must have been taken to ensure that the components are compatible with the design application. **Quality Factor π_Q = 6**
QUALITY LEVEL I — This level shall be assigned to commercial-grade components that are procured and used *without* thorough device qualification or lot-to-lot controls by the equipment manufacturer. However, **(a)** steps must have been taken to ensure that the components are compatible with the design application and manufacturing process; and **(b)** an effective feedback and corrective action program must be in place to identify and resolve problems quickly in manufacture and in the field. **Quality Factor π_Q = 3**
QUALITY LEVEL II — This level shall be assigned to components that meet requirements (a) and (b) of Quality Level I, plus the following: **(c)** purchase specifications must explicitly identify important characteristics (electrical, mechanical, thermal, and environmental) and acceptable quality levels (i.e., AQLs, Defects Per Million [DPMs], etc.) for lot control; **(d)** devices and device manufacturers must be qualified and identified on approved parts/ manufacturer's lists (device qualification must include appropriate life and endurance tests); **(e)** lot-to-lot controls, either by the equipment manufacturer or the device manufacturer, must be in place at adequate AQLs/DPMs to ensure consistent quality. **Quality Factor π_Q = 1**
QUALITY LEVEL III — This level shall be assigned to components that meet requirements (a) through (e) of Quality Levels I and II, plus the following: **(f)** device families must be requalified periodically; **(g)** lot-to-lot controls must include early life reliability control of 100% screening (temperature cycling and burn-in), which, *if the results warrant it*, may be reduced to a "reliability audit" (i.e., a sample basis) or to an acceptable "reliability monitor" with demonstrated and accepted cumulative early failure values of less than 200 ppm out to 10,000 hours; **(h)** where burn-in screening is used, the Percent Defective Allowed (PDA) shall be specified and shall not exceed 2%; and **(i)** an ongoing, continuous reliability improvement program must be implemented by both the device and equipment manufacturers. **Quality Factor π_Q = 0.8**

9.4 Environment Factor

Table 9-5 presents six equipment environments and gives the appropriate Environment Factor value π_E for each.

Table 9-5 Environmental Conditions and Multiplier Factors (π_E) (Sheet 1 of 2)

ENVIRONMENT	SYMBOL	π_E	NOMINAL ENVIRONMENTAL CONDITIONS
Ground, Fixed, Controlled	G_B	1	Vibration/shock stresses: Low Atmospheric variations: Low Temperature cycling stresses: Low Application examples: Central office, data center, environmentally controlled vaults, environmentally controlled remote shelters, and environmentally controlled customer premise areas.
Ground, Fixed, Uncontrolled (Limited)	G_L	1.2	Vibration/shock stresses: Low to Moderate Atmospheric variations: Low to Moderate Temperature cycling stresses: Moderate to High Factor assumes a ruggedized enclosure provides protection. Application examples: Weather-protected remote terminals, outdoor equipment, and radio tower equipment.
Ground, Fixed, Uncontrolled (Moderate)	G_F	1.5	Vibration/shock stress: Moderate to High Atmospheric variations: Low to Moderate Temperature cycling stresses: Moderate to High Factor assumes a ruggedized enclosure provides protection. Application examples: Remote terminals and outdoor equipment in manholes, and near direct path of railroad, highway, and air traffic.
Ground, Mobile (both vehicular mounted and portable)	G_M	2	Vibration/shock stress: Extreme Atmospheric variations: Low to Moderate Temperature cycling stresses: High (Variations due to transport and different locations) Application examples: Equipment that can be in rapid motion relative to the ground, including cell phones and hand-held devices, portable operating equipment, and test equipment.

Table 9-5 Environmental Conditions and Multiplier Factors (π_E) (Sheet 2 of 2)

ENVIRONMENT	SYMBOL	π_E	NOMINAL ENVIRONMENTAL CONDITIONS
Airborne, Commercial	A_C	3	Vibration/shock stress: Extreme Atmospheric variations: High Temperature cycling stresses: High (Variations due to transport and different locations at different altitudes) Application example: Passenger compartment of commercial aircraft.
Space-based, Commercial (low earth orbit)	S_C	See MIL-217 or other applicable standards	Vibration/shock stress: Extreme Atmospheric variations: High Temperature cycling stresses: High (Variations due to transport and different locations at different altitudes) Application example: Communication satellites.

NOTE: Chemical stresses that affect electronics (i.e., any airborne chemicals, including salts and those carried by dust) are currently not included in the environments listed in Table 9-5. Analysts should refer to standards and sources such as GR-357-CORE; GR-3108-CORE, *Generic Requirements for Network Equipment in the Outside Plant (OSP)*; or others to characterize and quantify the impacts of chemical contaminants on the useful life and failure rates of products.

