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colour
inside

Electric components – Reliability – Reference conditions for failure rates and stress models for conversion

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CONTENTS

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ELECTRIC COMPONENTS – RELIABILITY – REFERENCE CONDITIONS FOR FAILURE RATES AND STRESS MODELS FOR CONVERSION

FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 61709 has been prepared by IEC technical committee 56: Dependability.

This third edition cancels and replaces the second edition, published in 2011. This edition constitutes a technical revision. This third edition is a merger of IEC 61709:2011 and IEC TR 62380:2004.

This edition includes the following significant technical changes with respect to the previous edition:

a) addition of 4.5 Components choice, 4.6 Reliability growth during the deployment phase of new equipment, 4.7 How to use this document, and of Clause 19 Printed circuit boards (PCB) and Clause 20 Hybrid circuits with respect to IEC TR 62380;
b) addition of failure modes of components in Annex A;
c) modification of Annex B, Thermal model for semiconductors, adopted and revised from IEC TR 62380;
d) modification of Annex D, Considerations on mission profile;
e) modification of Annex E, Useful life models, adopted and revised from IEC TR 62380;
f) revision of Annex F (former B.2.6.4), Physics of failure;
g) addition of Annex G (former Annex C), Considerations for the design of a data base on failure rates, complemented with parts of IEC 60319;
h) addition of Annex H, Potential sources of failure rate data and methods of selection;
i) addition of Annex J, Presentation of component reliability data, based on IEC 60319.

The text of this standard is based on the following documents:

FDIS	Report on voting
56/1714/FDIS	56/1721/RVD

Full information on the voting for the approval of this standard 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 stability 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.

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The contents of the corrigendum of October 2019 have been included in this copy.

INTRODUCTION

This document is intended for the reliability prediction of electric components as used in equipment and is aimed at organizations that have their own data and describes how to state and use that data in order to perform reliability predictions.

It can also be used to allow an organization to set up a failure rate database and describes the reference conditions for which field failure rates should be stated. The reference conditions adopted in this document are typical of the majority of applications of components in equipment however when components operate under other conditions the users may consider stating these conditions as their reference conditions.

Using the presented stress models allows extrapolation of failure rates from reference conditions to other operating conditions which in turn permits the prediction of failure rates at assembly level. This allows estimation of the effect of design changes or changes in the environmental conditions on component reliability. Reliability prediction is most useful in the early design phase of ~~electrical~~ equipment. It can be used, for example, to identify potential reliability problems, the planning of logistic support strategies and the evaluation of designs.

The stress models contained herein are generic and are as simple as possible while still being comparable with more complex equations contained in other models. The predictions generated using this document have a wide range of prediction accuracy.

This document does not contain failure rates, but it describes how they can be stated and used. This approach allows a user to select the most relevant and up to date failure rates for the prediction from a source that they select. This document also contains information on how to select the data that can be used in the presented models.

The failure rates considered in this document are assumed to be constant, either for an unlimited period of operation (general case) or for limited periods. The limitation of life is called useful life and applies only for some few component families, reaching the wear-out failure period (during which the failure rate is increasing) within the normal period of use. It is hence assumed that during useful life, the failure rate can be considered constant for any practical use.

For the purposes of this document the term electric component includes the commonly used terms “electronic component”, “electrical component” and “electro-mechanical component”.

ELECTRIC COMPONENTS – RELIABILITY – REFERENCE CONDITIONS FOR FAILURE RATES AND STRESS MODELS FOR CONVERSION

1 Scope

This document gives guidance on ~~how~~ the use of failure rate data ~~can be employed~~ for reliability prediction of electric components used in equipment.

The method presented in this document uses the concept of reference conditions which are ~~numerical~~ the typical values of stresses that are observed by components in the majority of applications.

Reference conditions are useful since they ~~are the basis of the calculation of failure rate under any conditions by the application of stress models that take into account the actual operating~~ provide a known standard basis from which failure rates can be modified to account for differences in environment from the environments taken as reference conditions. Each user can use the reference conditions defined in this document or use their own. When failure rates stated at reference conditions are used it allows realistic reliability predictions to be made in the early design phase.

The stress models described herein are generic and can be used as a basis for conversion of failure rate data given at these reference conditions to actual operating conditions when needed and this simplifies the prediction approach. Conversion of failure rate data is only ~~permissible~~ possible within the specified functional limits of the components.

This document also gives guidance on how a database of component failure data can be constructed to provide failure rates that can be used with the included stress models. Reference conditions for failure rate data are specified, so that data from different sources can be compared on a uniform basis. If failure rate data are given in accordance with this document then ~~no~~ additional information on the specified conditions ~~is required~~ can be dispensed with.

This document does not provide base failure rates for components – rather it provides models that allow failure rates obtained by other means to be converted from one operating condition to another operating condition.

The prediction methodology described in this document assumes that the parts are being used within its useful life. The methods in this document have a general application but are specifically applied to a selection of component types as defined in Clauses 6 to 20 and I.2.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~IEC 60050-191, *International electrotechnical vocabulary – Part 191: Dependability and quality of service*~~

IEC 60050-192:2015, *International electrotechnical vocabulary – Part 192: Dependability*

~~IEC 60605-6, *Equipment reliability testing – Part 6: Tests for the validity and estimation of the constant failure rate and constant failure intensity*~~

~~IEC 60721-3-3, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 3: Stationary use at weather protected locations*~~

~~IEC 60721-3-4, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 4: Stationary use at non-weatherprotected locations*~~

~~IEC 60721-3-5, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 4: Ground vehicle installations*~~

~~IEC 60721-3-7, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 7: Portable and non-stationary use*~~

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC ~~60050-191~~ 60050-192 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
electric component
component with conductive terminals through which voltages or currents may be applied or delivered

Note 1 to entry: The term electric component includes the commonly used terms "electronic component", "electrical component" and "electro-mechanical component".

[SOURCE: IEC 61360-1:2009, 2.18, modified — Existing note deleted and Note 1 to entry added]

3.1.2
failure <of an item>
loss of ability to perform as required

~~Note 1 When the loss of ability is caused by a pre-existing latent fault, the failure occurs when a particular set of circumstances is encountered.~~

Note 1 to entry: A failure of an item is an event that results in a fault of that item~~, which is a state~~: see fault (IEC 60050-192:2015, 192-04-01).

Note 2 to entry: Qualifiers, such as catastrophic, critical, major, minor, marginal and insignificant, may be used to categorize failures according to the severity of consequences, the choice and definitions of severity criteria depending upon the field of application.

Note 3 to entry: Qualifiers, such as misuse, mishandling and weakness, may be used to categorize failures according to the cause of failure.

[SOURCE: IEC 60050-192:2015, 192-03-01]

3.1.3
failure mode
manner in which failure occurs

Note 1 to entry: A failure mode may be defined by the function lost or the state transition that occurred.

[SOURCE: IEC 60050-192:2015, 192-03-17]

3.1.4
instantaneous failure rate
failure rate
limit, if it exists, of the ~~ratio~~ quotient of the conditional probability that the ~~instant of a~~ failure of a non-repairable item occurs within time interval $(t, t + \Delta t)$, ~~to~~ by Δt, when Δt tends to zero, given that ~~it~~ failure has not ~~failed~~ occurred within time interval $(0, t)$

~~NOTE 1 The instantaneous failure rate, $\lambda(t)$, is expressed by the formula:~~

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{1}{\Delta t} \frac{F(t+\Delta t) - F(t)}{R(t)} = \frac{f(t)}{R(t)}$$

where $F(t)$ and $f(t)$ are, respectively, the distribution function and the probability density at the failure instant, and where $R(t)$ is the reliability function, related to the reliability $R(t_1, t_2)$ by $R(t) = R(0, t)$.

Note 1 to entry: See IEC 61703, *Mathematical expressions for reliability, availability, maintainability and maintenance support terms*, for more detail.

Note 2 to entry: Other terms used for instantaneous failure rate are: “hazard function”; “hazard rate”; and “force of mortality” (abbreviation FOM).

Note 3 to entry: $\lambda(t)$ in this document is assumed to be constant over time unless explicitly stated otherwise.

[SOURCE: IEC 60050-192:2015, 192-05-06, modified — Note 3 to entry added]

3.1.5
reference conditions
stresses selected so as to correspond to the majority of applications and usage of components in equipment

Note 1 to entry: Stresses include electrical stress, temperature and environmental conditions.

3.1.6
reference failure rate
failure rate stated under reference conditions given in IEC 61709

Note 1 to entry: The reference failure rate is specific to the component, i.e. it includes the effect of complexity, technology of the casing, dependence on manufacturers and the manufacturing process, etc.

3.1.7
duty cycle
specified sequence of operating conditions

Note 1 to entry: The duty cycle states whether components are continuously or intermittently stressed during their operation. Continuous duty means operation for a long duration with constant or changing loads (e.g. process controls, telephone switch). Intermittent duty means operation with constant or changing loads during up state (e.g. numerical controls for machinery, road traffic signals).

[SOURCE: IEC 60050-151:2001, 151-16-02, modified — Note 1 to entry added]

3.1.8
operating state <of an item>
state of performing as required

Note 1 to entry: For a component it means that it is energized and/or connected to a load.

[SOURCE: IEC 60050-192:2015, 192-02-04, modified — Notes 1 and 2 to entry replaced with a new Note 1 to entry]

3.1.9
non-operating state <of an item>
state of not performing any required function

Note 1 to entry: The adjective “non-operating” designates an item in a non-operating state.

Note 2 to entry: A component may be in a non-operating state because of a failure or because it is in an idle state (IEC 60050-192:2015, 192-02-14), if it is not required to be in an up state, in a standby state (IEC 60050-192:2015, 192-02-10), during the required time or in an externally disabled time (IEC 60050-192:2015, 192-02-24), when the non operation is due to absence of external resources.

[SOURCE: IEC 60050-192:2015, 192-02-06, modified — Note 2 to entry added]

3.1.10
dormant state
state of being inactive, but capable of becoming active

Note 1 to entry: For a component it means that it is ready to be energized and/or connected to a load.

3.1.11
standby state <of an item>
non-operating up state during required time

[SOURCE: IEC 60050-192:2015, 192-02-10]

3.1.12
storage state
state of being placed at a specific facility, and under stated conditions, without being energized and/or connected to a load

Note 1 to entry: For example the storage state of a component is not assembled to a piece of equipment.

3.1.13
prediction
computation process used to obtain the predicted value of a quantity

~~NOTE The term "prediction" may also be used to denote the predicted value of a quantity.~~

[SOURCE: IEC 60050-192:2015, 192-11-01]

3.1.14
component
constituent part of a device which cannot be physically divided into smaller parts without losing its particular function

[SOURCE: IEC 60050-151:2001, 151-11-21]

3.1.15
equipment
single apparatus or set of devices or apparatuses, or the set of main devices of an installation, or all devices necessary to perform a specific task

Note 1 to entry: Examples of equipment are a power transformer, the equipment of a substation, measuring equipment.

[SOURCE: IEC 60050-151:2001, 151-11-25]

3.1.16

useful life <of an item>

time interval, from first use until user requirements are no longer met, due to economics of operation and maintenance, or obsolescence

Note 1 to entry: In this context, "first use" excludes testing activities prior to hand-over of the item to the end-user.

[SOURCE: IEC 60050-192:2015, 192-02-27]

3.1.17

drift

difference between the final value of a characteristic at the end of a specified period and the initial value, all other operating conditions being held constant

Note 1 to entry: The use of the term "drift" to refer to the immediate change of a characteristic in direct response to changed operating conditions (for example, temperature) is deprecated.

[SOURCE: IEC 60747-1:2006, 3.6.1~~, modified~~]

3.1.18

virtual temperature <of a semiconductor device>

internal equivalent temperature

theoretical temperature which is based on a simplified representation of the thermal and electrical behaviour of the semiconductor device

Note 1 to entry: The virtual temperature is not necessarily the highest temperature in the device.

[SOURCE: IEC 60050-521:2002, 521-05-14, modified — Note 2 to entry deleted]

3.1.19

virtual (equivalent) junction temperature

virtual temperature of the junction of a semiconductor device

[SOURCE: IEC 60050-521:2002, 521-05-15]

3.1.20

ambient air temperature

the temperature, determined under prescribed conditions, of the air surrounding the complete device

Note 1 to entry: For devices installed inside an enclosure, it is the temperature of the air outside the enclosure.

[SOURCE: IEC TR 60943:1998, 1.3.1]

3.2 Symbols

In the normative part of this document, the following symbols are used. Other symbols are used and defined in the annexes.

~~E_a~~ Ea_1, Ea_2	activation energies of a failure process
A, C_i, k_0	constants
λ	failure rate under operating conditions
~~λ_f~~	~~failure rate at full stress for an assembly;~~
λ_{ref}	failure rate under reference conditions

$\lambda_{\text{component}}$	failure rate of a component
~~λ_{i}~~	~~failure rate during time spent idle for an assembly;~~
λ_{mode}	failure rate of a component's failure mode
~~λ_{p}~~	~~failure rate at part stress for an assembly;~~
~~λ_{S}~~	~~failure rate of a system;~~
π_{I}	current dependence factor
π_{E}	environmental application factor
π_{ES}	electrical stress dependence factor
~~π_{op}~~	~~stress factor for operating profile;~~
π_{S}	switching rate dependence factor
π_{T}	temperature dependence factor
π_{U}	voltage dependence factor
I_{op}	operating current
I_{rat}	rated current
I_{ref}	reference current
P_{op}	operating power dissipation
P_{ref}	reference power dissipation
P_{rat}	rated power dissipation
R_{th}	thermal resistance
$R_{\text{th, amb}}$	thermal resistance (to the environment)
S	number of operating cycles per hour
S_{ref}	reference number of operating cycle per hour
U_{op}	operating voltage
U_{rat}	rated voltage
U_{ref}	reference voltage
ΔT	actual self-heating in degrees Celsius
ΔT_{ref}	reference self-heating in ~~degrees Celsius~~ Kelvin
θ_0	reference ambient temperature in degrees Celsius
θ_{amb}	ambient temperature in degrees Celsius ~~– for capacitors the actual capacitor temperature;~~ ~~– for discrete semiconductors and optoelectronic components the actual junction temperature;~~ ~~– for inductors the actual winding temperature;~~ ~~– for integrated circuits (ICs) the actual virtual (equivalent) junction temperature;~~ ~~– for other electric components the actual ambient temperature;~~ ~~– for resistors the actual resistor element temperature;~~
T_0	reference ambient temperature in Kelvin
T_{amb}	ambient temperature in Kelvin
T_{op}	operating temperature in Kelvin
T_{ref}	reference temperature in Kelvin
θ_{op}	operating temperature in degrees Celsius – for integrated circuits (ICs) the actual virtual (equivalent) junction temperature;

- for discrete semiconductors and optoelectronic components the actual junction temperature;
- for capacitors the actual capacitor temperature;
- for resistors the actual resistor element temperature;
- for inductors the actual winding temperature;
- for other electric components the actual ambient temperature;

θ_{ref} reference temperature in degrees Celsius

- for ICs the reference virtual (equivalent) junction temperature;
- for discrete semiconductors and optoelectronic components the reference junction temperature;
- for capacitors the reference temperature of the capacitor;
- for resistors the reference temperature of the resistor element;
- for inductors the reference temperature of the winding;
- for other electric components the reference temperature of the component;

~~$R(t_1,t_2)$~~ ~~reliability between two times t_1 and t_2~~

~~t_p~~ ~~fraction of time with part stress for an assembly~~

~~t_i~~ ~~fraction of time spent idle for an assembly~~

~~t_f~~ ~~fraction of time with full stress for an assembly~~

~~β~~ ~~shape parameter of the Weibull distribution~~

4 Context and conditions

4.1 Failure modes and mechanisms

The characteristic preferred for reliability data of electric components is the (instantaneous) failure rate. It is to be noted that, although it is often generically defined as failure, the exact observed event that is measured is a failure mode.

In equipment a failure ~~(mode)~~ or functional loss is caused by a component failure ~~mode~~ where component failure mode is relevant to the application being carried out by the equipment.

It should be noted that a component has many features and only some may be used in the specific application. A function loss at the equipment level occurs only when there is a loss of the component feature that is used to support that function.

Furthermore a circuit requires the presence of component features according to what was defined by the designer; this may not encompass the total feature set of the component and may not use a particular feature to its full capacity as defined by the data sheet in terms of functional characteristics and ratings.

Handbooks usually define failure rate as an overall value, which includes all failure modes. This implies that component failure rate can be considered as the sum of the failure rates of all the modes, as follows:

$$\lambda_{\text{component}} = \sum_{i=1}^{n} \left(\lambda_{\text{mode}}\right)_i \tag{1}$$

where $\left(\lambda_{\text{mode}}\right)_i$ is the component failure rate in which the failure mode i occurs and n is the number of failure modes.

Failure modes are listed in Annex A ~~and more details about failures are contained in Annex B~~.

A failure is related to a failure mechanism, which is the basic material behaviour that results in the failure. For integrated circuits more detailed description is presented in Annex F.

4.2 Thermal modelling

Temperature is a relevant factor affecting failure rate. It is in fact known that temperature and temperature change has an effect on component reliability. For temperature change see 4.4. The temperature effect is more significant for some families (active components and aluminium capacitors with non-solid electrolyte). The models adopted are those which give the effect of temperature on the predominating failure mechanisms (which are not normally the "wear-out" mechanisms).

Thermal modelling of components should then be as accurate as possible, in particular thermal resistance for semiconductors should be measured in order to allow accurate evaluation of the internal temperature.

When thermal resistance cannot be measured, thermal resistance models provided in Annex B can be used.

4.3 ~~Operating~~ Mission profile consideration~~s~~

4.3.1 General

During their life, components experience different conditions of use that represent the major factors affecting component reliability: the complex of these conditions is defined as mission profile.

~~One of the major factors affecting component reliability is operating profile.~~

The mission profile defines the required function and the environmental condition as a function of time. This will vary according to the type of operation that is undertaken. This operation may be continuous over time at a fixed level, continuous over time at a variable level or sporadic over time at either a fixed level or a variable level. In some cases switch on and switch off could be significant and of more importance than the steady state operational conditions. Careful consideration of the ~~operating~~ mission profile is needed in order to fully understand how it affects the component reliability.

The ~~operating~~ mission profile can be considered to be based on calendar time or on the time of actual operation or it can be cycle based (e.g. how many times an item is used).

More considerations on mission profile are detailed in Annex D.

4.3.2 Operating and non-operating conditions

A mission profile can be decomposed in several phases, on the basis of the typical use. The main classification of these phases is between operating and non-operating conditions. Although this document deals with components, the conditions of use usually refer to the assembly (equipment or system), and can be defined as follows when they refer to components.

- Operating: the component is assembled, powered or connected to a load and functioning at nominal conditions. See 3.1.8.
- Stand-by: the component is assembled, powered or connected to a load, but not functioning or functioning at conditions lower than nominal. See 3.1.11.
- Dormant: the component is assembled, but not powered or connected to a load. See 4.3.3.
- Storage: the component is not assembled, hence not powered or connected to a load. During storage components are packed stored in a warehouse. See 4.3.4

4.3.3 Dormancy

A component is considered dormant (i.e. in a dormant state) when it is inactive (it does not provide any of the required functions), but it is capable of becoming active and properly operating on demand (energized and/or connected to a load). To be considered dormant it is assumed that the component is assembled to a piece of equipment, but no power is applied.

Components that are dormant may fail, but usually the dormant failure rate is considerably lower than the operating failure rate, assuming that the piece of equipment is maintained within its specified conditions, when non-operating.

4.3.4 Storage ~~conditions~~

Components that are under storage conditions are not immune from failure, particularly when the storing conditions are different from those specified. However the stress models for environmental application factors in this document may not apply since they only deal with operating conditions. Different failure mechanisms may exist under storage conditions that have not been considered in the models. Furthermore the case where storage conditions change the failure rate when the item is active are not dealt with in this document.

Storage conditions should be treated separately from operating conditions. They may affect the components' failure behaviour in later life.

More information on storage can be found in IEC PAS 62435. Storage conditions should be defined and controlled, in order to ensure the reliability of the components stored.

4.4 Environmental conditions

The environment contributes to failure that occurs in the life of the equipment. As a consequence the duration and intensity of environmental stresses should be included in the operational model of the equipment.

A more severe environment may cause the failures to occur more frequently than one that is less severe. There will usually be several aspects of the environment that will be pertinent to a specific failure and all may need to be understood. The locality of the environment is also important, for example on an aircraft the in-cabin and on-engine environments are very different.

The environment may be described in terms of several types of parameters and their associated interactions.

IEC 60721-3-3 describes the environment in terms of:

- climatic conditions;
- special climatic conditions;
- biological conditions;
- chemically active substances;
- mechanically active substances;
- mechanical conditions (both static and dynamic).

All the above listed conditions are in general relevant to the equipment's reliability (e.g. failure rate) and it is reasonable to consider that the reliability of components, and therefore of the equipment, decreases as the environmental stress increases (see IEC 60721 (all parts) for a detailed quantitative description of the environmental parameters for each environment).

In this document it is assumed that the climatic and mechanical conditions are the most significant and this is also valid for many standard applications of components, but there may be situations where, for example, chemical conditions could result in a higher failure rate.

Other factors influencing the failure rate can be nuclear, ultraviolet, infrared and electromagnetic radiation, acoustics, altitude, software security, six degrees of freedom vibration, explosive atmosphere environments, item induced conditions, and hostile weapons effects for military items.

Estimated failure rates generated using the models in this document are valid only if the coldest part temperature of the considered component is over the dew point temperature.

In this document only the climatic and mechanical parameters are used to describe the effect of the reference environments on failure rates. However, temperature is treated separately in this document. For simplicity it has been chosen to address three basic environments, conventionally named E1, E2 and E3. These environments refer to general field usage situations, considering the specific values of the environmental parameters. These are defined in Table 1.

Table 1 – Basic environments

E1	**Stationary use at weather-protected locations**	The environment is highly insensitive to the weather outdoors and humidity is controlled within defined limits. This is typical of telecommunications and computer equipment placed in buildings. This includes office situations.
E2	**Stationary use at partially weather-protected or non-weather-protected locations**	The environment offers thermal and mechanical stresses directly influenced by natural environmental conditions. It is typical of equipment installed outdoors.
E3	**Portable and non-stationary use, ground vehicle installation**	The environment offers mechanical stresses and severe thermal gradients. It is typical of equipment mounted on vehicles or that are hand portable.

~~Other environments can be defined, see 5.2.5 for details.~~

Table 2 shows the values of environmental parameters and their relationship to the classes indicated in the relevant IEC standards.

The effect of environment can be described as a change of failure rate, by applying an environmental application factor π_E (see Table 4). Note that π_E is a discrete factor since it is based on non-continuous data and summarizes a large number of different lower level factors.

It has to be noted, anyway, that most of the systems and equipment operate under controlled temperature and the effect of external environment is shielded by proper design decisions.

This document considers temperature cycle (operating times at different temperatures) in the mission profile, while rapid temperature changes are included in the environmental application factor, π_E (see 5.2.5).

The environmental application factors include all environmental parameters (excluding temperature, which has a specific model) such as rapid temperature changes, mechanical vibration, where no empirical models are available. The environmental application factors are used at equipment level.

Table 2 – Values of environmental parameters for basic environments

~~Basic environment~~	E1	E2	E3
Environmental parameters	**Stationary use at weather-protected locations**	**Stationary use at partially weather-protected or non-weather-protected locations**	**Portable and non-stationary use, ground vehicle installation**
Temperature rate of change	≤ 0,5° C/min	> 0,5° C/min	> 0,5° C/min
Stationary vibration, sinusoidal	2 Hz to 9 Hz <1,5 mm 9 Hz to 200 Hz ≤ 5 m/s^2	2 Hz to 9 Hz ≤3 mm 9 Hz to 200 Hz ≤ 10 m/s^2	2 Hz to 9 Hz >3 mm 9 Hz to 200 Hz ≥ 10 m/s^2 200 Hz to 500 Hz ≥15 m/s^2
Non-stationary vibration including shock	≤ 70 m/s^2	≤ 250 m/s^2	> 250 m/s^2
IEC 60721-3-3 Classes	3K1 3K2 3K3 3K4 3K5 3K6 3M1 3M2 3M3	3K7 3K7L 3K8 3K8H 3K8L 3K9 3K10 3M4 3M5 3M6 3M7	-
IEC 60721-3-4 Classes	-	-	4K1 4K2 4K3 4K4 4K4H 4K4L
IEC 60721-3-5 Classes	-	-	5K1 5K2 5K3 5K4 5K4H 5K4L 5K5 5K6 5M1 5M2 5M3
IEC 60721-3-7 Classes	-	-	7K1 7K2 7K3 7K4 7K5
ETS 300 019-1-3 Classes	3.1-3.2-3.3	3.4-3.5	-
ETS 300 019-1-4 Classes	-	4.1-4.1E	-
ETS 300 019-1-8 Classes	8.1 and Note	-	-
ETS 300 019-1-5 Classes	-	-	5.1-5.2
ETS 300 019-1-7 Classes	-	-	7.1 – 7.2 – 7.3 – 7.3E

This document ~~is written to contain~~ covers only the three environments for ~~the sake of~~ simplicity. The user can describe any environment using the same methodology and assess the proper environmental application effect π_E as described in 5.2.5.

4.5 Components choice

It is the responsibility of the manufacturer to ensure the life duration specified by the final user and that components used in equipment are compatible with the environment. Therefore, premature wear-out is assumed not to occur during the useful life period of the equipment in normal operating conditions, as prescribed by the final user.

However, some components may have a limited life duration, and so preventive maintenance has to be indicated to the final user. It is the responsibility of the component manufacturer to provide qualification and evaluation results of degradation mechanisms to the system manufacturer and to ensure that the appearance of wear-out mechanisms will be postponed beyond the useful life period of the equipment in normal operating conditions.

Good component and equipment reliability is not achieved without effort. Equipment reliability is built-in, starting from the initial design phases, by applying a rigorous quality assurance system, oriented toward improvement. This means that inadequate application of the rules for excellence in quality and reliability, taking into account the product type and its use and maintenance criticality, will affect reaching the objective.

Component failures, even those conventionally considered random, excluding wear-out and external causes, are due to manufacturing defects or misuse. These show their effects during operation.

Thus manufacturers and users have to adopt adequate preventive actions:

- qualification and control of the component manufacturing process;
- characterization and qualification of the components;
- acceptance tests;
- use of good design rules (thermal, electrical, mechanical).

This document does not describe quality levels since it does not consider quality levels lower than the best achievable set as design standards. Experience of poor quality cannot be considered in order to establish models, and waivers to the application of quality rules cannot be justified based on economic considerations when the total component/equipment cost, either of the manufacturer or of the user, is considered.

There are special applications such as space, avionics and submarine cables, where the impossibility – or at least the great difficulty – of performing maintenance, as well as for safety reasons, urge adoption of even more severe rules. These cases cannot be generalized and should be studied using specific experience with the equipment and the measures adopted (such as screening, burn-in, special quality assurance programmes).

Consequently, the equipment manufacturer has to choose component manufacturers who have the best "commercial practice" concerning quality, for example, those who comply with internationally recognized quality management systems, practise statistical process control and are approved under qualified manufacturing line approval (or able to be).

In these conditions, there are no longer any reasons to take into consideration quality factors, and the infant mortality period related to new component technology is neglected since only qualified production lines and stabilized ones are considered here.

When an equipment manufacturer uses a new component technology, and when such a manufacturer has not been able to justify the life duration in normal use conditions of its device, the equipment manufacturer has to undertake tests allowing justification of the life duration of this component to the final user.

4.6 Reliability growth during the deployment phase of new equipment

The models expounded in this document allow for calculating the failure rate of an electric item that is already in a mature production phase. However, prior to that, a newly developed item may have undergone some form of reliability growth process that is reflected by a decreasing failure rate during a more or less long period.

For instance, reliability growth is achieved by the correction of manufacturing issues such as the return of a process into control or the modification of a process to improve it. With respect to reliability growth in the field, it is the modifications to the item, its design, manufacturing or operation that lead to a more reliable item. For a comprehensive description of reliability processes and activities integrated into the product life cycle which contribute or provide for the product reliability growth, refer to IEC 61014.

A manufacturer should calibrate the reliability growth period according to its own experience. It was demonstrated experimentally on many electric items and with several manufacturers that the ratio between the failure rate during the starting period of deployment and the failure rate in the mature phase can be very different. Consequently, as soon as the observed failure rate during the beginning of the deployment of an electric item significantly exceeds the estimated value, a corrective action may have to be taken.

4.7 How to use this document

This document provides a method to convert failure rates from one set of operating conditions to another. To do this it uses the concept of failure rates at reference conditions and provides equations to convert them to other conditions.

