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Process management for avionics – Use of semiconductor devices outside manufacturers' specified temperature range

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PROCESS MANAGEMENT FOR AVIONICS – USE OF SEMICONDUCTOR DEVICES OUTSIDE MANUFACTURERS' SPECIFIED TEMPERATURE RANGE

FOREWORD

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IEC 62240, which is a technical report, has been prepared by IEC Technical Committee 107: Process management for avionics.

This Technical Report cancels and replaces IEC/PAS 62240 published in 2001. This first edition constitutes a technical revision.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
107/33/DTR	107/36/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

Traditionally, industries that produce electronic equipment for rugged applications have relied on the military specification system for semiconductor device standards; and upon manufacturers of military-specified devices as device sources. This assured the availability of semiconductor devices specified to operate over the temperature ranges required for electronic equipment in rugged applications. Many device manufacturers have exited the military market in recent years, resulting in decreased availability of devices specified to operate over wide temperature ranges. Following are some typical ambient temperature ranges at which devices are marketed:

Military:	–55 °C to +125 °C
Automotive:	–40 °C to +125 °C
Industrial:	–40 °C to +85 °C
Commercial:	0 °C to +70 °C

If there are no reasonable or practical alternatives, then a potential response is for equipment manufacturers to use devices in temperature ranges that are wider than those specified by the device manufacturer. This practice, properly documented and controlled, is used by electronic equipment manufacturers to meet the design goals of their equipment.

This technical report gives practices and procedures to select semiconductor devices; to assess their capability to operate; and to assure their intended quality in the wider temperature ranges. It also reports the documentation of such usage.

PROCESS MANAGEMENT FOR AVIONICS – USE OF SEMICONDUCTOR DEVICES OUTSIDE MANUFACTURERS' SPECIFIED TEMPERATURE RANGE

1 Scope

This technical report reports processes that exist for using semiconductor devices in wider temperature ranges than those specified by the device manufacturer.

This technical report reports on applications in which only the performance of the device is an issue. Even though the device is used at wider temperatures, the wider temperatures will be limited to those that do not compromise the system performance or application-specific reliability of the device in the application. Specifically, this technical report does not report on applications that require the device to function beyond the absolute maximum rating limits of the component specified by the manufacturer and with a margin to be considered.

NOTE Alternate means of thermal uprating may have been performed prior to the implementation reported in this technical report by the equipment manufacturer. Rationale for decisions made may have been valid considering the application, semiconductor market conditions, experience with the particular component manufacturer, etc. at the times these decisions were made. Field performance using these methods also may validate their use, however, their continued use should take into account the risk of changes to the subject devices such as feature size reductions, material changes, etc.

2 Normative references

The following referenced documents are indispensable for the application of this technical report. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62239, *Process management for avionics – Preparation of an electronic components management plan*

3 Terms and definitions

For the purposes of this technical report, the following terms and definitions are used herein and/or should be used when using devices outside the manufacturers' specified temperature ranges.

NOTE The terms *uprating* and *thermal uprating* are being used increasingly in avionics industry discussions and meetings, and clear definitions are included in this clause. They were coined as shorthand references to a special case of methods commonly used in selecting components for circuit design. This technical report describes the methods and processes for implementing this special case. All of the elements of these processes employ existing, commonly used engineering practices. No new or unique engineering knowledge is required to follow these processes: only a rigorous application of the overall approach.

3.1
absolute maximum ratings
limiting values of operating and environmental conditions applicable to any semiconductor device of a specific type as defined by its published data, which should not be exceeded under the worst possible conditions. These values are chosen by the device manufacturer to provide acceptable serviceability of the device, taking no responsibility for equipment variations, and the effects of changes in operating conditions due to variations in the characteristics of the device under consideration and all other electronic devices in the equipment

[IEC 60134:1961, Clause 4, modified]

3.2
ambient temperature
temperature of the environment in which a semiconductor device is operating

3.3
case temperature
temperature of the surface of a semiconductor device package during operation

3.4
circuit element functional mode analysis
documented analysis that determines minimum ranges and maximums of all functional characteristics of the assembly with respect to the related functional parameters of devices being uprated

3.5
device capability assessment
process of demonstrating that the device design is capable of providing the specified functionality, over the wider temperature range, for the required length of time. It assumes that the device has been qualified to operate within its specified temperature range, and includes additional testing or analysis to evaluate expected performance at the wider temperature range. Device capability assessment includes both performance and application-specific reliability

3.6
device quality assurance over the wider temperature range
additional testing or analysis required to assure that each individual device is capable of operating successfully in the required wider temperature range

3.7
ECMP
Electronic Components Management Plan

3.8
semiconductor devices
electronic devices that are not subject to disassembly without destruction or impairment of design use. They are sometimes called *electronic parts* or *piece parts*. Examples are diodes, integrated circuits, and transistors

3.9
electronic equipment
any item, for example, end item, sub-assembly, line-replaceable unit, shop-replaceable unit, or system produced by an electronic equipment manufacturer

3.10
junction temperature
temperature of the active region of the device in which the major part of the heat is generated

[International SEMATECH Official Dictionary, Rev 5.0, modified]

3.11
manufacturer-specified parameter limits
electrical parameter limits that are guaranteed by the device manufacturer when a device is used within the recommended operating conditions (see *Rating*)

3.12
manufacturer-specified temperature range
operating temperature range over which the component specifications, based on the component data sheet, are guaranteed by the component manufacturer (see *Rating*)

NOTE Manufacturer-specified temperature range is a subset of the recommended operating conditions.

3.13
may
indicates a course of action which is permissible within the limits of this technical report

3.14
parameter conformance assessment
process for thermal uprating in which devices are tested to assess their conformance to the manufacturer-specified parameter limits over the target temperature range

3.15
parameter characterisation
process of determining the typical and limiting values of electrical parameters by testing representative samples at room and extreme temperatures over the manufacturer's specified temperature range

3.16
parameter re-characterisation
process for thermal uprating in which the device parameters are characterised over the target temperature range, leading to a possible re-specification of the manufacturer-specified parameter limits

3.17
rating
value that establishes either a limiting capability or a limiting condition for a semiconductor device

3.18
recommended operating conditions
conditions for use of the component for which the component specifications, based on the component data sheet, are guaranteed by the component manufacturer (see *Rating*)

3.19
shall
indicates a mandatory requirement to be followed in order to conform to this technical report

3.20
should
indicates that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain course of action is deprecated but not prohibited

3.21
stress balancing
process for thermal uprating in which at least one of the device's electrical parameters is kept below its maximum allowable limit to reduce heat generation, thereby allowing operation at a higher ambient temperature than that specified by the device manufacturer

3.22
target temperature range
operating temperature range of the device in its required application

3.23
thermal uprating
process to assess the capability of a part to meet the performance requirements of the application in which the device is used outside the manufacturer's specified temperature range (see *Uprating*)

3.24
uprating
process to assess the capability of a device to meet the performance requirements of the application in which the device is used outside the manufacturer's specification range

NOTE Terms such as "upscreening", "retest", "up-temperature testing" and other similar variations are all deemed to be subsets of or encompassed by the overall uprating process.

3.25
wider temperature range
target temperature range outside the manufacturer-specified temperature range. It may include temperatures that are higher or lower than the manufacturer-specified temperature range, or both

3.26
will
expresses a declaration of intent

4 Objectives

The objectives of this technical report are:

– to ensure that device usage outside the manufacturers' specified temperature ranges is done only with appropriate justification; and
– to ensure that, if it is necessary to use devices outside the manufacturers' specified temperature ranges, it is done with documented and controlled processes that assure the integrity of the equipment.

5 Using devices outside the manufacturer's specified temperature ranges

Devices used outside the manufacturers specified temperature range **shall** be selected (5.1), their capability assessed (5.2), and their quality assured (5.3), and documented (5.4), as illustrated by the flow chart of Figure 1.

NOTE The headings of this clause are keyed to the actions and decisions of Figure 1.

5.1 Device selection, usage and alternatives

The equipment manufacturer **shall** design so that, initially and throughout life, no absolute-maximum value for the intended service is exceeded for any device under the worst probable operating conditions with respect to supply voltage variation, equipment device variation, equipment control adjustment, load variations, signal variation, environmental conditions, variation in characteristics of the device under consideration and of all other electronic devices in the equipment.

5.1.1 Alternatives

A review of alternatives **shall** be carried out prior to using a device outside the manufacturer's specified temperature range. If an alternative can be shown to be reasonable and practical then it **shall** be selected. The results of the evaluation **shall** be documented.

Examples of potential alternatives include:

- using a device specified over the required temperature range, with the identical function, but from a different manufacturer;
- using a device specified over the required temperature range, with the identical function, but a wider specified temperature range;
- using a device specified over the required temperature range, with the identical function, but a different package;
- using a device specified over the required temperature range, that has slightly different specified parameter limits, but which still meets the equipment design goals;
- using a device with the identical function, but a specified temperature range that still meets the application requirement;
- using a device specified over the required temperature range, but a different function, and compensating by making changes elsewhere in the equipment design;
- modifying the device's local operating environment, for example, adding cooling, etc.;
- modifying the equipment specified ambient temperature requirement, in co-operation with the customer;
- modifying the equipment operating or maintenance procedures, in co-operation with the customer; and
- negotiating with the device manufacturer to provide assurance over the wider temperature range.

For most applications, the preferred device for use in a wider temperature range should be the one for which the extension beyond the specified range is least.

NOTE As an example of this requirement, consider the case in which the required ambient temperature is 92 °C, and no device specified to operate above 85 °C is available. If the two available devices have specified maximum ambient temperatures of 70 °C and 85 °C, then the 85 °C device should, in the absence of other factors, be given preference regarding temperature.

5.1.2 Device technology

The technology of a device and its package **shall** be identified and understood in sufficient detail to assess the likelihood and consequences of potential failure mechanisms. It is recommended that the device manufacturer be consulted when a device is proposed for use outside manufacturers' specified temperature range. If the device manufacturer discourages the uprating process arguing technical reasons, the user needs to assess the impact of those reasons against the user's specific application.

5.1.3 Compliance with the Electronic Component Management Plan

All devices considered for use in wider temperature ranges **shall** be compliant with the equipment manufacturer's ECMP. It is necessary for ECMP requirements to be met only for the temperature range over which the device is specified, since requirements for wider temperatures are provided in this technical report.

NOTE IEC 62239 is recommended as a resource for an ECMP.

The use of devices outside the temperature ranges specified by the device manufacturer is discouraged; however, such usage may occur if other options prove to be impossible, unreasonable, or impractical. Justification for such usage may be based on availability, functionality, or other relevant criteria. In no case will such usage result in a design that:

– requires the device to operate at an operating or environmental stress level that significantly increases the risk of unstable device operation or loss of equipment function; or
– requires the device to operate beyond the device's maximum junction temperature or any other limiting temperature, as specified by the device manufacturer, or calculated directly from parameters specified by the device manufacturer.

5.2 Device capability assessment

The assessment of device capability needs to assure that not only are device parametrics acceptable, but also that device functionality and functionality of the related circuit are acceptable as well. Therefore, functional testing at the application or circuit level and higher levels as well is recommended.

5.2.1 Device package and internal construction capability assessment

Device qualification test data and other applicable data when available **shall** be analyzed to assure that they support the operation of the device over the end use temperature range and that the package and internal construction type used in device qualification is the same as that to be used in the end application.

Device qualification test data and other applicable data when available **shall** be analyzed to assure that the package and internal construction can withstand the stresses resulting from wider temperature cycling ranges, and that the package materials do not undergo deleterious phase changes or changes in material properties in the wider temperatures.

If this data is not available, then relevant testing based on the application should be considered.

5.2.2 Risk assessment (assembly level)

A preliminary risk assessment is prudent at this point to help guide decisions regarding the method(s) of capability assessment to be used, as well as how and when they should be applied. Understanding the risks on an application-specific basis enables "risk informed" decision-making and thereby a prediction of the impact of critical decisions.

The process for assessing risks should consider applicable factors associated with the use of devices beyond the manufacturers specified temperature range. Risk factors in this assessment may include:

– application criticality into which the device will be used;
– consequences of failure at device, circuit and system level;
– type or technology of device under consideration;
– manufacturer data available for the device;
– quality/reliability monitors employed by the manufacturer;
– comprehensiveness of production assembly-level screens performed at extended temperature;
– identification of both managed and unmanaged risks and cost models for each.

Details about the likelihood of occurrence, consequences of occurrence, and acceptable mitigation approaches for each identified risk should be generated. Each risk normally falls into one of the following categories:

– functionality risks – risks for which the consequences of occurrence are loss of equipment, loss of mission, or unacceptable performance. Functionality risks impair the product's capability to operate to the customer's specification;
– producibility risks – risks for which the consequences of occurrence are financial impacts (reduction in profitability). Producibility risks determine the probability of successfully manufacturing/fabricating the product (where "successfully" refers to some combination of schedule, manufacturing yield, quantity and other factors).

Several approaches are possible, and each approach constitutes a unique mixture of risk mitigation factors. The results of a preliminary risk assessment should provide insight and assistance to the selection of a viable approach or approaches for establishing the capability of devices being used outside the manufacturer's specified temperature range.

5.2.2.1 Device parameter re-characterisation

Device parameter re-characterisation consists of characterising the device parameters over a temperature range beyond that specified by the device manufacturer and, as a result, re-specifying some of the data sheet parameter values or tolerances in the wider temperature range. The device then may be used in applications in which the newly specified parameters provide the required functionality. To effectively assess device manufacturing variability, multiple date codes need to be considered, with the recognition that this may be application and usage rate dependent.

If device parameter re-characterisation is chosen for capability assessment, then the process described in Annex A **shall** be followed.

If device parameter re-characterisation is chosen for capability assessment, it **shall** be used in conjunction with a quality assurance process that includes device testing, as described in 5.3.1.

5.2.2.2 Device stress balancing

Device stress balancing consists of operating the device at an ambient temperature above that specified by the device manufacturer; and compensating by reducing at least one of the other operating parameters, for example, power, speed, to the extent that the junction temperature remains below its maximum rating, with acceptable specified margin.

If device stress balancing is chosen for capability assessment, then the process described in Annex B **shall** be followed.