Appendix A: Failure Rate Units

This document presents all failure rates in FITs, failures in 10^9 hours. Table A-1 is provided as an aid in interpreting FITs failure rates in terms of other equivalent reliability metrics.

Table A-1 Reliability Conversion Factor

From	To	Operation
FITs	Failures/10^6 hrs.	FITs $\times 10^{-3}$
FITs	% Failures/1000 hrs.	FITs $\times 10^{-4}$
FITs	% Failures/yr. or Failures/100 units/yr. or Annualized Failure Rate (AFR)	FITs/1142
FITs	% Failures/mo. or Failures/100 units/mo.	FITs/13700
FITs	MTBF[a]	$\frac{10^9 \text{ hours}}{\text{FITs}}$
Failures/10^6	FITs	Failures/10^6 hrs. $\times 10^3$
% Failures/1000 hrs.	FITs	% Failures/1000 hrs. $\times 10^4$
% Failures/yr. or Failures/100 units/yr. or Annualized Failure Rate (AFR)	FITs	% Failures/yr. $\times$ 1142
% Failures/mo. or Failures/100 units/mo.	FITs	% Failures/mo. $\times$ 13,700
MTBF[a]	FITs	$\frac{10^9}{\text{MTBF}}$

a. Mean time (hours) between failures.
MTTF (Mean Time To Failure) is the term typically used for non-repairable equipment. For this document, MTTF and MTBF (Mean Time Between Failures) are considered equivalent.

Appendix B: References

B.1 Telcordia Documents

1. FD-ARPP-01, *Automated Reliability Prediction Procedure (ARPP)*.
2. GR-63-CORE, *NEBS^{TM} Requirements: Physical Protection*.
3. GR-357-CORE, *Generic Requirements for Assuring the Reliability of Components Used in Telecommunications Equipment*.
4. SR-1171, *Methods and Procedures for System Reliability Analysis*.
5. GR-1217-CORE, *Generic Requirements for Separable Electrical Connectors Used in Telecommunications Hardware*.
6. SR-TSY-001369, *Introduction to Reliability of Laser Diodes and Modules*.
7. GR-2969-CORE, *Generic Requirements for the Design and Manufacture of Short-Life, Information-Handling Products and Equipment*.
8. GR-3108-CORE, *Generic Requirements for Network Equipment in the Outside Plant (OSP)*.

B.2 Non-Telcordia Documents

1. MIL-HDBK-217F, *Reliability Prediction of Electronic Equipment*.
2. Brush, G. G.; Healy, J. D.; and Liebesman, B. S.; "A Bayes Procedure for Combining Black Box Estimates and Laboratory Tests," *1984 Proceedings of the Annual Reliability and Maintainability Symposium*, IEEE, 1984, pp. 242-246.
3. Shooman, M. L., *Probabilistic Reliability: An Engineering Approach*, Krieger, 1990.

B.3 Documents on Derating

1. MIL-STD-975M, *MILITARY STANDARD: NASA STANDARD ELECTRICAL,ELECTRONIC,AND ELECTROMECHANICAL (EEE) PARTS LIST* (August 4 1994), Department of Defense.
2. MIL-STD-1547B, *MILITARY STANDARD: ELECTRONIC PARTS, MATERIALS, AND PROCESSES FOR SPACE AND LAUNCH VEHICLES* (01 DEC 1992), Department of Defense.
3. NAVSEA TE000-AB-GTP-010, P*arts Derating Requirements and Application Manual for Navy Electronic Equipment* (March 1991), U.S. Navy.
4. ECSS-Q-ST-30-11C, *SPACE PRODUCT ASSURANCE: DERATING - ELECTRICAL, ELECTROMECHANICAL, AND ELECTRONIC (EEE) COMPONENTS* (04-OCT-2011), European Space Agency.

5. MSFC-STD-3012, *MSFC TECHNICAL STANDARD ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL (EEE) PARTS MANAGEMENT AND CONTROL REQUIREMENTS FOR MSFC SPACE FLIGHT HARDWARE* (February 14, 2012), National Aeronautics and Space Administration.

6. SZZA013B, *Thermal Derating Curves for Logic-Products Packages, Application Report* (May 2009), Texas Instruments, Inc.

7. ANSI/GEIA STD-0008, *TechAmerica Standard Derating of Electronic Components* (February 9, 2012), American Nuclear Society Specification.