Reference conditions are defined as the most common set of environmental and operating conditions for the user. For example if an organization has most of its equipment operating at 30ºC then it should state failure rates at this operating temperature and define it as the reference conditions. The reason the organization should choose the typical operating conditions as the reference conditions is so that when they collect field reliability data they do not have to make any adjustments to it to account for environmental differences before using it.

If an organization does not have a typical operating environment then they should decide to set the reference conditions at a level that is most appropriate for them, or they can use the reference conditions that are defined in this document in Clauses 6 to 20. In this case when they collect field data they may have to make adjustments to the data to bring it all to a set of reference conditions so that it can be combined and compared.

Many organizations will not have their own reliability data and so will need to use other sources of data. This document can then be used to convert the failure rates from operating conditions to reference conditions or vice versa.

NOTE For example if an organization wants to perform a prediction for an equipment at an operating temperature of 34 ºC and the component being used are not covered by a single data source with some data coming from other multiple data handbooks then the base failure rates, which are stated at a particular and different level of environmental stress in each source, can be converted and combined using the equations in this document.

The equations in this document have been derived from empirical model fitting to field data and in some cases to the equations used in other standards and handbooks. This means that the equations here will give a generic fit to the data as is suitable in an international standard.

Figure 1 shows, for CMOS IC, a comparison of the temperature dependence of factors π_{T} stated in a number of prediction handbooks with the factor π_{T} stated in this document.

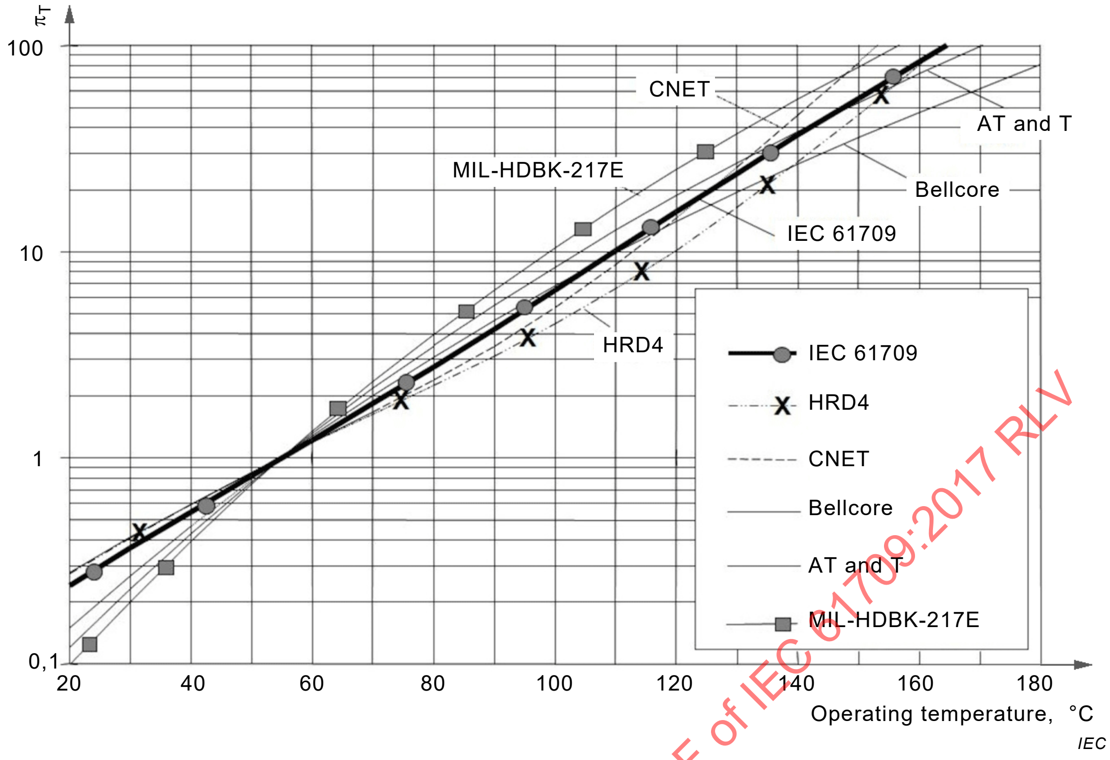


Figure 1 – Comparison of the temperature dependence of π_T for CMOS IC

Figure 1 demonstrates that the acceleration factors provided in this document are compatible with many acceleration factors given in prediction handbooks. The figure shows a fit to generic versions of the data from the prediction handbooks. The latest versions of the handbooks are detailed in H.5.3.

In order to use the equations given in this document then certain data will be required; this differs slightly by component type, but the most important data is a base failure rate stated at reference conditions. This can be obtained from field data (see IEC 60300-3-3, IEC 60300-3-5) or from manufacturer’s data or from other handbooks (see Annex H). If this data is not stated at reference conditions it can be converted to a reference condition by using the equations in this document. Knowledge of the operating environment at which the failure rate is stated is necessary in order to do this. When the failure rate is at reference conditions then it can be converted to other operating conditions using the equations contained in this document.

5 Generic reference conditions and stress models

5.1 Recommended generic reference conditions

Generic reference conditions are those ~~that apply to all component types~~ values of environmental factors that are defined by an organization as being typical of the sorts of environment the organization's equipment is subjected to during normal operations. ~~In this standard, these include electrical stress, temperature and environmental conditions. If it is appropriate and if models are available, these can be considered at the specific component level.~~ The factor could be any environmental factor the organization feels is relevant and apply to all component types.

This document, necessarily, takes a more limited view and defines the environmental factors of interest as being electrical stress, temperature and environmental conditions. Extensions to this set are not supported by this document.

Table 3 contains some recommendations that ~~should~~ can be used by an organization unless they are not appropriate to the normal working conditions of that organization's equipment. ~~The organization is then free to choose its own appropriate reference conditions.~~ Any organization should choose conditions closest to their actual experience if they differ from those given in Table 3.

The values chosen represent the majority of component operating conditions.

~~Generic models are not available.~~

Table 3 – Recommended reference conditions for environmental and mechanical stresses

Type of stress	Reference condition[a]
Ambient temperature[b]	θ_0 = 40 °C
Environmental condition	Environment E1 (see Table 1)
Special stresses	Not addressed in this document[c]

[a] The failure rates stated under these conditions apply only to components not damaged during transport and storage.

[b] The ambient temperature for the purposes of this document is the temperature of the medium next to the component during equipment operation, not taking into account any possible self-heating of the component. The surroundings of the component should be defined.

[c] Special stresses include wind, rain and snow, icing, drips, sprays or jets of water, dust (chemically active or not), effects of animal pests, corrosive gases, radioactive radiation, etc. These stresses may be significant contributors to failure however, as a general good practice; they should be addressed by design practices. There may be cases where their effect can be treated by applicable models. These stresses have such wide ranges of effects it would be inappropriate to address them in this document.

5.2 Generic stress models

5.2.1 General

Components may not always operate under the reference conditions. In such cases, ~~operational~~ operating conditions will result in failure rates different from those given for reference conditions. Therefore, models for stress factors, by which failure rates under reference conditions can be converted to values applying for operating conditions (actual ambient temperature and actual electrical stress on the components), and vice versa, may be required. In Clauses 6 to 20 specific stress models and values of π-factors for component categories are given and should be used for converting reference failure rates to field operational failure rates. π-factors are failure rate modifiers which are related to a specific stress or condition. They are a measure of the change of failure rate due to changes in that stress or condition. However, if more specific models are applicable for particular component types then these models should be used and their usage justified and reported.

The conversion of failure rates is only possible within the specified functional limits of the components.

The component failure rate under operating conditions is calculated as follows:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{I}} \times \pi_{\text{T}} \times \pi_{\text{E}} \times \pi_{\text{S}} \times \pi_{\text{ES}} \qquad (2)$$

where

λ_{ref} is the failure rate under reference conditions;

π_{U} is the voltage dependence factor;

π_{I} is the current dependence factor;

π_{T} is the temperature dependence factor;

π_{E} is the environmental application factor;

π_{S} is the switching rate dependence factor;

π_{ES} is the electrical stress dependence factor.

5.2.2 Stress factor for voltage dependence, π_{U}

$$\pi_{\mathrm{U}} = \exp\left\{ C_3 \left[\left(\frac{U_{\mathrm{op}}}{U_{\mathrm{rat}}} \right)^{C_2} - \left(\frac{U_{\mathrm{ref}}}{U_{\mathrm{rat}}} \right)^{C_2} \right] \right\} \tag{3}$$

where

U_{op} is the operating voltage in V;

U_{ref} is the reference voltage in V;

U_{rat} is the rated voltage in V;

C_2, C_3 are constants.

Equation (3) represents an empirical model to describe the voltage dependence of failure rates and is based on existing component reliability handbooks, existing component reliability data, and publicly available publications.

NOTE When dealing with absolute values of voltage as might be necessary for some component types then Equation 3 can be modified to $\pi_{\mathrm{U}} = \exp\left\{ C_1 \left(U_{\mathrm{op}}^{C_2} - U_{\mathrm{ref}}^{C_2} \right) \right\}$ where $C_1 = C_3 / U_{\mathrm{rat}}^{C_2}$.

5.2.3 Stress factor for current dependence, π_{I}

$$\pi_{\mathrm{I}} = \exp\left\{ C_4 \left[\left(\frac{I_{\mathrm{op}}}{I_{\mathrm{rat}}} \right)^{C_5} - \left(\frac{I_{\mathrm{ref}}}{I_{\mathrm{rat}}} \right)^{C_5} \right] \right\} \tag{4}$$

where

I_{op} is the operating current in A;

I_{ref} is the reference current in A;

I_{rat} is the rated current in A;

C_4, C_5 are constants.

Equation (4) represents an empirical model to describe the current dependence of failure rates and is based on existing component reliability handbooks, existing component reliability data, and publicly available publications.

5.2.4 Stress factor for temperature dependence, π_{T}

$$\pi_{\mathrm{T}} = \exp\left[\frac{Ea_1}{k_0} \left(\frac{1}{T_{\mathrm{ref}}} - \frac{1}{T_{\mathrm{op}}} \right) \right] \tag{5}$$

Equation (5) is an empirical model based on the Arrhenius equation and it describes the temperature dependence of the failure rates. Ideally this computation should be made for each failure mode, however it is common practice to perform this calculation using an average of all activation energies for all failure modes or for the dominant failure mode only. It should be noted that in this latter case, the activation energy may also be a function of temperature since it is related to the different activation energies of the underlying failure modes. However this effect is commonly ignored.

In certain cases a more complex model using two activation energies is appropriate to fit the temperature dependence of failure rates. In such a case the following~~ model, represented by~~ Equation (6) can be used. Use of the model with two activation energies (Ea_1, Ea_2) is considered sufficient to adequately model the temperature-failure rate relation. (This is sometimes known as competing risks; see JESD-85 for details.)

This extended Arrhenius equation is standardized to avoid temperature-dependent activation energies when changing the reference temperature, T_{ref}.

$$\pi_T = \frac{A \times \exp(Ea_1 \times z) + (1 - A) \times \exp(Ea_2 \times z)}{A \times \exp(Ea_1 \times z_{\text{ref}}) + (1 - A) \times \exp(Ea_2 \times z_{\text{ref}})} \tag{6}$$

with the auxiliary variables

$$z = \frac{1}{k_0}\left(\frac{1}{T_0} - \frac{1}{T_{\text{op}}}\right) \text{ and } z_{\text{ref}} = \frac{1}{k_0}\left(\frac{1}{T_0} - \frac{1}{T_{\text{ref}}}\right) \text{ in (eV)}^{-1}$$

where in Equations (5) and (6):

A is a constant;

Ea_1, Ea_2 are activation energies in eV;

k_0 = 8,616 × 10^{-5} eV/K;

T_0 = 313 K;

T_{ref} $= (\theta_{\text{ref}} + 273)$ in K;

T_{op} $= (\theta_{\text{op}} + 273)$ in K.

The temperatures θ_{ref} and θ_{op} in degrees Celsius above are as follows;

- for ICs:
  θ_{ref} : reference virtual (equivalent) junction temperature;
  θ_{op} : actual virtual (equivalent) junction temperature;
- for discrete semiconductors and optoelectronic components:
  θ_{ref} : reference junction temperature;
  θ_{op} : actual junction temperature;
- for capacitors:
  θ_{ref} : average (*) reference capacitor temperature;
  θ_{op} : average (*) actual capacitor temperature;
- for resistors:
  θ_{ref} : average (*) reference temperature of the resistor element (for example, film);
  θ_{op} : average (*) actual temperature of the resistor element;
- for inductors:

θ_{ref} : average (*) reference temperature of the winding;

θ_{op} : average (*) actual temperature of the winding;

– for other electric components:

θ_{ref} : average (*) reference ambient temperature;

θ_{op} : average (*) actual ambient temperature;

NOTE (*) In this case average means “over the entire body of the component”.

5.2.5 Environmental application factor, π_E

~~5.2.5.1 General~~

Some data handbooks contain guidance on transferring a failure rate estimate from one general environmental condition to another. The concept ~~seems~~ is logical, but it ~~bears~~ carries some risk. For that reason, this document focuses more on situations where base failure rates are gathered from environment conditions which are similar to those applied to the component in practice. ~~For more information see B.4.4.~~

The influence of environmental application conditions on the component depends essentially on the design of equipment; for example by using the equipment on ships or in the automotive field instead of in protected rooms (laboratory conditions), ~~no~~ the influence on the environmental application conditions ~~will exist~~ can be minimized, and in some cases can be removed entirely if the component is protected in some way within the equipment. Of course this will require some extra design effort and so may not be worth doing in all cases. Whether an environmental application influence occurs depends therefore essentially on the equipment manufacturer and it is the duty of an organization to design for a specific environment or if the impact of these stresses cannot be avoided, then specific studies are necessary for these pieces of equipment.

If the only failure rate data books available came from a source with very different environmental conditions, the need for an environmental application factor arises. To use such an environmental application factor means to assume that a more severe environment causes the activation of internal failure mechanisms in a predictable, more or less linear manner. There are situations where this assumption is wrong. When a component designed for ground equipment is used under severe shock and vibration conditions – these can destroy all components in a few hours – a π_E-factor could be calculated, but is not meaningful. The ~~only~~ best practical solution ~~is~~ should be to not use the component in that environment, but that is not always possible.

The environmental application factor, π_E, should therefore be handled with care.

Table 4 – Environmental application factor, π_E

Stationary use at weather-protected locations E1	Stationary use at partially weather-protected or non-weather-protected locations E2	Portable and non-stationary use, ground vehicle installation E3
1	2	4

NOTE Failure rate data books from a component supplier will often give guidance on how to transfer the failure rate to other operating and environmental conditions.

5.2.6 Dependence on switching rate, π_S

The factor π_S considers the number of operating cycles per hour, S, and only applies for relays in this document.

Factor π_S is not defined for $S < 0{,}01$.

a) $\pi_S = 1$ for ~~$0{,}01 < S < S_{\text{ref}}$~~ $0{,}01 \leq S \leq S_{\text{ref}}$ (7)

b) $\pi_S = S/S_{\text{ref}}$ for $S > S_{\text{ref}}$ (8)

where

S is the number of operating cycles per hour;

S_{ref} is the reference number of operating cycles per hour.

NOTE ~~For low operating cycles per hour ($S < 0{,}01$),~~ The factor π_S can be as much as 100 for hermetically sealed contacts, normally closed, or non-sealed contacts, normally open under small loads.

5.2.7 Dependence on electrical stress, π_{ES}

This π-factor is only applicable to certain devices and is explained in detail in the related clauses.

5.2.8 Other factors of influence

Other stress factors are given for individual types of components in Clauses 6 to 20 where the dependence is known.

At present, no generally applicable conversion methods can be given for the dependence of the failure rate on humidity, air pressure, mechanical stress, etc.

Stress factors will have to be based on vendor/user history in similar applications or appropriate testing.

If the failure rate dependence of these types of stress is known, it should be considered.

If the dependence of the failure rate under these types of stress is unknown but is expected to be a function of these types of stress, appropriate studies may be necessary.

~~6 Specific reference conditions and stress models~~

6 Integrated semiconductor circuits

6.1 Specific reference conditions

The following recommendations for reference temperatures given in Table 5 to Table 9 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment.

The reference self-heating, $\Delta T_{\text{ref}} = P_{\text{ref}} \times R_{\text{th, amb}}$, ~~shall~~ should be given when using reference temperatures other that those stated in the tables.

For any integrated circuit there are two thermal resistances generally considered; one between the junction and the case, and the other between the case and the environment. The thermal resistance, $R_{\text{th,amb}}$, above, should be the one that is most significant in the application under consideration.

When stating a failure rate for an ambient temperature of 40 °C, the reference power dissipation, P_{ref}, and the thermal resistance, $R_{\text{th,amb}}$, to the environment for which this value holds, ~~shall~~ should also be given.

Table 5 – Memory

Component			θ_{ref} °C	Note
Bipolar	RAM, FIFO	static	75	---
	PROM		75	
MOS, CMOS, BICMOS	RAM	dynamic	55	
	RAM, FIFO	static slow (≥ 30 ns) static fast (< 30 ns)	55	
	ROM mask		55	
	EPROM, OTPROM	UV erasable	55	
	FLASH		55	
	EEPROM, EAROM		55	

Table 6 – Microprocessors and peripherals, microcontrollers and signal processors

Component		θ_{ref} °C	Note
Bipolar		70	---
NMOS	No. of transistors ≤ 50 000	70	
	No. of transistors > 50 000	90	
CMOS	No. of transistors ≤ 5 000	50	
	No. of transistors > 5 000 to 50 000	60	
	No. of transistors > 50 000 to 500 000	80	
	No. of transistors > 500 000	90	
BICMOS		75	

Table 7 – Digital logic families and bus interfaces, bus driver and receiver circuits

Component			θ_{ref} °C	~~Note~~ Reference voltage
Bipolar	TTL, -LS, -A(L)S, -F	Logic	45	---
	Bus interface		55	
	TTL S	Logic + bus interface	80	
	ECL	10 000 100 000 10(LV)E(L) / 100(LV)E(I)(P)	65 75 60	
CMOS	HCMOS, CMOS B, ACMOS (FCT, HC, A(U),C, LVX), (LVC, LCX, LV) (VCX, ALVC, AVC, AHC, VHC) Logic Analog switches, Bus interface		45	$U_{\text{ref}} = 5\,\text{V}$
	Bus interface	GTL(p)	50	
	Bus driver / receiver RS422, RS423, RS485, CAN, etc. RS232, RS644/899, CML, etc.		55	
BICMOS	Logic		45	

Bus interface	ABT, BCT LVT, ALVT GTL(p) BTL, ETL	50 50 50 95	---
Bus driver / receiver		55	

Table 8 – Analog ICs

Component		θ_{ref} °C	~~Note~~ **Reference voltage ratio**
Operational amplifiers, comparators and voltage monitors	Bipolar, BIFET CMOS	55 45	$U_{\text{ref}}/U_{\text{rat}} = 0{,}7$
Reference elements	all technologies	45	---
Switch regulators	all technologies	55	
Power amplifiers and regulators (all technologies)	≤ 1 W > 1 W	70 90	
High frequency IC (> 100 MHz)			
HF modulator, demodulator PLL, VCO	bipolar CMOS, BICMOS	65 45	
Transmitter, receiver	bipolar CMOS, BICMOS	70 45	
Power amplifier / receiver	GaAs	80	

Table 9 – Application-specific ICs (ASICs)

Component			θ_{ref} °C	Note
ASICs, Full custom, Gate arrays, Telecom ICs, A/D-Converters				---
Bipolar	TTL		55	
	ECL		70	
	HV (> 50 V)		80	
NMOS			55	
CMOS, BICMOS	digital, analog / mixed	No. of transistors ≤ 50 000 No. of transistors >50 000 to 50 × 10^6 No. of transistors >50 × 10^6	55 70 80	
	HV (> 50 V)		75	
Programmable ASICs (PLD) non erasable				
Bipolar	TTL		80	
	ECL		85	
CMOS	(anti-fuses)		80	
Programmable ASICs (PLD) erasable				
NMOS, CMOS	RAM basis		80	
	EPROM basis EEPROM basis Flash-EPROM	No. of transistors ≤ 5 000 No. of transistors > 5 000	70 80 80	

6.2 Specific stress ~~factors~~ models

6.2.1 ~~Models~~ General

The specific stress models are given for converting the failure rates between different conditions. These stress models contain constants, which are average values for the individual component types, from various manufacturers, determined from field experience and laboratory tests.

~~The failure rate under operating conditions, from Equation (1), is:~~

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} \qquad \text{for digital CMOS and bipolar analog ICs} \tag{9}$$

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} \qquad \text{for all other ICs} \tag{10}$$

The stress factors for voltage and temperature dependence are specified in 6.2.2 and 6.2.3 respectively.

6.2.2 Voltage dependence, factor π_{U}

The voltage dependence is only taken into account for digital CMOS and bipolar analog ICs, according to Equation (3). The constants C_1, C_2 and C_3 given in Table 10 are used, unless other values are stated. The results are shown in Table 11 and Table 12.

Table 10 – Constants for voltage dependence

Integrated circuit	$U_{\text{ref}}/U_{\text{rat}}$	U_{ref}	C_1	C_2	C_3
Digital CMOS-family	–	5 V	0,1 V^{-1}	1	–
Analog	0,7	–	–	4,4	1,4

Table 11 – Factor π_{U} for digital CMOS-family ICs

U_{op} (V)	≤3	4	5	6	7	8	9	10	11	12	13	14	15
Factor π_{U}	0,8	0,9	1	1,1	1,2	1,3	1,5	1,6	1,8	2,0	2,2	2,5	2,7

Table 12 – Factor π_{U} for bipolar analog ICs

$U_{\text{op}}/U_{\text{rat}}$	≤0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
Factor π_{U}	0,75	0,77	0,80	0,87	1,0	1,3	1,8	3,0

6.2.3 Temperature dependence, factor π_{T}

The relationship given in Equation (6) applies only up to the rated junction temperature. The constants A, Ea_1 and Ea_2 given in Table 13 are used, unless other values have been stated. The results are shown in Table 14 and Table 15.

Table 13 – Constants for temperature dependence

	A	Ea_1 (eV)	Ea_2 (eV)
ICs (except EPROM, OTPROM, EEPROM, EAROM)	0,9	0,3	0,7
EPROM, OTPROM, EEPROM, EAROM	0,3	0,3	0,6

The factor π_T is obtained from Table 14 and Table 15:

– as a function of the actual virtual (equivalent) junction temperature;

$$\cancel{\theta_{op} = \theta_{amb} + P \times R_{th,amb}} \; \theta_{op} = \theta_{amb} + P_{op} \times R_{th,amb} \text{ in degrees Celsius,} \qquad (11)$$

– and as a function of the virtual (equivalent) junction temperature under reference conditions (see 6.1);

$$\theta_{ref} = 40 + \Delta T_{ref} \qquad \text{in degrees Celsius,} \qquad (12)$$

where ΔT_{ref} is measured or calculated as $\Delta T_{ref} = P_{ref} \times R_{th, amb}$.

Table 14 – Factor π_T for ICs (without EPROM; FLASH-EPROM; OTPROM; EEPROM; EAROM)

θ_{ref} °C (see 6.1)	Factor π_T for θ_{op} °C																				
	≤25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**130**	**140**	**150**	**175**
40	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,3	4,1	5,1	6,3	7,7	9,6	12	18	28	44	67	102	275
45	0,44	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,4	4,1	5,1	6,3	7,8	9,7	15	23	36	55	83	225
50	0,36	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,2	2,8	3,4	4,2	5,2	6,4	8	12	19	29	45	68	184
55	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,3	2,8	3,4	4,2	5,3	6,5	10	16	24	37	56	150
60	0,24	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,3	2,8	3,5	4,3	5,3	8,2	13	20	30	46	123
65	0,2	0,24	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,9	2,3	2,8	3,5	4,4	6,7	10	16	24	37	100
70	0,16	0,2	0,24	0,3	0,37	0,45	0,54	0,67	0,82	1	1,2	1,5	1,9	2,3	2,9	3,6	5,5	8,5	13	20	30	82
75	0,13	0,16	0,2	0,24	0,3	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,3	2,9	4,5	6,9	11	16	25	67
80	0,11	0,13	0,16	0,2	0,24	0,29	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,3	3,6	5,69	8,6	13	20	54
85	0,087	0,11	0,13	0,16	0,2	0,24	0,29	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,9	4,5	7	11	16	44
90	0,07	0,086	0,11	0,13	0,16	0,19	0,24	0,29	0,35	0,43	0,53	0,66	0,81	1	1,2	1,5	2,4	3,7	5,6	8,7	13	36
95	0,057	0,07	0,085	0,1	0,13	0,16	0,19	0,23	0,29	0,35	0,43	0,53	0,65	0,81	1	1,2	1,9	3	4,6	7	11	29
100	0,046	0,056	0,069	0,084	0,1	0,13	0,15	0,19	0,23	0,28	0,35	0,43	0,53	0,65	0,81	1	1,5	2,4	3,7	5,6	8,5	23

Table 15 – Factor π_T for EPROM; FLASH-EPROM; OTPROM; EEPROM; EAROM

θ_{ref} °C (see 6.1)	Factor π_T for θ_{op} °C																				
	≤25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**130**	**140**	**150**	**175**
55	0,16	0,22	0,3	0,41	0,55	0,75	1	1,3	1,8	2,3	3,1	4,0	5,2	6,7	8,6	11	18	28	43	65	96	238

7 Discrete semiconductors

7.1 Specific reference conditions

The following recommendations for reference temperatures given in Table 16 to Table 19 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment.

The reference self-heating, $\Delta T_{\text{ref}} = P_{\text{ref}} \times R_{\text{th, amb}}$, ~~shall~~ should be given when using other reference temperatures than those stated in the tables. When stating a failure rate for an ambient temperature of 40 °C, the reference power dissipation, P_{ref}, and the thermal resistance, $R_{\text{th, amb}}$, to the environment for which this value holds, ~~shall~~ should also be given.

For discrete semiconductors there are two thermal resistances generally considered; one between the junction and the case, the other between the case and the environment. The thermal resistance, $R_{\text{th,amb}}$, above, should be the one that is most significant in the application under consideration.

Table 16 – Transistors common, low frequency

Component		θ_{ref} °C	~~**Note**~~ **Reference voltage ratio**
Bipolar, universal	e.g. TO18, TO92, SOT(D)(3)23 or similar	55	$U_{\text{ref}}/U_{\text{rat}} = 0{,}5$
Transistor arrays		55	
Bipolar, low power	e.g. TO5, TO39, SOT223, SO8, SMA-SMC	85	
Bipolar, power	e.g. TO3, TO220, D(D)-Pack	100	
FET	junction MOS	55 55	
MOS power (SIPMOS)	e.g. TO3, TO220, D(D)-Pack	100	

Table 17 – Transistors, microwave, (e.g. RF > 800 MHz)

Component		θ_{ref} °C	~~**Note**~~ **Reference voltage ratio**
Bipolar	wide band, small signal power	55 125	$U_{\text{ref}}/U_{\text{rat}} = 0{,}5$
GaAs FET	small signal low noise medium power high power	95 110 145	
MOSFET	wide band, small signal power	55 125	

Table 18 – Diodes

Component	θ_{ref} °C	Note
Universal diode (also with avalanche characteristics)	55	---
Schottky diode	55	
Limiting diode (suppressor diode)	40	
Zener diode ($P_{\text{tot}} < 1$ W) voltage protection[a]	40	
Zener diode, power stabilization[b]	100	
Reference diode	45	
Microwave diode, small signal detector diode capacitance diode mixer diode pin diode	 45 45 70 55	
Microwave diode, power storage varactor gun diode impatt diode pin diode	 100 160 180 100	
High-voltage rectifier diode	85	

[a] If applied for voltage protection the calculation can be made without accounting for self-heating ($\theta_{\text{ref}} = 40°\text{C}$).

[b] If used for stabilization then the calculation ~~shall~~ should take self-heating into account.

Table 19 – Power semiconductors

Component	θ_{ref} °C	Note
Rectifier diodes (also with avalanche characteristics)	70	----
Rectifier bridges	85	
Schottky diodes	85	
Thyristors	85	
Triacs, diacs	85	
Specialized and custom-made power semiconductors	consult manufacturer	

7.2 Specific stress ~~factors~~ models

7.2.1 General

The specific stress models are given for converting the failure rates between different conditions. These stress models contain constants which are average values for the individual component types from various manufacturers (determined from field experience and laboratory tests).

~~6.2.2.2 Models~~

The failure rate under operating conditions, from Equation (2), is as follows:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} \quad \text{for transistors} \tag{13}$$

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} \quad \text{for diodes and power semiconductors} \tag{14}$$

NOTE 1 Diodes refer to general purpose diodes, Schottky diodes, voltage regulators and Zener diodes.