5.2.2.3 Device parameter conformance assessment

If device parameter conformance is chosen for capability assessment, then the devices **shall** be tested over the entire wider temperature range, according to the process described in Annex C.

Sampling procedures and failure criteria for device testing should be according to Annex C. Where less than 100 % are sampled, then device testing also **shall** include testing at a higher level of assembly over the entire wider temperature range.

5.2.2.4 Higher assembly level testing at temperature extremes

Higher assembly level testing at temperature extremes consists of testing the device over the entire wider assembly ambient temperature range, while the device is incorporated into a higher level of assembly.

If higher assembly level testing is chosen for capability assessment, then the process described in Annex D **shall** be followed.

NOTE 1 A higher level of assembly may include a module, a printed circuit card, another sub-assembly, or the end item.

NOTE 2 The intent of 5.2.2.3 and 5.2.2.4 is to ensure that, if testing is used to assess device capability, then each device is tested at least once over its entire wider operating ambient temperature range. Higher-assembly-level testing results are applicable only to the design revision of the assembly. For other assembly revisions, additional testing or analysis should be performed.

The following steps **shall** be followed:

a) Perform a Circuit Element Functional Mode Analysis to determine the device functions/parameters to be tested in order to assure assembly functionality across the target ambient temperature range.
b) Review the assembly level test plan to determine its capability to test the parameters required for successful operation in the assembly. If the test plan is not capable, and cannot be modified to be capable, than this method of uprating is rejected for the application.
c) Conduct the test, analyze the results, and document the conclusions.
d) Insert instructions in the maintenance procedures to require full acceptance test over the target ambient temperature range. This testing applies after every maintenance action that involves replacement of an electronic device at the assembly level for which the original capability assessment was performed, unless the maintenance manual provides adequate alternate procedures. This test should be conducted at an assembly level at which the original capability assessment was done, or higher.

5.2.3 Device reliability assurance

Device manufacturers generally qualify devices (including reliability assessment) using the same processes, regardless of the temperature ranges for which they are specified. Generally, they do not represent their products to have a guarantee of lifetime in any application, because they do not know what the use conditions will be. Caution should be exercised when using past experience of the device within the manufacturers specified temperature range to infer reliability outside of the manufacturers specified temperature range.

The application of each device and any related impacts on reliability should be assessed. New and/or accelerated failure mechanisms, which might be evident at the wider temperature range, should be clearly identified and their effects on reliability established. If deemed necessary, additional testing can be implemented to address application reliability concerns.

NOTE 1 The distribution of time that a device is actually operating beyond a device manufacturer's specified temperature range and the related impact on reliability need to be considered. Uprating conditions often occur only as "corner conditions" or for specified extreme environments which are seldom experienced. Device manufacturers should be consulted to assist in the assessment of related reliability impacts for these conditions.

The following steps **shall** be followed:

a) Qualify the devices according the requirements of the user's Electronic Component Management Plan, as specified in 5.1.2 of this technical report; qualify electrical performance of the devices over the intended range of operating and environmental conditions after a reliability stress conditioning exposure that reflects the life cycle of the application; and determine a margin, supported by analysis using adequate data from the intended application, between the maximum operating junction temperature and the absolute maximum rated junction temperature.

b) The absolute maximum rating of the junction temperature of the device as defined in clause 3 of this technical report, with a default margin of 20 °C should not be exceeded. Other margins may be used if the device user has data to justify them.

NOTE 2 Device reliability can decrease as junction temperature, *T*j, approaches maximum. This is a function of time in application at that temperature. If the average *T*j of the device is expected to approach maximum in the application, the reliability impact should be addressed. Note also that many avionics applications specify a high temperature environment in which the device is required to operate. The reliability impact on the device is not driven by a thermal condition that is very seldom experienced.

5.3 Device quality assurance in wider temperature ranges

Regardless of the process used to assure device capability, the quality assurance processes documented in the equipment manufacturer's ECMP **shall** be applied to the device.

5.3.1 Device parameter re-characterisation testing

If device parameter re-characterisation (5.2.2.1) is used for capability assessment, then the device quality **shall** be assured by testing incoming devices according to a defined sampling plan and effective supplier change notice monitoring.

NOTE The intent of this guideline is to monitor the devices to assure that, subsequent to the capability assurance activity, no changes are made in the design or manufacturing processes of the device that will adversely affect its capability in the wider temperature range.

5.3.2 Device parameter conformance testing

If device parameter conformance assessment (5.2.2.3) or higher assembly level testing at temperature extremes (5.2.2.4) is used for capability assessment, then the device quality **shall** be assured through device parameter conformance testing (this section), higher level assembly testing (5.3.3) or both, depending on the results of the risk assessment in 5.2.2. See Figure 1 for a flow chart of this process. If this method is used for quality assurance, the device assessment process **shall** be done initially by testing all individual devices before use in production equipment or by temperature testing all production equipment at the ambient temperature extremes.

Based on data derived from such testing, testing may be reduced or eliminated by satisfactory test history and by effective supplier change notice monitoring. The sampling rate, confidence limits, and decision criteria **shall** be as stated in Annex C.

5.3.3 Higher level assembly testing

If higher assembly level testing at temperature extremes (5.2.2.4) or device parameter conformance assessment (5.2.2.3) is used for capability assessment, then the device quality **shall** be assured through device parameter conformance testing (5.3.2), higher level assembly testing (this subclause), or both, depending on the results of the risk assessment in 5.2.2. See Figure 1 for flow chart showing this process. If this subclause is chosen for quality assurance, a process similar to that outlined in Annex D **shall** be used to determine the capability of the assembly test to validate the uprated device at the target temperature. Assembly level tests are designed to test basic functional performance of an assembly or device. Typically, all functions or "key characteristics" of the end product are typically verified at the sub-assembly or end-item level. The difference between the typical case and the process described here is that the device's role in these functions, or "key characteristics", of the assembly are traced, and its capability verified by assembly test over the target temperature range.

5.3.4 Change monitoring

Device data (such as product change notices or manufacturer data) **shall** be monitored to give warning of device changes that may affect the capability of the device to operate over the wider temperature range as established in 5.2.

The requirement for monitoring component design and component manufacturing process change data is no different than the related requirement in the IEC 62239 ECMP specification.

5.3.5 Failure data collection and analysis

Failure data should be collected for all uprated devices. When clear trends are evident, the data should be analysed and corrective action taken.

Failures of devices used in wider temperature range should be analysed to establish the root cause of the failure.

When failure analysis is conducted, the results **shall** be documented.

5.4 Documentation

For each instance of device usage outside the manufacturers specified temperature range, relevant information **shall** be documented and stored in a controlled, retrievable format:

The documented information should include:

– equipment in which the device is used;
– device identification;
– required operating temperature range;
– manufacturer-specified operating temperature of the device;
– alternatives considered and rejected;
– process for assuring device capability in the wider temperature range (including test and analysis results);
– process for assuring device quality in the wider temperature range (including test and analysis results);
– required signatures;
– risk assessment results.

NOTE 1 Required signatures include those of the responsible authorities within the equipment designer's organisation and, if required, those of the customers.

NOTE 2 The form of Figure 2 is recommended for use in documenting semiconductor device usage in wider temperature ranges.

5.5 Device identification

All device identification processes **shall** be consistent with other industry processes.

For each instance in which a device has been determined as having met the application's wider temperature range requirements, through parameter re-characterisation or (5.2.2.2) or device testing (5.2.2.4), the device's status **shall** be identified as having met the requirements specified in the design activity's uprating specification. The identification requirements **shall** be as specified in the design activity's uprating specification and include the design activity's unique identifier such as the CAGE code, logo, or acronym and the part number assigned by the design activity. For each occurrence of uprating the parts **shall** be separately identified as meeting the requirements of the application. The method of identification **shall** enable all relevant activities such as spares and maintenance to establish that the device has met the requirements of parameter re-characterisation or (5.2.2.2) or device testing (5.2.2.4).

If the device is marked then marking **shall** be in addition to the existing/original manufacturer's marking and be readable when the device is mounted in its application. All markings applied **shall** be permanent and legible.

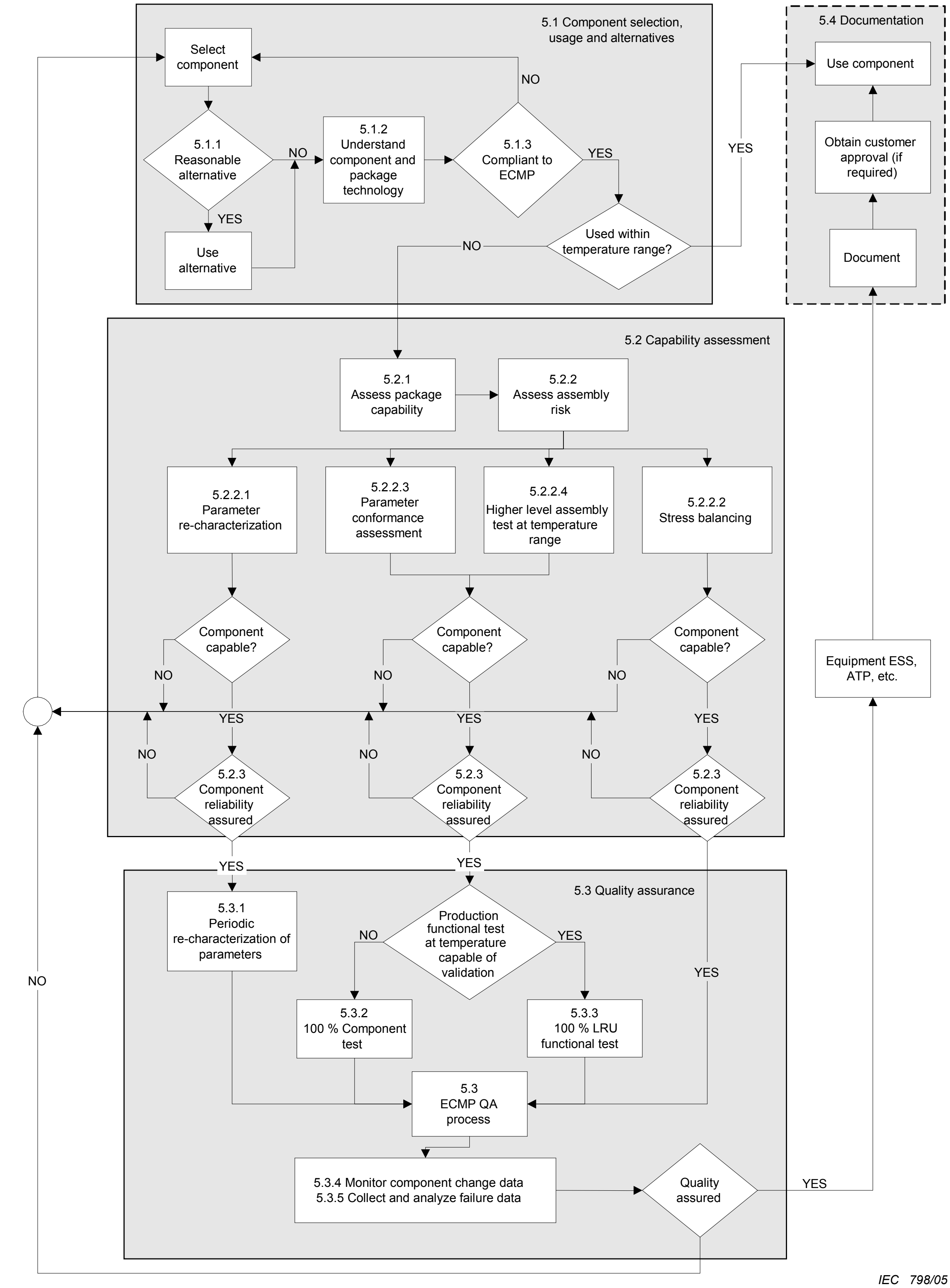

Figure 1 – Flow chart for semiconductor devices in wider temperature ranges

WIDER TEMPERATURE RANGE DEVICE USAGE REPORT	
Equipment name (if applicable)_______________ Equipment ID no. (if applicable)______________ Name ______________ ID no. before uprate______________	Date _____________ Program manager ______________ Component engineer ___________ ID no. after uprate_________________
Equipment required temperature range: Manufacturer's specified device temperature range:	Max. ________ Min. ________ (Ambient) Max. ________ Min. ________ (Ambient)
Is the device compliant to the equipment manufacturer's electronic component management plan? Yes _____ No _____	
What alternate solutions were evaluated, and why were they rejected?	
Capability assessment process: Is the package capable? _____	Device parameter re-characterisation _____ Device stress balancing _____ Assembly testing _____ Device testing _____
Is the device capable of operating in the required temperature range without significantly increased risk of catastrophic failure, unstable operation, loss of equipment function, or adversely affecting the application-specific reliability of the device? (Reference or attach capability assessment report)	
Quality assurance process:	Sample plan and monitoring _____ 100 % LRU test _____ 100 % Device test ______
Is the device's quality assured? (reference or attach QA Plan)	
Approvals ____	

IEC 799/05

Figure 2 – Report form for documenting device usage in wider temperature ranges

Annex A
(informative)

Device parameter re-characterisation

A.1 Glossary of Symbols

The following terms and definitions are used in this Annex.