B.4 Telcordia Documents Referencing SR-332 or a Predecessor

Document No.	Title	Reference
GR-1500-CORE	*Generic Requirements for Powering Telecommunications Load Equipment (TLE) in Telecommunications Systems*	SR-332
GR-151-CORE	*Generic Requirements for 24-, 48-, 130- and 140-Volt Central Office Power Plant Rectifiers*	SR-332
GR-239-CORE	*Generic Requirements for Indoor Telephone Network Interface Devices (NIDs)*	SR-332
GR-2525-CORE	*Generic Requirements and Design Considerations for Mechanized Distributing Frames*	SR-332
GR-264-CORE	*Generic Requirements for Optical Fiber Cleavers*	SR-332
GR-284-CORE	*Reliability and Quality Switching Systems Generic Requirements (RQSSGR)*	SR-332
GR-3109-CORE	*Generic Criteria for Packet Voice Integrated Digital Loop Carrier (PV-IDLC) Systems*	SR-332
GR-312-CORE	*Functional Criteria for the DS1 Interface Connector*	SR-332
GR-320-CORE	*Fundamental Generic Requirements for Metallic Digital Signal Cross-Connect Systems DSX-1, -1C, -2, -3*	SR-332
GR-468-CORE	*Generic Reliability Assurance Requirements for Optoelectronic Devices Used in Telecommunications Equipment*	SR-332
GR-499-CORE	*Transport Systems Generic Requirements (TSGR): Common Requirements*	SR-332
GR-57-CORE	*Functional Criteria for Digital Loop Carrier (DLC) Systems*	SR-332
GR-874-CORE	*An Introduction to the Reliability and Quality Generic Requirements (RQGR)*	SR-332
GR-909-CORE	*Generic Criteria for Fiber in the Loop Systems*	SR-332

GR-929-CORE	*Reliability and Quality Measurements for Telecommunications Systems (RQMS-Wireline)*	SR-332
ROADMAP-TO-NEBS-1	*Telcordia Roadmap to NEBS Documents*	SR-332
ROADMAP-TO-RELIABILITY-1	*Telcordia Roadmap to Reliability Documents*	SR-332
TA-TSY-000038	*Digital Fiber Optic Systems Requirements and Objectives*	TA-000-23620-84-01
TA-TSY-000278	*Digital Data System (DDS) - T1 Data Multiplexer (T1DM) Requirements*	TA-000-23620-84-01
GR-1217-CORE	*Generic Requirements for Separable Electrical Connectors Used in Telecommunications Hardware*	TR-NWT-000332
GR-1515-CORE	*Generic Requirements for the Detection and Control of Thermal Runaway in VRLA Batteries*	TR-NWT-000332
GR-2830-CORE	*Primary Reference Sources: Generic Criteria*	TR-NWT-000332
GR-2834-CORE	*Generic Requirements for Basic Electrical, Mechanical & Environmental Criteria for Outside Plant Equipment*	TR-NWT-000332
GR-2841-CORE	*Generic Requirements for Operations Systems Platform Reliability*	TR-NWT-000332
GR-2883-CORE	*Generic Requirements for Fiber Optic Filters*	TR-NWT-000332
GR-2912-CORE	*Generic Requirements for Reliability in Manufacturing*	TR-NWT-000332
GR-324-CORE	*Maintenance Termination Unit: Generic Requirements for Application on Single-Party Loop Start Lines*	TR-NWT-000332
SR-3244	*Reliability Concerns With Lightwave Components*	TR-NWT-000332
TA-NWT-000406	*DC Bulk Power System for Confined Locations*	TR-NWT-000332
TA-NWT-001210	*Generic Requirements for High-Bit-Rate Digital Subscriber Lines*	TR-NWT-000332
TR-NWT-000154	*Generic Requirements for 24-, 48-, 130- and 140-Volt Central Office Power Plant Control and Distribution Equipment*	TR-NWT-000332
TR-NWT-000930	*Generic Requirements for Hybrid Microcircuits Used in Telecommunications Equipment*	TR-NWT-000332