NOTE 2 Power semiconductors refer to rectifier diodes, bridge diodes, thyristors, triacs and diacs.

The stress factors for voltage and temperature dependence are given in 7.2.2 and 7.2.3 respectively. Current may also be a significant factor.

7.2.2 Voltage dependence for transistors, factor π_U

The voltage dependence is only taken into account for transistors according to Equation (3). The constants C_2 and C_3 given in Table 20 are used, unless other values are stated. The results are shown in Table 21.

Table 20 – Constants for voltage dependence of transistors

U_{ref}/U_{rat}	C_2	C_3
0,5	8,0	1,4

Table 21 – Factor π_U for transistors

U_{op}/U_{rat}	≤ 0,6	0,65	0,7	0,75	0,8	0,85	0,9	0,95	1
Factor π_U	1	1,04	1,08	1,14	1,26	1,46	1,82	2,52	4

7.2.3 Temperature dependence, factor π_T

The relationship given in Equation (6) applies only up to the maximum permissible junction temperature. The constants A, Ea_1 and Ea_2 given in Table 22 are used, unless other values have been stated. The results are shown in Table 23 and Table 24.

Table 22 – Constants for temperature dependence of discrete semiconductors

Component	A	Ea_1 (eV)	Ea_2 (eV)
Transistors, reference and microwave diodes	0,9	0,3	0,7
Diodes (without reference and microwave diodes) Power semiconductors [a]	1,0	0,4	–

[a] Rectifier diodes, bridge rectifiers, Schottky diodes, thyristors, triacs and diacs

The factor π_T is obtained from Table 23 and Table 24:

- as a function of the actual junction temperature;

~~$\theta_{op} = \theta_{amb} + P \times R_{th,amb}$~~ $\theta_{op} = \theta_{amb} + P_{op} \times R_{th,amb}$ in degrees Celsius, (15)

- and as a function of the junction temperature under reference conditions (see 7.1);

$\theta_{ref} = 40 + \Delta T_{ref}$ in degrees Celsius, (16)

where ΔT_{ref} is measured or calculated as $\Delta T_{ref} = P_{ref} \times R_{th,amb}$.

Table 23 – Factor π_T for transistors, reference and microwave diodes

θ_{ref} °C (see 7.1)	Factor π_T for θ_{op} °C																										
	≤ 25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**125**	**130**	**140**	**145**	**150**	**160**	**175**	**180**	**200**
40	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,3	4,1	5,1	6,3	7,7	9,6	12	18	28	35	44	67	83	102	153	275	332	689
45	0,44	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,4	4,1	5,1	6,3	7,8	9,7	15	23	29	36	55	68	83	125	225	272	563
55	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,3	2,8	3,4	4,2	5,3	6,5	10	16	19	24	37	45	56	84	150	182	377
70	0,16	0,2	0,24	0,3	0,37	0,45	0,54	0,67	0,82	1	1,2	1,5	1,9	2,3	2,9	3,6	5,5	8,5	11	13	20	25	30	46	82	99	206
85	0,087	0,11	0,13	0,16	0,2	0,24	0,29	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,9	4,5	5,6	7	11	13	16	24	44	53	110
95	0,057	0,07	0,085	0,10	0,13	0,16	0,19	0,23	0,29	0,35	0,43	0,53	0,65	0,81	1	1,2	1,9	3	3,7	4,6	7	8,6	11	16	29	35	72
100	0,046	0,056	0,069	0,084	0,1	0,13	0,15	0,19	0,23	0,28	0,35	0,43	0,53	0,65	0,81	1	1,5	2,4	3,0	3,7	5,6	6,9	8,5	13	23	28	58
110	0,03	0,036	0,045	0,055	0,067	0,081	0,099	0,12	0,15	0,18	0,22	0,28	0,34	0,42	0,52	0,65	1	1,5	1,9	2,4	3,6	4,5	5,6	8,3	15	18	38
125	0,015	0,019	0,023	0,028	0,035	0,043	0,052	0,063	0,078	0,095	0,12	0,14	0,18	0,22	0,27	0,34	0,52	0,81	1	1,2	1,9	2,3	2,9	4,3	7,8	9,4	20
145	0,0066	0,0081	0,0099	0,012	0,015	0,018	0,022	0,027	0,033	0,041	0,05	0,061	0,076	0,094	0,12	0,14	0,22	0,34	0,43	0,53	0,81	1	1,2	1,85	3,3	4,0	8,3
160	0,0035	0,0054	0,0044	0,0066	0,0080	0,0098	0,012	0,015	0,018	0,022	0,027	0,033	0,041	0,051	0,063	0,074	0,12	0,19	0,24	0,3	0,44	0,54	0,67	1	1,87	2,2	4,6
180	0,0016	0,0020	0,0025	0,0030	0,0037	0,0045	0,0055	0,0067	0,0082	0,01	0,012	0,015	0,019	0,023	0,029	0,036	0,055	0,085	0,11	0,13	0,2	0,25	0,31	0,46	0,83	1	2,1

Table 24 – Factor π_T for diodes (without reference and microwave diodes) and power semiconductors

θ_{ref} °C (see 7.1)	Factor π_T for θ_{op} °C																										
	≤25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**125**	**130**	**140**	**145**	**150**	**160**	**175**	**180**	**200**
40	0,47	0,61	0,79	1	1,3	1,6	2	2,4	3	3,7	4,4	5,4	6,5	7,7	9,2	11	15	20	24	27	36	41	47	61	87	98	151
55	0,24	0,31	0,4	0,51	0,64	0,80	1	1,2	1,5	1,9	2,3	2,7	3,3	3,9	4,7	5,5	7,6	10	12	14	18	21	24	31	44	50	77
70	0,13	0,17	0,21	0,27	0,35	0,43	0,54	0,67	0,82	1	1,2	1,5	1,8	2,1	2,5	3,0	4,1	5,6	6,5	7,5	9,9	11,3	13	17	24	27	41
85	0,074	0,095	0,12	0,16	0,2	0,25	0,31	0,38	0,46	0,57	0,69	0,83	1	1,2	1,4	1,7	2,3	3,2	3,7	4,3	5,6	6,4	7,3	9,5	14	15	23
100	0,044	0,056	0,072	0,092	0,12	0,15	0,18	0,22	0,28	0,34	0,41	0,49	0,59	0,71	0,84	1	1,4	1,9	2,2	2,5	3,3	3,8	4,4	5,6	8,0	9,0	14

8 Optoelectronic components

8.1 Specific reference conditions

The following recommendations for reference temperatures given in Table 25 to Table 29 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment.

The reference self-heating, $\Delta T_{\text{ref}} = P_{\text{ref}} \times R_{\text{th, amb}}$, ~~shall~~ should be given when using reference temperatures other than those stated in the tables.

When stating a failure rate for an ambient temperature of 40 °C, the reference power dissipation, P_{ref}, and the thermal resistance, $R_{\text{th,amb}}$, to the environment for which this value holds, ~~shall~~ should also be given.

For optoelectronic components there are two thermal resistances generally considered: one between the junction and the case, the other between the case and the environment. The thermal resistance, $R_{\text{th,amb}}$, above, should be the one that is most significant in the application under consideration.

Table 25 – Optoelectronic semiconductor signal receivers

Component	Reference junction temperature θ_{ref} °C	~~Note~~ Reference voltage ratio
Phototransistor plastic and hermetically enclosed	45	$U_{\text{ref}}/U_{\text{rat}} = 0{,}5$
Photodiode (Si and Si PIN, InP, InP APD, Ge, Ge APD)	45	---
Photo element	45	
Detector module	40	
Solar component	40	

Table 26 – LEDs, IREDs, laser diodes and transmitter components

Component	Reference junction temperature θ_{ref} °C	~~Note~~ Reference current ratio
LED visible light (radial and SMT, large power packages (> 100 mA DC))	45	$I_{\text{ref}}/I_{\text{rat}} = 0{,}5$
LED IRED ((Al)GaAs, InP)	75	
Laser diode (GaAs 880 nm, InP 1 300 nm, InP 1 500 nm)	75	---
Laser array, pump laser / pump laser cooled (GaAS 980 nm, InP 1 480 nm)	45	
Laser-transmitter modules	consult manufacturer	
Displays (LED)	55	
Displays (LCD, vacuum florescence)	consult manufacturer	
Semiconductor optical amplifier (SOA)	45	
Fibre (EDFA)	consult manufacturer	
Modulators (InP, $LiNbO_3$)	40	

Table 27 – Optocouplers and light barriers

Component		Reference junction temperature θ_{ref} °C	Note
Optocoupler	with bipolar output	55	---
	with FET output	65	
	with subsequent electronics	55	
	with subsequent power electronics	65	
Light barrier	with diode output / transistor output	55	
	with subsequent electronics	55	

Table 28 – Passive optical components

Component	Reference junction temperature θ_{ref} °C	Note
Optical waveguide connector (n-fold)	40	---
Optical fibre pigtail (one driver and one connector)	40	
Fibre	40	No temperature dependence to consider
Dispersion compensating fibre (DCF)	40	
Isolators	40	
Circulators	40	
Optical multiplexer, demultiplexer (thin film, arrayed-waveguide grating (AWG))	40	
Optical attenuators (fixed value, electromechanical)	40	
Switch (electromagnetical, MEMs)	40	
Coupler, splitter, filter (thin film, Bragg)	40	

Table 29 – Transceiver, transponder and optical sub-equipment

Component		Reference junction temperature θ_{ref} °C	Note
Transceiver, Transponder	SFF, SFP	40	---
	Xponder / Long haul tuneable	Consult manufacturer	
Optical spectrum analyzer (OPA, complex / OSA, complex)			
Active dispersion compensator			
Wavelength selective switch			
Wavelength blocker			
Ground trip current (GTC) interrupter (electro-mechanical)		40	No temperature dependence to consider

8.2 Specific stress ~~factors~~ models

8.2.1 General

The specific stress models are given for converting the failure rates between different conditions. These stress models contain constants. They are average values for the individual component types from various manufacturers (determined from field experience and laboratory tests).

~~6.3.2.2 Models~~

The failure rate under operating conditions according to Equation (2) is:

$\lambda = \lambda_{\mathrm{ref}} \times \pi_{\mathrm{u}} \times \pi_{\mathrm{T}}$	for phototransistors	(17)
$\lambda = \lambda_{\mathrm{ref}} \times \pi_{\mathrm{T}}$	for other optical semiconductor signal receivers, optocouplers and light barriers, optical waveguide connectors, optical fibre pigtails, transceivers, transponders	(18)
$\lambda = \lambda_{\mathrm{ref}} \times \pi_{\mathrm{I}} \times \pi_{\mathrm{T}}$	for light-emitting diodes (LEDs) and infrared-emitting diodes (IREDs)	(19)
$\lambda = \lambda_{\mathrm{ref}}$	for other optical components	(20)

The stress factors for voltage, current, and temperature dependence are given in 8.2.2 to 8.2.4.

8.2.2 Voltage dependence, factor π_{U}

The voltage dependence is only taken into account for phototransistors according to Equation (3). The constants C_2 and C_3 given in Table 30 are used, unless other values are stated. The results are shown in Table 31.

Table 30 – Constants for voltage dependence of phototransistors

$\frac{U_{\mathrm{ref}}}{U_{\mathrm{rat}}}$	C_2	C_3
0,5	8,0	1,4

Table 31 – Factor π_{U} for phototransistors

$\frac{U_{\mathrm{op}}}{U_{\mathrm{rat}}}$	≤ 0,6	0,65	0,7	0,75	0,8	0,85	0,9	0,95	1
Factor π_{U}	1	1,04	1,08	1,14	1,26	1,46	1,82	2,52	4

8.2.3 Current dependence, factor π_{I}

The current dependence is only taken into account for LEDs and IREDs, according to Equation (4). The constants C_4 and C_5 given in Table 32 are used, unless other values are stated. The results are shown in Table 33.

Table 32 – Constants for current dependence of LEDs and IREDs

$\frac{I_{\text{ref}}}{I_{\text{rat}}}$	C_4	C_5
0,5	1,4	8,0

Table 33 – Factor π_{I} for LEDs and IREDs

$\frac{I_{\text{op}}}{I_{\text{rat}}}$	**≤ 0,6**	**0,65**	**0,7**	**0,75**	**0,8**	**0,85**	**0,9**	**0,95**	**1**
Factor π_{I}	1	1,04	1,08	1,14	1,26	1,46	1,82	2,52	4

8.2.4 Temperature dependence, factor π_{T}

The relationship given in Equation (5) applies only up to the maximum permissible junction temperature. The values for the constant Ea_1 given in Table 34 are used, unless other values have been stated. The results are shown in Table 35.

Table 34 – Constants for temperature dependence of optoelectronic components

Component		**Ea_1** (eV)
Optical semiconductor signal receiver	Si	0,3
	InP	0,7
	Ge	0,6
Light-emitting diodes (LED)		0,65
Infrared-emitting diodes (IRED)	(Al)GaAs	0,65
	InP	1,0
Semiconductor laser	GaAs	0,6
	InP	0,8
Optocoupler and light barriers		0,5
Optical waveguide connector; optical fibre pigtail		0,3
Transceiver, transponder		0,4

The factor π_{T} is obtained from Table 35:

– as a function of the actual junction temperature;

$$\theta_{\text{op}} = \theta_{\text{amb}} + P_{\text{op}} \times R_{\text{th,amb}} \quad \text{in degrees Celsius,} \tag{21}$$

– and as a function of the junction temperature under reference conditions (see 8.1);

$$\theta_{\text{ref}} = 40 + \Delta T_{\text{ref}} \quad \text{in degrees Celsius,} \tag{22}$$

where ΔT_{ref} is measured or calculated as $\Delta T_{\text{ref}} = P_{\text{ref}} \times R_{\text{th,amb}}$.

Table 35 – Factor π_T for optical components

Optical semiconductor signal receiver																	
	θ_{ref} °C	**Factor π_T for θ_{op}** °C															
		≤ 25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
Si	40	0,57	0,69	0,83	1	1,2	1,4	1,7	2	2,3	2,6	3,1	3,5	4	4,6	5,3	6
	45	0,48	0,58	0,7	0,84	1	1,2	1,4	1,6	1,9	2,2	2,6	3	3,4	3,9	4,4	5
InP	40	0,27	0,42	0,66	1	1,5	2,2	3,3	4,8	6,8	9,7	14	19	26	36	48	65
	45	0,18	0,28	0,44	0,66	1	1,5	2,2	3,2	4,5	6,4	9	13	17	24	32	43
Ge	40	0,33	0,48	0,7	1	1,4	2	2,8	3,8	5,2	7	9,4	12	16	21	28	36
	45	0,23	0,34	0,49	0,7	1	1,4	1,9	2,7	3,7	4,9	6,6	8,8	12	15	20	25
LED (visible light and IRED)																	
	θ_{ref} °C	**Factor π_T for θ_{op}** °C															
		≤ 25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
(Al)GaAs	45	0,20	0,31	0,46	0,68	1	1,4	2,1	2,9	4,1	5,6	7,7	11	14	19	25	33
	55	0,099	0,15	0,22	0,33	0,49	0,7	1	1,4	2	2,7	3,7	5,1	6,9	9,2	12	16
	75	0,026	0,04	0,06	0,088	0,13	0,19	0,27	0,38	0,53	0,73	1	1,4	1,8	2,4	3,2	4,3
InP	75	0,004	0,007	0,013	0,024	0,043	0,076	0,13	0,22	0,37	0,62	1	1,6	2,5	4	6,1	9,3
Semiconductor laser																	
	θ_{ref} °C	**Factor π_T for θ_{op}** °C															
		≤ 25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
GaAs	75	0,035	0,051	0,074	0,11	0,15	0,21	0,3	0,41	0,55	0,75	1	1,3	1,7	2,3	3	3,8
InP	75	0,035	0,051	0,074	0,11	0,15	0,21	0,3	0,41	0,55	0,75	1	1,3	1,7	2,3	3	3,8
Optocoupler and light barrier																	
	θ_{ref} °C	**Factor π_T for θ_{op}** °C															
		≤ 25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
	55	0,17	0,23	0,32	0,43	0,57	0,76	1	1,3	1,7	2,2	2,8	3,5	4,4	5,5	6,8	8,5
	65	0,1	0,14	0,19	0,25	0,34	0,45	0,59	0,77	1	1,3	1,6	2,07	2,6	3,3	4,05	5,01
Optical waveguide connector; optical fibre pigtail; modulator; wavelength selective switch; wavelength blocker																	
	θ_{ref} °C	**Factor π_T for θ_{op}** °C															
		≤ 25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
	40	0,57	0,69	0,83	1	1,2	1,4	1,7	2	2,3	2,6	3,1	3,5	4	4,6	5,3	6
Transceiver, transponder																	
	θ_{ref} °C	**Factor π_T for θ_{op}** °C															
		≤ 25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
	40	0,47	0,61	0,79	1	1,3	1,6	2	2,4	3	3,7	4,4	5,4	6,5	7,7	9,2	11

9 Capacitors

9.1 Specific reference conditions

The recommendations for reference temperatures given in Table 36 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment.

Table 36 – Capacitors

Type of capacitor	**Reference capacitor temperature** θ_{ref} °C	~~**Note**~~ **Reference voltage ratio**
Metal foil Polystyrol, polypropylene, polycarbonate, polyethylene terephthalate	40	50 % of rated voltage at 40 °C $U_{ref} / U_{rat} = 0{,}5$
Metallized film Polypropylene, polycarbonate, polyethylene terephthalate, acetyl cellulose		
Metallized paper (film)		
Mica		
Glass		
Acetyl cellulose		
Ceramic		
Deposited capacitors for hybrid circuits		
Tantalum electrolytic – non-solid electrolyte – solid electrolyte		
Aluminium electrolytic – non-solid electrolyte – solid and polymer electrolyte	40	80 % of rated voltage at 40 °C $U_{ref} / U_{rat} = 0{,}8$
Variable	40	----

9.2 Specific stress ~~factors~~ model

9.2.1 ~~Model~~ General

The failure rate under operating conditions according to Equation (2) is:

$$\lambda = \lambda_{ref} \times \pi_U \times \pi_T \tag{23}$$

NOTE Aluminium electrolytic components with non-solid electrolyte are electrochemical components with an especially wide technology range. Therefore the given constants and factors are just estimates of the values. More specific values ~~may~~ can be given in the relevant component specifications or ~~may~~ can be agreed upon between user and manufacturer.

The stress factors for voltage and temperature dependence are given in 9.2.2 and 9.2.3.

9.2.2 Voltage dependence, factor π_U

The voltage dependence is only taken into account for fixed capacitors, according to Equation (3).

For variable capacitors, $\pi_U = 1$.

The constants C_2 and C_3 given in Table 37 are used, unless other values are stated. The results are shown in Table 38.

Table 37 – Constants for voltage dependence of capacitors

Type of capacitor	$\frac{U_{ref}}{U_{rat}}$	C_2	C_3
Paper, metallized paper Metallized polypropylene film Metallized polyethylene terephthalate film Metallized cellulose acetate film	0,5	1,07	3,45
Polycarbonate film metal foil Metallized polycarbonate film	0,5	1,50	4,56
Polystyrene film Polyethylene terephthalate film metal foil Polypropylene film metal foil	0,5	1,29	4,0
Glass	0,5	1,11	4,33
Mica	0,5	1,12	2,98
Ceramic	0,5	1,0	4,0
Deposited capacitors for hybrid circuits	0,5	1,0	4,0
Aluminium electrolytic, non-solid electrolyte	0,8	1,0	1,36
Aluminium electrolytic, solid electrolyte	0,8	1,9	3,0
Tantalum electrolytic, non-solid electrolyte	0,5	1,0	1,05
Tantalum electrolytic, solid electrolyte	0,5	1,04	9,8

Table 38 – Factor π_U for capacitors

Type of capacitor	**Factor π_U for U_{op}/U_{rat}**									
	0,1	**0,2**	**0,3**	**0,4**	**0,5**	**0,6**	**0,7**	**0,8**	**0,9**	**1**
Paper, metallized paper Metallized polypropylene film Metallized polyethylene terephthalate film Metallized cellulose acetate film	0,26	0,36	0,50	0,71	1,0	1,40	2,0	2,9	4,2	6,1
Polycarbonate film metal foil Metallized polycarbonate film	0,23	0,30	0,42	0,63	1,0	1,7	2,9	5,2	9,8	19
Polystyrene film Polyethylene terephthalate film metal foil Polypropylene film metal foil	0,24	0,32	0,45	0,66	1,0	1,5	2,4	3,9	6,4	11
Glass	0,19	0,28	0,42	0,64	1,0	1,6	2,5	4,0	6,3	10
Mica	0,32	0,42	0,55	0,74	1,0	1,4	1,9	2,6	3,6	5
Ceramic	0,20	0,30	0,45	0,67	1,0	1,5	2,2	3,3	5,0	7,4
Deposited capacitors for hybrid circuits	0,20	0,30	0,45	0,67	1,0	1,5	2,2	3,3	5,0	7,4
Aluminium electrolytic, non-solid electrolyte	0,39	0,44	0,51	0,58	0,67	0,76	0,87	1,0	1,2	1,3
Aluminium electrolytic, solid electrolyte	0,15	0,16	0,19	0,24	0,31	0,44	0,64	1,0	1,6	2,8
Tantalum electrolytic, non-solid electrolyte	0,66	0,73	0,81	0,90	1,0	1,1	1,2	1,4	1,5	1,7
Tantalum electrolytic, solid electrolyte	0,021	0,054	0,14	0,37	1,0	2,7	7,4	20	56	154

9.2.3 Temperature dependence, factor π_T

The relationship given in Equation (6) applies only up to the maximum permissible component temperature. The constants A, Ea_1 and Ea_2 given in Table 39 are used, unless other values have been stated. The results are shown in Table 40.

Table 39 – Constants for temperature dependence of capacitors

Type of capacitor	A	Ea_1 eV	Ea_2 eV
Paper Metallized paper Metallized polypropylene film Metallized polyethylene terephthalate film Metallized acetyl cellulose film Polyethylene terephthalate film metal foil Polypropylene film metal foil Polystyrene film metal foil Metallized paper film	0,999	0,5	1,59
Polycarbonate film metal foil, Metallized polycarbonate film	0,998	0,57	1,63
Glass, mica	0,86	0,27	0,84
Ceramic	1,0	0,35	–
Deposited capacitors for hybrid circuits	1,0	0,15	–
Aluminium electrolytic, non-solid electrolyte	0,87	0,5	0,95
Aluminium electrolytic, solid electrolyte	0,40	0,14	0
Tantalum electrolytic, non-solid electrolyte	0,35	0,54	0
Tantalum electrolytic, solid electrolyte	0,961	0,27	1,1
Variable	1,0	0,15	–

The factor π_T is obtained from Table 40:

- as a function of the actual capacitor temperature;

$$\theta_{op} = \theta_{amb} + \Delta T \quad \text{in degrees Celsius,} \qquad (24)$$

where ΔT is the temperature change due to operating conditions;

- and as a function of the capacitor temperature under reference conditions (see Table 36);

$$\theta_{ref} = 40\,°\text{C} \qquad (25)$$

Table 40 – Factor π_{T} for capacitors

Type of capacitor	Capacitor temperature under reference conditions θ_{ref} °C	Factor π_{T} for θ_{op} °C[a]													
		≤ 20	30	40	50	60	70	80	85	90	100	105	110	120	125
Paper, Metallized paper, Metallized polypropylene film, Metallized polyethylene terephthalate film, Metallized acetyl cellulose film, Polyethylene terephthalate film metal foil, Polypropylene film metal foil, Polystyrene film metal foil, Metallized paper film	40	0,28	0,54	1,0	1,8	3,1	5,2	9	12	16	33	49	77	210	350
Polycarbonate film metal foil, Metallized polycarbonate film	40	0,24	0,50	1,0	1,9	3,6	6,7	13	18	27	63	100	170	510	900
Glass, mica	40	0,45	0,67	1,0	1,5	2,5	4,2	7,5	10	-	-	-	-	-	-
Ceramic	40	0,41	0,65	1,0	1,5	2,2	3,1	4,4	5,1	6	8,1	9,3	11	14	16
Aluminium electrolytic, non-solid electrolyte	40	0,26	0,51	1,0	1,9	3,7	7,2	14	20	28	55	77	110	210	290
Deposited capacitors for hybrid circuits	40	0,68	0,83	1,0	1,2	1,4	1,6	1,9	2	2,2	2,5	2,6	2,8	3,1	3,3
Aluminium electrolytic, solid electrolyte	40	0,88	0,94	1,0	1,1	1,2	1,2	1,3	1,4	1,4	1,5	1,6	1,6	1,8	1,8
Tantalum electrolytic, non-solid electrolyte	40	0,74	0,83	1,0	1,3	1,8	2,7	4	5	-	-	-	-	-	-
Tantalum electrolytic, solid electrolyte	40	0,49	0,7	1,0	1,45	2,2	3,7	7	10	15	32	49	73	170	250
Variable	40	0,68	0,83	1,0	1,2	1,4	1,6	1,9	2	2,2	2,5	2,6	2,8	3,1	3,3

[a] The relationships given apply up to the rated capacitor temperature only.

10 Resistors and resistor networks

10.1 Specific reference conditions

The recommendations for reference resistor element temperatures given in Table 41 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment. The reference self-heating, ΔT_{ref}, ~~shall~~ should be given when using other reference temperatures.

Table 41 – Resistors and resistor networks

Component	Reference resistor element temperature θ_{ref} °C	~~Note~~ Reference power ratio
Carbon film	55	50 % of rated power at 40 °C $P_{\text{ref}}/P_{\text{rat}} = 0{,}5$
Metal film	55	
Deposited thin film resistors for hybrid circuits	55	
Deposited thick film resistors for hybrid circuits	55	
Networks (film circuits) per resistor element	55	
Metal-oxide	85	
Wire-wound	85	
Variable	55	

10.2 Specific stress ~~factors~~ models

10.2.1 ~~Model~~ General

The failure rate under operating conditions according to Equation (2) is:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} \tag{26}$$

The stress factors for temperature dependence are given in 10.2.2.

10.2.2 Temperature dependence, factor π_{T}

The relationship given in Equation (6) applies only up to the maximum permissible resistor element temperature. The constants A, Ea_1 and Ea_2 given in Table 42 are used, unless other values have been stated. The results are shown in Table 43.

Table 42 – Constants for temperature dependence of resistors

A	Ea_1 eV	Ea_2 eV
0,873	0,16	0,44

The factor π_{T} is obtained from Table 43:

- as a function of the average actual temperature of the resistor element;

  $$\theta_{\text{op}} = \theta_{\text{amb}} + \Delta T \quad \text{in degrees Celsius,} \tag{27}$$

  where ~~$\Delta T = P \times R_{\text{th,amb}} = (\theta_{\text{max}} - 40) \times (P/P_{\text{rat}})$~~, $\Delta T = P_{\text{op}} \times R_{\text{th,amb}} = (\theta_{\text{max}} - 40) \times (P_{\text{op}}/P_{\text{rat}})$ in degrees Celsius, is the temperature change due to operation (with θ_{max} as maximum resistor element temperature);
- and as a function of the average temperature of the resistor element under reference conditions (see Table 41);

  $$\theta_{\text{ref}} = 40 + \Delta T_{\text{ref}} \tag{28}$$

Table 43 – Factor π_T for resistors

Component	θ_{ref} °C (see 10.1)	Factor π_T for θ_{op} °C											
		≤ 25	30	40	50	60	70	80	90	100	110	120	125
Resistors	55	0,49	0,56	0,71	0,89	1,1	1,4	1,8	2,2	2,8	3,6	4,6	5,1
	85	0,25	0,28	0,35	0,45	0,56	0,71	0,89	1,1	1,4	1,8	2,3	2,6

11 Inductors, transformers and coils

11.1 Reference conditions

The recommendations for reference temperatures given in Table 44 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment. The reference self-heating, ΔT_{ref}, ~~shall~~ should be given when using other reference temperatures.

Table 44 – Inductors, transformers and coils

Component		Average reference winding temperature θ_{ref} °C	~~Note~~ Reference power ratio
Inductors for EMC applications	≤ 3A > 3A	60 85	50 % of rated power at 40 °C $P_{ref}/P_{rat} = 0{,}5$
Low frequency inductors and transformers	≤ 25 kHz	55	
High frequency inductors and transformers	> 25 kHz	55	
Mains transformers and transformers for switched-mode power supplies		85	

11.2 Specific stress ~~factors~~ model

11.2.1 ~~Model~~ General

The failure rate under operating conditions according to Equation (2) is:

$$\lambda = \lambda_{ref} \times \pi_T \tag{29}$$

The stress factors for temperature dependence are given in 11.2.2.