T_{room}:	Room temperature (25 °C)
$T_{rated\text{-}max}$:	Maximum temperature at which part manufacturer guarantees operation of a part in accordance with the published data sheet
$T_{rated\text{-}min}$:	Minimum temperature at which part manufacturer guarantees operation of a part in accordance with the published data sheet
$T_{req\text{-}max}$:	Maximum temperature at which the part is required to operate in a system
$T_{req\text{-}min}$:	Minimum temperature at which the part is required to operate in a system
$T_{test\text{-}max}$:	Maximum temperature at which the part is tested, usually more than $T_{req\text{-}max}$
$T_{test\text{-}min}$:	Minimum temperature at which the part is tested, usually less than $T_{req\text{-}min}$
UL:	Maximum limit of a parameter value in the part manufacturer specified temperature range (Specified by part manufacturer)
LL:	Minimum limit of a parameter value in the part manufacturer specified temperature range (Specified by part manufacturer)
UL_{Max}:	Maximum allowable upper limit for a parameter for proper system operation
LL_{Min}:	Minimum allowable upper limit for a parameter for proper system operation
UL_{New}:	New maximum parameter value limit if the parameter limit is modified
LL_{New}:	New minimum parameter value limit if the parameter limit is modified
M_{UL}:	Margin of tested parameter value at extremes of target application temperature range with UL
M_{LL}:	Margin of tested parameter value at extremes of target application temperature range with LL
$M_{UL\text{-}req}$:	Required margin of tested parameter value at extremes of target application temperature range with parameter limit
$M_{LL\text{-}req}$:	Required margin of tested parameter value at extremes of target application temperature range with parameter limit
E:	Precision of sampling for mean of a parameter
E_A:	Measurement inaccuracy
σ:	Population standard deviation
s:	Sample standard deviation
n:	multiplier for standard deviation (typically 3)
μ:	Mean of a population

Part manufacturer specified temperature range	The operating temperature range over which the component specifications, based on the component data sheet, are guaranteed by the component manufacturer. The range between $T_{\text{rated-min}}$ and $T_{\text{rated-max}}$
Target temperature range	The operating temperature range of the part in its required application. This temperature range may be wider than the part manufacturer specified temperature range. The range between $T_{\text{req-min}}$ and $T_{\text{req-max}}$
Test temperature range	The temperature range over which a part is tested for parameter re-characterisation The range between $T_{\text{test-min}}$ and $T_{\text{test-max}}$

Equation A.1 gives the relationship of the above temperatures:

a) $T_{\text{test–min}} \le T_{\text{req–min}} \le T_{\text{rated–min}} \le T_{\text{room}}$

b) $T_{\text{room}} \le T_{\text{rated–max}} \le T_{\text{req–max}} \le T_{\text{test–max}}$ Equation A.1

It should be noted that for the conditions expressed in Equation A.1 above, parameter re-characterisation can apply for either condition a), condition b) or both.

A.2 Rationale for parameter re-characterisation

A.2.1 General

The re-characterisation process is conducted by the user of the device, or a designated test facility. It measures electrical parameters and their variations over a target temperature range that is wider than that specified by the device manufacturer. Based on test results, the data sheet parameters may be used as published, or modified if test results so indicate. It may be necessary to maintain the data sheet parameters for some target temperature ranges, and to modify others. The new parameter limits may not be applicable to all applications. Figure A.1 illustrates the rationale for parameter re-characterisation.

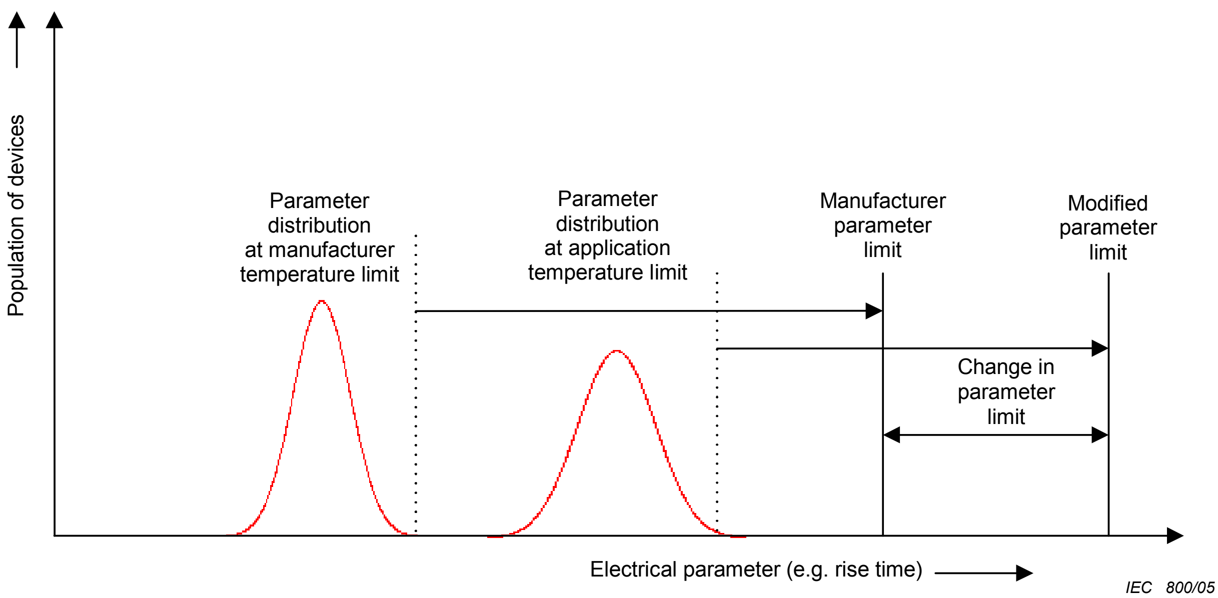

Figure A.1 – Parameter re-characterisation

A.2.2 Assessment for uprateability

Before any testing is performed, data from all available sources should be analysed to determine if it is reasonable to attempt parameter re-characterisation. Typical sources of such data include users of similar devices in similar applications, test laboratories, manufacturers, and industry organisations.

Device manufacturers' processes assure the quality of devices within their specified temperature limits. If they can be obtained from the device manufacturer, data from these processes may provide insight about a device's expected performance over the target temperature range. Simulation models, for example, the BSIM3 model for short channel MOSFETs, may be used to estimate the effects of temperature variation on device parameters, and therefore may be used to assess their "uprateability [1][1]."

A.3 Capability assurance

A.3.1 Description

Parameter re-characterisation is a method of thermal uprating in which the part parameters are characterised over the target temperature range, using processes similar to those used by the device manufacturer for original device characterisation. If parameter re-characterisation is successful, the device may be used in applications in which the re-characterised parameters are acceptable.

A.3.2 Parameter re-characterisation process

Figure A.2 shows a flow diagram of the parameter re-characterisation process.

A.3.2.1 Critical parameter selection

All electrical parameters that are critical to the application should be identified and re-characterised over the entire target temperature range of the application. Possible interdependence of datasheet parameters, for example, logic voltage dependence on supply voltage, should be considered in deciding which parameters to include.

A.3.2.2 Sample size determination

Sample sizes for parameter re-characterisation should be sufficiently large to provide reasonable assurance that normal variations in the re-characterised parameters will not cause the parameters to be outside their re-characterised limits. The sample size should be determined for each instance of parameter re-characterisation. To effectively assess device manufacturing variability, multiple date codes need to be considered, with the recognition that this may be application and usage rate dependent. Factors to be considered may include:

– number of devices available for testing,
– types of parameters to be tested,
– target temperature,
– resources required to conduct the tests,
– desired confidence level for the results,
– desired parameter margins, and
– other factors relevant to the device and the application.

[1] Figures in square brackets refer to the references given in Clause A.6.

For each instance of parameter re-characterisation, the following information should be included in the uprating documentation:

– process used to determine the sample size,
– statistical distribution (assumed or known) of the parameters,
– confidence level, and
– other relevant information.

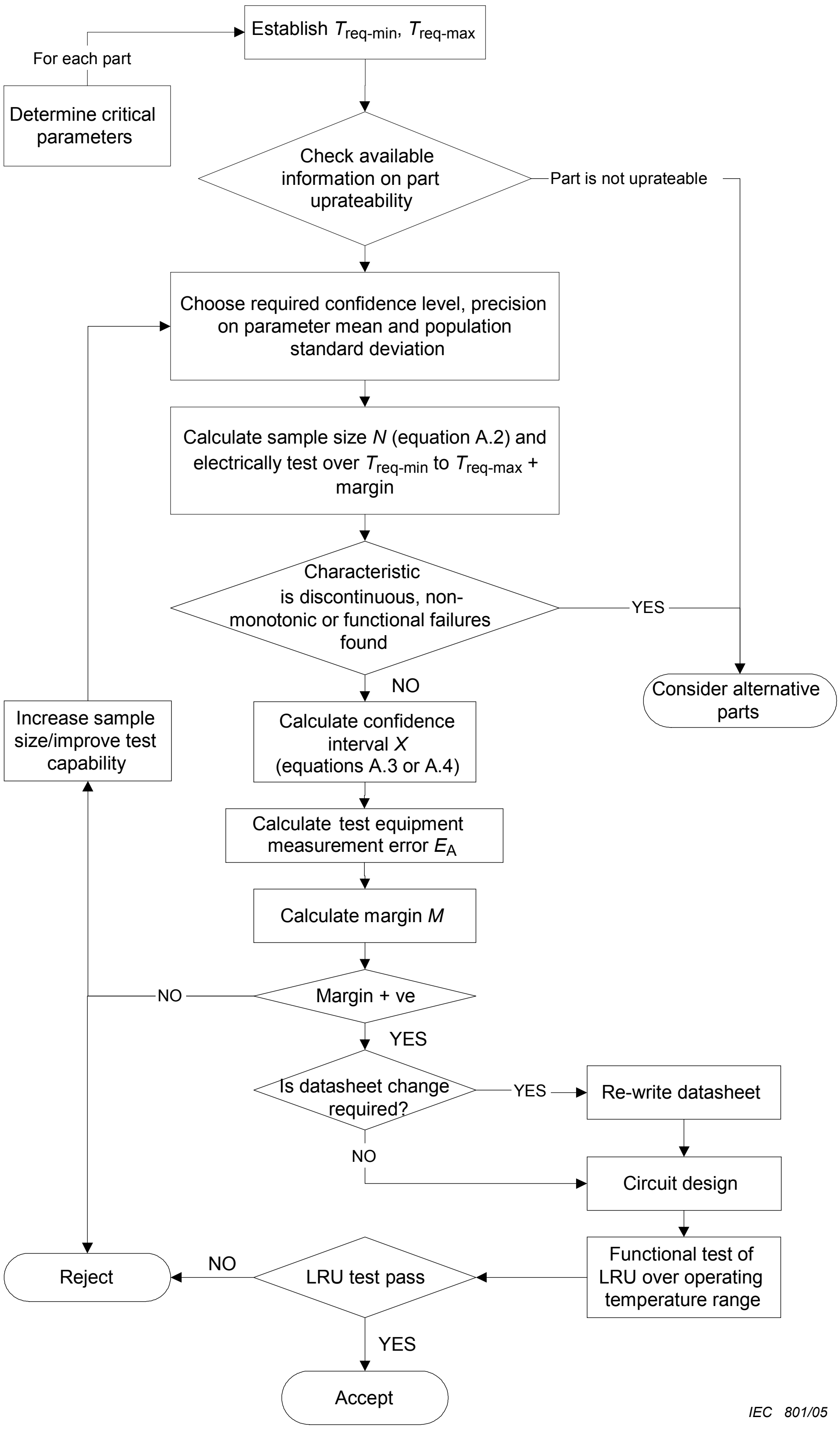

Figure A.2 – Flow diagram of parameter re-characterisation capability assurance process

In most instances, a normal distribution is assumed. For the normal distribution, the sample size, N, is [2][3]:

$$N = \left[\frac{Z_{\alpha/2} \times \sigma}{E} \right]^2 \qquad \text{Equation A.2}$$

where

E is the required precision on the parameter mean,

$Z_{\alpha/2}$ is the value of standard normal variable at confidence level $(1 - \sigma) \times 100$ %, and

σ is the standard deviation of the population.

In this equation, the sample mean is within $\pm E$ of the true mean, with a probability of $(1 - \sigma)$. Table A.1 shows the results of an example calculation (standard deviation values were obtained from typical device data).

Table A.1 – Example of sample size calculation

	Precision (E)	Standard deviation (σ)	Sample size		
			σ = 90 %	σ = 95 %	σ = 99 %
Propagation delay	0,2 ns	0,3 ns	7	9	15
Input current	0,005 µA	0,006 7 µA	5	7	12
Supply current	0,15 µA	0,2 µA	5	7	12

NOTE 1 If it is known that another distribution fits the data, then appropriate statistics should be used.

NOTE 2 To be completely rigorous, each parameter at each test temperature has its own specific distribution. In practice, this degree of detailed knowledge is rarely available. Unless there is evidence to the contrary, and it is acceptable to assume that the same distribution parameters apply to all electrical test parameters at all test temperatures.

For large sample sizes, i.e., greater than thirty (case 1), the confidence interval estimate of the mean is:

$$\overline{X} \pm \left(Z_{1-\alpha/2} \times \frac{\sigma}{\sqrt{N}} \right) \qquad \text{Equation A.3}$$

For small sample sizes, i.e., less than thirty (case 2), then the Student's t distribution should be used, and the confidence interval estimate of the mean is:

$$\overline{X} \pm \left(t_{1-\alpha/2} \times \frac{s}{\sqrt{N}} \right) \qquad \text{Equation A.4}$$

Where s is the sample standard deviation and $t_{\alpha/2;N-1}$ is the value of the Student's t distribution at the confidence level $(1 - \alpha) \times 100$ % and $N - 1$ degrees of freedom.

A.3.2.3 Testing

Parameter re-characterisation tests should be conducted over the entire target temperature range, and should also consider temperature margins above the maximum and below the minimum target temperatures. During the parameter re-characterisation process, the device absolute temperature limits should be known and understood; and exceeding any of these absolute limits during this process should be controlled and performed only to provide additional understanding of device behaviour. Devices used in actual applications should not exceed absolute maximum ratings.

Tests should be conducted at various temperatures within the target temperature range. The number of test temperatures, and the intervals between them, may not be the same for all instances of parameter re-characterisation. Factors to be considered in determining the test temperatures may include:

– device manufacturer's specified temperature range;
– other thermal data obtained from the device manufacturer, for example, thermal conductivity, etc.;
– target temperature range;
– other uses of the test data, for example, performance derating; and
– previous relevant experience with the device.

Additional test temperatures may be specified on the basis of tests conducted during parameter re-characterisation. For example, if a plot of a given parameter vs. temperature indicates the relationship may not be linear, additional tests should be performed to determine its exact nature.

A device may satisfy its parameter specifications, but still fail to function in an application. Therefore, functional testing at the application or circuit level and higher levels as well should be considered. For digital devices, gate level design information is required to develop software to achieve specific fault coverage. If the full set of test vectors is not available, the percent fault coverage is difficult to determine without detailed knowledge of device architecture. Again, functional testing at the application or circuit level should be considered.