TR-NWT-001223	*Generic Requirements for DC Power Board Fuses*	TR-NWT-000332
TA-TSY-000192	*Digital Data System (DDS) Multipoint Junction Unit (MJU) Requirements*	TR-TSY-000332
TR-TSY-000752	*Microwave Digital Radio Systems Criteria*	TR-TSY-000332
TR-TSY-000754	*ISDN Primary Rate Access Transport System Requirements*	TR-TSY-000332
TR-TSY-000967	*Generic Requirements for a Low-Power Telecommunications Power Supply/Rectifier*	TR-TSY-000332
TR-TSY-001003	*Generic Requirements for Embedded DC-To-DC Converters*	TR-TSY-000332
GR-1110-CORE	*Broadband Switching System (BSS) Generic Requirements*	TR-332
GR-1221-CORE	*Generic Reliability Assurance Requirements for Passive Optical Components*	TR-332
GR-1312-CORE	*Generic Requirements for Optical Fiber Amplifiers and Proprietary Dense Wavelength-Division Multiplexed Systems*	TR-332
GR-1339-CORE	*Generic Reliability Requirements for Digital Cross-Connect Systems*	TR-332
GR-196-CORE	*Generic Requirements for Optical Time Domain Reflectometer (OTDR)-Type Equipment*	TR-332
GR-198-CORE	*Generic Requirements for Optical Loss Test Sets*	TR-332
GR-2853-CORE	*Generic Requirements for AM/Digital Video Laser Transmitters, Optical Fiber Amplifiers, and Receivers*	TR-332
GR-2875-CORE	*Generic Requirements for Digital Interface Systems*	TR-332
GR-2903-CORE	*Reliability Assurance Practices for Fiber Optic Data Links*	TR-332
GR-2947-CORE	*Generic Requirements for Portable Polarization Mode Dispersion Test Sets*	TR-332
GR-2952-CORE	*Generic Requirements for Portable Wavelength Division Multiplexer Analyzers*	TR-332
GR-2957-CORE	*Generic Requirements for Below-Ground Flywheel Energy Storage Systems*	TR-332
GR-2969-CORE	*Generic Requirements for the Design and Manufacture of Short-Life, Information-Handling Products and Equipment*	TR-332

GR-3013-CORE	*Generic Reliability Assurance Requirements for Optoelectronic Devices Used in Short-Life, Information-Handling Products and Equipment*	TR-332
GR-357-CORE	*Generic Requirements for Assuring the Reliability of Components Used in Telecommunications Equipment*	TR-332
GR-378-CORE	*Generic Requirements for Timing Signal Generators*	TR-332
GR-418-CORE	*Generic Reliability Assurance Requirements for Fiber Optic Transport Systems*	TR-332
GR-454-CORE	*Generic Requirements for Supplier-Provided Documentation*	TR-332
GR-49-CORE	*Generic Requirements For Outdoor Telephone Network Interface Devices (NIDs)*	TR-332
GR-512-CORE	*LSSGR: Reliability, Section 12*	TR-332
GR-761-CORE	*Generic Criteria for Chromatic Dispersion Test Sets*	TR-332
GR-910-CORE	*Generic Requirements for Fiber Optic Attenuators*	TR-332
GR-947-CORE	*Generic Requirements for A -48 Volts Telecommunications Switchmode Rectifier/Power Supply*	TR-332
SR-5096	*Optical Network Reliability OXC and OADM Reliability Analysis*	TR-332

B.5 Reference Notes

All documents are subject to change, and their citations in this document reflect the most current information available at the time of this printing. Readers are advised to check the current status and availability of all documents.

B.6 Contact Customer Service

Customer Service
One Ericsson Drive
Piscataway, NJ 08854
+1.844.251.0201 (Worldwide)
E-mail: **buss.document-info@ericsson.com**
Web site: Telcordia **SuperStore**

B.7 Order Documents Online From the Telcordia SuperStore

Go to the Telcordia **SuperStore** Web site. Use the following **menu bar** to navigate the Store. Instructions to find products are listed below.

A. If you know the document number:

— Enter the number in the **Document Number** box (e.g., SR-332) on the **menu bar** and press Enter.

The *Full Description* page for the document will be displayed. Ordering information is at the bottom of each description page.

B. If you do not know the document number:

— Click on **Advanced Search** on the **menu bar** and press Enter.

— Enter available search information in the **Keywords**, **Title**, **Document Number**, or **Date** fields. Click Submit Search.

— Click on the desired product match to view the *Full Description* page.

C. If you know only a partial document number:

— Enter the partial number in the **Document Number** box on the **menu bar** and press Enter.

— Click on the desired product match from the drop-down menu to display the *Full Description* page for the selected document; or, select *View Full List* to display the *Search Results* page that lists the product matches.

— Click on the desired product match to view the *Full Description* page.

D. If you would like to search for documents by specific technologies:

— Click on **Documents** on the **menu bar**, then select areas of interest.

B.8 Web Sites for Generic Requirements Information

The **GR Web site** discusses the GR development process and how GR participation can benefit your company. Once at this site, select from the following menu:

INFORMATION SUPERSTORE
GR DEVELOPMENT
What's New in Generic Requirements (GRs) and Consulting
Invitations for Participation
About GRs
Funding Participant Benefits
New Releases/Top Picks
Industry Topics

To receive the latest information on new GR products and services, please visit the **GR Web site** and click on **Stay Informed** to send a request.