11.2.2 Temperature dependence, factor π_T

The relationship given in Equation (6) applies only up to the maximum permissible winding temperature. The constants A, Ea_1 and Ea_2 given in Table 45 are used, unless other values have been stated. The results are shown in Table 46.

Table 45 – Constants for temperature dependence of inductors, transformers and coils

A	Ea_1 eV	Ea_2 eV
0,996	0,06	1,13

The factor π_T is obtained from Table 46:

- as a function of the actual average winding temperature;

$$\theta_{op} = \theta_{amb} + \Delta T \quad \text{in degrees Celsius} \tag{30}$$

where ΔT is the temperature change due to operating conditions;

- and as a function of the average winding temperature under reference conditions (see Table 44);

$$\theta_{ref} = 40 + \Delta T_{ref} \quad \text{in degrees Celsius} \tag{31}$$

where ΔT_{ref} is measured or calculated at $0{,}5 \times P_{rat}$.

Table 46 – Factor π_T for inductors, transformers and coils

Component	θ_{ref} °C (see 11.1)		**Factor π_T for θ_{op} °C**											
		≤ 25	**30**	**40**	**50**	**60**	**70**	**80**	**85**	**90**	**100**	**110**	**120**	**125**
Inductors, transformers, coils	55	0,79	0,82	0,89	0,96	1,1	1,2	1,5	1,9	2,3	4,3	8,8	19	29
	60	0,75	0,78	0,84	0,91	1	1,1	1,5	1,8	2,2	4	8,4	18	27
	85	0,43	0,44	0,48	0,52	0,57	0,66	0,83	1	1,3	2,3	4,8	10	15

12 Microwave devices

12.1 Specific reference conditions

The reference conditions are given in Table 47.

Table 47 – Microwave devices

Component	**Reference component temperature** θ_{ref} °C	**Note**
Microwave elements	40	Temperature and electrical stress have no impact on the failure rates.
Coaxial and wave guides		
Load		
Attenuator fixed		
Attenuator variable		
Fixed elements		
Directional couplers		
Fixed stubs		
Cavities		
Variable elements		
Tuned stubs	40	
Tuned cavities		
Ferrite device (transmitter)		
Ferrite device (receiver)		
RF/microwave passives		
Filter		
Isolator		
Circulator		
Splitter/combiner		
Synthesizer		

12.2 Specific stress ~~factors~~ models

No ~~values~~ models are currently known from experience in applying temperature and electrical stresses.

13 Other passive components

13.1 Specific reference conditions

The reference conditions are given in Table 48.

Table 48 – Other passive components

Component	Reference component temperature θ_{ref} °C	Note
Varistors	40	Temperature and electrical stress have no impact on the failure rates.
PTC thermistors, NTC thermistors		
Surge arresters		
Ceramic resonators		
Filters		
Surface wave filters (SAW), Surface wave oscillators (SAW-oscillators), voltage controlled oscillators (VCO)		
Piezoelectric components (transducers and sensors)		
Crystals		
Crystal oscillators: XO (clock), VCXO (voltage controlled), TCXO (temperature compensated), OCXO (oven controlled)		
Feed-through capacitors, feed-through filters		
Fuses		

13.2 Specific stress ~~factors~~ models

No ~~values~~ models are currently known from experience in applying temperature and electrical stresses.

14 Electrical connections

14.1 Specific reference conditions

The reference conditions are given in Table 49.

Table 49 – Electrical connections

Component	Conductor cross-section mm^2	θ_{ref} °C	~~Note~~ Reference current ratio
Solder (manual, machine)	-	40	50 % of rated current for the connected conductor $I_{ref} / I_{rat} = 0,5$
Wire bond for hybrid circuits (Al, Au)	-		
Wire-wrap	0,05 to 0,5		
Crimp (manual, machine)	0,05 to 300		
Termi-point	0,1 to 0,5		
Press in	0,3 to 2		
Insulation displacement	0,05 to 1		
Screw	0,5 to 16		
Clamp (elastic force)	0,5 to 16		

14.2 Specific stress ~~factors~~ models

No ~~values~~ models are currently known from experience in applying temperature and electrical stresses.

15 Connectors and sockets

15.1 Reference conditions

The reference conditions are given in Table 50.

Table 50 – Connectors and sockets

Component	θ_{ref} °C	Note
Plug-in contacts that ~~shall~~ should be inserted without electrical load (gold or comparably corrosion-resistant, silver, tin, others) NOTE These also include connectors that can be inserted with a limited electrical load according to the data sheet.	40	Operating current within the limits stated in the data sheet
Plug-in contacts that are intended to be inserted under electrical load		
Coaxial plugs		
Time period: Up to the time interval that 90 % of the components survive. Duty cycle: For the electrical stress, the duty cycle is continuously or intermittently in operating state. Plugging frequency: ≤ 1 plugging cycle per 1 000 hours.		

15.2 Specific stress ~~factors~~ models

No ~~values~~ models are currently known from experience in applying temperature and electrical stresses.

16 Relays

16.1 Reference conditions

Information contained in Clause 16 does not cover all today's relays technology.

The reference conditions are given in Table 51.

Table 51 – Relays

Component	Electrical contact stress	θ_{ref} °C	~~Note~~ Reference number of operating cycles per hour
Low duty relays:	$(0{,}5 < U \leq U_{\text{rat}})$ V AC and $(0 < I \leq 0{,}1)$ A by resistive load	40	$\pi_S = 1$
General purpose relays:	$(0 < U \leq 13)$ V and $(0{,}1 < I \leq I_{\text{rat}})$ A by resistive load and AC		
Automotive relays:	$(0 < U \leq 13)$ V and $(0{,}1 < I \leq I_{\text{rat}})$ A by resistive load		
Operating current within the limits stated in the data sheet			
Electrical contact stress (See stress regions in 16.2.3, Figure 2)			
Time period:	Up to the time interval that 90 % of the relays survive.		
Duty cycle:	The duty cycle can be chosen within the limits set by the relay's specification (for coil and contact assembly).		
Operating cycles:	Up to the maximum number of operating cycles specified in the data sheet.		

16.2 Specific stress ~~factors~~ models

16.2.1 ~~Model~~ General

The failure rate under operating conditions is:

$$\lambda = \lambda_{\text{ref}} \times \pi_{ES} \times \pi_S \times \pi_T \tag{32}$$

where

π_{ES} is the electrical stress dependence factor;

π_S is the switching rate dependence factor;

π_T is the temperature dependence factor.

The values of the stress factors are given in 16.2.3 and 16.2.4.

16.2.2 Dependence on switching rate, factor π_S

The factor π_S considers the number of operating cycles per hour, S, according to Equations (7) and (8). Factor π_S is not defined for $S < 0{,}01$.

π_S ~~= 1 for $S \leq 1$~~

π_S ~~= S for $S > 1$~~

a) $\pi_S = 1$ for $0{,}01 \leq S \leq S_{\text{ref}}$ (33)

b) $\pi_S = S / S_{\text{ref}}$ for $S > S_{\text{ref}}$ (34)

where

S is the number of operating cycles per hour;

S_{ref} is the reference number of operating cycles per hour.

NOTE The factor π_S can be as much as 100 for hermetically sealed contacts, normally closed, or non-sealed contacts, normally open under small loads.

16.2.3 Dependence on electrical stress, factor π_{ES}

The factors π_{ES} given in Table 52 to Table 54 are based on the selection of the stress region in Figure 2 and the type of load.

Contacts where surge suppression is used can be treated like contacts under resistive load.

The rated current I_{rat} and the rated switching voltage U_{rat} are obtained from the relay detail specification of the individual relay type.

If different electrical stress conditions are used, a mission profile should be considered (otherwise the higher stress factor should be applied).

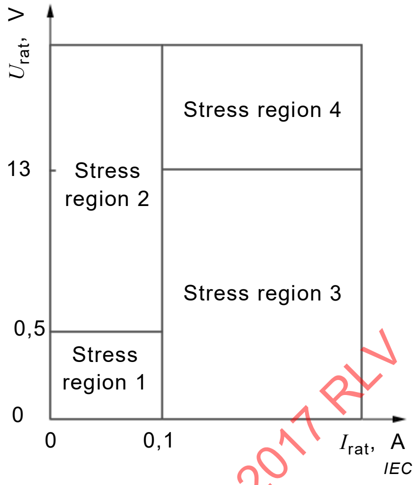


Figure 2 – Selection of stress regions in accordance with current and voltage-operating conditions

Table 52 – Factor π_{ES} for low current relays

Stress region (see Figure 2)	**Factor π_{ES} for:**		
	Resistive load	**Capacitive[a] and incandescent lamp load**	**Inductive load**
1	2	2	–
2	1	8	8
3	2	20	40
4	8	40	–

[a] Maximum current peak (see relay detail specification) not to be exceeded.

Table 53 – Factor π_{ES} for general purpose relays

Stress region (see Figure 2)	**Factor π_{ES} for:**					
	Resistive load		**Capacitive[a] and incandescent lamp load**		**Inductive load**	
	DC	**AC**	**DC**	**AC**	**DC**	**AC**
1 without Au-coating	50	50	2	1	–	–
1 with Au-coating	20	10	2	1	–	–
2	20	10	10	5	10	5
3	2	1	10	5	20	10
4	10	2	10	5	50	20

[a] Maximum current peak (see relay detail specification) not to be exceeded.

Table 54 – Factor π_{ES} for automotive relays

Stress region (see Figure 2)	Factor π_{ES} [a] for: Resistive load	Capacitive[b] and incandescent lamp load	Inductive load
3	1	2 (1)	2 (1)
4	1	2 (1)	5 (1)

[a] Values in parentheses are valid for tungsten pre-contact.

[b] Maximum current peak (see relay detail specification) not to be exceeded.

16.2.4 Temperature dependence, factor π_T

The relationships given in Equations (5) and (6) apply only up to the maximum permissible component temperature. The formula constants A, Ea_1 and Ea_2 given in Table 55 are used, unless other values have been stated.

Table 55 – Constants for temperature dependence of relays

Supporting construction	A	Ea_1 eV	Ea_2 eV
Plastic	1,0	0,175	–
Metal, glass, ceramic	0,006	0,646	0

The calculated factors π_T are shown in Table 56 and are dependent on the ambient temperature, θ_{amb} .

Table 56 – Factor π_T for relays

Supporting construction	Factor π_T for the average ambient temperature θ_{amb} [a]			
	≤ 40 °C	70 °C	100 °C	125 °C
Plastic	1	1,8	2,8	4
Metal, glass, ceramic	1	1	1,3	2

[a] Valid only up to the maximum permissible ambient temperature according to the relay detail specification.

17 Switches and push-buttons

17.1 Specific reference conditions

The reference conditions are given in Table 57.

Table 57 – Switches and push-buttons

Component	Electrical contact stress	θ_{ref} °C	Note
Dip fix and encoding switches:	within the limits of the data sheet	---	Operating current within the limits stated in the data sheet Electrical contact stress (see stress regions in Figure 3)
Switches and push-buttons for light-current applications:	$(0{,}5 < U \leq U_{\text{ref}})$ V AC and $(0{,}1 < I \leq I_{\text{ref}})$ A by resistive load		
Switches and push-buttons for higher load:	$(0{,}5 < U \leq 13)$ V and $(0{,}1 < I \leq I_{\text{ref}})$ A by resistive load		
Time period:	Up to the time interval that 90 % of the switches and push-buttons survive.		
Duty cycle:	The duty cycle can be chosen within the limits set by the specification.		

17.2 Specific stress ~~factors~~ models

17.2.1 ~~Model~~ General

The failure rate under operating conditions is:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{ES}} \tag{35}$$

where π_{ES} is the electrical stress dependence factor. The values of the stress factors are given in 17.2.2.

17.2.2 Dependence on electrical stress, factor π_{ES}

a) for dip fix, coding switches and foil push-buttons:

$\pi_{\text{ES}} = 1$

b) for other switches and push-buttons:

The factors π_{ES} given in Table 58 and Table 59 are based on the selection of the stress region in Figure 3 and the type of load.

The rated current I_{rat} and the rated switching voltage U_{rat} are obtained from the data sheet of the individual switches and push-button types.

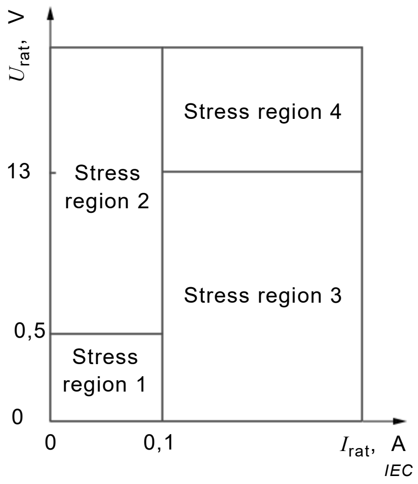


Figure 3 – Selection of stress regions in accordance with current and voltage-operating conditions

Table 58 – Factor π_{ES} for switches and push-buttons for low electrical stress

Stress region (see Figure 3)	**Factor π_{ES} for:**		
	Resistive load	**Capacitive[a] and incandescent lamp load**	**Inductive load**
1	2	2	–
2	1	8	8
3	2	20	40
4	8	40	–

[a] Maximum current peak (see data sheet) not to be exceeded.

Table 59 – Factor π_{ES} for switches and push-buttons for higher electrical stress

Stress region (see Figure 3)	**Factor π_{ES} for:**					
	Resistive load		**Capacitive[a] and incandescent lamp load**		**Inductive load**	
	DC	**AC**	**DC**	**AC**	**DC**	**AC**
1 Without Au-coating	50	50	2	1	–	–
1 With Au-coating	20	10	2	1	–	–
2	20	10	10	5	10	5
3	2	1	10	5	20	10
4	10	2	10	5	50	20

[a] Maximum current peak (see data sheet) not to be exceeded.

18 Signal and pilot lamps

18.1 Specific reference conditions

The reference conditions are given in Table 60.

Table 60 – Signal and pilot lamps

Component	**Ambient temperature** θ_{ref} °C	**Note**
Incandescent lamps	40	Rated voltage according to specifications
Glow lamps		
Time period: Up to the time interval that 93,5 % of the lamps survive. Duty cycle: The duty cycle is continuously in operating state; for intermittent operation the operating time is the sum of the periods alight.		

18.2 Specific stress ~~factors~~ models

18.2.1 ~~Model~~ General

The failure rate under operating conditions, as a function of the operating voltage, is calculated according to Equation (2) as follows:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \qquad (36)$$

18.2.2 Voltage dependence, factor π_U

The stress factor π_U for voltage dependence is given in Table 61.

Table 61 – Factor π_U for signal and pilot lamps

Type of lamp		**Factor π_U for U_{op}/U_{rat}**										
		≤ 0,70	**0,80**	**0,85**	**0,90**	**0,95**	**1,0**	**1,05**	**1,1**	**1,15**	**1,2**	**1,30**
Incandescent lamps	Signal and pilot lamps; railway-signalling lamps; low voltage traffic-light lamps	0,02	0,10	0,20	0,30	0,60	1,0	1,70	3,0	4,50	7,0	17,0
	Halogen lamps	–	–	–	–	0,60	1,0	1,7	3,0	–	–	–
	High voltage traffic-light lamps	–	–	–	–	0,60	1,0	2,0	4,0	–	–	–
Glow lamps	(with necessary series resistance)	–	–	–	0,5	0,7	1	1,3	1,6	2,0	–	–

NOTE 1 The failure rate, irrespective of construction and stress, may be higher for DC operation, higher ambient temperature, stress due to mechanical impact and electrical surges, or non-standard switching profiles.

NOTE 2 Consult the manufacturer for additional information.

19 Printed circuit boards (PCB)

Failures of PCBs should be taken into account in the stated failure rate for machine-soldered connections (see 14.1).

20 Hybrid circuits

A hybrid integrated circuit, hybrid microcircuit, or simply hybrid, is a miniaturized electronic circuit manufactured of individual devices, such as semiconductor devices (transistors and diodes) and passive components (resistors, inductors, transformers, and capacitors), bonded to a substrate or printed circuit board. A hybrid circuit is a circuit where two or more technologies are combined (SMD, ASIC and flexible circuit technology). Hybrid circuits have gradually become synonymous with circuits, where one of the methods used is thick film technology, whereby tracks and resistors are printed on a ceramic substrate.

A hybrid circuit is not considered a component in this document, in agreement with what is declared in its introduction and scope. In fact a hybrid is to be considered an assembly, also if miniaturized, but not an electric component.

Deposited capacitors and thick or thin film resistors are considered in the specific component clauses.

Annex A
(normative)

Failure modes of components

The failure mode is a description of what constitutes failure for a particular component type. There are generally three types of failure – complete, partial or degraded and drift – however most data handbooks do not make this distinction, giving a total failure rate of a component that represents failure in all modes.

However information on failure modes is useful since it is the rate of occurrence of failure modes that is observed. This information is also a useful input into reliability analysis, such as diagnostics coverage, and in safety analysis in order to calculate criticality of systems.

Annex A contains details on ~~summary~~ failure modes that are useful for this purpose. These ~~summary~~ modes are higher level, usually as perceived at circuit level, than the actual physical modes that they represent and will often include within them a number of lower level modes.

The data presented herein has been derived from a number of sources such as those listed in Annex H and in IEC TR 62380. The tables give a means of allocating estimated failure rate to specific failure modes when given a specific value for total failure rate.

For prediction purposes, component failure modes can be found in Table A.1 to Table A.7.

Table A.1 – Failure modes: ICs (digital)

~~Component~~	~~Input/output fixed to 0~~ ~~%~~	~~Input/output fixed to 1~~ ~~%~~
~~ICs (digital)~~	~~50~~	~~50~~

Environment type	Input/output fixed to 1 Stuck at U_{cc} %	Input/output fixed to 0 Stuck at ground %	Open circuit %
Stationary use at weather-protected locations E1[a]	50	50	-
Stationary use at partially weather-protected or non-weather-protected locations E2[a] Portable and non-stationary use, ground vehicle installation E3[a]	5	5	90

NOTE For digital ICs the signal pins can be defined as inputs or outputs. When a failure occurs, for each input or output pin, there are three chances:

- the (internal) failure caused the signal to be fixed at the logical level=1;
- the (internal) failure caused the signal to be fixed at logical level=0;
- the pin is no more internally connected.

The logical level=1, in terms of voltage, is usually the value of U_{cc} (positive supply voltage), while the logical level=0 is usually ground (U = 0).

Sometimes there are different voltages, hence it is more appropriate to speak in terms of stuck-at-1 or stuck-at-0 for the fixed signal at the failed pin.

For interface circuits, almost all defects are open circuits.

[a] See Table 1.

Table A.2 – Failure modes: transistors, diodes, optocouplers

~~Component~~		Short circuit %	Open circuit %	Drift %	Forward leakage current drift %
Transistors	Silicon	85	15		-
	GaAs	95	5		-
Diodes	Silicon	~~85~~ 80	~~15~~ 20		-
	GaAs	95	5		-
Zener diodes		70	20	10	
Thyristors		20	20		60
Optocouplers		10	50	40	-
Laser diodes		85	15	-	-

Table A.3 – Failure modes: LEDs

	Short circuit (forward degradation) %	Open circuit %	Optical coupling, or fibre %
Light emitting diode modules package type: with window	70	10	20
Light emitting diode modules package type: with fibre	40	10	50

Table A.4 – Failure modes: laser diodes and modules

	Diode failure %	Coupling failure %	Broken fibre %
Laser diodes modules 1,3 µm/1,55 µm modules	(degradation of the spectrum, current increase) 10	(high drop in output power) 90	-
Pump laser modules (0,98 µm 1,48 µm)	(high current increase) 90	(high drop in output power) 10	-
Modules (transmission) 0,85 µm modules (monomode fibre 9/125)	(no laser effect, degradation of the spectrum, current increase) 80	(high drop in output power) 10	(no output power) 10
Compact disks 0,85 µm modules (monomode fibre 9/125)	(no laser effect, degradation of the spectrum, current increase) 100	-	-

Table A.5 – Failure modes: photodiodes and receiver modules

	Short circuit (reverse degradation) %	Open circuit %	Coupling %
Photodiodes and receiver modules for telecommunications package type: with window	80	20	-
Photodiodes and receiver modules for telecommunications package type: with fibre	40	10	50

Table A.6 – Failure modes: capacitors

~~Component~~			Short circuit %	Open circuit %	Drift %
Ceramic	NPO-COG Fixed ceramic dielectric capacitors – Defined temperature coefficient – Class I		70	10	20
	X7R-X5R		90	10	-
	5ZU-Y5V-Y4T		90	10	-
	Feedthrough capacitors		70	30	-
Aluminium electrolytic	non-solid electrolyte	nominal voltage < 350 V	30	30	40
		nominal voltage > 350 V	50	-	50
	solid electrolyte		10	90	-
Tantalum electrolytic	non-solid electrolyte		80	20	-
	solid electrolyte		80	20	-
Metallized film			10	90	-
Mica			40	40	20
Variable ceramic capacitors, disks (dielectric ceramic)			40	10	50
Other technologies			10	90	-
Fixed plastic, paper, dielectric capacitors – Radio interference suppression capacitors (plastic, paper)			10	90	-
Thermistors with negative temperature coefficient (NTC)			70	10	20

Table A.7 – Failure modes: Resistors, inductive devices, relays

~~Component~~		Open circuit %	Short circuit %	Drift %
Resistors	Carbon film	100	-	-
	Metal film	40	-	60
	High dissipation film resistors	100	0	
	Wire-wound	100	-	-
	Variable (non wirewound cermet potentiometer)	80	-	20
	Resistors network (surface mounting resistors and resistive array)	40	-	60
Inductive devices		80	20	-
Relays	General purpose	80	20	-
	Power relays	80	20	-
	~~Mercury relays~~	~~50~~	~~50~~	
	Solid state relays	80	20	-
	Coaxial relays	80	20	-

Annex B
(informative)

Thermal model for semiconductors

B.1 Thermal model

This document defines the equipment ambient temperature θ_a as the average temperature around the equipment. According to IEC TR 60943 it is the air surrounding the complete device and, for devices installed inside an enclosure, it is the temperature of the air outside the enclosure.

Inside the equipment/system, there is a temperature distribution that depends on the position of the parts that dissipate power. Even if each unit in the equipment has its own temperature distribution (depending on the type of component and its position), a component ambient temperature θ_{ac} is conventionally defined, that is constant for all components in the unit, obtained by averaging the temperatures near each component. This hypothesis is generally valid for electronic units, although sometimes those that dissipate a lot of power in a single point should be excluded, in fact when a unit has areas with temperatures significantly different from θ_{ac}, for thermal modelling purposes they should be considered as two separate units.

More precisely, the component ambient temperature θ_{ac} is the temperature that would be found at the point where the component is installed supposing it could be removed (with or without heat sink). This is equivalent to supposing that there are no components that by themselves significantly influence the ambient temperature for nearby components. In other words, it is as if between each component and the others there would be a zone of separation that has a temperature equal to the component ambient temperature, that is a characteristic of the whole unit (see Figure B.1).

Situations that do not correspond to this hypothesis are handled by considering separately the parts of the unit as if they were thermally separate units, each with its own value of θ_{ac}.

Each unit inside the equipment therefore has its own thermal difference ($\Delta\theta_{a-ac}$) between the equipment ambient temperature and the component ambient temperature. This difference is assumed to be constant for each value of θ_a throughout the whole range of the latter in the range of temperatures considered normal for electric equipment, and depending on the power dissipated by the entire unit.

For all components of a unit:

$$\theta_{ac} = \theta_a + \Delta\theta_{a-ac} \qquad \text{(B.1)}$$

where

θ_{ac} is the component ambient temperature (°C);

θ_a is the equipment ambient temperature (°C);

$\Delta\theta_{a-ac}$ is the difference between the equipment and component ambient temperatures (K).

In order to define or calculate the failure rate of the components, the component temperature also has to be evaluated:

$$\theta_j = \theta_{ac} + \Delta\theta_{ac-j} \qquad \text{(B.2)}$$

junction temperature, for integrated circuits and semiconductors

$\theta_{\mathrm{c}} = \theta_{\mathrm{ac}} + \Delta\theta_{\mathrm{ac-c}}$ body temperature, for passive components subjected to dissipation (B.3)

In conclusion, the general thermal model can be summarized as:

$$\Delta\theta_{\mathrm{ac-c}} = P \times R_{\mathrm{th,\,ac-j}} \tag{B.4}$$

$$\Delta\theta_{\mathrm{ac-c}} = P \times R_{\mathrm{th,\,ac-c}} \tag{B.5}$$

where

P is the component power dissipation;

$R_{\mathrm{th,\,ac-j}}$ is the thermal resistance between component ambient temperature and junction temperature;

$R_{\mathrm{th,ac-c}}$ is the thermal resistance between component ambient temperature and body temperature.

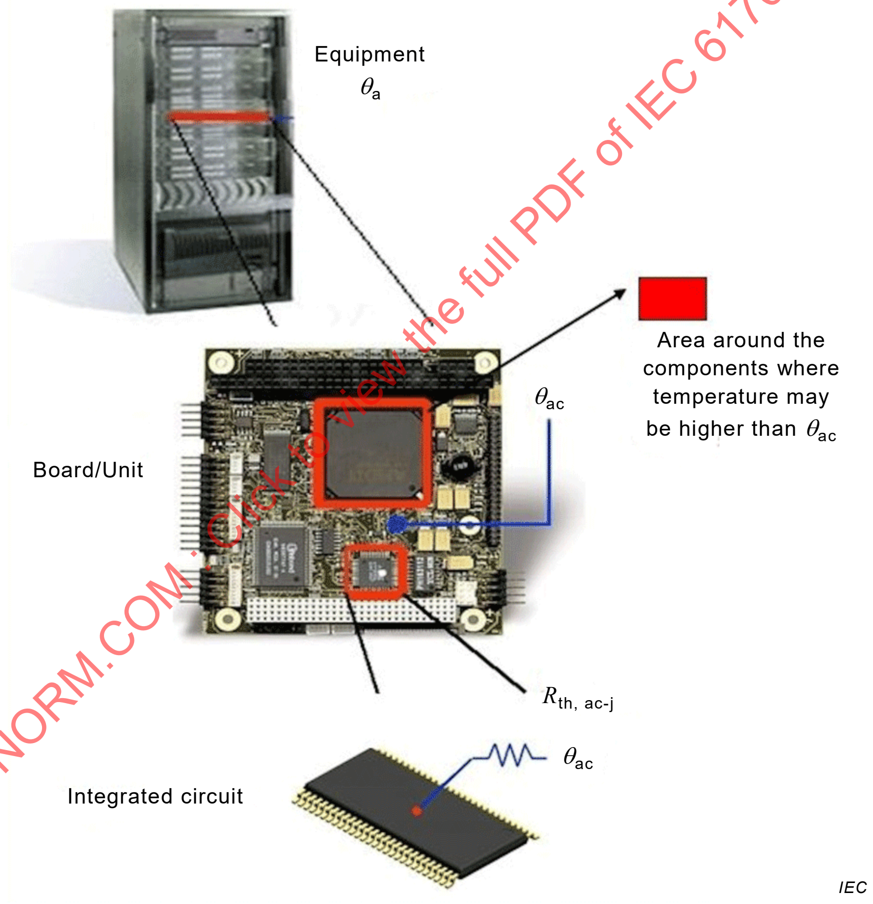


Figure B.1 – Temperatures inside equipment

B.2 Junction temperature calculation

When it is not possible to obtain the junction temperature value using the appropriate tools of the experimental thermal analysis the junction temperature value can be calculated as a function of the mean power dissipation P and of the device thermal resistance.

The simplified equation proposed here is sufficiently accurate for reliability calculations:

$$\theta_j = \theta_{\mathrm{ac}} + P \times R_{\mathrm{th,\,ac-j}} \tag{B.6}$$

$$\theta_{\mathrm{j}} = \theta_{\mathrm{case}} + P \times R_{\mathrm{th,\,c\text{-}j}} \tag{B.7}$$

where

θ_{j}	is the junction temperature (°C);
θ_{ac}	is the component ambient temperature (°C);
θ_{case}	is the case temperature (°C);
P	is the component power dissipation (W);
$R_{\mathrm{th,\,ac-j}}$	is the thermal resistance component ambient-junction (°C/W);
$R_{\mathrm{th,c-j}}$	is the junction-case thermal resistance (°C/W).

B.3 Thermal resistance evaluation

The preferred method is to take the thermal resistance value specified or published by the manufacturers (see Figure B.2).