Testing may be performed in-house or at an external test house. In either case, the equipment supplier is responsible for the tests and their results.

Prior to parameter re-characterisation testing, a set of requirements and limitations on the electrical parameters should be developed. The requirements and limitations depend on the application.

Acceptable upper ($M_{\text{UL-req}}$) and lower ($M_{\text{LL-req}}$) margin limits should be established for each modified parameter.

A.3.2.4 Assessment of electrical test results

If the test results indicate that there are no functional failures, if no discontinuities are observed in any of the parameter vs. temperature plots, and if the modified parameter limits are acceptable for the application, then the uprating process can be considered successful.

A.3.2.5 Re-characterised parameter value calculation

Re-characterised parameter values include both the nominal values and their limits. The limits are determined by combining variations due to sampling, parameter values, and test equipment accuracy to the nominal values. Figure A.4 illustrates the method by which they are combined.

A.3.2.5.1 Nominal values

The nominal value of a re-characterised electrical parameter is the value selected for use in designing equipment with the re-characterised device. It may be constant over the target temperature range, or it may vary with temperature in a predicted manner. Usually, the mean value of the test results for a given parameter at a given temperature is designated as the nominal value, although other values may be chosen if warranted.

A.3.2.5.2 Variation

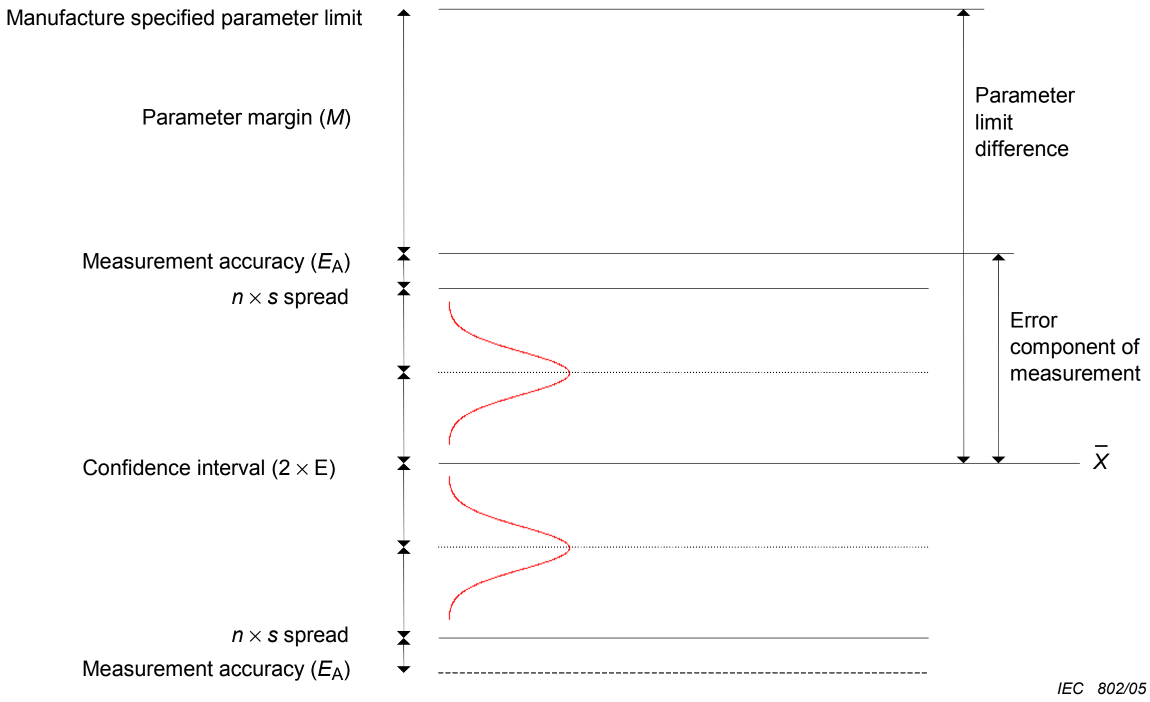

Figure A.3 – Margin in electrical parameter measurement based on the results of sample test

Variation due to sampling is the confidence interval described in A.3.2.2. It is shown as $2\times E$ in Figure A.3.

Parameter variation is shown as $n\times s$ in Figure A.3. Usually, the standard deviation of the test sample is used as the measure of parameter variation, with the number of standard deviations, n, determined on the basis of acceptable risk. Variation in test equipment accuracy is shown as E_{A} in Figure A.3. Test equipment accuracy is calculated with standard methods found in basic statistics texts. It may vary according to test temperature.

A.3.2.5.3 Margin calculation

The parameter margin, *M,* is calculated by:

$$M = UL - \overline{X} - E_{\mathrm{A}} - n\times s - E \qquad \text{Equation A.5}$$

A.3.2.6 Parameter limit modification

If a given parameter margin is considered inadequate ($M < 0$), then the data sheet parameter limits may be modified to provide new limits to be used in equipment design. Parameter limit modification begins with the selection of the required margin for a given temperature. Potential variations calculated in A.3.2.5.1, A.3.2.5.2, and A.3.2.5.3 are added to, or subtracted from, the nominal value of the parameter at the given temperature. If the modified parameter values thus obtained are beyond the maximum and minimum parameter limits determined in A.3.2.5, then the device is not uprateable through parameter re-characterisation. Figure A.4 shows an example of the parameter limit modification process. In this example, the new parameter limit is below the maximum allowable parameter limit, and thus acceptable.

Table A.2 shows an example of re-characterising a 0 °C to 70 °C rated part to a –55 °C to 125 °C part.

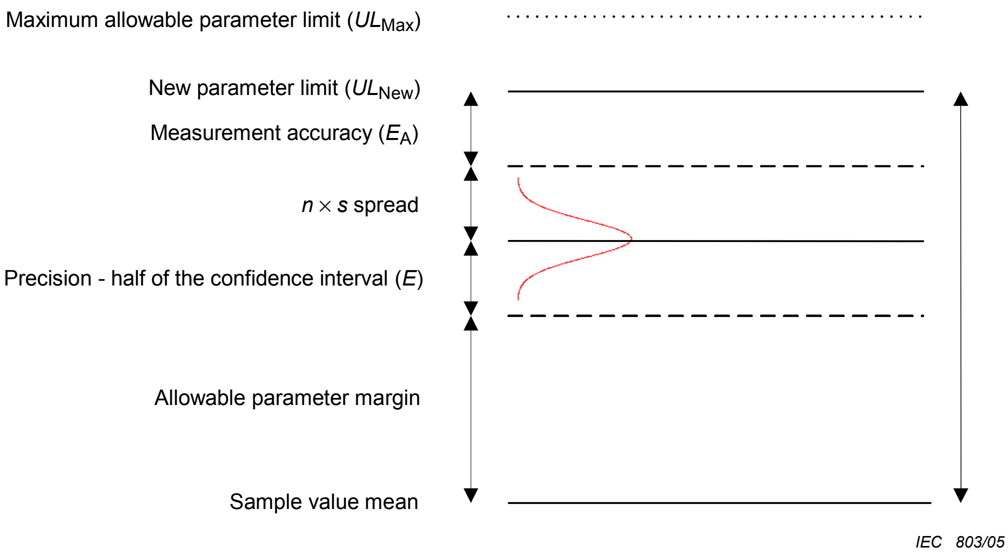

Figure A.4 – Schematic diagram of parameter limit modifications

Table A.2 – Parameter re-characterisation example: SN74ALS244 Octal Buffer/Driver

Parameter		Commercial limit	Military limit	Measured value at military limit	Derated limit (calculated)[a)]
t_{PLH} (ns)	Min.	2,0	1,0	5,1	1,8
	Max.	10,0	16,0	12,8	15,2
t_{PHL} (ns)	Min.	3,0	3,0	6,7	1,9
	Max.	10,0	12,0	10,2	11,1
V_{OH} (V)	Min.	3,50	3,50	3,75	3,31
V_{OL} (V)	Max.	0,40	0,40	0,18	0,42
I_{CCH} (mA)	Min.	9,00	9,00	9,10	7,65
	Max.	17,00	18,00	14,14	18,60
I_{CCL} (mA)	Min.	15,00	15,00	14,71	14,50
	Max.	24,00	25,00	19,36	26,00

[a)] Assumes same degree of errors and standard deviation at all temperatures. The margins at the commercial temperature limit are maintained at military temperature limit

A.3.3 Application capability assessment

A representative sample of the assembly containing the devices that have been uprated by parameter re-characterisation should be tested to verify that they will perform their intended function. The uprating process can be considered successful only if the higher level assembly performs properly.

A.4 Quality assurance

The ongoing quality of successfully uprated devices should be by monitoring the device process change notices (PCN) obtainable from the device manufacturer or distributor; and by equipment level tests over the target temperature range, plus (or minus) a margin[2]. Functional testing should be sufficiently rigorous to verify all system functional requirements.

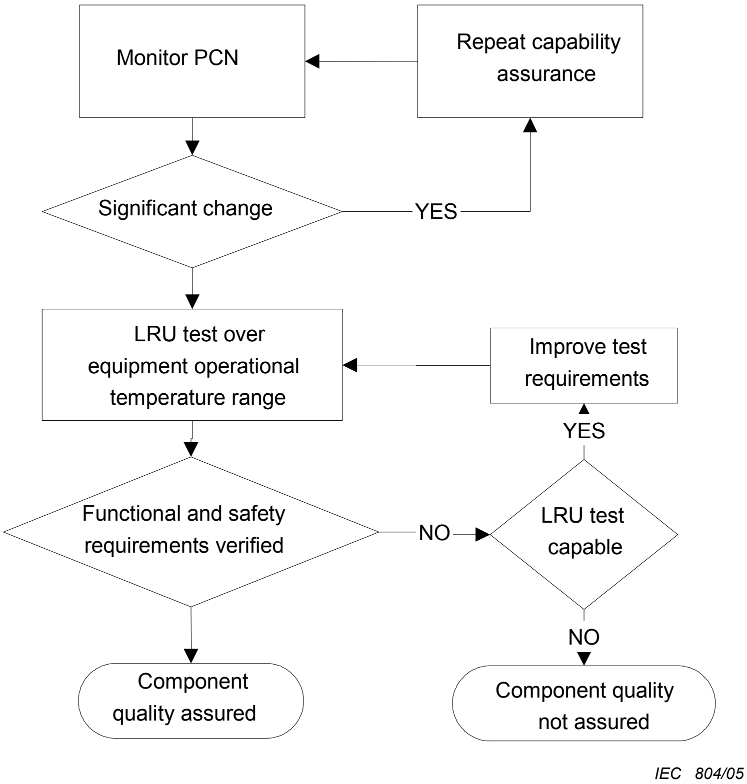

Figure A.5 – Parameter re-characterisation part quality assurance

A.5 Factors to be considered in parameter re-characterisation

Data used in initial uprateability assessments may not be an accurate indicator of expected future performance.

Simulation models should be used with caution. When they are made available to the public, they are often 'sanitized' to mask proprietary information, and thus may not be accurate indicators of the analog behaviour of devices.[1] The uprateability assessment process should be used only to eliminate unpromising candidate devices, and not as a substitute for electrical testing.

Data sheets do not always list all electrical parameters. This is especially true for degradation type parameters for example, gate current, substrate current, trigger currents for latchup, etc. These parameters may not be important in manufacturer-specified temperature ranges, but could be significant at target temperature ranges. When the manufacturers' test procedures are not available, it is difficult to measure these parameters, and they must be estimated.

2 To account for system variations, it may be advisable to test the systems beyond its specified temperature limits. However, operating a system beyond its temperature specifications may overstress other components of the system besides the candidate part and result in invalid failures.

If the initial assessment indicates that any such parameters could be of concern at the target temperature, then the revised datasheet should include limiting values for these parameters.

Some device lots may include outliers [5], which limits the efficacy of sample testing (see Figure A.6).

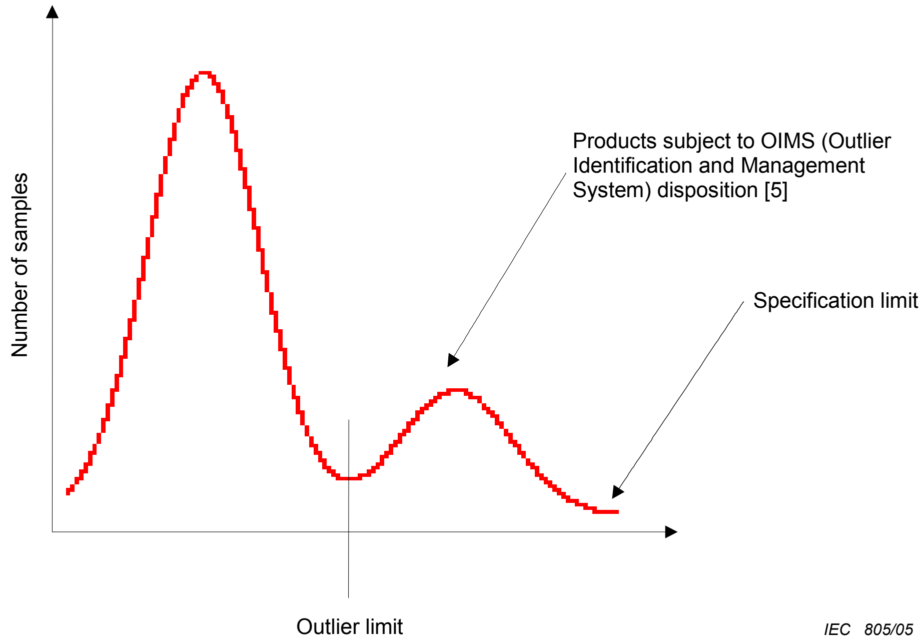

Figure A.6 – Schematic of outlier products that may invalidate sample testing

If the test temperature range does not extend beyond the target temperature range, it is difficult to detect discontinuities in the parameter vs. temperature curves. Likewise, if the test temperature intervals are too wide, discontinuities within the test temperature range may be missed. If the test results indicate non-monotonic behaviour, then additional temperature points may have to be added. Figure A.7 shows an example of an intermediate peak of an electrical parameter.