B.9 Licensing Agreements for Telcordia Documents

Telcordia licensing agreements are designed to fit specific business needs, whether those needs are for

- A single document
- A select group of documents
- A complete collection of documents.

For information on the Ericsson **Enterprise License (EL)**, please **click here**.

Appendix C: Glossary

C.1 Acronyms

AC — Alternating Current

AFR — Annualized Failure Rate

AIS — Alarm Indication Signal

AQL — Acceptable Quality Level

ARPP — Automated Reliability Prediction Procedure

AWG — Arrayed Wave Guide

CMOS — Complementary Metal-Oxide Semiconductor

CW — Continuous Wave

CWDM — Coarse Wavelength Division Multiplexer

DC — Direct Current

DFB — Distributed Feedback

DPM — Defects Per Million

DRAM — Dynamic Random Access Memory

DWDM — Dense Wavelength Division Multiplexer

ECC — Error Correcting Code

EPROM — Erasable Programmable Read Only Memory

FITs — Failures per billion device hours

GR — Generic Requirements

HIC — Hybrid Integrated Circuit

HTOL — High Temperature Operating Life

IC — Integrated Circuit

IFR — In-Field Repair

IR — Infrared

ITU — International Telecommunication Union

JEDEC — Joint Electron Device Engineering Council

LCD — Liquid Crystal Display

LED — Light Emitting Diode

LDMOS — Laterally Diffused Metal-Oxide Semiconductor

MOS — Metal-Oxide Semiconductor

MTBF — Mean Time Between Failures

MTTF — Mean Time to Failure

NMOS — N-type Metal-Oxide Semiconductor

NPN — P-type semi-conductor is sandwiched between two N-type semiconductors

OADM — Optical Add-Drop Multiplexer

PAL — Program Array Logic

PCB — Printed Circuit Board

PDA — Percent Defective Allowed

pHEMT — pseudomorphic High Electron Mobility Transistor

PIN — Positive Intrinsic Negative

PLC — Planar Lightwave Circuit

PNP — N-type semiconductor is sandwiched between two P-type semiconductors

PPTC — Polymetric Positive Temperature Coefficient

PROM — Programmable Read Only Memory

RAM — Random Access Memory

RDT — Reliability Demonstration Test

RF — Radio Frequency

RoHS — Restriction of Hazardous Substances

ROM — Read Only Memory

RPP — Reliability Prediction Procedure

SMD — Surface Mount Device

SMT — Surface Mount Technology

SR — Special Report

SRAM — Static Random Access Memory

SPDT — Single Pole Double Throw

SSD — Solid State Drive/Disk

UCL — Upper Confidence Level

VOA — Variable Optical Attenuation

WDM — Wavelength Division Multiplexer

C.2 Definition of Terms

Arrayed Wave Guide	A specific type of multiplexer/demultiplexer fabricated on a chip (a Planar Lightwave Circuit [PLC]) with different waveguides of varying lengths to combine or separate the different channels of information carried in an optical signal.
Burn-in	The operation of a device under accelerated temperature or other stress conditions to stabilize its performance.
Circuit Pack	A printed wiring board assembly containing inserted components. Also referred to as "plug-in."
Component	Any electrical part (e.g., integrated circuit, diode, resistor) with distinct electrical characteristics.
Device	Any electrical part (e.g., integrated circuit, diode, resistor) with distinct electrical characteristics.
Dispersion	Spreading in time when different wavelengths of light travel at different speeds within a fiber (or other optical waveguide) and so arrive at different times at the far end.
Dispersion Compensating Module	A module is designed to have the opposite dispersion characteristics of the fiber being compensated for, and so bring the different wavelengths back into temporal alignment. Current implementations include a spool of fiber or a grating based design.
Distributed Feedback Laser	A single frequency (wavelength) laser, usually a semiconductor laser, with a cavity that acts as a distributed reflector within the laser. Note that an electro-absorption modulator may be fabricated onto the same chip as a Distributed Feedback (DFB) laser.
Early Life Factor	Ratio of the early life (approximately first year) failure rate to the steady-state failure rate.
Electro-Absorption Modulator	Modulates the intensity of light by taking advantage of materials that cause light to be absorbed when an electric field is applied in a direction perpendicular to the waveguide. Commonly fabricated on semiconductors, an electro-absorption modulator can be fabricated on the same chip as a DFB laser.
Error Correcting Code	Code in which each data signal conforms to specific rules of construction so that departures from this construction in the received signal can generally be automatically detected and corrected.
Failure Rate	Failures in 10^9 operating hours (FITs).
Hermetic	Gas-tight enclosure that is completely sealed by fusion or other comparable means to ensure a low rate of gas leakage over a long period of time.