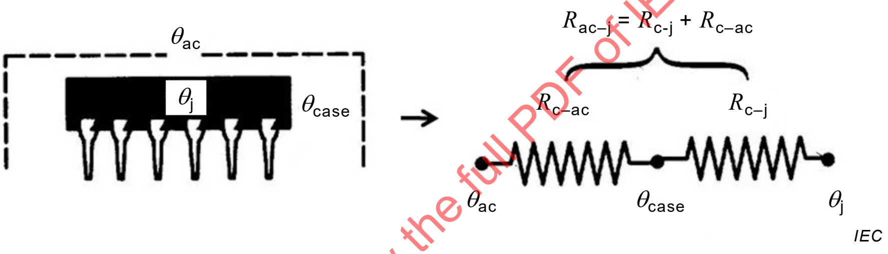


Figure B.2 – Thermal resistance model

If the device thermal resistance values are not directly available (measurements, manufacturer data), they can be calculated as a function of the package type, the pin number and the airflow factor.

Table B.1 – Thermal resistance as a function of package type, pin number and airflow factor

	$R_{\text{th, c-j}}$ °C/W	$R_{\text{th, ac-j}}$ °C/W
DIL package ceramic	$0{,}23\left(10+\frac{1520}{N+3}\right)$	$(0{,}23+0{,}66K)\left(10+\frac{1520}{N+3}\right)$
DIL package plastic	$0{,}33\left(10+\frac{1520}{N+3}\right)$	$(0{,}33+0{,}66K)\left(10+\frac{1520}{N+3}\right)$
PLCC package plastic	$0{,}28\left(15+\frac{1600}{N+3}\right)$	$(0{,}28+0{,}72K)\left(15+\frac{1600}{N+3}\right)$
SOJ and SOL package plastic	$0{,}28\left(15+\frac{1760}{N+3}\right)$	$(0{,}28+0{,}72K)\left(15+\frac{1760}{N+3}\right)$
PGA package ceramic	$0{,}33\left(10+\frac{1440}{N+3}\right)$	$(0{,}33+0{,}66K)\left(10+\frac{1440}{N+3}\right)$
QFP package plastic	$0{,}4\left(27+\frac{2260}{N+3}\right)$	$(0{,}4+0{,}6K)\left(27+\frac{2260}{N+3}\right)$
BGA package plastic	$0{,}4\left(6{,}6+\frac{1{,}1\times 10^6}{N^2}\right)$	$(0{,}4+0{,}6K)\left(6{,}6+\frac{1{,}1\times 10^6}{N^2}\right)$

where

N is the number of pins of the package;

K is the airflow factor given, according to the air velocity v in m/s, by the following equation

$$K=\frac{0{,}59\times v+1{,}11}{v+0{,}7} \qquad \text{(B.8)}$$

where v is the air velocity in m/s. Typical values of v and K are given in Table B.2.

Table B.2 – Typical values of v are K

	v m/s	K
Natural convection	0,15	1,4
Slightly assisted cooling	0,5	1,2
Fan assisted cooling	1	1
Forced cooling	4	0,7

B.4 Power dissipation of an integrated circuit *P*

The power dissipation of an integrated circuit (where experimental values are not available) can be calculated considering its composing elements:

- a constant part from the direct current supply (P_{DC});
- a frequency dependent part (P_{f});
- duty cycle, for device with standby mode (P_{stby}).

P_{DC} and P_{f} calculation can be performed using Table B.3:

Table B.3 – Values of P_{DC} and P_{f}

Type		P_{DC} W	P_{f} W
MOS, Bipolar, ECL, GaAs		$U_{\mathrm{cc\ Nom}}\, I_{\mathrm{cc\ Max}}$	0
CMOS	ACT	$1{,}6\ 10^{-3}\ U_{\mathrm{cc\ Nom}}\, N_1$	$U_{\mathrm{cc}}^{\ 2}\, f_{\mathrm{op}} 10^{-6}\, (C_{\mathrm{pd}} N_2 + C_{\mathrm{L}} N_3)$
	other	$U_{\mathrm{cc\ Nom}}\, I_{\mathrm{cc\ Max}}$ [a]	$U_{\mathrm{cc}}^{\ 2}\, f_{\mathrm{op}} 10^{-6}\, (C_{\mathrm{pd}} N_2 + C_{\mathrm{L}} N_3)$
	memories	$U_{\mathrm{cc\ Nom}}\, I_{\mathrm{cc\ Max}}$	0
BICMOS		$U_{\mathrm{cc\ Nom}}\, I_{\mathrm{cc\ Max}}$	$U_{\mathrm{cc}}^{\ 2}\, f_{\mathrm{op}} 10^{-6}\, (C_{\mathrm{pd}} N_2 + C_{\mathrm{L}} N_3)$

[a] Normally $P_{\mathrm{f}} = 0$

where

$U_{\mathrm{cc\ Nom}}$ is the nominal voltage (V)
(default value $U_{\mathrm{cc\ Nom}}$ = 3 V, for BICMOS $U_{\mathrm{cc\ Nom}}$ = 1 V to 1,8 V);

$I_{\mathrm{cc\ Max}}$ is the maximum supply current (A);

f_{op} is the operation frequency (MHz);

C_{L} is the load capacitance (default value C_{L} = 50 pF);

C_{pd} is the power dissipation capacitance (pF);

N_1 is the number of inputs;

N_2 is the number of function elements;

N_3 is the number of outputs.

If a linear device has more than one current supply, P_{DC} is calculated separately for every supply and the values are summed.

The sum of P_{DC} and P_{f}, calculated in the conditions defined above, identifies the power dissipation in the worst case P_{WC} and it is a value representative of the values dispersion of different manufacturers and of different production lots.

For semi-custom integrated circuits (gate arrays and cell based), the power dissipation calculation is complex because the knowledge of the device internal composition is required, in relation to its use (registers, flip-flop and latches number).

The calculation has to be extended considering every case and it is convenient for these devices to define the maximum worst case power P_{fWC} as that one related to the maximum admitted operating frequency.

The worst case power value at the operating frequency is given by

$$P_{WC} = \frac{P_{fWC} f_{op} + P_{DC}(f_{max} - f_{op})}{f_{max}} \tag{B.9}$$

where

P_{fWC}	is the worst case power dissipation at the maximum frequency (W);
P_{DC}	is the DC power dissipation (W);
f_{op}	is the operating frequency (MHz);
f_{max}	is the maximum operating frequency (MHz);

f_{max} = 30 MHz (HC, HCT), f_{max} = 50 MHz (AC, ACT), f_{max} = 100 MHz (BICMOS).

A conventional value of the power dissipation P_{op} to be used in the junction temperature calculation is:

$$P_{op} = P_{WC} \frac{(P_{DC} + 3{,}5)}{3 \cdot P_{WC} + 5} \tag{B.10}$$

For devices with a standby mode, particularly memories, the power dissipation P_{av} is calculated considering the duty cycle:

$$P_{av} = P_{op} \frac{D}{100} + P_{stby} \frac{(100 - D)}{100} \tag{B.11}$$

where

P_{stby}	is the standby power dissipation (W);
D	is the duty cycle (%).

Annex C
(informative)

Failure rate prediction

C.1 General

Reliability predictions are conducted during the whole life cycle of equipment at various levels and degrees of detail, in order to evaluate, determine and improve the dependability of the equipment.

Successful reliability prediction of equipment generally requires a model that considers the structure of the equipment. The level of detail in that model will depend on the information available at the time (e.g. parts list, circuit diagram), and several reliability models are available depending on the problem (e.g. reliability block diagrams, fault tree analysis, state-space methods).

During the conceptual and early design phase, failure rate prediction is applicable to estimate equipment failure rate in order to check if reliability targets may be achieved and to help make decisions about the architecture for the product (e.g. use of redundancy, cooling).

Reliability prediction calculations should begin as early as possible, at the start of the equipment design phase, even if not all the applicable conditions can yet be known: in this case default values can be used provisionally, to help determine those conditions which are as yet unknown. These default values will then gradually be updated as the definitive conditions are identified.

This method is far preferable to the simplified calculation method (for which all the values are replaced by default values, including those, which are already known). The calculations should therefore be prepared in such a way as to enable values to be modified easily.

The procedures in this document can be used to carry out failure rate prediction at reference and operating conditions ~~(parts count and parts stress method)~~ (prediction at reference conditions is also known as part count prediction which assumes an average stress on all components, while prediction at operating conditions, also known as part stress method takes the individual load on each component into account. The part count method is usually used in the early phase of the design, while part stress prediction is used later when the detailed design has been made. For part count prediction see C.2.4.2 and for part stress see C.2.4.3.).

C.2 Failure rate prediction for assemblies

C.2.1 General

Failure rate prediction is usually performed at assembly level. Predictions are useful for several important activities in the life cycle of equipment where they are used, in addition to many other important procedures, to ~~assure~~ ensure reliability goals.

Examples of such activities:

- assess whether reliability goals can be reached;
- identify and mitigate potential design weaknesses;
- compare alternative designs;
- evaluate designs;
- provide input data for higher level assembly dependability analysis;
- conduct cost calculations (e.g. life-cycle costs);

- establish objectives for reliability tests;
- plan logistic support strategies (e.g. spare parts and resources).

Failure rate prediction is often used in combination with other tools which can be used to improve the process of prediction by making it more representative of reality by allowing assembly structure and measures of importance to be introduced.

Failure rates to be used for spare parts provisioning and life-cycle costs calculation require particular attention. For these activities, failure rates should include all causes, even design errors, equipment and dependent (pattern) failures, to provide a realistic figure of what is happening or will happen in field during the operation phase of the life cycle. See also Annex F (database).

C.2.2 Assumptions and limitations

Failure rate predictions are based on the following assumptions, resulting from focussing on physical failures occurring at random over time.

Assumptions of failure rate predictions are as follows:

- the prediction model assumes that a failure of any component will lead to a failure of the assembly~~. Component failure rates needed for the prediction are assumed to be constant for the time period considered.~~;
- component failures are treated as independent of each other; no distinction is made between complete, partial and drift failures;
- components are used within their specifications;
- design and manufacturing processes of the components and assembly under consideration are under control;
- failure rates are assumed to be constant either for an unlimited period of operation (general case) or for a given limited period of interest (e.g. useful life). Although this is known to be realistic for some components for ~~the majority~~ others it is not. However the assumption greatly simplifies the task;
- apart from a few exceptions the wear-out failure period is never reached by electric components; in the same way it is accepted, again apart from some exceptions, that the added risks of failure during the first few months of operation can be disregarded.

Limitations of failure rate predictions are as follows:

- they cannot provide proof that a reliability goal has been achieved;
- due to the statistical nature of the information available, prediction works best for large component and assembly counts;
- results are dependent on the trustworthiness of the source data;
- the assumption of constant component failure rates may not always be true; in such cases this method may lead to incorrect results and other models may need to be used to determine ~~end-of~~ useful life ~~or life expectancy~~;
- failure rate data ~~books~~ and stress models may not exist for new component types;
- stresses that are not considered may predominate and influence the failure rate.

C.2.3 Process for failure rate prediction

The process for reliability prediction using failure rates consists of the following steps:

a) Define and understand the assembly to be analysed:
  - obtain information on structure, such as functional and reliability block diagrams, if available, in order to check if series assumption is valid;
  - obtain bill of materials ~~or part lists~~;

  - obtain component specifications or data sheets for all components used in cases where parts stress analysis is to be carried out;
  - obtain circuit diagrams and schematic diagrams if needed;
  - define the boundaries from the assembly specifications and schematic diagrams;
  - identify the functions and specification of the assembly, in particular understanding what a failure is.

b) When carrying out failure rate prediction at operating conditions, obtain information on operating conditions for each component when different from stated reference conditions:

  - identify the operating temperatures;
  - determine the actual electrical stresses;
  - determine ~~operating~~ mission profiles if necessary;
  - identify relevant environmental stresses;
  - select the data source according to the guidance given in Annex H;
  - use the stress models as defined in 5.2;
  - sum up the component failure rates.

c) Document the results, justification for choices and any assumptions made:

  - no guidance on presentation of results is given since many organizations define their own report structure or use those predefined in commercial software;
  - the justification process for the data sources and methods used should be documented;
  - any assumptions made should be listed so that the validity of the prediction can be assessed.

C.2.4 Prediction models

C.2.4.1 General

The failure rate of the assembly is calculated by summing up the failure rates of each component in each category. This applies under the assumption that a failure of any component is assumed to lead to equipment failure otherwise known as a chain or series configuration.

The following models assume that the component failure rate under reference or operating conditions is constant. Justification for use of a constant failure rate assumption should be given. This may take the form of analyses of likely failure mechanisms, related failure distributions, etc.

C.2.4.2 Failure rate prediction at reference conditions ~~(Parts count)~~

Prediction at reference conditions (also called part count prediction) allows a prediction at a very early stage in the design process and is therefore very useful for feasibility studies, comparing design options and prioritizing analytic activities. Further it allows regulatory authorities to evaluate a design for example for a SIL level (see IEC 61508) without detailed knowledge of the design.

If the time to failure is exponentially distributed over the considered time interval then the failure rate for ~~equipment~~ an assembly in a series configuration under reference conditions is calculated as follows:

$$\lambda_{\mathrm{S,ref}} = \sum_{i=1}^{n} (\lambda_{\mathrm{ref}})_i \tag{C.1}$$

where

$\lambda_{\mathrm{S,ref}}$ is the failure rate of an assembly under reference conditions;

λ_{ref} is the component failure rate under reference conditions;

n is the number of components.

The reference conditions adopted are typical for the majority of applications of components in equipment. It is assumed that the failure rate used under reference conditions is specific to the component, i.e. it includes the effects of complexity, technology of the casing, different manufacturers and the manufacturing process, etc.

C.2.4.3 Failure rate prediction at operating conditions ~~(Parts stress analysis)~~

Components may not always operate under the reference conditions. In such cases, the real operational conditions will result in failure rates different from those given for reference conditions (also called part stress prediction). Therefore, models for stress factors, by which failure rates under reference conditions can be converted to values applying for operating conditions (actual ambient temperature and actual electrical stress on the components), and vice versa, may be needed.

The failure rate for assemblies under operating conditions is calculated as follows:

$$\lambda_{\mathrm{S}} = \sum_{i=1}^{n} (\lambda)_i = \sum_{i=1}^{n} (\lambda_{\mathrm{ref}} \times \pi_{\mathrm{U}} \times \pi_{\mathrm{I}} \times \pi_{\mathrm{T}} \times \pi_{\mathrm{E}} \times \pi_{\mathrm{S}} \times \pi_{\mathrm{ES}})_i \tag{C.2}$$

where

λ_{ref} is the component failure rate under reference conditions;

π_{U} is the voltage dependence factor;

π_{I} is the current dependence factor;

π_{T} is the temperature dependence factor;

π_{E} is the environmental application factor;

π_{S} is the switching rate dependence factor;

π_{ES} is the electrical stress dependence factor;

n is the number of components.

In Clauses 6 to 20 specific stress models and values for component categories are given for the π-factors and should be used for converting reference failure rates to field operational failure rates. However, if more specific models are applicable for particular component types then these models should be used and their usage justified and documented.

Conversion of failure rates is only possible within the specified functional limits of the components.

~~B.2.5 Consideration of operating profiles~~

~~B.2.5.1 General~~

~~The duration of stress (sum of rated operating times, and non-operating times) can affect the failure rate. A (maximum) time period of stress over which failure rate was observed should~~

~~therefore always be included in a failure rate specification. This is the time in which the given constant failure rate can be expected to occur.~~

~~Mechanical stresses of components higher than those permitted by the component specification should be avoided by the appropriate equipment design. If higher stresses cannot be avoided, they should be taken into account when performing the equipment reliability prediction.~~

~~B.2.5.2 Operating profile for components~~

~~Components are sometimes not continuously stressed during the operating time of equipment. There can be breaks with no electrical stress during operating periods of the assembly. This can be taken into account by the stress factor for operating profile,~~ π_{op} ~~. The failure rate for intermittent operation is then obtained using Equation (B.3):~~

$$\lambda_{\text{op}} = \lambda \times \pi_{\text{op}} \qquad \text{~~(B.3)~~}$$

~~with~~

$$\pi_{\text{op}} = W + \rho \times (1 - W) \qquad \text{~~(B.4)~~}$$

~~where~~

~~λ is the failure rate for the specific component:~~

- ~~for failure rate predictions at reference conditions,~~ ~~$\lambda = \lambda_{\text{ref}}$;~~
- ~~for failure rate predictions at operating conditions, the failure rate according to the equations stated in Clause 6 based on Equation (2).~~

π_{op} ~~is the stress factor for operating profile;~~

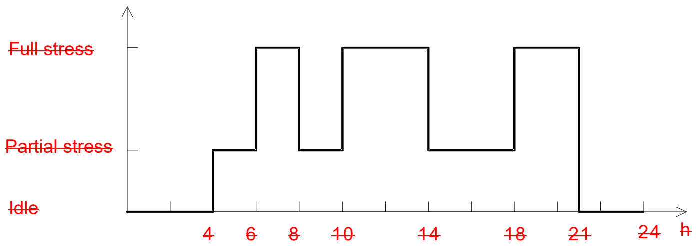
~~W is the ratio of operating time of component with stress to operating time of equipment,~~ $0 \le W \le 1$~~;~~

~~ρ is a constant. This is the proportion of components that fail with no electrical stress applied and this takes into account that even non-stressed components may fail,~~ $0 \le \rho \le 1$~~; a typical assumption is~~ $\rho = 0{,}1$ ~~when no values are known from experience.~~

~~B.2.5.3 Operating profile for assemblies~~

~~The failure rate depends on the stress. For example, if an assembly is in operation 24 h a day then it will, on average, fail more often in one year as the same assembly that is only in operation 12 h a day, assuming that the operating conditions are similar. A failure rate prediction can also consider different stress levels. By consideration of stress duration and stress levels, the difference between predicted failure rates and the observed failure rates can be kept low.~~

~~The actual stresses occurring with alternating stress levels can be combined to one stress profile. A stress profile states the actual duration of stress levels during a defined calendar time, e.g. one day. Figure B.1 shows a possible stress profile over one day.~~



~~IEC 1371/11~~

~~**Figure B.1 – Stress profile**~~

~~The failure rate for alternating stress, λ_{as}, as shown in Figure B.2 is the weighted average of the failure rates under different stress levels.~~

$$\lambda_{as} = \frac{1}{t_f + t_p + t_i}\left(t_f\lambda_f + t_p\lambda_p + t_i\lambda_i\right) \qquad \text{(B.5)}$$

~~where~~

t_f ~~is the fraction of time with full stress;~~

t_p ~~is the fraction of time with part stress;~~

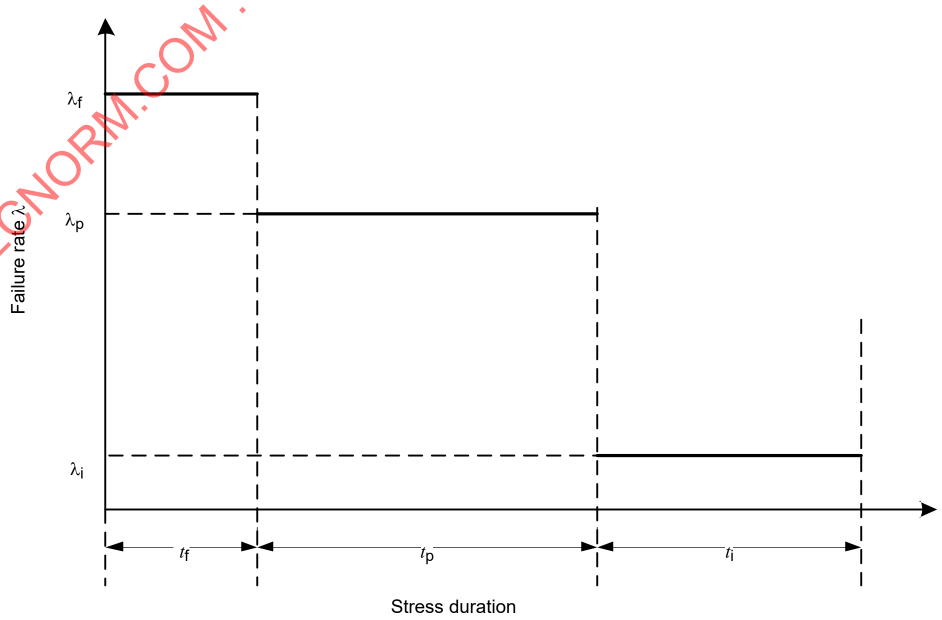
t_i ~~is the fraction of time at idle;~~

λ_f ~~is the failure rate at full stress for the assembly;~~

λ_p ~~is the failure rate at part stress for the assembly;~~

λ_i ~~is the failure rate during time at idle for the assembly.~~

~~The failure rate during idle time will be assumed to be~~ $\lambda_i = 0{,}1 \times \lambda_f$ ~~, if no other information is available.~~



~~IEC 1372/11~~

~~**Figure B.2 – Averaging failure rates**~~

C.2.5 Other methods of reliability prediction

C.2.5.1 Similarity analysis

Similarity analysis includes the use of in-service equipment performance data to compare newly designed equipment with predecessor equipment for predicting end item reliability when the uses and stresses are similar. The method of similarity analysis is described in IEC 62308.

C.2.5.2 Simulation

Simulation is an empirical approach to equipment modelling that can allow the building of real-world models and attempt to use them to predict what is likely to happen to equipment in the future. The underlying techniques used in this process involve random sampling from failure distributions, and representation of equipment structure using such techniques as mathematical models, reaction kinetics models and empirical models. These techniques allow the building of fairly realistic models of complex equipment that can be used to understand their failure behaviour under various operating conditions and predict what the reliability will be at some future time.

C.2.5.3 Testing

Failure rate data can also be obtained from tests. It can be from testing of equipment or components. Normally testing of equipment is carried out by the equipment manufacturer while testing of components is usually carried out by the component manufacturer.

The test conditions will seldom be the same as the reference conditions; often the test will be accelerated, i.e. with increased stresses compared to the reference conditions. In these cases the failure rate information has to be transformed to reference conditions using the equations given in Clauses 6 to 20. The failure rate should be estimated based on statistical models such as, for example, the exponential distribution, the Weibull distribution, the normal distribution or the lognormal distribution.

In many cases no failures will occur during the test~~, in that case~~ and the manufacturer will then often state the failure rate as 60 % upper confidence limit. ~~However to compare this data with data from the field which is often stated as 50 % upper confidence limit, the test data will have to be transformed to 50 % upper confidence limit.~~ When comparing test data (or field data) coming from different samples a guide can be found in IEC 60300-3-5 and IEC 61710.

When reporting failure rates based on test, the test conditions should be listed together with the statistical estimation of the failure rates and any transformation from test conditions to reference conditions. The empirical factors used for this transformation should be justified.

Care should be taken that the stress in an accelerated test does not introduce failure modes that are not relevant for the use of the component.

C.2.5.4 Physics of failure

Physics of failure (PoF) is an approach to reliability prediction modelling where the goal is to use physical principles with appropriate failure probability density distributions to design for failure-free operation and/or specify reliability targets and to predict failure times for components. It uses knowledge of root-cause failure processes in an attempt to identify the "weakest link" of a design to ensure that the planned equipment life is exceeded by the design. The approach can also be used for new components made from new materials, technologies and processes if basic physical and stress information is available. This methodology addresses the useful life of a product (see Annex F).

C.2.6 Validity considerations of reliability models and predictions

To use any quantitative reliability prediction method it is necessary to be aware of its validity. Like all engineering models, the failure rate models are approximations of reality, and are based on the best field data that could be obtained for a wide variety of parts and equipment. This data is then analysed and adapted, with many simplifying assumptions, to create usable models. Then when a model is used, further assumptions for the design parameters such as stress and temperature are made.

Thus a reliability prediction for equipment should not be treated as an absolute value for its field failure rate. It is generally agreed that these predictions can be good when used for relative comparisons, such as comparing design alternatives, or comparing equipment. Note also that reliability predictions do not account for unsuitable design decisions, substandard quality control for purchased parts, bad workmanship, poor product level quality control, overstressed field operation, etc.

Arguments for the reliability models and predictions, as given in this document, are as follows:

- often reliance is placed on failure rate data gathered from a variety of sources representing average conditions, however the accuracy and validity of such data may be questionable;
- for new technology components, failure rate data may not be available for all components as even the most recently published data is inevitably out of date;
- while the failure rate models given may indicate that a low failure rate can be achieved through a reduction in a single stress, in practice other stresses may predominate and render single stress reductions alone ineffective in achieving high reliability;
- the methods provide only broad estimates of reliability;
- the assumption of constant failure rate during the useful life ~~period~~ of an item is not always valid but such an assumption provides suitable values for comparative analysis.

C.3 Component considerations

C.3.1 Component model

In this document a component is considered to consist of the actual component itself (e.g. silicon die), the encapsulation (e.g. case) and connection points. How the connection points are attached to the circuit board, also called the attachment system (e.g. solder joint), are treated separately in Clause 14 and this means that failures in the attachment system should be treated as component failures when using this document.

It is assumed that any failure rate used under reference conditions is specific to the component, i.e. it includes the effect of component complexity, technology of the casing, ~~dependence on~~ materials used, component construction, manufacturers and the manufacturing process, etc.

Care should be taken when using failure rate data from some data sources since some sources include the attachment system in the component failure rates and some do not.

C.3.2 Components classification

Component identification is the most important element of any codification system because it establishes a unique identification for every component. The identification consists of the minimum data required to establish clearly the essential characteristics of the component, i.e. those characteristics that give it a unique character and differentiate it from all others. A number of component classification systems are briefly described in Annex I.

This document recommends the use of IEC 61360 (all parts) which provides a clear and unambiguous definition of characteristic properties of all elements of electrotechnical equipment from basic components to subassemblies and full equipment. This document only uses the component-related aspects of IEC 61360 (all parts). The component coding elements of IEC 61360 (all parts) are described in Annex I.

C.4 General consideration about failure rate

C.4.1 General

The failure rate of an electric component depends on many influences, such as operating phase, failure criterion, duration of stress, operating mode (continuous or intermittent), ambient temperature and temperature cycling rate, humidity, electrical stress, cyclical switching rate, mechanical stress, air pressure and special stresses. It should be noted that a failure rate value, without knowledge of the conditions under which it was observed or is to be expected, provides no real information. For this reason, the values of the relevant factors of influence should always be given when stating a failure rate. It is possible to state how the failure rate depends on some of these influences. This dependence applies only within the specified limit values of the components.

Estimated values of the failure rates can be derived either from life tests or from field data. These estimated failure rates only apply under the conditions that applied during the tests or field observation. The rules according to which such estimates are derived depend on the statistical distribution function applying, i.e. whether "constant failure rate period" (exponential distribution) or "early life and wear-out failure period" (for example, Weibull distribution) exist. If the distribution over time of the failures is known, and estimated values of the failure rate have been calculated, the result should be interpreted statistically.

The dimension of failure rates is the number of failures per unit time ~~(FIT)~~, but it is worth noting that the time measure can be replaced by cycles, number of operations, etc. depending on the component type. Generally component failure rates are given in one of two standard forms, either as number of failures per 10^6 h or in number of failures per 10^9 h. ~~In the latter case the acronym FIT is often used.~~

C.4.2 General behaviour of the failure rate of components

The general behaviour of the failure rate can be modelled by the Weibull distribution (see IEC 61649:2008, Clause 8). Its shape parameter, β, models three periods in the lifecycle, which can be ~~simply~~ explained as follows:

a) Early life failure period ($\beta < 1$)

   For some components, at the start of the operating period, a higher failure rate is sometimes observed which decreases with time. Early life failures occur due to manufacturing processes and material weaknesses that do not result in failures in tests performed before shipping.

   There are a few components that will exhibit decreasing failure rate in use. This is usually due to problems in the component manufacturing process as well as to handling problems (ESD, mechanical damages, etc.). This document does not support prediction of these component types and if early life failures are still to be expected for a component, the beginning of the phase of constant failure rate should be specified.

   This document assumes constant failure rates hence it is assumed that any early life failures are removed by process control or by screening (see IEC 61163-2).

b) Constant failure rate period ($\beta = 1$)

   Here, as the term suggests, the failure rate is constant. In some cases this occurs because competing failure rates produce an averaging effect that make it appear as if the failure rate is constant when the underlying failure rates of the individual competing failure modes are not.

   Generally electric components operate in the constant failure rate phase (from end of early life failure period to start of wear-out failure period) and are dealt with in this document. This behaviour can be most easily modelled by the exponential distribution and procedures for verification of constant failure rate can be found in IEC 60605-6. For components showing limited variations of the failure rate within the useful life, for example electromechanical components showing wear-out, the assumption of constant failure rate can be maintained by using the average failure rate during the useful life.

c) Wear-out failure period ($\beta > 1$)

This period shows an increasing failure rate due to the dominating effects of wear-out, ageing or fatigue (see also Annex F).