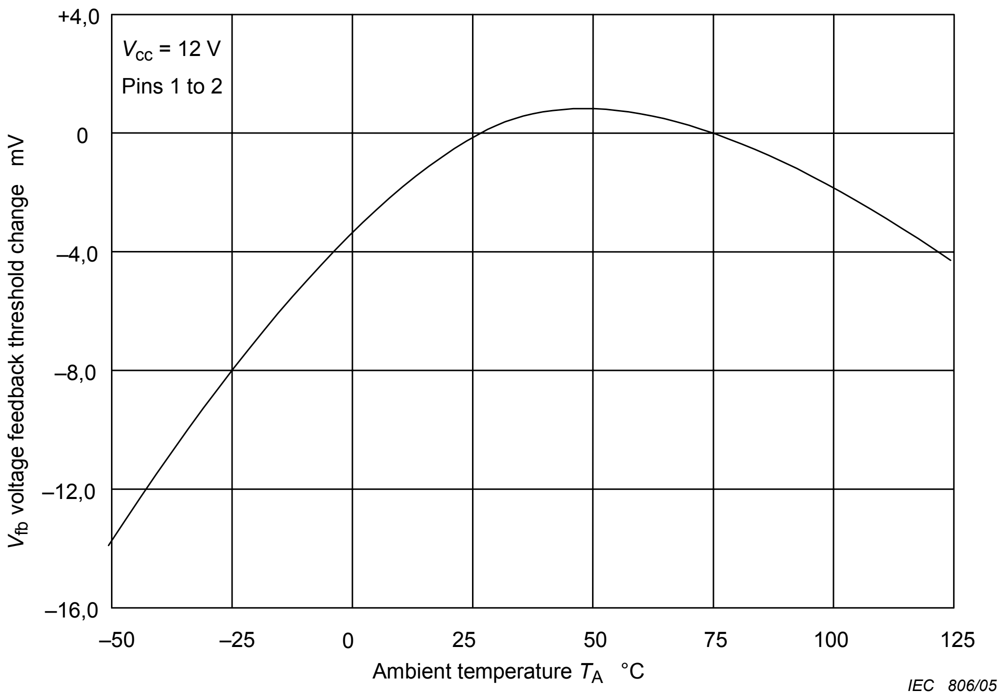

Figure A.7 – Example of intermediate peak of an electrical parameter: voltage feedback input threshold change for Motorola MC34261 power factor controller [4]

During initial characterisation, it is also necessary to check for hysteresis in electrical test data, but hysteresis tests can be eliminated if the testing does not reveal its existence. Hysteresis may be observed during temperature characterisation because (a) part characteristics change due to exposure to high or low temperature, or (b) thermal equilibrium is not reached. If hysteresis effects are observed, then dwell times at temperature should be increased. If that is not successful, then other damage possibilities should be investigated. If no other possible reason for failure is found, then the device may not be a candidate for uprating.

Inflection points observed in electrical parameters observed at extreme temperature ranges should always be tested to determine if the failure type is hard or soft. Also, it should be determined if the failures are due to changes in device characteristics, which could result from device failure, or from the effects of extreme temperatures on testing fixtures and equipment.

A.6 References

[1] Micron Semiconductor*, "TN-00-07 – IBIS Behavioural Models,"* 1998.

[2] Montgomery, D. C., and Runger, G. C., *Applied Statistics and Probability for Engineers*, John Wiley and Sons, Inc., New York, New York, 1994.

[3] Pfaffenberger R., and Patterson J., *Statistical Methods*, Irwin Publishers, 1987.

[4] Motorola, "*Data sheet of MC34261, Power factor controller*," 1996.

[5] EIA, "*EIA/JESD 62, Outlier Identification and Management System for Electronic Components*" February 1998.

<table>
<tr><td colspan="3">DEVICE PARAMETER RE-CHARACTERISATION REPORT</td></tr>
<tr><td colspan="2">Device description:
Device mfr.:
Comp. mfr. part no.:
Equipment mfr. dwg. no:</td><td>Equipment name:
Equipment part no:
Program manager:
Date:</td></tr>
<tr><td>1.</td><td>Rated temperature range (case or ambient):</td><td></td></tr>
<tr><td>2.</td><td>Usage temperature range (case or ambient):</td><td></td></tr>
<tr><td>3.</td><td>Test specification No(s).
Parametric:
Functional:</td><td></td></tr>
<tr><td>4.</td><td>Device date code(s):</td><td></td></tr>
<tr><td>5.</td><td>#Sample size:</td><td></td></tr>
<tr><td>6.</td><td>#Functional test passed:</td><td></td></tr>
<tr><td>7.</td><td>#Functional test failed:</td><td></td></tr>
<tr><td>8.</td><td>Test date:</td><td></td></tr>
<tr><td>9.</td><td>Test results report:</td><td></td></tr>
<tr><td>10.</td><td colspan="2">Approvals:</td></tr>
</table>

IEC 807/05

Figure A.8 – Report form for documenting device parameter re-characterisation

Annex B
(informative)

Stress balancing

B.1 General

Stress balancing takes advantage of the power-temperature trade-off opportunity in a given application. It requires less testing than parameter conformance assessment and parameter re-characterisation, since testing is done only to confirm analytical results in the specific application. See Clause 3 for the definition of stress balancing.

B.2 Glossary of symbols

T_A: Ambient temperature

$T_{A\text{-}Max}$: Manufacturer-specified maximum ambient temperature

T_J: Junction temperature

$T_{Up\text{-}Max}$: Maximum temperature up to which the device can be uprated

T_{App}: Ambient temperature limit required for the application

T_M: The margin by which the Iso-T_J curve is derated

ΔT_A: Change in the ambient temperature

P: Power dissipation

P_{Min}: Minimum power dissipation at which the device can be operated in the system, calculated from maximum allowable limits on electrical parameters

P_{Max}: Manufacturer specified maximum power dissipation at $T_{A\text{-}Max}$

P_{App}: Power dissipation of the device at application temperature limit, T_{App}

P'_{App}: Power dissipation of the device at the application limit, without margins on the Iso-T_J curve

P_M: The derating achieved in power dissipation, as a result of the margin put on the Iso-T_J curve. $P_M = P'_{App} - P_{App}$

ΔP: Change in the power dissipation

V_{CC}: Supply voltage

I_{CC}: Quiescent supply current

C_{PD}: Power dissipation capacitance/buffer

C_L: Load capacitance/buffer

f: Frequency of operation of the device

θ_{JA}: Junction to ambient thermal resistance

B.3 Stress balancing

B.3.1 General

For active semiconductor devices:

$$T_J = T_A + P \times \theta_{JA} \qquad \text{Equation B.1}$$

where

T_J is the junction temperature,

T_A is the ambient temperature,

P is the power dissipation, and

θ_{JA} is the junction to ambient thermal resistance.

If the junction temperature of a semiconductor device remains constant, then the performance of the device should not change. The power dissipation of a device is often a function of some electrical parameter (for example: operating voltage, frequency); thus a trade-off can thus be made between ambient temperature and an electrical parameter. From Equation B.1, a higher ambient temperature is allowed if the power dissipation is reduced sufficiently to keep the junction temperature constant. The steps to be followed in stress balancing are listed in B.3.2 through B.3.7, and shown schematically in Figure B.5.

B.3.2 Determine the ambient temperature extremes

B.3.3 Determine parameter relationship to power dissipation

The goal of this step is to determine which electrical parameters can be derated[3], and by how much, and to calculate the amount by which the dissipated power must be reduced in the proposed application, in order to uprate the device.

NOTE Various factors, such as device technology, device family, and electrical function, must be considered in selecting the parameters that most significantly affect power dissipation, and therefore should be selected for reduction. As examples, the relationship between power dissipation and effective operating frequency is essentially linear for CMOS devices; and changing the device operating voltage may reduce dissipated power. Other possibilities include reducing the output current, reducing the fan-out, or altering the duty cycle of the device. It may be necessary to reduce more than one parameter to obtain the desired reduction in dissipated power.

B.3.4 Determine the dissipated power vs. ambient temperature relationship

B.3.4.1 General

The goal of this step is to produce a graphical representation of the relationship between device power dissipation and the ambient temperature, as defined in Equation B.1. The power dissipation is plotted against the ambient temperature, keeping the junction temperature constant. The *Iso-*T_J plot, an example of which is shown in Figure B.1, can be constructed using either of the two processes described in B.3.4.2 and B.3.4.3.

NOTE A generalised Iso-T_J curve is shown in Figure B.1. The curve is drawn for power dissipation values that lie between the minimum power dissipation of the device (P_{Min}) and the maximum specified power (P_{Max}). To account for inaccuracies[4] in the data and calculations, the curve is moved towards the horizontal axis by a suitable amount, T_M. T_M can be viewed as the junction temperature margin. The application power (P_{App}) as calculated from the Iso-T_J curve would also have a reduced value, with a margin PM as illustrated in Figure B.1. A corresponding temperature range above the maximum operating ambient temperature ($T_{A\text{-}Max}$) is thus obtained. The temperature corresponding to P_{Min} is the maximum temperature at which the device can be used in the application. This is denoted by $T_{Up\text{-}Max}$. As such, the area bounded by P_{Max} – P_{Min} – I – I' is the uprated operating area.

---

3 Derating is the practice of limiting thermal, electrical or mechanical stresses on electronic parts to levels below the manufacturer's specified ratings. As the term is used here, it may be said that we *derate* one or more *parameters* in order to *uprate* a *component*.

4 The inaccuracies may be in the calculation of power dissipation, in the determination of the thermal characteristics of the part and due to unavailability of accurate thermal resistance of the part.

Combinations of power and temperature values in this area correspond to junction temperatures lower than that established by the Iso-T_J Curve with margins I – I'.

B.3.4.2 Constructing the Iso-T_J curve using thermal resistance

If Equation B.1 is modified as follows:

$$T_A = -\theta_{JA} \times P + T_J \qquad \text{Equation B.2}$$

then a plot of power dissipation vs. ambient temperature yields a straight line with slope $-\theta_{JA}$. If the line passes through the point ($T_{A\text{-Max}}$, P_{Max}), where P_{Max} is the maximum power dissipation specified by the manufacturer at the specified maximum operating ambient temperature, $T_{A\text{-Max}}$, then it is called the Iso-T_J curve.

NOTE To plot the Iso-T_J curve, the junction to ambient thermal resistance must be known. Some data sheets include θ_{JA} in a thermal characteristic section. The thermal resistance value in the application also depends on factors such as thermal conductivity of the printed circuit board, proximity and power dissipation of neighboring devices, airflow speed and pattern, coolant physical properties, die size, and thermal radiation properties of the surrounding surfaces. Most of these factors impact the thermal impedance from case-to-ambient, and not all of them can be modeled accurately early in the design process. In spite of these difficulties, the electrical and mechanical designers should work together to determine the thermal resistance data in the application using the best information available. Whenever possible, the test or simulation conditions under which the thermal resistance data were determined should be obtained from the device manufacturer before the thermal resistance data are used. The data used early in the design stage must be verified by testing in the application environment, later in the development process.

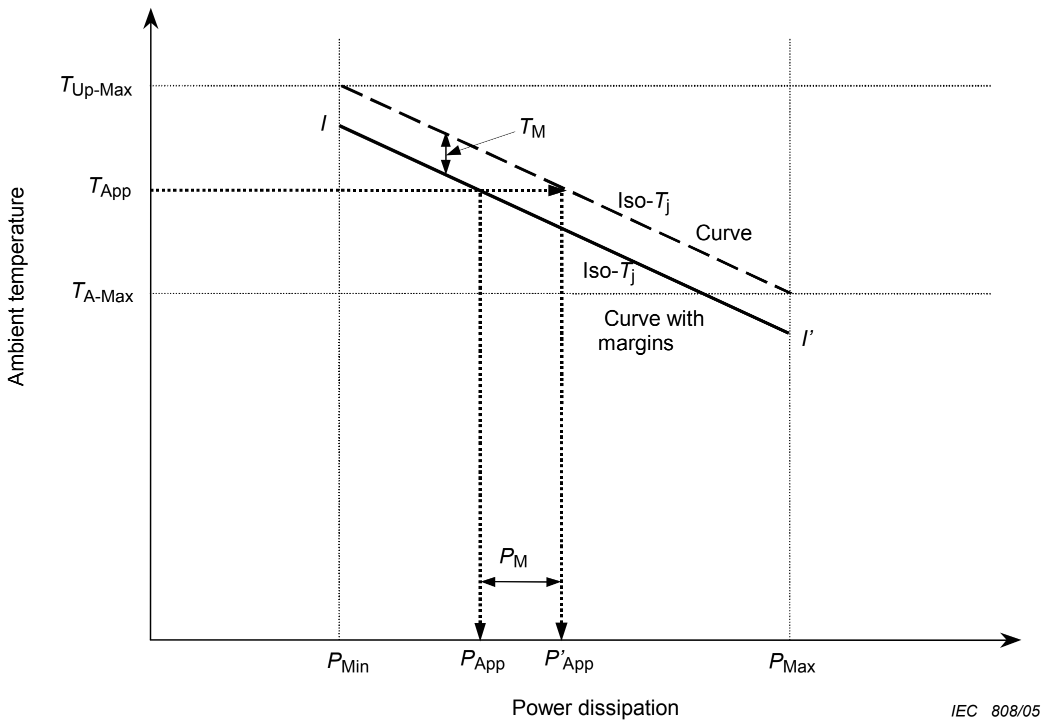

Figure B.1 – Iso-T_J curve: the relationship between ambient temperature and dissipated power

B.3.4.3 Constructing the Iso-T_J curve using thermal analysis

Thermal simulation software may be used to evaluate the performance of the device in the application, provided that its range of applicability includes the required application temperature, power, etc. Typical steps of stress balancing may be:

a) Develop a thermal model of the device.

b) Conduct thermal simulation using the device as the ‘device under test’ in the manufacturer’s thermal test setup. The model is valid if the device thermal simulation compares satisfactorily with the thermal data provided by the manufacturer.

c) Model the application environment with different values of power dissipation within the device.

d) Develop the power/ temperature relationship from the application thermal model.