Interleaver	Used to combine two optical signals, each carrying multiple optical channels (wavelengths). One signal contains odd-numbered channels (according to the ITU grid), and the other contains even-numbered channels. The resulting signal contains all channels. Interleavers are often bidirectional and so could be used to de-interleave channels as well.
Lithium Niobate Modulator	An electrically controlled optical signal modulator (typically amplitude modulation - on/off) that works by splitting a signal into two paths and either recombining them as is to achieve full amplitude, or by delaying one path by applying an electric field to a lithium niobate waveguide and recombining the signals 180° out of phase to give zero amplitude.
Non-hermetic	Not airtight, e.g., a plastic encapsulated integrated circuit.
Non-Serial System	A system in which the failure of any unit may or may not result in the failure of the entire system. A non-serial system may have fully or partially redundant components.
Optical Add-Drop Multiplexer	A device multiplexes (adds) or demultiplexes (drops) one of the standard ITU Dense Wavelength Division Multiplexer (DWDM) or Coarse WDM (CWDM) channels (wavelengths) onto or from an optical signal for transmission through a fiber. Sometimes referred to as a WDM or a wavelength coupler.
Optical Isolator	Device that permits light to travel in one direction (e.g., from input to output) but does not allow light to pass in the reverse direction (e.g., from output to input). Analogous to a diode in electronics, which allows current to pass in one direction only.
Optical Module	A small packaged assembly that includes a laser diode/LED/detector and easy means for electrical connections and optical couplings.
Optical Switch	Device that allows optical input to be passed to any one of a number of outputs, or to select from any one of a number of optical inputs to be sent to a single output.
Planar Lightwave Circuit	Optical device produced using integrated circuit manufacturing techniques to imprint optical waveguides and other related features onto a chip (e.g., silica on silicon).
Steady-State Failure Rate	The constant failure rate after early life (approximately one year of operation).
Serial System	A system in which the failure of any unit results in the failure of the entire system.
System, System Level	A complete assembly that performs an operational function.
Unit, Unit Level	An assembly of devices (e.g., circuit pack, module, plug-in, racks, and power supplies).

Enterprise License Agreement

For Telcordia Technical Documents consisting of Generic Requirements (GRs), Special Reports (SRs), Technical References (TRs), Technical Advisories (TAs), Family of Requirements (FRs), Family of Documents (FDs) (collectively "Licensed Product(s)")

IMPORTANT! PLEASE READ CAREFULLY.

USE OF THIS LICENSED PRODUCT INDICATES THAT YOU ("LICENSEE") HAVE READ AND ACCEPT THE TERMS OF THIS AGREEMENT.

1. LICENSE GRANT

Ericsson Inc. ("Ericsson") grants to Licensee under this Enterprise License Agreement ("Agreement") a personal, non-exclusive, non-transferable, limited license to use this Licensed Product by employees of Licensee for internal business purposes only. All intellectual property rights, title and interest in all Licensed Product(s) furnished to Licensee remain in Ericsson. This License does not preclude the execution of additional license agreements with Licensee for the Licensed Product(s).

Ericsson has exclusive rights to all Licensed Product(s) which are protected by United States and international copyright laws.

2. LICENSEE'S USE:

a) Licensee may place the Licensed Product(s) on a server, internal web site, or other electronic computing platform shared or accessible to employees or affiliates of Licensee. Licensee may make paper and electronic copies of Licensed Product(s) as determined by Licensee to be necessary for Licensee's internal purposes; provided all copies of the Licensed Product(s) shall bear the same copyright and disclaimer notices legend as appear on the Licensed Product(s) originally furnished to Licensee by Ericsson.

b) Subject to the preceding paragraph, and conditioned upon Licensee sublicensing the rights as set forth herein, Licensee may reproduce and distribute Licensed Product(s) to "Affiliates" defined as (i) the parent entity (corporation or partnership) which directly or indirectly owns the majority of the outstanding shares or interests of Licensee, (ii) a sibling entity (corporation or partnership) the majority of whose outstanding shares or interests are owned by its parent entity, or (iii) a subsidiary entity (corporation or partnership) the majority of whose outstanding shares or interests are owned by Licensee, provided, however, that such entity shall continue to remain an Affiliate hereunder only as long as the applicable ownership interest as described above exists. Licensee may sublicense the rights granted in this section to an Affiliate, provided Licensee shall remain responsible for any breach by such Affiliate. Licensee shall ensure that such Affiliate agrees to be bound by the rights, obligations and limitations set forth herein, and Licensee shall ensure that Ericsson shall have the right of direct enforcement of such obligations against such Affiliate. If a direct enforcement claim is denied, for any reason, it is agreed that Ericsson may assert such claim against Licensee.