This document assumes that for ~~these~~ most components the failure rate is averaged for the time interval specified in the data sheet. Since this document only covers the useful life of the component, it is important to know when the useful life ends for a given component due to wear-out. Some suppliers define this point as where a certain percentage of failures have occurred (e.g. 10 %). Others define the end-of-life as being when the failure rate has increased by a certain factor (e.g. failure rate doubled).

This limitation to the useful life of the component is reasonable since for the vast majority of components, the wear-out failure period (during which failures take on a systematic character) is far away from the periods of use (which can typically range from 3 to 20 years).

There are three cases in which the occurrence of wear-out failures should be taken into account (the failure rate of which increases with time):

1) For some families, if due care is not taken, the wear-out mechanisms may give rise to systematic failures after too short a period of time: metallization electro-migration in active components, for example. This risk needs to be eliminated by a good product design, and it is important to ensure this by qualification testing. In other words, it should not be taken into account for a prediction, and should be eliminated by qualification testing and by technical evaluation, which are, therefore, of critical importance.
2) For some (very few) component families, the wear-out failure period is relatively short. For these families, this document explains how to express the period for which the failure rate can be considered constant. This useful life is subject to influencing factors. Such families include relays, aluminium capacitors (with non-solid electrolyte), laser diodes, optocouplers, power transistors in cyclic operation, connectors and switches and keyboards.
3) In some cases a component operates solely in the wear-out phase due to its physical or chemical nature. This group include chemically-based components, components where use is made of a physical degradation mechanism and nearly all components where there is a mechanical interaction. These component types will always be in the wear-out phase and so the failure rate will always be increasing. This can often be confirmed by Weibull analysis of failure data (see IEC 61649 for details).

The time points which separate these operating periods cannot be determined exactly. In general terms the time dependence curve for any single component type could be significantly different. When interpreting reliability figures it is important to determine the physical reality of failure modes and distributions.

For more details on these different phases refer to IEC 61649 and IEC 62308.

C.4.3 Expected values of failure rate

It is recommended to state failure rate data for components under environmental and operating conditions close to the conditions in field use. This results in the most relevant predictions. Therefore data from previous products and from field data from the organization doing the analysis is preferred.

Values determined from a life test with a single sample – or the confidence limits derived from it – often do not provide enough information. Therefore the resulting dispersions of the predicted values for modules and equipment may be too great.

Failure rate data, stated according to this document, should therefore be taken as statistical "expected values" for operation under the given reference conditions for the time period given and the total population, i.e. it is to be expected that in future use, under the conditions given, the averages obtained will be the values cited.

C.4.4 Sources of variation in failure rates

A failure rate generated from collecting data on equipment will be dependent upon all the circumstances under which the equipment operates. Consequently, the failure rate data should only be used for predictions on equipment in which the circumstances are similar. if the circumstances are different then the predicted failure rate will need to be adjusted.

Unfortunately, the circumstances of a data collection are rarely adequately described, Therefore, any data will be based on some explicit assumptions, some implicit assumptions, and some assumptions that are not addressed in this document.

It is important to appreciate that a failure rate is not an intrinsic and immutable property of a piece of equipment. An engineer involved either in collecting or using data should fully understand the factors that influence failure rate derivation and use.

Circumstances that can create variations in failure rates are:

- Component detail

  When collecting data, it is possible that information that is important to the differentiation of failure rate is lost. This is often the case when a taxonomy or categorization is used to group component types.

- Suitability for service

  Suitability for service is related to the quality of a component. When making a prediction the analyst ~~shall~~ should, wherever possible, try to assess the validity of the assumptions made for the particular situation and establish if the equipment represented by the data was properly fabricated, used appropriate materials of construction, was properly maintained, was operated within design conditions and was designed to appropriate standards.

- Failure mode combinations

  Great care therefore should be taken when using failure data to ensure that the definition of failure modes used to gather the failure data is the same as the definition of failure modes that are being ~~predicted~~ expected and is not a mix of different failure mode definitions. This is of particular importance when handbook data or failure data provided by an external source is used. If the types of failure mode definition cannot be identified, then the outcome of any prediction may not match the actual observed behaviour. See 4.1 and Annex A for more details on failure modes.

- Maintenance

  The maintenance strategy for equipment will significantly affect both the number and severity of failures. An inadequate preventive maintenance programme will not prevent failures, a cursory routine inspection programme may detect some potential failures, and a full preventive maintenance programme may pick up potential failures as incipient failures rather than ~~delaying~~ waiting until they occur.

Annex D
(informative)

Considerations on mission profile

D.1 General

Mission profile is defined as the complex of conditions of use experienced by components during their life.

The mission profile defines the required function and the environmental condition as a function of time. This will vary according to the type of operation that is undertaken. This operation may be continuous over time at a fixed level, continuous over time at a variable level or sporadic over time at either a fixed level or a variable level. In some cases switch on and switch off could be significant and of more importance than the steady state operational conditions. Careful consideration of the mission profile is needed in order to fully understand how it affects the component reliability.

The mission profile can be considered to be based on calendar time or on the time of actual operation or it can be cycle based (e.g. how many times an item is used).

The duration of stress (sum of rated operating times, and non-operating times) can affect the failure rate. A (maximum) time period of stress over which failure rate was observed should therefore always be included in a failure rate specification. This is the time in which the given constant failure rate can be expected to occur.

Mechanical stresses of components higher than those permitted by the component specification should be avoided by the appropriate equipment design. If higher stresses cannot be avoided, they should be taken into account when performing the equipment reliability prediction.

The conditions of use are usually referred to the assembly (equipment or system), then the mission profile is typically defined for the assembly (equipment or system) and conditions for components are derived from it.

D.2 Dormancy

Components are sometimes not continuously stressed during the operating time of the assembly. There can be breaks with no electrical stress during operating periods of the assembly, also indicated as dormancy. This can be taken into account by the stress factor for mission profile, π_{op} .

When the only variation on component conditions is dormancy, the failure rate for intermittent operation between an operating condition and a dormant condition is obtained using Equation (D.1)

$$\lambda_{\mathrm{op}} = \lambda \times \pi_{\mathrm{op}} \tag{D.1}$$

with

$$\pi_{\mathrm{op}} = W + \rho \times (1 - W) \tag{D.2}$$

where

λ_{op} is the failure rate, when dormant conditions occur;

λ is the failure rate for the specific component:

- for failure rate predictions at reference conditions, $\lambda = \lambda_{\text{ref}}$;
- and for failure rate predictions at operating conditions, the failure rate according to the equation stated in 5.2.1 based on Equation (2);

π_{op} is the operating stress factor;

W is the ratio of operating time of component with stress to operating time of assembly, $0 \le W \le 1$;

ρ is a constant. This is the failure rate reduction factor from nominal operating conditions to dormant conditions (no electrical stress applied) and takes into account that even non-stressed components may fail, $0 \le \rho \le 1$; a typical assumption is $\rho = 0{,}1$ when no values are known from experience.

D.3 Mission profile

Sometimes during operation, a component is subjected to different stress levels, which imply different failure rates, since the failure rate depends on the stress.

For example, if a component is in operation 24 hours a day then it will, on average, fail more often in one year as the same component that is only in operation 12 hours a day, assuming that the operating conditions are similar. A failure rate prediction should consider those different stress levels. By consideration of stress duration and stress levels, the difference between predicted failure rates and the observed failure rates can be kept low.

The actual stresses occurring with alternating stress levels can be combined into one mission profile. A mission profile states the actual duration of stress levels during a defined calendar time, for example one day. Figure D.1 shows a possible mission profile over one day.

Stress levels refer to any of the applicable factors relevant to the specific component, in particular temperature and electrical stress, which directly influence component failure rate.

In Figure D.1 any of the indicated partial stress can be:

- a reduced operating temperature;
- a reduced electrical stress (stand-by);
- any reduced stress, specific for the considered component;
- different operation environment (different environmental application factor π_E values).

This document considers temperature cycle (operating times at different temperatures) in the mission profile, but in this context does not consider rapid temperature changes or humidity, which are included in the environmental application factor π_E (see 5.2.5).

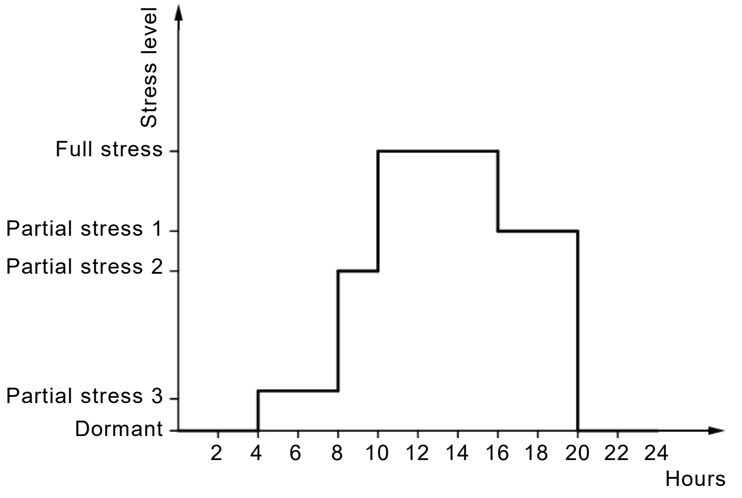


Figure D.1 – Mission profile

The failure rate for a mission profile, λ_{as} , as shown in Figure D.1 is the weighted average of the failure rates under different stress levels

$$\lambda_{\text{as}} = \frac{1}{t_{\text{f}} + \sum_{i=1}^{N} t_{\text{p},i} + t_{\text{d}}} \left(t_{\text{f}} \lambda_{\text{f}} + \sum_{i=1}^{N} t_{\text{p},i} \lambda_{\text{p},i} + t_{\text{d}} \lambda_{\text{d}} \right) \tag{D.3}$$

with

$$\lambda_{\text{d}} = \rho \times \lambda_{\text{f}} \tag{D.4}$$

where

t_{f}	is the fraction of time with full (nominal) stress;
$t_{\text{p},i}$	is the fraction of time with partial stress i;
t_{d}	is the fraction of time at dormant conditions;
λ_{f}	is the failure rate at full (nominal) stress;
$\lambda_{\text{p},i}$	is the failure rate at partial stress i;
λ_{d}	is the failure rate during dormancy;
ρ	is the reduction factor from operating conditions to dormant conditions (no electrical stress applied); a typical assumption is $\rho = 0{,}1$ if no other information is available;
N	is the number of stress levels.

D.4 Example of mission profile

The failure rate of assemblies is needed for the planning of stock holding. The assembly operates with an average daily operation time of 12 hours with full stress, six hours at partial stress with reduced failure rate and six hours dormant.

The following failure rates were predicted:

- $2\,400 \cdot 10^{-9}$ h^{-1} at full stress;
- $1\,400 \cdot 10^{-9}$ h^{-1} at partial stress;
- 10 % of failure rate at full stress is assumed for dormant state (see D.2).

The failure rate for alternating stress is as follows:

$$\lambda_{\text{as}} = \frac{1}{t_{\text{f}} + t_{\text{p}} + t_i} \left(t_{\text{f}} \lambda_{\text{f}} + t_{\text{p}} \lambda_{\text{p}} + t_i \lambda_i \right) = \frac{1}{24} \left(12 \cdot 2\,400 + 6 \cdot 1400 + 6 \cdot 0{,}1 \cdot 2\,400 \right) \cdot 10^{-9}\ \text{h}^{-1} = 1610\ \cdot 10^{-9}\ \text{h}^{-1}$$

Annex E
(informative)

Useful life models

E.1 General

Failure rates dealt with in this document are assumed to be constant either for an unlimited period of operation (general case) or for limited periods. The limitation of useful life applies only for some few component families, reaching the wear-out failure period (during which failures take on a systematic character) within normal period of use.

For these families, Annex E gives useful life models taken from different sources, such as those listed in Annex H and in particular from IEC TR 62380, explaining how to express the period for which the failure rate can be considered constant. This useful life is subject to influencing factors and may be expressed either as a unit of time (normally hours) or as a number of cycles.

Such families include power transistors in cyclic operation, optocouplers, laser diodes, aluminium capacitors (with non-solid electrolyte), relays, switches, keyboards and connectors.

For these component families, it is important to ensure that the useful life given is consistent with the intended duration of use. If not, room for manoeuvring is fairly restricted: stresses can be reduced, or the component family can be changed (or the sub-family, for example with aluminium capacitors with non-solid electrolyte there are several types characterized by different qualification tests).

The operating time should not exceed the useful life value since beyond this time, the failure rate λ cannot be assumed to be constant.

E.2 Power transistors

The useful life of power transistors under cycling mode is given by a maximum number of cycles S. This number of cycles is limited to:

$$S = 10^{7} \times e^{-0{,}05\,\Delta T_{\mathrm{j}}} \qquad \text{(E.1)}$$

with ΔT_{j} as junction temperature range.

E.3 Optocouplers

E.3.1 Useful life L

Depending factors for the useful life of optocouplers are the

- junction temperature θ_{j} expressed by factor L_0 ;
- input current I_{F} (operating and test condition) expressed by κ_0 and κ_2;
- transfer ratio m defined through final/initial transfer ratio expressed by κ_1;
- cumulative failure ratio (in percent) expressed by κ_3.

The useful life of the optocoupler in hours is given by

$$L = L_0 \times \kappa_0 \times \kappa_1 \times \kappa_2 \times \kappa_3 \quad \text{(E.2)}$$

E.3.2 Factor L_0

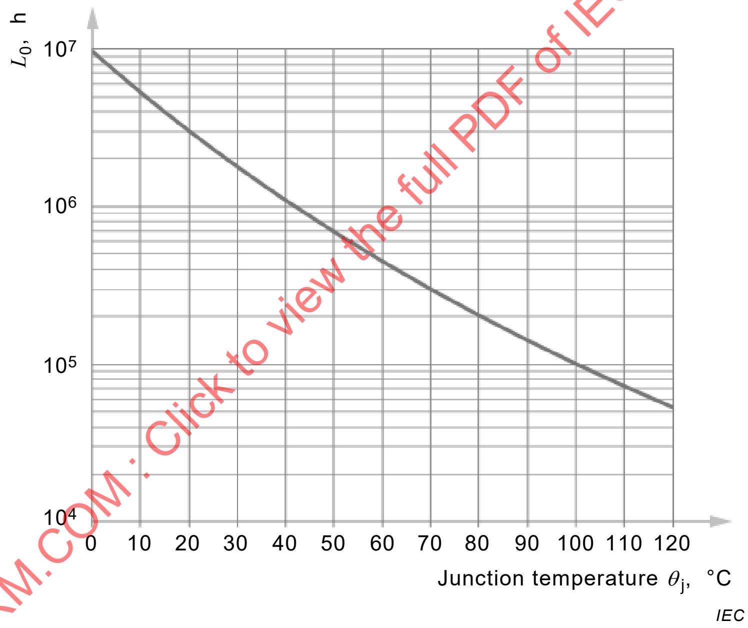
The factor L_0 which is a function of the junction temperature θ_j gives the useful life at reference conditions:

- operating input current I_F = 50 mA (κ_0 = 1);
- transfer ratio m = 0,5 (κ_1 = 1);
- test input current I_F = 1 mA (κ_2 = 1);
- cumulative failure ratio 10 % (κ_3 = 1).

and can be expressed by the following equation

$$L_0 = 0{,}4 \times \exp\left(\frac{4640}{\theta_j + 273}\right) \quad \text{(E.3)}$$

or derived by the following graph



NOTE For moulded plastic optocouplers, the junction temperature is limited to 90 °C.

E.3.3 Factor κ_0

The factor κ_0 is giving the influence of the operating input current and is defined by

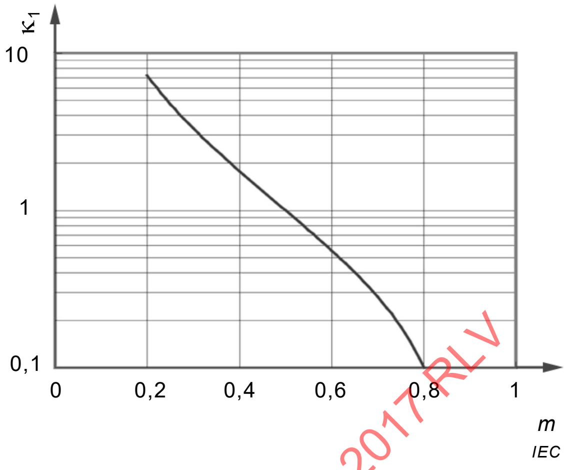
$$\kappa_0 = \frac{50}{\text{input current (operating, mA)}} \quad \text{(E.4)}$$

E.3.4 Factor κ_1

The factor κ_1 is a function of the selected transfer ratio where

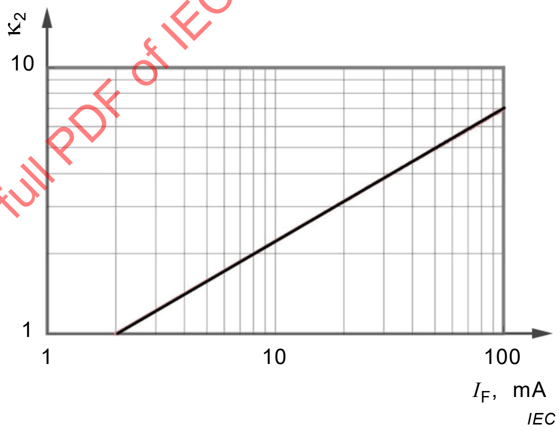
$$m = \frac{\text{Final transfer ratio}}{\text{Initial transfer ratio}}$$

and can be derived from the graph.



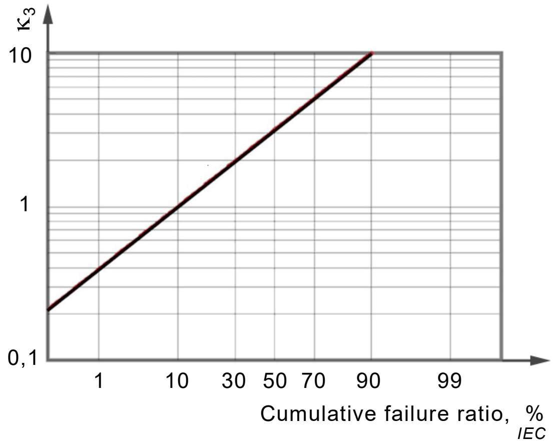
E.3.5 Factor κ_2

The factor κ_2 is a function of the current I_F measured at the transfer ratio (testing conditions) and can be derived from the graph.



E.3.6 Factor κ_3

The factor κ_3 depends on the cumulative failure ratio given in percent as shown in the graph.



E.4 LED and LED modules

E.4.1 Useful life L

Depending factors for useful life of light emitting diode[1] modules are the

- junction temperature θ_j expressed by factor L_0 ;
- operating input current expressed by κ_0;
- optical power ratio m defined through final/initial optical power expressed by κ_1;
- measurement current I_F expressed by κ_2;
- cumulative failure ratio (in percent) expressed by κ_3.

Useful life of LED and LED modules in hours is given by

$$L = L_0 \times \kappa_0 \times \kappa_1 \times \kappa_2 \times \kappa_3 \qquad \text{(E.5)}$$

E.4.2 Factor L_0

The factor L_0 which is a function of the junction temperature θ_j gives the useful life at the following reference conditions:

- operating input current I_F = 100 mA (κ_0 = 1);
- optical power ratio m = 0,5: (κ_1 = 1);
- optical power measuring current I_F = 100 mA (κ_2 = 1);
- cumulative failure ratio 10 % (κ_3 = 1).

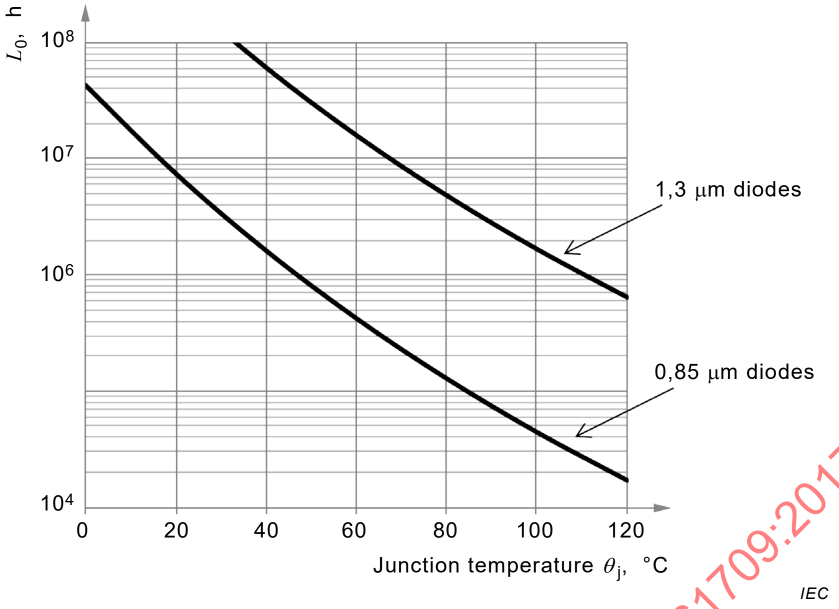
and can be expressed by the following equations.

Diode type	Factor L_0 expressed in hours
0,85 µm diodes	$L_0 = 2{,}3 \cdot 10^5 \times \exp\left(7000 \times \left(\frac{1}{\theta_j + 273} - \frac{1}{343}\right)\right)$ (E.6) (0,6 eV)
1,3 µm diodes	$L_0 = 8{,}7 \cdot 10^6 \times \exp\left(7000 \times \left(\frac{1}{\theta_j + 273} - \frac{1}{343}\right)\right)$ (E.7) (0,6 eV)

or can be derived by the following graph.

---

[1] According to IEC 62007.



E.4.3 Factor κ_0

The factor κ_0 gives the influence of the operating input current and is defined by

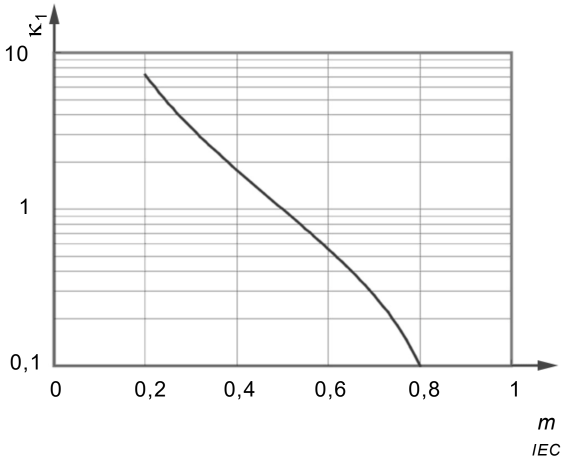
$$\kappa_0 = \frac{100}{\text{operating input current (mA)}} \tag{E.8}$$

E.4.4 Factor κ_1

The factor κ_1 is a function of the selected optical power ratio where

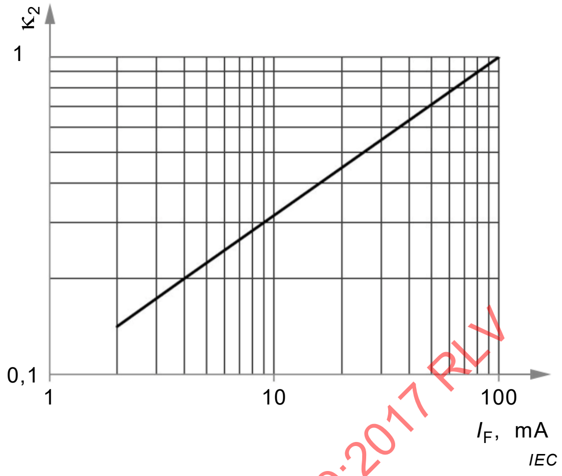
$$m = \frac{\text{final optical power}}{\text{initial optical power}}$$

and can be derived from the graph.



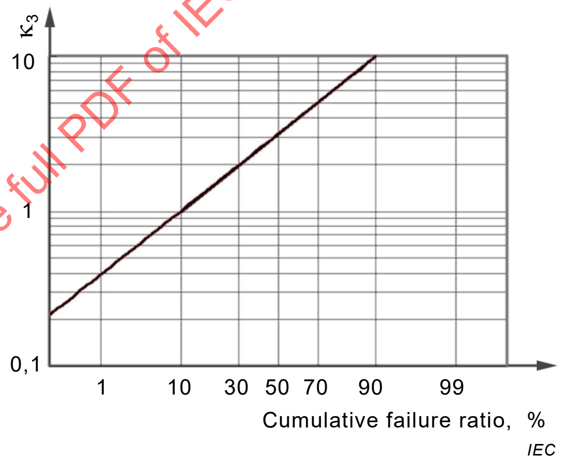
E.4.5 Factor κ_2

The factor κ_2 is a function of the optical power measuring current I_F and can be derived from the graph.



E.4.6 Factor κ_3

The factor κ_3 depends on the cumulative failure ratio given in percent as shown in the graph.



E.5 Aluminium, non-solid electrolyte capacitors

The main influencing factor for useful life L of non-solid electrolyte aluminium capacitors is the capacitor temperature θ_C in °C.

NOTE Other factors as applied voltage and ripple current to life are disregarded at this stage.

Useful life in hours is given by

$$L = QTD \times 2^{\left(\frac{\theta_M + 5 - \theta_C}{10}\right)} \quad (E.9)$$

where

QTD is the qualification test duration in hours;

θ_M is the maximum temperature of the climatic category in degrees Celsius;

$\theta_C = \theta_{ambient} + 5$ is the capacitor temperature in degrees Celsius.

The “qualification test duration” depends on the technology type and can also be denoted as “base lifetime” of the capacitor.

E.6 Relays

According to IEC technical committee 94 (All-or-nothing electrical relays) there are no general models for the useful life of relays.

Data on useful life can be obtained from data sheets or directly from manufacturers of the component type or, if not available, suitable life tests should be performed according to IEC 61810-2, IEC 61810-2-1 and IEC 61812-1.

E.7 Switches and keyboards

Failure rate of switches and keyboards is assumed to be constant but only within the specified number of switching cycles.

Examples for useful life limitation are given in Table E.1.

Table E.1 – Useful life limitations for switches and keyboards

Type	Limitations (cycles)
Toggle and push button switches	Between 20 000 and 100 000
Rotary switches	20 000
Keyboards	Between 500 000 and 1 000 000

E.8 Connectors

Useful life of connectors is limited. The number of mating/unmating cycles should not exceed the specified value (or the value given by the manufacturer).

Annex F
(informative)

Physics of failure

F.1 General

The physics of failure (PoF) approach proactively incorporates reliability into the design process by establishing a scientific basis for evaluating new materials, structures, and electronics technologies. Information to plan tests and screens, and to determine electrical and thermal-mechanical stress margins are identified by the approach.

The PoF approach encourages innovative, cost-effective design through the use of realistic reliability assessment and is an attempt to identify the "weakest link" of a design to ensure that the required equipment life and reliability is exceeded by the design.

The methodology generally ignores the issue of defects escaping from the manufacturing process and assumes that product reliability is strictly governed by the predicted life of the weakest link.

At the integrated circuit level for instance, example models address microcircuit die attach fatigue, bond wire flexure fatigue and die fatigue cracking. The models are very complex and require detailed device geometry information and materials properties. In general, the models are most useful in the early stages of designing devices but not at the assembly level when flexibility no longer exists to change device designs.

The PoF approach is not only a tool to allow better and more effective designs but it can be an aid for cost-effective approaches for improving the entire approach to building electronic systems. However an understanding of the PoF is necessary in applications which afford little opportunity for testing, or for reliability growth.

Reliability assessments based on PoF methods incorporate reliability into the design process with the intention that the system meets the user requirements. Predicting the reliability of electronics is a hard engineering task since there are too many factors, both controllable and uncontrollable, which cannot be readily identified, quantified, or combined into an all-inclusive and deterministic equation. However, some progress has been made to simplify the prediction process. For example software exists which will predict the fatigue life of solder joints, component leads, and plated through holes. This software is based on finite element analysis (FEA) and the results of such complex FEA of assemblies have become an integral part of the design process, and provide a more comprehensive reliability prediction process than was available in the past.

In PoF based prediction modelling a probabilistic mechanics based approach is used. The goal is to use PoF principles with appropriate failure probability density distributions to design for failure-free operation and predict times for components now available, as well as new components resulting from new materials, technologies and processes. The stress-margin approach, using models based on PoF analysis is used as an alternative to standard stress based approaches.

Much of the focus on PoF has been on the failure of integrated circuits and so a brief outline of failure mechanisms as a basis for a PoF approach is given in F.2.

Failure mechanisms details and models for many other device types can be found in such repositories as RIAC WARP.