NOTE The value of thermal resistance also varies with power dissipation and temperature. This is accounted for in thermal simulation, but not in the simplistic single parameter approach described in B.3.4.2, which assumes θ_{JA} to be constant for the temperature and power dissipation range under consideration. The Iso-T_J curve obtained by thermal analysis or simulation therefore may not be linear, and the thermal characterisation obtained in this subclause is likely to be more accurate.

B.3.5 Assess applicability of the method

If the required maximum system temperature is lower than $T_{Up\text{-}Max}$, then the device can be uprated by stress balancing. If the required maximum system temperature is greater than $T_{Up\text{-}Max}$, then the required power dissipation is lower than P_{Min}, and other options should be considered.

A horizontal line drawn through the required ambient temperature (on the vertical axis) intersects the Iso-T_J curve at a power dissipation value (on the horizontal axis) equal to the maximum power (P_{App}) that the device is allowed to dissipate at the application temperature. All selected electrical parameters are then modified to maintain the device power dissipation below P_{App}.

B.3.6 Determine the new parameter values

Figure B.2 shows a generalized plot of an electrical parameter vs. the dissipated power for the “allowable” range of power dissipation between P_{Min} and P_{Max}. The vertical line corresponds to the application power dissipation, P_{App}, of the uprated device. The value of the electrical parameter at the point where this line intersects the vertical axis is the value of the electrical parameter, as modified by stress balancing.

NOTE The changes made to the electrical parameters to reduce power dissipation may change other electrical parameters of the device. For example, if the supply voltage of an operational amplifier is reduced, its frequency range and output current also will change; and it will saturate at a lower input voltage. These effects should be taken into account while designing with the uprated device.

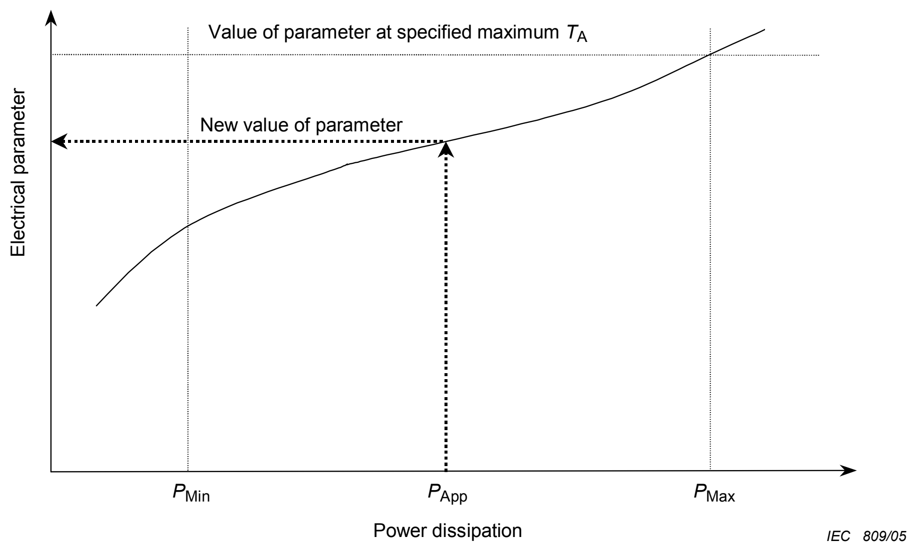

Figure B.2 – Graph of electrical parameters versus dissipated power

B.3.7 Conduct parametric and functional tests

After successful completion of steps B.3.2 through B.3.6, parametric and functional tests are performed at the target application temperature, using the new values of electrical parameters. This is done to

a) ensure that the device and the system operate satisfactorily with the newly calculated conditions;
b) verify that the device will operate successfully in the new conditions;
c) check for discontinuities and changes in parameter trends in the vicinity of the extreme target application temperature; and
d) check the adequacy of margins for the extreme target application temperature and selected derated parameters from B.3.4.

The tests may be done at the device level, or using devices in the application. A device may satisfy its parameter specifications, but still fail to function in an application. Therefore, functional testing at the application or circuit level and higher levels as well should be considered.

NOTE 1 In choosing the sample size of devices to be tested, consideration should be given to margins, confidence testing, and variations in the parameter values. The tests may be parametric go/no-go tests. The device is considered successfully uprated for the application if the test results demonstrate that the device can operate successfully in the application over the full target application temperature.

NOTE 2 Tests on devices and systems typically are not of sufficient duration to allow thermal equilibrium to be reached. It may therefore be necessary to power up the system to allow the system device to reach thermal equilibrium prior to testing.

B.4 Application example

B.4.1 General

This example is presented courtesy of the University of Maryland, CALCE from a 1999 paper: "*Stress Balancing: A Method for Use of Electronic Parts Outside the Manufacturer Specified Temperature Range*."

The Fairchild MM74HC244 is used here as an example to illustrate the stress balancing process for a hypothetical system. The maximum application ambient temperature is 85 °C and the minimum application ambient temperature is –40 °C. The MM74HC244 is an octal 3-state buffer, which is typically used to buffer a bus before connecting to input or output devices. It is a CMOS logic device rated for –40 °C to 85 °C ambient temperature range, and is available in a plastic dual-in-line package. The data sheet recommends operation at a supply voltage (V_{CC}) of 2 V, 4,5 V or 6 V. Absolute maximum rating for power dissipation at 65 °C is 600 mW, with a derating factor of –12 mW/°C above 65 °C. This means that the maximum power dissipation of the device at 85 °C (maximum operating ambient temperature limit) is 360 mW. For this example, assume that the digital logic levels of the system are 4,4 V (minimum) for high and 0,1 V (maximum) for low. From the data sheet, this requires V_{CC} = 6 V.

B.4.2 Determine the ambient temperature extremes

The system ambient temperature range is –40 °C to +85 °C, however it is assumed that a 15 °C temperature rise occurs from ambient outside the equipment to ambient temperature near the device, due to internal heating effects while the equipment is operating. This results in a –40 °C to +100 °C ambient temperature environment for the device.

B.4.3 Select the parameters that can be derated

CMOS devices typically have negligible quiescent power consumption compared to the power dissipation during switching. The power dissipation (P) of a CMOS device is given by the equation:

$$P = (C_{\mathrm{PD}} + C_{\mathrm{L}})V_{\mathrm{CC}}^{2} f + V_{\mathrm{CC}} I_{\mathrm{CC}} \qquad \text{Equation B.3}$$

where

C_{PD} is the power dissipation capacitance,

C_{L} is the load capacitance,

f is the switching frequency,

I_{CC} is the quiescent supply current, and

V_{CC} is the supply voltage.

From the Fairchild data sheet:

C_{pd} = 50 pF/buffer[5], and

I_{CC} (maximum specified, for V_{CC} = 6 V) = 160 µA.

The load capacitance (C_{L}) is assumed 50 pF, which is the value used for test conditions in the data sheet.

From Equation B.3, power dissipation can be reduced either by reducing the supply voltage or the operating frequency. In this application, however, a change in V_{CC} will directly affect the logic levels of the system, so V_{CC} cannot be changed. Thus in this example, the operating frequency is reduced from its maximum capability. The frequency at a power dissipation of 360 mW, at V_{CC} = 6 V is 13 MHz, and it is assumed that the system requirement is for the device be operated at a frequency no less than 3,5 MHz. This means that the minimum power dissipation is 100 mW.

NOTE In CMOS circuits, the value of load capacitance, C_{L}, may not be known precisely. The primary contributor to load capacitance in digital logic circuits is the capacitance added due to the PWB when the devices are installed. A conservative maximum estimate of C_{L} should be made for calculating the power dissipation. After the PWB design is done, the actual value of C_{L} may be re-substituted into Equation B.3 to obtain a better estimate.

B.4.4 Construct an Iso-Tj Plot

An Iso-T_{J} curve for the MM74HC244 plotted from the Fairchild data sheet, is shown in Figure B.3. The specified maximum power is 360 mW at a maximum ambient temperature of 85 °C, so the curve passes through the (360 mW, 85 °C) point.

B.4.5 Determine whether or Not the device can be uprated

The minimum power at which the buffer can operate in the system is calculated as 100 mW (see B.5.2). The slope of the Iso-T_{J} curve is –83,3 °C/W (corresponding to –12 mW/°C power derating), which is higher than the thermal resistance value quoted by Fairchild for this device (61 °C/W). The maximum ambient temperature at which the device can be uprated ($T_{\mathrm{Up\text{-}Max}}$) is 106 °C. At the maximum application ambient temperature (100 °C), it is observed that the new power value is 170 mW. The device can thus be operated at 100 °C, if the power dissipation is kept below 170 mW.

5 It should be noted that there are eight buffers in the MM74HC244.

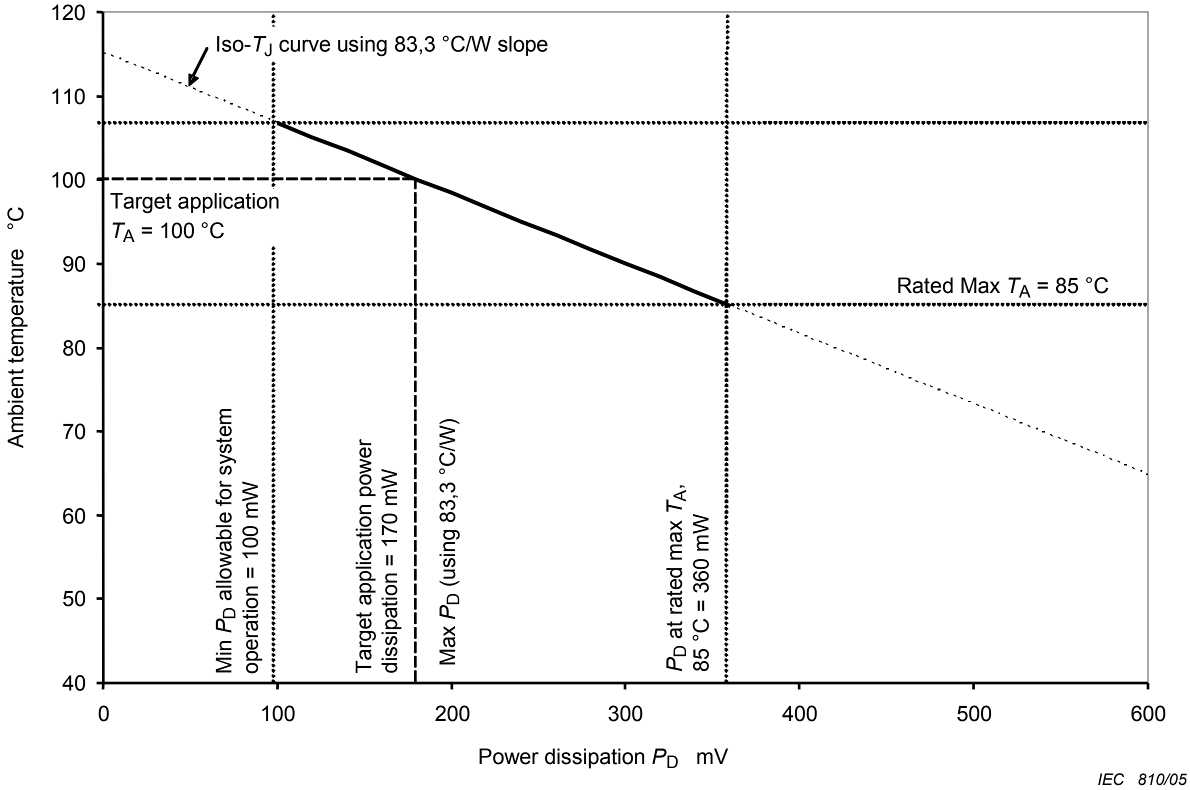

Figure B.3 – Iso-TJ curve for the Fairchild MM74HC244

B.4.6 Determine the new parameter values

As specified in B.4.3, the minimum power at which the buffer can operate in the system is 100 mW and the maximum specified output power is 360 mW. Using Equation B.3, operating frequency is plotted versus power dissipation, and is shown in Figure B.4. From the data sheet values and application conditions, the equation for the curve is:

$$P = 2{,}88 \times 10^{-8} f + 9{,}6 \times 10^{-4} \text{ watts} \qquad \text{Equation B.4}$$

Figure B.4 is plotted with the data sheet specified values for the various parameters, with V_{CC} = 6 V and C_L = 50 pF. It is also noted that there are eight buffers in the MM74HC244N.

From Figure B.4, the frequency is 6 MHz at 170 mW. Thus the device can be used at an ambient temperature of 100 °C, if the frequency is maintained at (or below) 6 MHz. This value may be further derated, depending upon the equipment manufacturer's design practices.

NOTE A relatively simple logic device is used in this example. For more complex devices, the assumption that the maximum operating junction temperature is the average temperature across the die surface may not be accurate, due to hot spots. When possible, this type of information should be requested from the device manufacturer; or an increased margin above the junction temperature maximums plotted from Figure B.1 should be used.

B.4.7 Conduct parametric and functional tests

Normally, the device is tested at $T_{A\text{-Max}}$ to ensure that the device will operate satisfactorily in the required environment.