c) Licensee must treat the Licensed Product(s) like any other copyrighted material.

d) Licensee may make reference to the Licensed Products in creating specifications and related documentation (the "Licensee Documentation").

e) Licensee may, in marketing or in conjunction with the sale of a product or related services (collectively, "Licensee Product"), make reference to the Licensed Product utilized in the development of Licensee Product; provided that Licensee shall make no statement, representation or warranty on behalf of Ericsson, including but not limited to, a certification by Ericsson of a product's or related service's compliance with the Licensed Product, unless otherwise agreed to by the parties in writing.

f) The foregoing license does not include the right to (i) make copies of the Licensed Product(s) for sale, or (ii) transfer to third parties other than Affiliates as provided above, or (iii) copy or incorporate any portions of the Licensed Product into Licensee Documentation, or (iv) create derivative works for sale.
g) It is understood that nothing in this Agreement grants or is intended to grant any license, express or implied, to any patents, or software.
h) Licensee shall immediately notify Ericsson (i) of any unauthorized attempt by a third party to access the Licensed Product, or (ii) if Licensee becomes aware of any unauthorized use or disclosure of any Licensed Product.

3. AUDITS

Upon reasonable written notice to Licensee, Ericsson shall have the right to review Licensee's compliance with the terms and conditions of this Agreement. If such review reveals a violation of the requirements set forth herein, in addition to any other remedies it may have, Ericsson may terminate this Agreement in accordance with the Termination section of this Agreement.

4. FEES AND PAYMENTS

All fees and charges due hereunder shall be paid in full within thirty (30) days of the date of the invoice. All payments required hereunder shall be nonrefundable. Overdue payments are subject to a late payment charge, calculated and compounded monthly, and calculated at an annual rate of either (1) one percent (1%) over the prime rate available in New York City, as published in The Wall Street Journal on the first Monday (or the next bank business day) following the payment due date; or (2) 18 percent (18%), whichever shall be higher. If the amount of the late payment charge exceeds the maximum permitted by law, the charge will be reduced to that maximum amount.

Licensee shall pay or reimburse Ericsson for all sales or use taxes, duties, or levies imposed by any authority, government or government agency (other than those levied on the net income of Ericsson) in connection with this Agreement. If Ericsson is required to collect a tax to be paid by Licensee, Licensee shall pay this tax on demand. If Licensee fails to pay these taxes, duties or levies, Licensee shall pay all reasonable expenses incurred by Ericsson, including reasonable attorney's fees, to collect such taxes, duties or levies.

Ericsson shall provide Licensee with one (1) copy of the Licensed Product. Upon request, an additional copy in electronic media will be provided to Licensee at a cost of $150.00. Additional copies will be limited to one copy at the latter fee. Please contact our Customer Service Center at buss.document-info@ericsson.com, 1.844.251.0201 (USA and Canada), or 1.913.241.6682 (All others).

5. DISCLAIMER OF WARRANTIES

THE LICENSED PRODUCT IS PROVIDED "AS IS" WITHOUT WARRANTY OF ANY KIND, EITHER EXPRESS OR IMPLIED, INCLUDING, BUT NOT LIMITED TO THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, EVEN IF ERICSSON HAS BEEN MADE AWARE OF SUCH PURPOSE, OR ANY WARRANTY AGAINST INFRINGEMENT OF PATENTS OR OTHER INTELLECTUAL PROPERTY RIGHTS. LICENSEE ASSUMES RESPONSIBILITY FOR THE SELECTION OF THE LICENSED PRODUCT TO ACHIEVE ITS INTENDED RESULTS, AND FOR THE USE AND RESULTS OBTAINED FROM THE LICENSED PRODUCT.

6. LIMITATION OF LIABILITY

IN NO EVENT WILL ERICSSON BE LIABLE TO LICENSEE FOR ANY DAMAGES, INCLUDING DIRECT DAMAGES, LOST PROFITS, OR OTHER INDIRECT, SPECIAL, INCIDENTAL, EXEMPLARY OR CONSEQUENTIAL DAMAGES ARISING OUT OF THIS AGREEMENT, EVEN IF ERICSSON HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

7. THIRD PARTY PRODUCTS AND INFORMATION WARRANTY

Ericsson does not warrant third party products or information which Ericsson may use to prepare the Licensed Product. Third party products or information may be warranted by third parties as expressly provided in the documentation accompanying the third party product or information, if any. Licensee's exclusive remedy under any third party warranty is as provided in the third party documentation accompanying the third party product or information, if any.