F.2 Failure mechanisms of integrated circuits

The end of life period of an integrated circuit is supposed to appear far beyond the utilization period of the equipment. This assumption has to be assessed by a preliminary qualification.

The main observed failures in semiconductors are caused by thermomechanical constraints applied to components mounted on PCBs. The failure rate related to the humidity is insignificant (for active components, especially since the general use of nitride based passivation). Furthermore, in these studied environments no defect related to mechanical shocks or to vibrations or to chemical contamination has been observed. Consequently, these failure mechanisms have not been taken into account in the models.

The main failure mechanisms are listed in Table F.1.

Table F.1 – Failure mechanism for Integrated circuits

Type	Silicon technologies	GaAs technologies	Packages
Mechanisms	Electromigration Oxides ageing Hot electrons Charge gain and charge loss	Gate sink Ohmic contact degradation Gate and drain lagging Electromigration Thermal fatigue Purple plague	Thermal fatigue Purple plague

The integrated circuit model used in this document does not include the failure rate due to soft errors, when the function is fully retrievable without outside intervention, for example provoked by the creation of electron-hole pair by the passage of alpha particle emitted by the package materials. This failure rate due to soft errors may be of the same order of magnitude as the intrinsic failure rate, especially for dynamic memories.

For interface circuits, the integrated circuit models used in this document include a failure rate considered to be constant, due to external electrical influences. This failure rate depends on the electrical environment of the equipment, given that the equipment does have primary or secondary protections, depending on the state of the art of the period observed. (For the purposes of this document, interface circuits are taken to be circuits or devices connecting the equipment to the outside environment.)

Annex G
(informative)

Considerations for the design of a data base on failure rates

G.1 General

~~For the successful implementation and maintenance of a failure rate database, an organizational framework is needed which assures that dependability data are collected and converted to information suitable for the database. Regular updating and also removal of outdated information are both equally important.~~

This document requires failure rates in order to be useful. These can be obtained from a number of sources the most useful of which would be field usage data, the second most useful would be test related data, most probably obtained from the component manufacturers.

The basic idea behind the information given in the following clauses is that there is a collection of ~~dependability~~ reliability data, which is converted to input for the database, from where it can be retrieved by people or organizations in order to make failure rate calculations on the next higher level of aggregation.

G.2 Data collection acquisition – collection process

Guidance on data collection is given in IEC 60300-3-2.

G.3 Which data to collect and how to collect it

The use of failure data drives the way it should be collected. The final use should hence be clearly defined before setting up the data collection equipment as, once it is developed, it is very difficult and costly to make changes because some information is missing, which is vital for the end-user.

The prediction models are not intended to describe the physical behaviour of the components or explain their failure mechanisms, but to represent the best estimate based on observed data. They seek to represent what happens to equipment in real field conditions in the steady-state part of the life cycle.

When the final purpose for using failure models is to provide design objectives, data coming from the field should be suitably filtered in order to eliminate from the observed population those items that have not yet reached reliability maturity, i.e. items affected by equipment failures, design errors, or infant mortality.

When analysing field data that has come from testing and repair in repair centres, a specific topic to be carefully considered is diagnostics coverage. In fact, more than one component (or even a large number) may be removed during repair, and the percentage “no fault found” (NFF) may be above the generally accepted limit of around 20 %, which is considered to be the minimum that is normally achievable.

On the other hand, if the result is aimed at spare parts dimensioning (logistics), either at component or equipment level, other situations should be considered when deciding what data to collect:

- no fault found (NFF);
- imperfect diagnostics;
- incorrect use of components that lead to systematic failures;

- maintenance not correctly performed and human errors;
- external factors (electrical and environmental);
- the learning curve of manufacturing processes;
- the case where multiple components are removed to carry out a repair;
- the case when a component failure causes the failure of other components.

G.4 Calculation and decision making

Failure rates in the database are derived from all or some of the reported information. Ideally they are determined from the field while also taking test results from external sources into account and then adapting these to the reference conditions.

For data obtained from the field, all failures should be included that can be reproduced during the testing of the replaced equipment (e.g. subassemblies). The individual reasons for failures are not important here (e.g. manufacturing fault of a component, stress, external effects within the range of the specified values). Experience shows that in some of the rejected equipment no failures can be found. These pieces of equipment should be not considered for the determination of the failure rate. It can be necessary for users to take these NFF parts into account separately when planning spare-parts logistics.

For data obtained from test, the principles of IEC 60300-3-5 should be followed.

While confidence limits are of value for interval estimates of the data determined from tests, they are not reasonable for expected values.

G.5 Data descriptions

As a minimum any data base should contain information on the following.

1) Component identification and specification data
    a) Identification
    b) Component technology
2) Specification of component
    a) Electrical specification of component
    b) Environmental specification of component.
3) Component field related data
    a) Method of selection of monitored components
    b) Field conditions
    c) Data on failures during field operation
4) Component test related data
    a) Method of selection of test components
    b) Test conditions
    c) Data on failures during test

For a solely field failure database item 4 would be omitted, and for a test database item 3 would be omitted.

The following clauses outline the minimum recommended contents of these data items.

G.6 Identification of components

G.6.1 General

The information supplied to identify the components should be in accordance with the relevant IEC or internationally recognized management quality systems publications for the component type under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other component specifications should be used and the source of the specifications stated. As a minimum, the following information should be given. Only information applicable to a particular component type should be supplied.

Examples of the specific information required for different component types can be found in IEC 61360-4.

G.6.2 Component identification

- A description of the component type with sufficient details to uniquely identify the component type, for example N-channel V-MOS transistor. When available, specification numbers should be given.
- The component part number. If available, a universal part number, for example stock number, should be given; otherwise a part number specific to the component manufacturer may be given.
- Name of the manufacturer and place of manufacture. The purpose of these references is to allow access to more detailed information if required.
- The date of manufacture or lot number or other production batch related identification. This information will allow access to other components that were produced at the same time as the sample should a problem arise.
- The production status of the component, for example development sample, pre-production, standard production, mature technology.
- Information regarding compliance with other recognized standards should be given whenever possible.

G.6.3 Component technology

- A description of the basic component technology, for example metal film resistor.
- A general description of the production process, for example ion beam epitaxy.
- Packaging information, for example plastic, hermetic weld.
- Thermal resistance, for example Rthj-a, Rthj-c.
- Complexity of circuit.
- Method of termination, for example endcaps, DIL, SMD.

G.7 Specification of components

G.7.1 General

The information supplied to specify the components should be in accordance with the relevant IEC or internationally recognized management quality systems publications for the component type under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other component specifications should be used and the source of the specifications stated. As a minimum, the following information should be given.

G.7.2 Electrical specification of components

- Relevant information about ratings and characteristics should be supplied. These references taken from the applicable component specifications will depend on the type of test performed. For example, if power cycling tests are performed then the ratings for power dissipation should be given.

- Information should be given about any pre-test screening the components to be tested may have undergone. The results of such screening should be given.

G.7.3 Environmental specification of components

Information should be given regarding the maximum environmental conditions the components can withstand, for example temperature, humidity, acceleration.

G.8 Field related issues data

G.8.1 General

The field environmental conditions should be those described in the relevant IEC or internationally recognized management quality systems publications for the components in operation whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other specifications should be used and the source of the specifications stated. The following minimum information should be supplied.

G.8.2 Actual field conditions

- The source of the results, for example the quality assurance department of the manufacturer.
- A description of the field conditions used, for example the electrical, mechanical and environmental conditions. The field conditions should be identified by quoting the relevant IEC or other test specifications where possible.
- The number of components exposed to the field conditions. Where a component is available in a number of different values, for example resistors, capacitors, the values present and the quantity of each value should be stated.
- A description of the characteristic measured, for example resistance, and the measuring conditions. Where the measurement conditions are specified by IEC or other specifications, then the specification number should be given.
- If more than one method of characteristic measurement is permissible then a description of the method used should be given. This description should contain all relevant details.
- The operation start date, duration and measurement intervals should be stated.

G.8.3 Data on field failures

- The number of failures observed, categorized by environmental conditions and type of failure modes should be stated with percentage occurrence. Identified failure mechanisms should be stated with their associated activation energies and temperature ranges.
- The times at which the failures occurred or were verified.
- Special events during operation, for example events which might have affected the results.
- Complete data from operation should be presented whenever possible but if data from operations are discarded, these data and the reasons why they are not given in the presentation or results, should be given separately.
- Failure criteria for the components (for degradation failures as well as for catastrophic failures), are normally defined by the requirements given by the specification to which reference is made in the field report. If failure criteria for the components are not given by the reference specification, they should be stated.
- Failure rate which can be assumed to be constant.
- The operating time of components during which the failure rate is assumed to be constant should be indicated (i.e. useful life). Failure rates found will preferably be stated in failures per 10^9 h of operation. The value of 60 % is often used as the upper confidence level for failure rates.

- Failure rate which cannot be assumed to be constant.
  - The operating test time can be divided into a number of separate periods and the results for each of these periods evaluated separately. The necessary time periods which have to be distinguished and the number of failures which occur during each time period should be given. If the results can be satisfactorily approximated by a mathematical function, it would be useful to present these functions, as well as the period during which they are applicable. In all cases, mean lifetime, failure distribution and the influence of derating should be stated. For life-limited components, an appropriate model should be suggested.
- Influence of stresses.
  - As failure rates are dependent on the type and the intensity of stress, all failure rate data should be presented with the applied stress levels. Furthermore, it can be important to know the correlation between failure rate and stress (temperature, power, vibration, etc.) and, where possible, the activation energy of the failure mechanism should be supplied. Therefore, failure rate values obtained at different stress levels should be supplied separately.

G.9 Test related issues data

G.9.1 General

The test and sampling conditions should be those described in the relevant IEC or internationally recognized management quality systems publications for the components under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other test specifications should be used and the source of the specifications stated. The following minimum information should be supplied.

G.9.2 Actual test conditions

- The source of the results, for example the quality assurance department of the manufacturer.
- A description of the test conditions used, for example the electrical, mechanical and environmental conditions. The test conditions should be identified by quoting the relevant IEC or other test specifications where possible.
- The number of components under test. Where a component is available in a number of different values, for example resistors, capacitors, the values tested and the quantity of each value should be stated.
- A description of the characteristic measured, for example resistance, and the measuring conditions. Where the measurement conditions are specified by IEC or other specifications, then the specification number should be given.
- If more than one method of characteristic measurement is permissible then a description of the method used should be given. This description should contain all relevant details.
- The test start date, duration and measurement intervals should be stated.
- Where a delay exists between the cessation of the test and the commencement of measurements, then the time duration should be stated. The storage conditions during this delay should also be stated. Any conditioning stress applied to the components before measurement should also be stated.

G.9.3 Data on test failures

- The number of failures observed, categorized by test conditions and type of failure modes should be stated with percentage occurrence. Identified failure mechanisms should be stated with their associated activation energies and temperature ranges.
- The times at which the failures occurred or were verified.
- Special events during testing, for example events which might have affected the results.

- Complete data from tests should be presented whenever possible but if data from tests are discarded, these data and the reasons why they are not given in the presentation or results, should be given separately.
- Failure criteria for the components (for degradation failures as well as for catastrophic failures), are normally defined by the requirements given by the specification to which reference is made in the test report. If failure criteria for the components are not given by the reference specification, they should be stated.
- Failure rate which can be assumed to be constant.
    - The test time of components during which the failure rate is assumed to be constant should be indicated (i.e. useful life). Failure rates found will preferably be stated in failures per 10^9 h of operation. The value of 60 % is often used as the upper confidence level for failure rates.
- Failure rate which cannot be assumed to be constant.
    - The total test time can be divided into a number of separate periods and the results for each of these periods evaluated separately. The necessary time periods which have to be distinguished and the number of failures which occur during each time period should be given. If the results can be satisfactorily approximated by a mathematical function, it would be useful to present these functions, as well as the period during which they are applicable. In all cases, mean lifetime, failure distribution and the influence of derating should be stated. For life-limited components, an appropriate model should be suggested.
- Influence of stresses.
    - As failure rates are dependent on the type and the intensity of stress, all failure rate data should be presented with the applied stress levels. Furthermore, it can be important to know the correlation between failure rate and stress (temperature, power, vibration, etc.) and, where possible, the activation energy of the failure mechanism should be supplied. Therefore, failure rate values obtained at different stress levels should be supplied separately.

G.10 Failure rate database attributes

Table G.1 describes some of the attributes of a database suitable for reliability prediction.

Table G.1 – Reliability prediction database attributes

Categories of information	Detailed information	Purpose
Component identification	Manufacturer Part No Link to datasheet	To filter for component, product line and manufacturer
Component categorization	Component main category Technology Complexity Mechanical size Housing Thermal considerations	To filter for similar items.
	Compliance issues – standards – certificates	To filter for parts which fulfil certain regulative requirements.
	Manufacturing specific information like hazardous substance issues, packaging, lot sizes, tests performed during manufacturing, etc.	To allow for checking against manufacturing issues, which could be rejection criteria.
Usage categorization	Function/Purpose Environmental conditions	To filter for specific types of application of the part, which cause a certain set of electrical stress.
(Reference) Failure rate		To state the failure rate applicable to the reference conditions given.
(Reference) Conditions		To state the conditions applicable to the reference failure rate given.
Stress model	π-factors applicable and their mathematical combination	To determine how to convert failure rates from reference conditions to application operating conditions.
Information related to elements of the stress model	Parameters, formulae or tables necessary to determine the value of the relevant π-factor	To determine the values for the π-factors.
Data considered for calculation of the failure rate or reference to the detailed calculation	Reference to detailed calculation. Component hours	To retrieve the full story. To estimate the relevance and credibility of the data.
Confidence interval (if any)	Data such as upper, lower limit, probabilities	To estimate the accuracy of the failure rate given.
Further information concerning the data forming the basis for the failure rate	Age of data Component hours Failures Confidence limit and related data	
Originator information	Originator of the calculation Date of issue Date of storage in database	To ensure traceability.

~~Two concrete examples for using IEC 61709 as a basis for the development of a reliable failure rate database are the company handbooks IRPH:2003 and SN 29500 (see data source 8 and 9 in Table D.5).~~

Annex H
(informative)

Potential sources of failure rate data and methods of selection

H.1 General

When performing reliability prediction, it is advisable to use current reliable sources of field data whenever they are available and applicable as long as they are valid for the equipment. Annex H gives some guidance on how to select appropriate sources.

H.2 Data source selection

Data should be obtained from the following sources in the given order of preference:

- user data;
- manufacturer's data;
- handbook data.

If user data is available for the prediction then it should be used. If no user data is available then the manufacturer’s data should be examined and, if judged suitable, used. If no manufacturer’s data is available then handbook data or other data should be examined and, if judged suitable, used.

If no data source can be found, a risk assessment should be performed to determine the necessity tasks for obtaining further data, for example by a reliability test programme, whether to use expert judgement or whether to accept the fact that data is not available for the particular component under consideration. ~~Risk assessment techniques are described, for example, in IEC 60300-3-9.~~

In all cases however, in order to ensure that ~~any~~ work ~~performed~~ is technically correct, it is necessary to present justification for the choices made while the work is performed. It is normally necessary to justify the use of reliability prediction as a valid reliability technique before justifying the actual method and data sources used. In order to justify the use of the technique, in this case reliability prediction, there are a number of considerations that need to be made:

- if reliability prediction is the only way to perform the task or generate information then the justification should say why this is the only way;
- if reliability prediction is not the only way, yet it is the best way, then the justification should say why this is the best way;
- if reliability prediction is not the only way nor the best way then the justification should specify why it is being used.

Once reliability prediction is justified then the actual prediction methodology (parts count or parts stress or some hybrid) should be justified. This is carried out in the same manner as the justification for prediction:

- if method “X” is the only way to perform the prediction then the justification should say why this is the only way;
- if method “X” is not the only way to perform the prediction, yet it is the best way, then the justification should say why this is the best way;
- if method “X” is not the only way nor the best way then the justification should specify why it is being used.

Once the methodology is justified, the data sources used as input data should be justified. This is done in the same manner as above.

The justification should be recorded so that the decisions made during the process can be defended at some later date. The justification information can be used along with the results of a prediction as part of any ~~reliability~~ dependability case (as defined, for example, ~~by DEF00-42-3~~ in IEC 62741).

H.3 User data

User data is that which has been produced by the organization performing the prediction for the sole purpose of deriving reliability information about components that can be obtained in no other way. Data can be, for instance, from in house testing, user field experience, lessons learned, or expert judgement.

If user data is available, check whether data is collected and presented in accordance with applicable standards and a detailed review of data collection and analysis processes should be made. IEC 60300-3-2 and IEC 60300-3-5 are available guides to these processes.

For field data the following should be reviewed: data collection procedures, relevance of failures, and analysis techniques. Data required to quantify the prediction model is obtained from sources such as ~~company~~ warranty records, customer maintenance records, component suppliers, or expert elicitation from design or field service engineers. If field failure rate data has been collected then the conditions (environmental and functional stresses) for which the values are valid should also be stated.

For test data the following should be reviewed: tests and tests conditions applied to the components, lot sampling, number of lots, manufacturing, testing period, and failure analysis. When using failure rates that have been determined under laboratory test conditions a distinction should be made in the way in which failure rates are obtained, since in most cases, the failure criteria applicable to the test are not directly transferable to field applications and it is therefore advisable to use field data wherever it is available and applicable.

The failure rates stated should be understood as expected values for the stated time interval and the entirety of lots, and they should be operated under the stated conditions, i.e. it is to be expected that in future use under the given conditions the stated values will, on average, be obtained. Confidence limits for expected values of components are not reasonable because they only apply for estimated failure rates based on life tests.

H.4 Manufacturer’s data

Manufacturer’s data is that which is supplied by the manufacturer based on tests of a particular component.

If manufacturer’s data is available, check whether data is collected and presented in accordance with applicable standards and a detailed review of data collection and analysis processes should be made. IEC 60300-3-2 and IEC 60300-3-5 are available guides to these processes.

For manufacturer's data the following should be reviewed: tests and tests conditions applied to the components, lot sampling, number of lots, manufacturing and testing period, and failure analysis.

If a manufacturer's stated values originate from accelerated tests with high stresses and have been converted to normal levels of stress for a long period through undifferentiated use of conversion factors, they may deviate from the values observed in operation. Due to the different procedures used to determine failure rates by the manufacturer (e.g. worst case tolerance) and by the user (e.g. function maintained despite parameter changes, fault propagation law), more favourable values may be obtained.

H.5 Handbook reliability data

H.5.1 General

Failure rate data of components are published in several ~~well-known~~ reliability handbooks. Usually the data published is component data obtained from equipment in specific applications, for example telephone exchanges. In some cases the source of the data is unspecified and may not be obtained from field data. Due to this reason, failure rate predictions often differ significantly from field observations and can often lead to misleading conclusions.

Table H.2 provides information to the user concerning data sources for component failure rate determination. This list is not comprehensive and not necessarily maintained up to date, and is not intended to give a preference for sources. It remains up to the user to determine which data source is relevant for their application. Note that there are a number of handbooks and standards that describe reliability prediction, but only those that contain data are listed here. This information is given for the convenience of users of this document and does not constitute an endorsement by the IEC.

H.5.2 Using handbook data with this document

The following steps are recommended:

Step (1) Select an appropriate handbook (see H.5.3);

Step (2) Define reference conditions, for example those stated in this document (see Clauses 6 to 20);

Step (3) Determine the failure rate with these conditions.

Example:

For a general-purpose transistor, the failure rate at reference conditions should be determined. Results are given in Table H.1.

Step (1) Select a Handbook, e.g. MIL-HDBK-217F, 1995 (it serves here only as an example)

Step (2) Define reference conditions (see 7.1)

Reference junction temperature: $\theta_{\text{ref}} = 55\,°\text{C}$,

Voltage ratio: $U_{\text{ref}}/U_{\text{rat}} = 0{,}5$ (U_{ref} is 50 % of rated voltage)

Step (3) Determine failure rate at reference conditions (e.g. from MIL-HDBK-217F:1995, Clause 6.6)

$$\lambda_{\text{p}} = \lambda_{\text{b}} \times \pi_{\text{T}} \times \pi_{\text{R}} \times \pi_{\text{S}} \times \pi_{\text{Q}} \times \pi_{\text{E}}$$

$$\lambda_b = 0{,}18 \cdot 10^{-6}\ \text{h}^{-1}$$

$$\pi_{\text{T}} = 1{,}9 \text{ for } \theta_{\text{ref}} = 55\,°\text{C}$$

$$\pi_{\text{R}} = 0{,}43 \text{ for rated power} < 0{,}1\ \text{W}$$

$$\pi_{\text{S}} = 0{,}21 \text{ for } V_{\text{s}} \equiv U_{\text{ref}}/U_{\text{rat}} = 0{,}5$$

$$\pi_{\text{Q}} = 1,\ \pi_{\text{E}} = 1$$

$$\lambda_{\text{ref}} \equiv \lambda_{\text{p}} = 0{,}18 \cdot 10^{-6}\ \text{h} \times 1{,}9 \times 0{,}43 \times 0{,}21 \times 1 \times 1 \approx 30{,}9 \cdot 10^{-9}\ \text{h}^{-1}$$

Table H.1 – Result of calculation for transistors common, low frequency

Component	θ_{ref} °C	$U_{\text{ref}}/U_{\text{rat}}$	λ_{ref}
Bipolar, universal e.g. TO18, TO92, SOT(D)(3)23 or similar	55	0,5	$30{,}9 \cdot 10^{-9}$ h^{-1}
Transistor arrays	55		
Bipolar, low power e.g. TO5, TO39, SOT223, SO8, SMA-SMC	85		
Bipolar, power e.g. TO3, TO220, D(D)-Pack	100		
FET junction MOS	55 55		
MOS power (SIPMOS) e.g. TO3, TO220, D(D)-Pack	100		

H.5.3 List of available handbooks

Table H.2 – Sources of reliability data (in alphabetical order)

Data source	Short description
1. AT&T Reliability manual Klinger, David J.,Yoshinao Nakada, and Maria A. Menendez, Editors, AT&T Reliability Manual, Van Nostrand Reinhold, 1990, ISBN:0442318480	The AT&T reliability manual outlines prediction models and contains component failure data. The main prediction models include a decreasing hazard rate model for early life failures, which is modelled using Weibull data, and a steady- state hazard rate model using constant failure rate data. In this respect the handbook is unique.
~~2. Data collection for non electric reliability handbook. Volume 3, section 1, failure rate data (continued)~~ ~~National Technical information services. http://www.ntis.gov/search/product.aspx?ABBR=AD841108~~	~~The computer printout of non-electronic data is presented in three sections: Section I - Failure rate data, Section II - Stress level data/ part number, and Section III - Failure mode distributions~~
2. Prediction of component failure rates for PSA on nuclear power plants 1982-1997 Available as a paper: “Prediction of component failure rates for PSA on nuclear power plants 1982-1997”. Author; KIRIMOTO YOSHIHIRO (Cent. Res. Inst. of Electr. Power Ind., Nucl. Inf. Center) MATSUZAKI AKIHIRO(Cent. Res. Inst. of Electr. Power Ind., Nucl. Inf. Center) SASAKI ATSUSHI(Cent. Res. Inst. of Electr. Power Ind., Nucl. Inf. Center) Journal title; Denryoku Chuo Kenkyujo Genshiryoku Joho Senta Hokoku Journal Code:L2958A VOL.;NO.P00001;PAGE.104P(2001)	This document describes the revised component failure rate calculated by re-prediction on 49 Japanese light water reactors from 1982 to 1997.
3. FIDES Available on the internet	FIDES is a reliability data handbook developed by a consortium of French industry under the supervision of the French Department of Defense (DGA). The FIDES methodology is based on physics of failures and is supported by the analysis of test data, field returns and existing modelling
4. Guidelines for process equipment reliability data – With data tables Available from Center for Chemical Process Safety/AIChE ISBN: 978-0-8169-0422-8 Electronic ISBN: 978-1-59124-568-1.	These guidelines were written to provide process safety practitioners and their managers with the information required to estimate statistical failure rates for pumps, valves, heat exchangers, instruments and other chemical process equipment. The failure rates are essential for making a chemical process risk analysis to predict the risk of various process and facility scenarios.

Data source	Short description
5. HRD5: British Telecom Handbook of reliability data This method is available in a number of commercial reliability software packages.	HRD5 is a reliability standard developed by British Telecommunications plc that also provides models for a wide range of components. In general, HRD5 is similar to CNET 93, but provides simpler models and requires fewer data parameters for analysis.
6. IEEE ~~Gold book~~ 493-2007 Available from IEEE Customer Service	The IEEE ~~Gold~~ book with recommended practice for the design of reliable, industrial and commercial power equipment provides data concerning equipment reliability used in industrial and commercial power distribution equipment.
7. IRPH 2003: Italtel Reliability prediction Handbook Available from Italtel spa - Italy	The Italtel prediction handbook was first published in 1993 as the result of collaboration among many European organizations and companies, in particular a study group involving British Telecom, Italtel and CNET. The result of these studies lead to the publication of three virtually identical Handbooks, by CNET (RDF 93), Italtel (IRPH 93) and British Telecom (HRD 5). IRPH 2003 adopts the failure rate models of IEC 61709 (1996), with some simplifications to make them easier to use. Reference failure rates are mainly derived from field data and based on a collaboration with Siemens.
8. ~~MIL217~~ HDBK-217 Plus Available on the internet	Reliability Information Analysis Center (RIAC) replacement prediction methodology for MIL-HDBK-217
9. MIL-HDBK-217 MIL-HDBK-217F Reliability prediction of electronic equipment Available on the internet	MIL-HDBK-217, Reliability prediction of electronic equipment, has been the mainstay of reliability predictions for about 40 years ~~but it has not been updated since 1995, and at the current time of writing there are no plans by the Military to update it in the future~~.
10. ~~NPRD-95~~ NPRD 2016 Available on the internet	~~NPRD-95~~ NPRD 2016 data provides failure rates for a wide variety of items, including mechanical and electro-mechanical parts and assemblies. The document provides detailed failure rate data on over 25 000 parts for numerous part categories grouped by environment and quality level.
11. ~~NSWC-94/L07~~ NSWC-11 Handbook of reliability prediction procedures for mechanical equipment. Available on the internet	This handbook, developed by the Naval Surface Warfare Center – Carderock Division provides failure rate models for fundamental classes of mechanical components.
12. Offshore and onshore reliability data (OREDA) Available from Oreda	The handbooks contain reliability data from offshore equipment compiled in a form that can easily be used for various safety, reliability and maintenance analysis.
13. UTE C80-810 Available from AFNOR	This handbook is known as UTE C80-810 Reliability data handbook. This handbook covers most of the same components as MIL-HDBK-217. This handbook was originally named RDF.
~~14. PRISM (RAC / EPRD)~~ ~~Available from:~~ ~~http://src.alionscience.com/prism~~	~~The RAC (EPRD) Electronic parts reliability data handbook database is the same as that previously used to support the MIL-HDBK-217, and is supported by a software tool marketed under the name of PRISM~~
14. Reliability data for safety instrumented equipment PDS data handbook, 2006 Edition Available on the internet	Reliability data dossiers for field devices (sensors, valves) and control logic (electronics) are presented, including data for subsea equipment.

Data source	Short description
~~15. RDF:2003~~ ~~The standard is available at:~~ ~~UTE~~ ~~Union Technique de l'électricité et de la Communication~~ ~~l'Immeuble VOLTA~~ ~~33, avenue du Général Leclerc~~ ~~BP 23~~ ~~92262 Fontenay-aux-Roses Cedex, France~~	~~RDF:2003 is the latest version of the CNET handbook.~~ ~~This handbook has been adopted by UTEC and is known as UTEC80810 Reliability data handbook. This handbook covers most of the same components as MIL-HDBK-217~~
15. Failure Mode/Mechanism Distributions FMD-2016 Available on the internet	FMD-2016 Databook contains field failure mode and mechanism distribution data on a variety of electrical, mechanical, and electromechanical parts and assemblies.
~~16. IEC/TR 62380 – Reliability data handbook — Universal model for reliability prediction of electronics components, PCBs and equipment~~ ~~Available from:~~ ~~IEC standards stockist~~	~~This technical report provides elements to calculate failure rate of mounted electronic components. It makes equipment reliability optimization studies easier to carry out, thanks to the introduction of influence factors.~~ ~~**WARNING**: Some of the procedures in IEC/TR 62380 conflict with those in this standard~~
16. Safety Equipment Reliability Handbook ~~– 2nd~~ 4th Edition Available from ISA (International Society of Automation)	This publication contains information on failure rates, failure mode distributions, diagnostic detection capability, and common cause susceptibility. This handbook was created to supply that information in a format specific to safety integrity verification. The data is formatted such that it can be directly used in safety verifications and to allow for easy comparison of equipment items or designs.
17. Siemens SN 29500 Available from Siemens AG Corporate Technology	The Siemens SN 29500 failure rates of components and expected values method was developed by Siemens AG for use of Siemens and Siemens associates as a uniform basis for reliability prediction. SN 29500 is based on IEC 61709 and states failure rates under reference conditions as described in this document.
~~18. Reliability failure rate/mode handbook, section 3.1, integrated circuit failure rates~~ ~~Available from:~~ ~~RIAC, 6000 Flanagan Road, Suite 3, Utica NY 13502-1348~~ ~~Phone: 315.351.4200~~ ~~Toll free: 877.363 RIAC (7422)~~	~~This document includes a set of tables giving experienced field failure rates, of integrated circuits, a prediction procedure for hybrid microcircuits and a set of graphs giving failure rates of IC's as a function of temperature obtained primarily from laboratory tests of IC's at elevated temperatures~~
18. TELCORDIA SR-332 This method is available in a number of commercial reliability software packages.	The SR–332, Reliability prediction procedure for electronic equipment, documents the recommended methods for predicting device and unit hardware reliability.
19. Various software	Many pieces of reliability software contain reliability data. In many cases this is data taken from one of the above sources but in some cases the data is unique to the software.