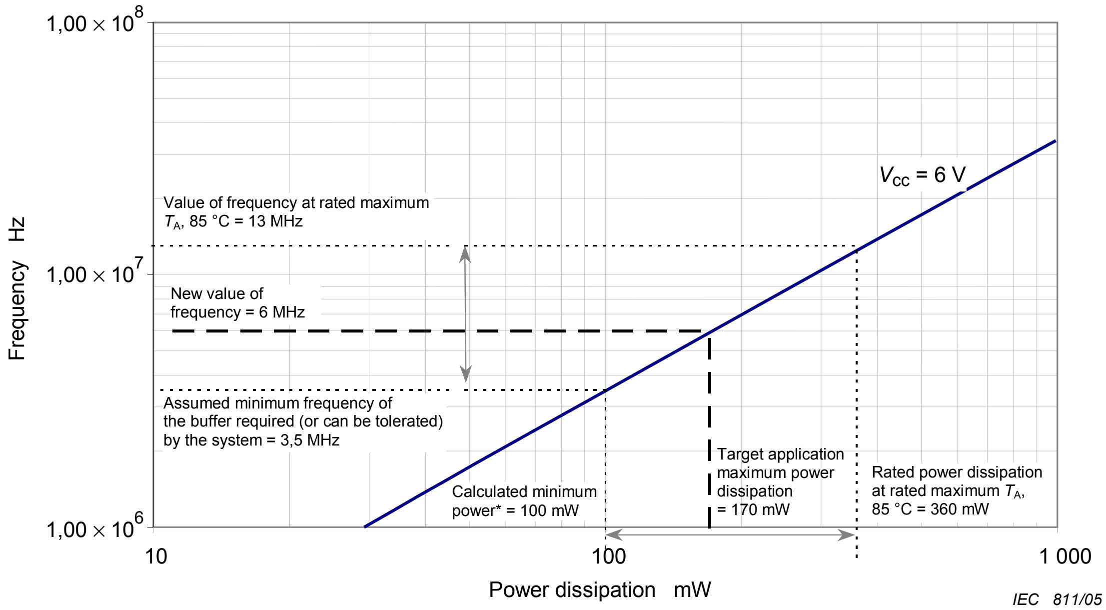

Figure B.4 – Power versus frequency curve for the Fairchild MM74HC244

B.5 Other notes

B.5.1 Margins

The ambient temperature and dissipated power used in the calculations for stress balancing are manufacturer-specified, and have the manufacturers' intended margins. The derated value of power dissipation also has these margins. It may be prudent to add additional margin (P_M) in calculating the application power P_{App} to compensate for inaccuracies in thermal modeling, value of θ_{JA} and actual ambient temperature near the device in the application. The device electrical parameters, which are calculated from the derated value of power dissipation, should also be subject to derating. This is to accommodate the errors inherent in the process; however, adequate precautions need to be taken while using this process.

If a parametric pass/fail test is used to test the devices after stress balancing analysis, the test should be carried out at the target application temperature plus an appropriate thermal margin. This will ensure that some margins exist at the target application temperature.

B.5.2 Cautions and limitations

Although stress balancing appears to be straightforward, there are certain hidden difficulties. Data sheet junction temperature limits should be used with extreme caution for calculations in stress balancing, because they do not reflect the maximum junction temperature at which the device would operate. Thermal resistance values of a device are application dependent. If they are used to construct the Iso-T_J curve, thermal validation by test or analysis should also be done.

The power dissipated by the device is the power that is lost as heat, and is not the same as the output power. For CMOS devices, all the power drawn by the device is dissipated, because the output current is negligible. However, for certain devices, data sheets may list only output power. The dissipated power will have to be calculated from additional data obtained from the manufacturer.

Stress balancing can be used for uprating devices above the rated maximum temperature limit only. The relationship given in Equation B.2 does not apply to evaluating devices for use below the manufacturer-minimum specified temperature limit. Other methods like parameter re-characterisation may be used for operation of devices below the specified temperature range.

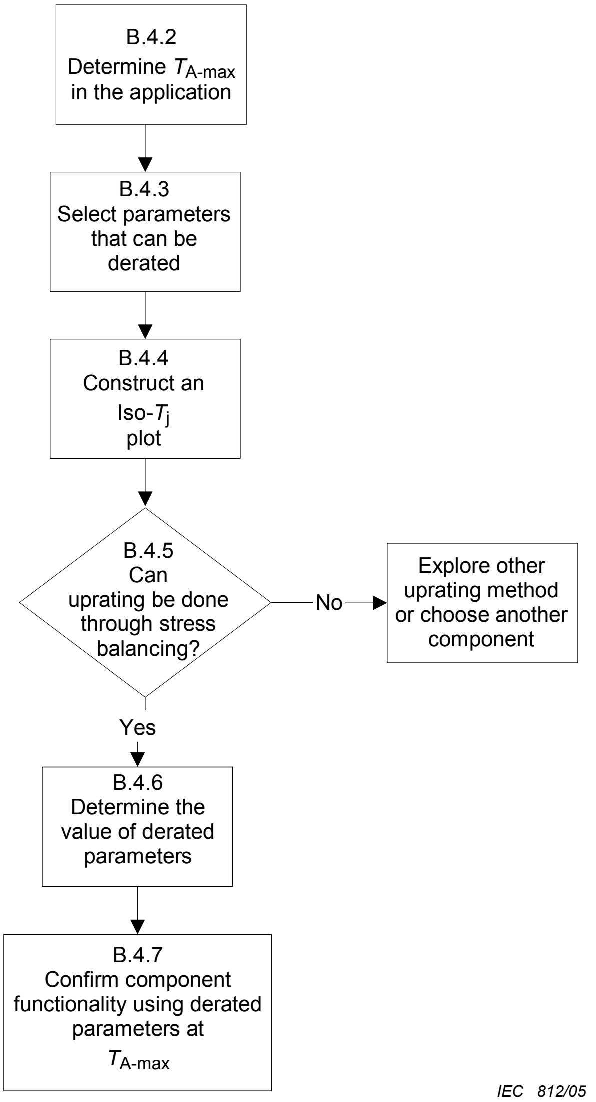

Figure B.5 – Flow chart for stress balancing

DEVICE STRESS BALANCING REPORT		
Device description: Device mfr.: Comp. mfr. part no: Equipment mfr. dwg. no:	Equipment name: Equipment part no: Program manager: Date:	
1.	Rated temperature range (case or ambient):	
2.	Usage temperature range (case or ambient):	
3.	Test specification No(s). Parametric: Functional:	
4.	Parameter(s) chosen for derating:	
5.	Iso-T_J plot (please attach separate sheet):	
6.	Amount of margin (or derating) below junction temperature maximum to be used:	
7.	Power dissipation in device with derated parameter:	
8.	Derated value of parameter, chosen from (4):	
9.	Verification test results agree with calculated value (document results and attach):	
10.	Approvals:	

IEC 813/05

Figure B.6 – Report form for documenting stress balancing

Annex C
(informative)

Parameter conformance assessment

C.1 General

Device parameter conformance assessment consists of evaluating electrical parameters at target thermal test points that are higher or lower than the manufacturers' specified ratings. For this uprating method, the specifications, conditions, and test limits used are the manufacturers published data sheet parameters.

The following references to statistical methods are suggested as tools in determining the statistical confidence in the options listed in this annex.

Montgomery D. C., and Runger G. C., "*Applied Statistics and Probability for Engineers*," John Wiley and Sons, Inc., New York, 1994

Pfaffenberger R., and Patterson J., "*Statistical Methods*," Irwin Publishers, 1987

Ireson G., "*Reliability Handbook*," 1966

C.2 Test plan

C.2.1 General

A test plan should be defined that documents the required tests, process steps, test methods, and number of samples. Figure C.3 shows a flow diagram of parameter conformance assessment testing.

C.2.2 Critical parameters

All critical application parameters should be identified, and values obtained from the manufacturer's published data sheet. Ideally, all electrical parameters should be tested; however, this is not always possible or practical. For example, it may be difficult to conduct a complete functional test if the applicable test program is not available from the device manufacturer. The manufacturer's specified test parameters (with the exception of the test temperature limits) should be used as device performance specifications for parameter conformance assessment.

C.2.3 Minimum allowable test margin

Factors to be considered in developing the test plan for parameter conformance assessment are the specified temperature range of the device, the target temperature range, and previous experience with the device. The test plan should include the temperatures at which tests are conducted, and the test sample size for each temperature. Target temperature information may be obtained from the initial assessment of the equipment environmental requirements and the results of thermal analysis. If so indicated by the initial assessment and thermal analysis, fluid dynamic conditions, such as air speed and direction, should be considered in determining the target temperature and test conditions. All available thermal environment data should be used to calibrate the test equipment to represent the application environment. The type of temperature specification, for example, ambient, case, or junction, should be considered in selecting the test temperature range. The accuracy of the thermal assessment method and the test also should be considered.

These test margins provide additional confidence in the applicability of the test results over the target temperature range. Figure C.1 shows the relationship of the various temperatures.

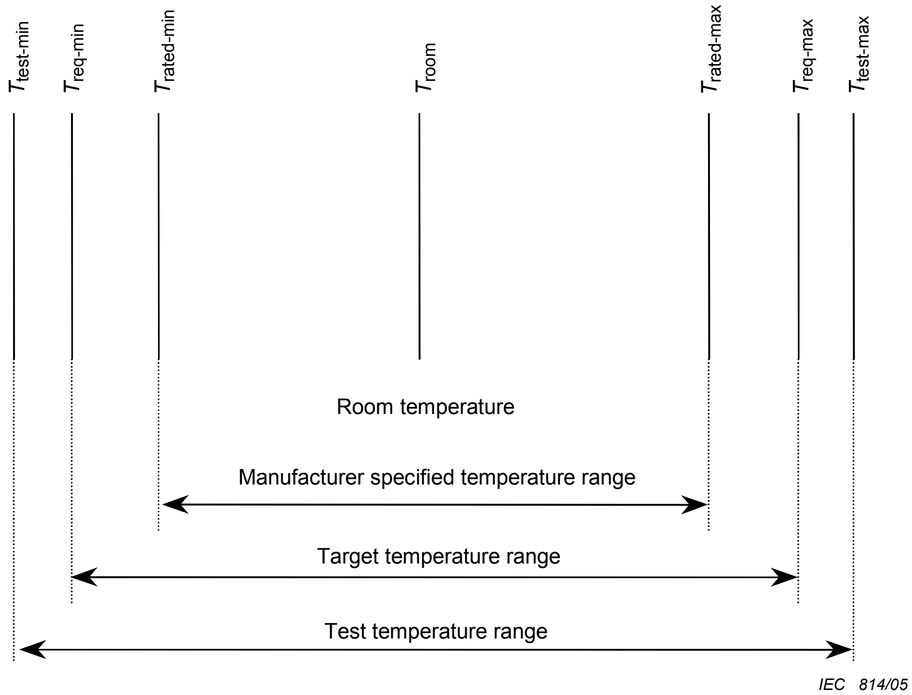

Figure C.1– Relationship of temperature ratings, requirements and margins

C.2.4 Test options

C.2.4.1 General

The two options for parameter conformance assessment are (a) Test at the minimum allowable margin, C.2.4.2, and (b) Determine the margin by incremental temperature testing, C.2.4.3. The selected option should be followed by the appropriate quality assurance process to assure that future devices will exhibit the required parameter values at the target temperatures. During either test option, the device absolute temperature limits should be known and understood. Exceeding any of these absolute limits during either process should be controlled and performed only to provide additional understanding of device behavior and related margins. Devices used in actual applications should not exceed absolute maximum ratings. A device may satisfy its parameter specifications, but still fail to function in an application. Therefore, functional testing at the application or circuit level and higher levels as well should be considered.

C.2.4.2 Test at the minimum allowable margin

In this option, parameters are tested at target temperatures above or below the maximum or minimum specified temperature limits. Adequate margins should be added (for target temperature limits above the specified maximum) or subtracted (for target temperatures below the specified minimum) to the target temperature limits.

NOTE Typical margins are 2 °C to 5 °C.

Sample sizes for this option should be large enough to provide the desired statistical confidence that the parameter conformance process is successful. The required confidence level, its method of calculation, and results of the calculations should be documented for each device uprated by parameter conformance assessment.

Parametric pass-fail tests should be conducted for all critical electrical parameters being assessed. The parameter test limits should be those of the device manufacturer's data sheet. If this process is successful, then the quality assurance process of C.2.5 should be followed. If the process is unsuccessful, then either the device should not be considered uprateable, or another uprating process should be considered.

C.2.4.3 Determine the margin by incremental temperature testing

C.2.4.3.1 General

In this option, devices are tested at or near the maximum (or minimum) specified temperature limit; and then at successively higher (or lower) temperature increments until the parameter of interest no longer conforms to the limits of the data sheet. The recommended temperature increment is 5 °C. The distribution of the temperatures at which non-conformance is observed, and new temperature specification limits are determined from them.

If

$$T_{\text{req-max}} < (X - CI_X) - A \times CL_\sigma - TE, \qquad \text{Equation C.1}$$

where

X is the sample mean,

CI_X is the confidence interval of the mean,

A is the number of standard deviations for the margin, and

CL_σ is the confidence level for standard deviation

TE is the margin to account for test equipment error,

then the device is capable of being used in the application in question

C.2.4.3.2 Example: Determine the margin by incremental temperature testing

C.2.4.3.2.1 General

The following conditions are assumed for this example:

- device temperature rating of 0 to 70 °C,
- application ambient temperature range near device is –40 °C to +85 °C,
- initial test sample is 10 devices,
- the mean fallout temperature of the 10 devices is 130 °C,
- the standard deviation of the mean fallout temperature for the 10 devices is 6 °C,
- the confidence level chosen for this application is 95 %,
- the margin or "A" term in Equation 10 is chosen to be 4σ.

(Test equipment error is not accounted for in this example)

Sample sizes for this option are determined on the basis of the observed type of statistical distribution of non-conformance temperatures, the parameters of the distribution, the desired temperature margin, and the desired statistical confidence in the results. All of this information should be included in the documentation for each instance of this activity. Figure C.2 illustrates the relationship between mean fallout temperature, $T_{\text{req-max}}$ and a typical curve representing the device fallout probability at each temperature.

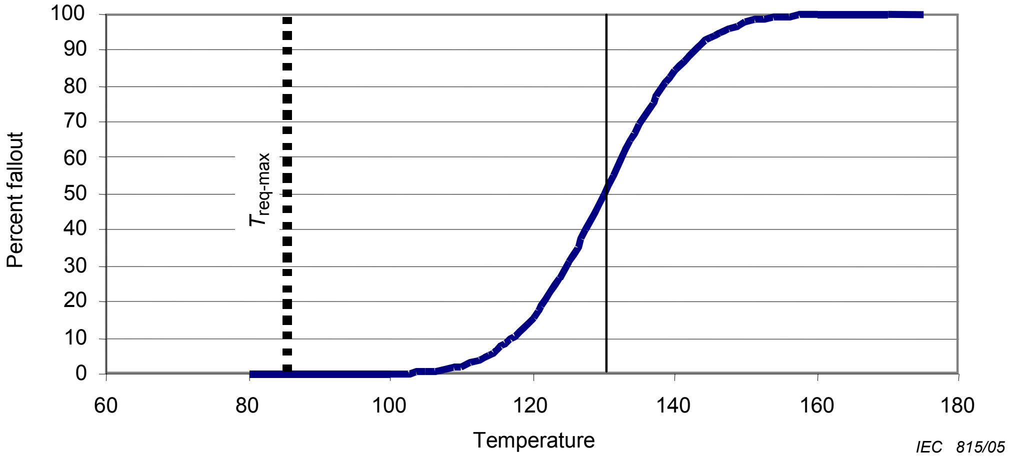

Figure C.2 – Typical Fallout Distribution versus $T_{\text{req-max}}$

C.2.4.3.2.2 Confidence interval for mean fallout temperature

The equation for calculating the one-sided confidence interval for the mean when the variance is unknown, is

$$CI_X = t_{\gamma,n-1} \times S / \sqrt{n} \qquad \text{Equation C.2}$$

where

$t_{\gamma,n-1}$ is the percentile of the t distribution,

γ is the confidence limit,

$n-1$ is the degrees of freedom.

n is the sample size, and

S is the standard deviation.