8. RETURN POLICY

Licensed Product(s) that have been delivered electronically (downloaded from the SuperStore or received via email) are ***not*** eligible for credits, refunds or returns, even if duplicative with Licensed Product(s) that are the subject of prior or contemporaneous orders. Licensee assumes all responsibility for managing its inventory of Licensed Product(s).

9. TERMINATION

If Licensee breaches one or more of its obligations under this Agreement, Ericsson may elect at any time, in addition to any other remedy, to terminate the license and rights granted. Prior to the termination, Ericsson must give Licensee two (2) months written notice specifying the breach. Ericsson may terminate the license and rights granted if Licensee does not remedy all breaches specified in the written notice within the two (2) month notice period. Upon termination of the license and rights granted, Licensee shall destroy or return all Licensed Product(s), including all copies, and certify in writing to Ericsson the destruction or return.

10. PUBLICITY

Notwithstanding anything herein to the contrary, each party is prohibited from using in advertising, publicity, promotion, marketing, or other similar activity, any name, trade name, trademark, or other designation including any abbreviation, contraction or simulation of the other without the prior, express, written permission of the other.

11. ASSIGNMENT

Neither this Agreement nor any license, rights or obligations hereunder shall be assignable or transferable (in insolvency proceedings, by mergers, by purchase, by operation of law or otherwise) by Licensee without the written consent of Ericsson. Any such purported assignment or transfer shall be void without such written consent.

12. GENERAL

Export/Re-export. Licensee acknowledges that any commodities and/or technical data provided under this Agreement may be subject to the Export Administration Regulations (http://www.ecfr.gov, Title 15-Commerce and Foreign Trade, Volume 2, Section VII, Subchapter C-Export Administration Regulations, collectively, “the EAR”) administered by the Bureau of Industry and Security of the U.S. Department of Commerce (http://www.bis.doc.gov) and that any export or re-export thereof must be in compliance with the EAR, either through license or appropriate license exception. Licensee agrees that it shall not export or re-export, directly or indirectly, either during the term of this Agreement or after its termination or expiration, any commodities and/or technical data (or direct products thereof) received from Ericsson under this Agreement in any form to destinations in Country Group E (as specified in Supplement No. 1 to Part 740 of the EAR, as modified from time to time by the U.S. Department of Commerce), or to destinations, entities or persons that are otherwise controlled or embargoed under U.S. law. Licensee acknowledges it is not a foreign national of Country Group E or a denied party on U.S. export regulations.

Foreign Tax Payment. For a Licensee which is not a United States corporation, Ericsson will not accept remittance of less than the full amount billed to Licensee as full payment unless:

a. Licensee withholds that amount to satisfy tax withholding requirements imposed by the country (other than the United States) in which Licensee resides or in which Licensee has accepted delivery of the Licensed Product; and

b. Licensee furnishes a receipt issued by the withholding tax jurisdiction and certifying deposit of the withheld amount into its treasury or other tax depository to Ericsson’s sole credit, or a certification on Licensee’s stationery that Licensee has deposited the withheld amount into its tax jurisdiction's treasury or other tax depository to Ericsson's sole credit.

Further, to ensure the orderly processing of Ericsson tax returns, Licensee shall provide to Ericsson a summary of all amounts withheld during the year no later than ten business days after December 31 of each year addressed to: Ericsson Inc., 6300 Legacy Dr., Plano, Texas 75024, Attn: Tax Management Department.

Governing Law. This Agreement is a contract between Ericsson and the Licensee of the Licensed Product. This contract is to be interpreted in the federal and state courts of New Jersey, in accordance with the laws of the State of New Jersey without regard to its conflict of laws principles, and the parties consent to the jurisdiction of such courts for this purpose.

Entire Agreement. Licensee further agrees that this is the complete and exclusive statement of the Agreement between Licensee and Ericsson and supersedes any proposal or prior Agreement, oral or written, or any other communication between us relating to the subject matter of this Agreement.

All questions about this Agreement should be directed to:

Ericsson Inc.
Customer Service Center (IDO)
One Ericsson Drive
Piscataway, NJ 08854
Phone: +1.844.251.0201 (USA and Canada) or +1.913.241.6682 (All others)
Email: buss.document-info@ericsson.com

END OF TERMS AND CONDITIONS

Rev. 01/2017