For this example, the following confidence interval would result:

$$3{,}478\,^\circ\text{C} = 1{,}833 \times 6^\circ\text{C} / 3{,}16$$

C.2.4.3.2.3 Confidence level for standard deviation of mean failure temperature

The equation for calculating the confidence level for the standard deviation is;

$$\sigma_u^{\ 2} = (n-1) \times S^2 / \chi^2_{1-\gamma,n-1}\,, \qquad \text{Equation C.3}$$

where

$\sigma_u^{\ 2}$ is the variance, and

$X^2_{1-\gamma,n-1}$ is the percentile of the X^2 distribution

This equation actually computes the upper confidence interval of the variance ($\sigma_u^{\ 2}$).

The confidence limit for the standard deviation is the square root of the variance of the confidence limit. For this example, the following confidence limit would result:

$$9{,}86\ ^\circ\mathrm{C} = \sqrt{9 \times (6\ ^\circ\mathrm{C})^2 / 3{,}33}$$

C.2.4.3.2.4 Result of example

From the Equation C.1:

$$87{,}07\ ^\circ\mathrm{C} = (130\ ^\circ\mathrm{C} - 3{,}478\ ^\circ\mathrm{C}) - 4\sigma \times 9{,}86\ ^\circ\mathrm{C}$$

This means that within a 95 % confidence, no more than 60 ppm of these parts will not perform per the manufacturer's specification at or below 87 °C. If this capability is sufficient for the application under consideration, the device can be used in the application with some ongoing device or product monitors reference in C.2.5.

C.2.5 Quality assurance

Quality assurance may be established by device level test per 5.3.2 prior to assembly or higher level assembly testing per 5.3.3.

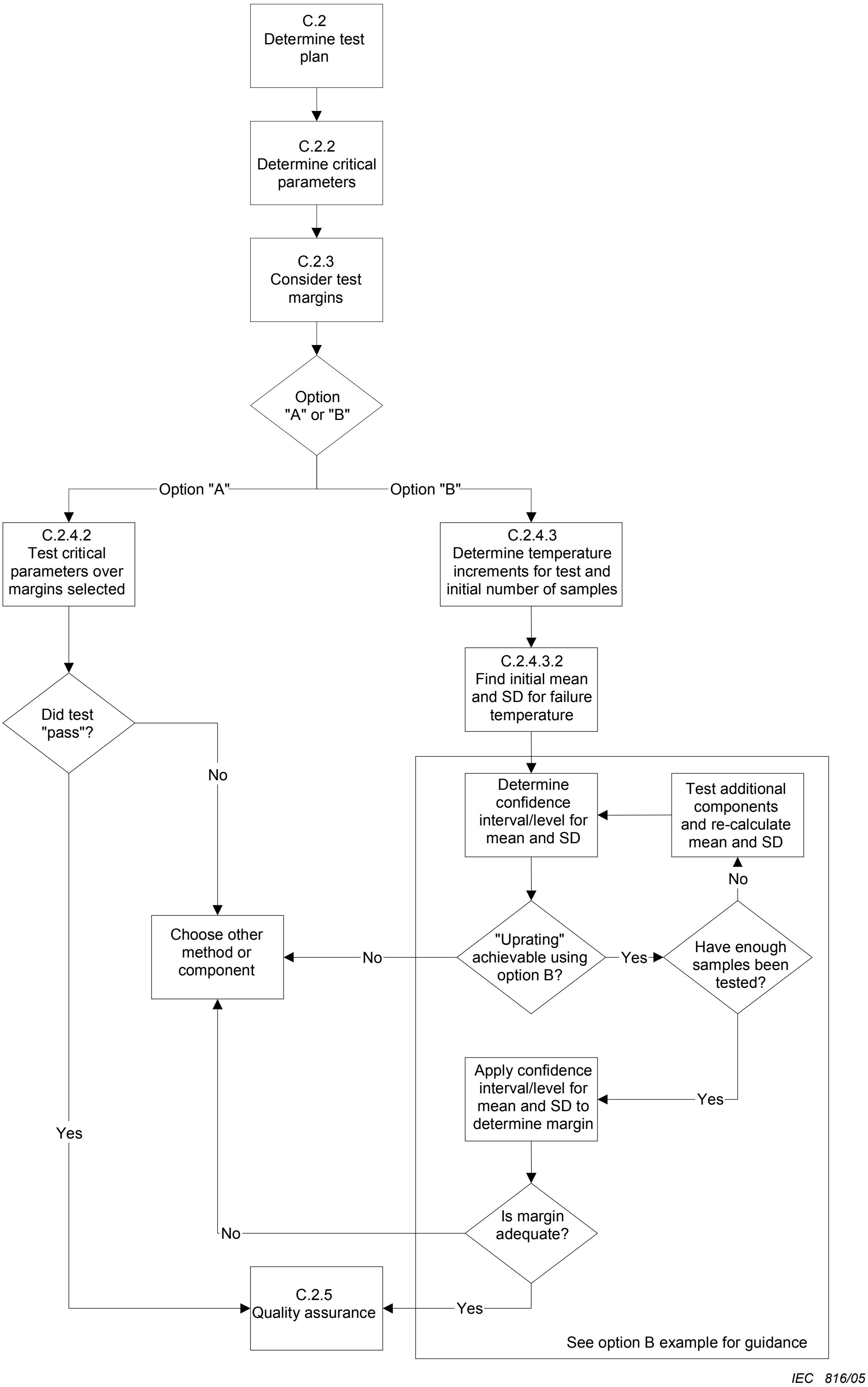

Figure C.3– Parameter conformance assessment flow

PARAMETER CONFORMANCE TESTING REPORT (to be completed for each lot)		
Device description: Device mfr.: Comp. mfr. part no: Equipment mfr. part no: Sampling plan ref.:		Incoming lot traveller ref: Date:
1.	Test specification No(s). Parametric: Functional:	
2.	Device date code(s):	
3.	#Sample size:	
4.	#Functional and parametric test passed: (Record all test temperatures, and list results for each temperature separately.)	
5.	#Functional or parametric test failed: (Record all test temperatures, and list results for each temperature separately.)	
6.	Test date:	
7.	Test results report:	
8.	Approvals:	

IEC 817/05

Figure C.4– Report form for documenting parameter conformance testing

Annex D
(informative)

Higher assembly level testing

D.1 General

Uprating by assembly test is a method of thermally uprating devices by testing the assemblies that contain them. Tests are conducted at the assembly level to verify by test correlation that the devices function satisfactorily at the target application temperature range.

This process is to be used to demonstrate the capability of a device to provide the needed function and performance as it is applied in a larger assembly containing other devices and functions, over the target application temperature range. This does not imply assessment of full device capability for all its specified performance characteristics. Only those performance characteristics that are important to the proper performance in the application in which it is used are assessed. Thus, devices that demonstrate acceptance in one application are not automatically approved for other applications.

Typically, assembly level tests are designed to test basic functional performance of an assembly or device. All functions or key characteristics of the end product are checked at some point in the quality assurance process, whether at the circuit card level or end product level or somewhere in between. The difference between the typical case and the process described here is that the device's role in these functions, or "key characteristics", of the assembly must be traced and capability verified by assembly test over the target application temperature range

D.2 Process

If assembly level testing is used, the following process should be followed.

D.2.1 Analysis of circuit and assembly test definition

The major steps of the assembly test process are:

a) Determine minimums, ranges and maximums of all functional characteristics of the assembly with respect to the device being uprated. (Failure modes and effects analysis, fault tree analysis, etc. may be used.)

b) Assure that the test stimulates and monitors the functional and performance characteristics of the assembly identified in a) above.

D.2.2 Perform assembly test

Perform the test on 100 % of the assemblies over the target application temperature range, (test margins are recommended). The testing performed at this level must be able to determine if the device or devices being uprated adversely affect performance or functionality of the assembly.

NOTE This test may be a separate test or may be included in the acceptance test procedure.

D.2.3 Document results

Document all information from assessment of the device's function in the assembly, the assembly's key characteristics, the assembly test coverage (related to the device being uprated) and the test results.

D.2.4 Maintenance notification

a) Identify the assembly as one that contains devices uprated by assembly level test.
b) Notify all maintainers (and others with a need to know) of the assembly that it contains devices uprated by assembly level test.
c) Prepare and provide appropriate information necessary to facilitate the maintenance and other logistics functions.

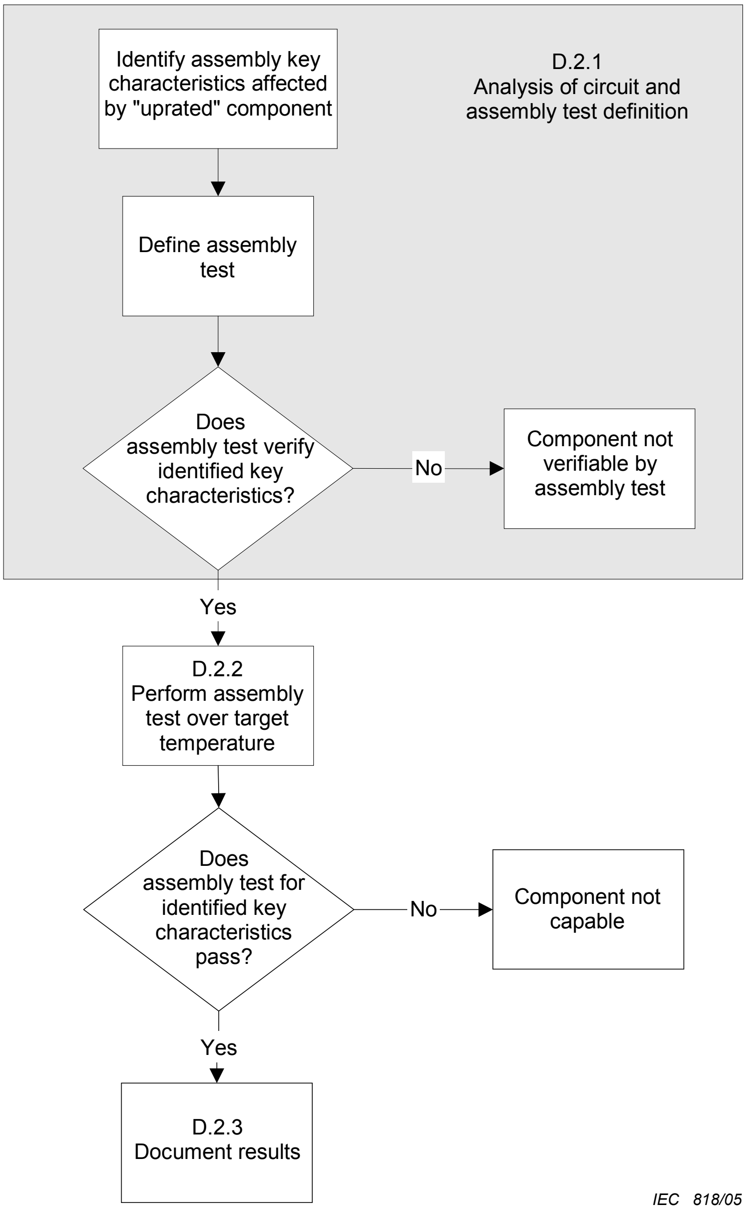

Figure D.1 – Flow chart of higher level assembly testing

HIGHER LEVEL ASSEMBLY TEST AT TEMPERATURE EXTREMES REPORT	
Device description: Device mfr.: Comp. mfr. part no: Equipment mfr. dwg. no:	Equipment name: Equipment part no: Program manager: Date:

1.	Rated temperature range (case or ambient):	
2.	Usage temperature range (case or ambient):	
3.	Test specification No(s). Parametric: Functional:	
4.	Determine key characteristics of assembly:	
5.	Determine "uprated" device's role in each key characteristic:	
6.	For each key characteristic upon which the "uprated" device has an effect, document that relationship and effect and ensure that the key characteristic is verified at the application extreme temperature:	
7.	Verify the device using the assembly test at the wider temperature range plus an appropriate temperature margin:	
8.	Did all key characteristics identified in step 6 pass?	
9.	Document results of steps 5, 6, 7 and 8:	
10.	Approvals:	

IEC 819/05

Figure D.2 – Report form for documenting higher level assembly test at temperature extremes

Bibliography

IEC 60134:1961, *Rating systems for electronic tubes and valves and analogous semi-conductor devices*

International SEMATECH Official Dictionary, Rev. 5.0

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- librarian ❑
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- safety engineer ❑
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- product research ❑
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- quality assessment ❑
- certification ❑
- technical documentation ❑
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- manufacturing ❑
- other...

Q5 This standard meets my needs: *(tick one)*

- not at all ❑
- nearly ❑
- fairly well ❑
- exactly ❑

Q6 If you ticked NOT AT ALL in Question 5 the reason is: *(tick all that apply)*

- standard is out of date ❑
- standard is incomplete ❑
- standard is too academic ❑
- standard is too superficial ❑
- title is misleading ❑
- I made the wrong choice ❑
- other ....

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(2) below average,
(3) average,
(4) above average,
(5) exceptional,
(6) not applicable

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- quality of writing....................................
- technical contents.................................
- logic of arrangement of contents ....
- tables, charts, graphs, figures...............
- other ....

Q8 I read/use the: *(tick one)*

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- English text only ❑
- both English and French texts ❑

Q9 Please share any comment on any aspect of the IEC that you would like us to know:

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