Annex I
(informative)

Overview of component classification

I.1 General

Component identification is the most important element of any codification system because it establishes a unique identification for every item of supply. The identification consists of the minimum data required to establish clearly the essential characteristics of the item, i.e. those characteristics that give it a unique character and differentiate it from all others. Annex I gives a brief overview of the generic component description standards which may be encountered. Unfortunately it is not possible to give a translation table between these descriptions and the one used in this document.

This document recommends the use of the IEC 61360 standards to define the component type. This component tree is described in Table I.1 and will allow users of the IEC 61360 descriptions to find component models easily in this document.

I.2 The IEC 61360 system

This document provides a basis for the clear and unambiguous definition of characteristic properties (data element types) of all elements of electrotechnical equipment from basic components to subassemblies and full equipment. Although originally conceived in the context of providing a basis for the exchange of information on electric components, it may be used in areas outside the original conception such as assemblies of components and electrotechnical equipment and sub-equipment.

It provides for establishing a classification hierarchy and the allocation of applicable and relevant properties to each of the classes so established in order to describe fully the characteristics of objects belonging to that class and hence it facilitates the exchange of data describing electrotechnical equipment through a defined structure in order for the information to be exchanged in a computer-sensible form.

The part of IEC 61360 that is of interest is IEC 61360-4 which provides the IEC reference collection of classes and associated characteristic properties for electric components and materials used in electrotechnical equipment. Table I.1 contains the classification tree for IEC 61360-4 cross-referenced against the relevant clause in this document. In cases where no such data exists in this document, the clause is noted as “N/A” (not available). Where this document contains lower level detail in terms of component types than in IEC 61360-4, then the clause will have “+” noted beside it.

In Table I.1 below, the headings L1 to L5 represent the descriptive level tags given in IEC 61360-4~~:2005~~. Each level tag adds another layer of description to the component type. Note that for completeness each of these descriptions ~~shall~~ should have the terms “IECREF:CO:EE” for “IEC reference collection, Components, Electric-Electronic” or “IECREF:CO:EM” for “IEC reference collection, Components, Electromechanical” placed in front of it. Hence the full code for a “fixed air capacitor” would be “IECREF:CO:EE:CAP:FIX:AIR”.

Note also that only the component categories are listed in Table I.1, the geometric data has been omitted.

Table I.1 – Classification tree (IEC 61360-4)

Component description	IEC 61360-4 classification tree					Clause in this document
	L1	L2	L3	L4	L5	
ELECTRIC COMPONENTS						
Amplifier	AMP					6+
Amplifier, low frequency	AMP	LF				6+
Amplifier, low frequency power	AMP	LF	PWA			6+
Amplifier, low frequency voltage	AMP	LF	VTA			6+
Amplifier, low frequency voltage differential	AMP	LF	VTA	DFA		6+
Amplifier, low frequency voltage differential AC-coupled	AMP	LF	VTA	DFA	ACA	6+
Amplifier, low frequency voltage differential DC-coupled	AMP	LF	VTA	DFA	OPA	6+
Amplifier, low frequency voltage single sided	AMP	LF	VTA	SSA		6+
Amplifier, radio frequency	AMP	RF				6+
Amplifier, wide band	AMP	WB				6+
Antenna	ANT					N/A
Antenna, capacitive (whip)	ANT	CAP				N/A
Antenna, inductive (ferroceptor)	ANY	IND				N/A
Antenna, resistive (tuned dipole)	ANY	RES				N/A
Battery	BAT					N/A
Battery, primary	BAT	PRI				N/A
Battery, secondary	BAT	SEC				N/A
Capacitor	CAP					9+
Capacitor, fixed	CAP	FIX				9+
Capacitor, fixed air	CAP	FIX	AIR			9+
Capacitor, fixed ceramic	CAP	FIX	CER			9+
Capacitor, fixed ceramic, class 1	CAP	FIX	CER	CL1		9+
Capacitor, fixed ceramic, class 2	CAP	FIX	CER	CL2		9+
Capacitor, fixed, electrolytic	CAP	FIX	ELC			9+
Capacitor, fixed electrolytic with solid tantalum electrolyte	CAP	FIX	ELC	STAN		9+
Capacitor, fixed electrolytic with non-solid tantalum electrolyte	CAP	FIX	ELC	NTAN		9+
Capacitor, fixed electrolytic with solid aluminium electrolyte	CAP	FIX	ELC	SAL		9+
Capacitor, fixed electrolytic with non-solid aluminium electrolyte	CAP	FIX	ELC	NAL		9+
Capacitor, fixed, film	CAP	FIX	FLM			9+
Capacitor, fixed, glass	CAP	FIX	GLS			9+
Capacitor, fixed, mica	CAP	FIX	MIC			9+
Capacitor, fixed, multilayer	CAP	FIX	MLAY			9+
Capacitor, fixed, paper	CAP	FIX	PAP			9+

Component description	**IEC 61360-4 classification tree**					**Clause in this document**
	L1	**L2**	**L3**	**L4**	**L5**	
Capacitor, variable	CAP	VAR				9+
Conductor	CND					N/A
Conductor, bare	CND	BAR				N/A
Conductor, insulated	CND	INS				N/A
Conductor, insulated, cable	CND	INS	CBL			N/A
Conductor, insulated, cable, power	CND	INS	CBL	POW		N/A
Conductor, insulated, cable, signal	CND	INS	CBL	SIG		N/A
Conductor, insulated, cable, signal, low frequency	CND	INS	CBL	SIG	LF	N/A
Conductor, insulated, cable signal, high frequency	CND	INS	CBL	SIG	HF	N/A
Conductor, insulated, insulated wire (single conductor)	CND	INS	IWR			N/A
Delay line	DEL					N/A
Diode device	DID					7+
Diode device, bridge rectifier	DID	BRI				7+
Diode device, diode	DID	DIO				7+
Diode device, diode, break over diode	DID	DIO	BOD			7+
Diode device, diode, rectifier diode	DID	DIO	REC			7+
Diode device, diode, signal diode	DID	DIO	SIG			7+
Diode device, diode, stabilizer diode	DID	DIO	STB			7+
Diode device, diode, stabilizer diode, current regulator	DID	DIO	STB	CUR		7+
Diode device, diode, stabilizer diode, voltage reference	DID	DIO	STB	REF		7+
Diode device, diode, stabilizer diode, voltage regulator	DID	DIO	STB	REG		7+
Diode device, diode, stabilizer diode, stabistor	DID	DIO	STB	STA		7+
Diode device, diode, stabilizer diode, transient suppressor	DID	DIO	STB	SUP		7+
Diode device, diode, variable	DID	DIO				7+
Diode device, voltage multiplier	DID	VMP				7+
Fibre optics	FIBOPTIC					8+
Fibre optics, links	FIBOPTIC	LINKS				8+
Fibre optics, connectors	FIBOPTIC	CONN				8+
Fibre optics, switched	FIBOPTIC	SWI				8+
Fibre optics, branches	FIBOPTIC	BRA				8+
Fibre optics, couplers/splitters	FIBOPTIC	COUP				8+
Fibre optics, attenuators	FIBOPTIC	ATT				8+
Fibre optics, detectors	FIBOPTIC	DET				8+
Fibre optics, isolators	FIBOPTIC	ISOL				8+
Fibre optics, networks	FIBOPTIC	NETW				8+
Fibre optics, light sources	FIBOPTIC	SOURC				8+
Fibre optics, modulators	FIBOPTIC	MOD				8+

Component description	IEC 61360-4 classification tree					Clause in this document
	L1	L2	L3	L4	L5	
Fibre optics, transmitters/receivers	FIBOPTIC	TXRX				8+
Fibre optics, waveguides	FIBOPTIC	WG				8+
Fibre optics, cables	FIBOPTIC	CAB				8+
Fibre optics, filters	FIBOPTIC	FIL				8+
Fibre optics, lens	FIBOPTIC	LENS				8+
Filter	FIL					12
IC	IC					6+
IC, analog/digital	IC	AD				6+
IC, analog	IC	ANA				6+
IC, digital	IC	DIG				6+
IC, digital, combinational sequential interface (CSI)	IC	DIG	CSI			6+
IC, digital, microcontroller	IC	DIG	MUC			6+
IC, digital, microprocessor	IC	DIG	MUP			6+
IC, digital, programmable logic device (PLD)	IC	DIG	PLD			6+
IC, digital, storage	IC	DIG	STO			6+
IC, digital, storage, CAM	IC	DIG	STO	CAM		6+
IC, digital, storage, CCD	IC	DIG	STO	CCD		6+
IC, digital, storage, RAM	IC	DIG	STO	RAM		6+
IC, digital, storage, RAM, dynamic	IC	DIG	STO	RAM	DRAM	6+
IC, digital, storage, RAM, static	IC	DIG	STO	RAM	SRAM	6+
IC, digital, storage, ROM	IC	DIG	STO	ROM		6+
IC, digital, storage, register	IC	DIG	STO	REG		6+
IC, periodic/DC	IC	PER				6+
Inductor	IND					11+
Inductor, fixed	IND	FIX				11+
Inductor, fixed, deflection units	IND	FIX	DFL			11+
Inductor, fixed, choke	IND	FIX	CHOKE			11+
Inductor, fixed, coil	IND	FIX	COIL			11+
Inductor, fixed, linearity control unit	IND	FIX	LININUT			11+
Inductor, fixed, antenna inductors	IND	FIX	ANT			11+
Inductor, fixed, solenoids	IND	FIX	SOL			11+
Inductor, variable	IND	VAR				11+
Lamp	LAM					18+
LCD	LCD					8+
Microwave components	MIC					12+
Optoelectronic device	OPT					8+
Optoelectronic device, image pickup device	OPT	IMAGE				8+
Optoelectronic device, photocoupler	OPT	PHC				8+
Optoelectronic device, photoemmiter	OPT	PHE				8+

Component description	IEC 61360-4 classification tree					Clause in this document
	L1	L2	L3	L4	L5	
Optoelectronic device, photoemmiter, infrared emitting diode	OPT	PHE	IRD			8+
Optoelectronic device, photoemmiter, LASER	OPT	PHE	LAS			8+
Optoelectronic device, photoemmiter, LED	OPT	PHE	LED			8+
Optoelectronic device, photosensor	OPT	PHS				8+
Optoelectronic device, photosensor, infrared	OPT	PHS	IR			8+
Optoelectronic device, photosensor, ultraviolet	OPT	PHS	U			8+
Optoelectronic device, photosensor, visible radiation	OPT	PHS	VIS			8+
Oscillator	OSC					13+
Piezoelectric device	PE					13+
Printed wiring circuit	PWC					N/A
Resistor	RES					10+
Resistor, fixed	RES	FIX				10+
Resistor, fixed, linear	RES	FIX	LIN			10+
Resistor, fixed, linear, resistor network	RES	FIX	LIN	MUL		10+
Resistor, fixed, linear, single	RES	FIX	LIN	SIN		10+
Resistor, fixed, linear, single, chip	RES	FIX	LIN	SIN	CHIP	10+
Resistor, fixed, linear, single, fusing	RES	FIX	LIN	SIN	FUS	10+
Resistor, fixed, linear, single, low power	RES	FIX	LIN	SIN	LP	10+
Resistor, fixed, linear, single, precision	RES	FIX	LIN	SIN	PREC	10+
Resistor, fixed, linear, single, power	RES	FIX	LIN	SIN	PWR	10+
Resistor, fixed, linear, single, PTC	RES	FIX	LIN	SIN	THERM	10+
Resistor, fixed, non-linear	RES	FIX	NLN			10+
Resistor, fixed, non-linear, light dependent	RES	FIX	NLN	LDR		10+
Resistor, fixed, non-linear, thermistor	RES	FIX	NLN	TDR		10+
Resistor, fixed, non-linear, thermistor, NTC	RES	FIX	NLN	TDR	NTC	10+
Resistor, fixed, non-linear, thermistor, PTC	RES	FIX	NLN	TDR	PTC	10+
Resistor, fixed, non-linear, varistor	RES	FIX	NLN	VDR		10+
Resistor, variable	RES	VAR				10+
Resistor, variable, potentiometer	RES	VAR	POT			10+
Resistor, variable, potentiometer, preset	RES	VAR	POT	PRESET		10+
Resistor, variable, potentiometer, rotary precision	RES	VAR	POT	PRECROT		10+
Resistor, variable, potentiometer, slide	RES	VAR	POT	SLIDE		10+

Component description	**IEC 61360-4 classification tree**					**Clause in this document**
	L1	**L2**	**L3**	**L4**	**L5**	
Resistor, variable, potentiometer, low power rotary	RES	VAR	POT	LPROT		10+
Resistor, variable, potentiometer, power rotary	RES	VAR	POT	PWRPROT		10+
Resistor, variable, two terminal	RES	VAR	TT			10+
Resonator	RESON					13+
Sensor	SEN					N/A
Sensor, relative humidity	SEN	HUM				N/A
Sensor, light	SEN	LGT				N/A
Sensor, magnetic field strength	SEN	MGN				N/A
Sensor, nuclear	SEN	NCL				N/A
Sensor, pressure	SEN	PRS				N/A
Sensor, proximity	SEN	PRX				N/A
Sensor, temperature	SEN	TMP				N/A
Spark gaps	SPARK					N/A
Spark gaps, air	SPARK	AIR				N/A
Spark gaps, gas filled	SPARK	GAS				N/A
Transformers	TFM					11+
Transformers, power	TFM	POW				11+
Transformers, power, fixed	TFM	POW	FIX			11+
Transformers, power, variable	TFM	POW	VAR			11+
Transformers, signal	TFM	SIG				11+
Transformers, signal, fixed	TFM	SIG	FIX			11+
Transformers, signal, variable	TFM	SIG	VAR			11+
Transistors	TRA					7+
Transistors, bipolar	TRA	BIP				7+
Transistors, bipolar, power	TRA	BIP	POW			7+
Transistors, bipolar, power, low frequency	TRA	BIP	POW	LF		7+
Transistors, bipolar, power, high frequency	TRA	BIP	POW	HF		7+
Transistors, bipolar, signal	TRA	BIP	SIG			7+
Transistors, bipolar, signal, low frequency	TRA	BIP	SIG	LF		7+
Transistors, bipolar, signal, high frequency	TRA	BIP	SIG	HF		7+
Transistors, FET	TRA	FET				7+
Transistors, FET, power	TRA	FET	POW			7+
Transistors, FET, power, low frequency	TRA	FET	POW	LF		7+
Transistors, FET, power, high frequency	TRA	FET	POW	HF		7+
Transistors, FET, small signal	TRA	FET	SIG			7+
Trigger device	TRG					7+
Trigger device, DIAC	TRG	DIA				7+
Trigger device, thyristor	TRG	THY				7+
Trigger device, thyristor, fast turn off	TRG	THY	FTO			7+
Trigger device, thyristor, gate turn off	TRG	THY	GTO			7+

Component description	IEC 61360-4 classification tree					Clause in this document
	L1	L2	L3	L4	L5	
Trigger device, thyristor, reverse blocking	TRG	THY	RVB			7+
Trigger device, TRIAC	TRG	TRI				7+
Tubes	TUB					N/A
Tubes, CRT	TUB	CRT				N/A
Tubes, CRT, colour display	TUB	CRT	COL			N/A
Tubes, CRT, monochrome display	TUB	CRT	MCR			N/A
Tubes, gas filled	TUB	GAS				N/A
Tubes, photo sensitive	TUB	PHO				N/A
Tubes, space charge controlled	TUB	SCC				N/A
Tubes, space charge wave	TUB	SCW				N/A
Tuner	TUN					N/A
ELECTROMECHANICAL COMPONENTS						
Connector	CON					14+
Connector, circular	CON	CIRC				14+
Connector, IC	CON	IC				14+
Connector, plug and jack	CON	JACK				14+
Connector, plug and jack, plug assembly	CON	JACK	ASSY			14+
Connector, plug and jack, complex jack boards	CON	JACK	CMPLX			14+
Connector, plug and jack, concentric type	CON	JACK	CONC			14+
Connector, plug and jack, concentric type, jack	CON	JACK	CONC	JACK		14+
Connector, plug and jack, concentric type, multiple	CON	JACK	CONC	MULT		14+
Connector, plug and jack, concentric type, plug	CON	JACK	CONC	PLUG		14+
Connector, plug and jack, pin type	CON	JACK	PIN			14+
Connector, plug and jack, pin type, jack	CON	JACK	PIN	JACK		14+
Connector, plug and jack, pin type, multiple jack	CON	JACK	PIN	MULT		14+
Connector, plug and jack, pin type, plug	CON	JACK	PIN	PLUG		14+
Connector, plug and jack, pin type, shielded jack	CON	JACK	PIN	SHLD		14+
Connector, plug and jack, D.C. power type	CON	JACK	PWR			14+
Connector, plug and jack, D.C. power type, car	CON	JACK	PWR	CAR		14+
Connector, plug and jack, D.C. power type, jack	CON	JACK	PWR	JACK		14+
Connector, plug and jack, D.C. power type, plug	CON	JACK	PWR	PLUG		14+
Connector, modular	CON	MOD				14+
Connector, printed circuit board	CON	PCB				14+
Connector, rectangular	CON	RECT				14+

Component description	**IEC 61360-4 classification tree**					**Clause in this document**
	L1	**L2**	**L3**	**L4**	**L5**	
Connector, radio frequency	CON	RF				14+
Connector, sockets	CON	SOCK				14+
Connector, sockets, antenna feeder	CON	SOCK	ANT			14+
Connector, sockets, fuse holder	CON	SOCK	FUSE			14+
Connector, sockets, IC	CON	SOCK	IC			14+
Connector, sockets, light	CON	SOCK	LIGHT			14+
Connector, sockets, PCB	CON	SOCK	PCB			14+
Connector, sockets, power socket	CON	SOCK	PWR			14+
Connector, sockets, signal socket	CON	SOCK	SIG			14+
Connector, sockets, transistor	CON	SOCK	TRA			14+
Connector, sockets, tube	CON	SOCK	TUBE			14+
Connector, sockets, quartz crystal	CON	SOCK	XTAL			14+
Connector, terminals	CON	TERM				14+
Connector, terminals, array	CON	TERM	ARRY			14+
Connector, terminals, board	CON	TERM	BRD			14+
Connector, terminals, rod	CON	TERM	ROD			14+
Connector, terminals, small	CON	TERM	SM			14+
Connector part	CONPART					14+
Connector part, contact	CONPART	CONTACT				14+
Connector part, accessories	CONPART	ACCY				14+
Connector part, tool	CONPART	TOOL				14+
Connector part, shell	CONPART	SHELL				14+
Connector part, insert	CONPART	INSERT				14+
Fuse	FUS					13+
Fuse, current activated	FUS	CUR				13+
Fuse, thermally activated	FUS	TERM				13+
Loudspeaker	LSP					N/A
Loudspeaker, electromagnetic	LSP	ELM				N/A
Loudspeaker, electrostatic	LSP	ELS				N/A
Loudspeaker, ionic	LSP	ION				N/A
Loudspeaker, magnetodynamic	LSP	MGD				N/A
Loudspeaker, magnetostrictive	LSP	MGS				N/A
Loudspeaker, moving conductor	LSP	MVC				N/A
Loudspeaker, piezoelectric	LSP	PXE				N/A
Loudspeaker, pneumatic	LSP	PNM				N/A
Microphone	MIC					N/A
Motor	MOT					N/A
Motor, linear	MOT	LIN				N/A
Motor, linear, AC	MOT	LIN	AC			N/A
Motor, linear, DC	MOT	LIN	DC			N/A
Motor, linear, step	MOT	LIN	STP			N/A
Motor, linear, universal	MOT	LIN	UNI			N/A
Motor, rotational	MOT	ROT				N/A

Component description	IEC 61360-4 classification tree					Clause in this document
	L1	L2	L3	L4	L5	
Motor, rotational, AC	MOT	ROT	AC			N/A
Motor, rotational, DC	MOT	ROT	DC			N/A
Motor, rotational, step	MOT	ROT	STP			N/A
Motor, rotational, universal	MOT	ROT	UNI			N/A
Relay	REL					16+
Switch	SWI					17+
Switch, mechanical	SWI	MEC				17+
Switch, reed	SWI	REE				17+
Switch, thermostatic	SWI	THE				17+
MAGNETIC PARTS						
Hard magnetic part	HRD					N/A
Soft magnetic part	SFT					N/A

I.3 Other systems

I.3.1 General

This information is given for the convenience of users of this document and does not constitute an endorsement by the IEC.

I.3.2 NATO stock numbers

The NATO Codification System (NCS) has been in place since the mid-1950s. It provides standards for the use of common stock identification equipment throughout the NATO alliance. The NCS identification process is based on the "item of supply" concept, a term which refers to an item required for acquisition in order to satisfy a logistics need. It can consist of one or many "items of production" (i.e. a product of a specific manufacturer) having equivalent "fundamental characteristics". The NCS provides NATO countries with uniform and common equipment for the identification, classification, and stock numbering of items of supply.

I.3.3 UNSPSC codes

The United Nations Standard Products and Services Code® (UNSPSC®) provides an open, global multi-sector standard for efficient, accurate classification of products and services. This code is used to classify all products and services. It was jointly developed by the United Nations Development Programme (UNDP) and Dun & Bradstreet Corporation (D & B) in 1998.

I.3.4 STEP/EXPRESS

STEP (Standard for the Exchange of Product data) is the colloquial term for ISO 10303-31:1994~~. STEP is developed by ISO TC184/SC4~~ and is targeted at the exchange of data describing a product between computer aided engineering equipment (e.g. CAD, CAM), and also long-term retention of such data.

EXPRESS is the language used within STEP to formally define the semantics of the data. It is a lexical object information modelling language and is defined in ISO 10303-11:2004. EXPRESS is used in many other activities outside STEP.

I.3.5 IECQ

IECQ is a body that awards qualification of various different types to the manufacturers of components. In order to do this it specifies the standards (called blank detail specifications) that a component ~~shall~~ should meet. Each of these standards has a number and components of that particular quality are often called by the number of the relevant standard~~, for instance discrete semiconductor devices are coded under the QC 700000 generic specification~~.

I.3.6 ECALS

The computer readable standard dictionary of semiconductor devices and general electronic components (usually referred to as the "ECALS Dictionary") was developed by the standardization project of the ECALS steering committee of the Japan Electronic and Information Technology Industries Association (JEITA). It is based on the standard developed in the ECALS-2 project on development of a global supply chain foundation for semiconductors and electronic components, one of the advanced information development experimental tasks of the Ministry of International Trade and Industry (MITI) of Japan through the Information-Technology Promotion Agency of Japan. For harmonization with ~~international~~ standards, the ECALS Dictionary has been developed pursuant and with reference to IEC 61360 (all parts) and to ISO 13584 (all parts) to the greatest possible extent.

I.3.7 ISO 13584

ISO 13584 is not a series of standards that defines electric components per se, it comprises however a series of ~~International~~ standards for the computer-sensible representation and exchange of part library data. The objective is to provide a mechanism capable of transferring parts library data, independent of any application which uses a parts library data base. The nature of this description makes it suitable not only for the exchange of files containing parts, but also as a basis for implementing and sharing databases of parts library data.

I.3.8 MIL specifications

A United States defence standard, often called a military standard, "MIL-STD", or "MIL-SPEC", is used to help achieve standardization objectives by the U.S. Department of Defence. According to the Government Accountability Office (GAO), military specifications "describe the physical and/or operational characteristics of a product", while military standards detail the processes and materials to be used to make the product. The GAO acknowledges, however, that the terms are often used interchangeably.

The MIL-SPEC documents define various component types, for instance MIL-C-18312 describes fixed capacitors with a metallized paper-plastic, or plastic film dielectric, for use in direct current application and packaged in a hermetically sealed metal case. In many organizations the component types become known by the MIL specification number (in this case, 18312).

Annex J
(informative)

Presentation of component reliability data

J.1 General

This document requires failure rates in order to be useful. As has already been explained (see H.5.3) these can be obtained from a number of sources, the most useful of which would be from field operation data. The second best sources is to obtain the data from component manufacturers and Annex J outlines how this data should be presented for use with this document. It is most likely that this form of manufacture data will be derived from tests.

Annex J outlines the content of a report generated by the component manufacturer and describes the data that should be contained within it. This is based on the standard IEC 60319 and replaces guidance previously provided by that standard.

It is essential for component manufacturers to present reliability data for users in order to make decisions on use as well as predict failure rates and risks. It is essential that the component manufacturers provide summary data on reliability characteristics and factors affecting the failure rate prediction of the components in the component data sheets. It is essential that this is provided in a concise fashion. It should not be necessary for users to look at several documents to get the basic data. In order to be concise, detailed reliability test data should be provided separately if required.

As a minimum any manufacturer’s data report should contain information on the following:

1) Component identification and specification data
    a) Identification
    b) Component technology
2) Specification of component
    a) Electrical specification of component
    b) Environmental specification of component
3) Component test related data
    a) Method of selection of test components
    b) Test conditions
    c) Data on failures during test

The following clauses outline the minimum recommended contents of these data items.

J.2 Identification of components

J.2.1 General

The information supplied to identify the components should be in accordance with the relevant IEC or internationally recognized management quality systems publications for the component type under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other component specifications should be used and the source of the specifications stated. As a minimum, the following information should be given. Only information applicable to a particular component type should be supplied.

Examples of the specific information required for different component types can be found in IEC 61360-4.

J.2.2 Component identification

- A description of the component type with sufficient details to uniquely identify the component type, for example N-channel V-MOS transistor. When available, specification numbers should be given.
- The component part number. If available, a universal part number, for example stock number, should be given; otherwise a part number specific to the component manufacturer may be given.
- Name of the manufacturer and place of manufacture. The purpose of these references is to allow access to more detailed information if required.
- The date of manufacture or lot number or other production batch related identification.
- The production status of the component, for example development sample, pre-production, standard production, mature technology.
- Information regarding compliance with other recognized standards should be given whenever possible.

J.2.3 Component technology

- A description of the basic component technology, for example metal film resistor.
- A general description of the production process, for example ion beam epitaxy.
- Packaging information, for example plastic, hermetic weld.
- Thermal resistance, for example $R_{\text{thj-a}}$, $R_{\text{thj-c}}$.
- Complexity of circuit.
- Method of termination, for example end caps, DIL, SMD.

J.3 Specification of components

J.3.1 General

The information supplied to specify the components should be in accordance with the relevant IEC or internationally recognized management quality systems publications for the component type under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other component specifications should be used and the source of the specifications stated. As a minimum, the following information should be given.

J.3.2 Electrical specification of components

- Relevant information about ratings and characteristics should be supplied. These references taken from the applicable component specifications will depend on the type of test performed. For example, if power cycling tests are performed then the ratings for power dissipation should be given.
- Information should be given about any pre-test screening the components to be tested may have undergone. The results of such screening should be given.

J.3.3 Environmental specification of components

Information should be given regarding the maximum environmental conditions the components can withstand, for example temperature, humidity, acceleration.

J.4 Test related issues data

J.4.1 General

The test and sampling conditions should be those described in the relevant IEC or internationally recognized management quality systems publications for the components under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other test specifications should be used and the source of the specifications stated. The following minimum information should be supplied.

Data obtained from reliability tests should be presented using graphical methods whenever possible.

J.4.2 Actual test conditions

- The source of the results, for example the quality assurance department of the manufacturer.
- A description of the test conditions used, for example the electrical, mechanical and environmental conditions. The test conditions should be identified by quoting the relevant test specifications where possible.
- The number of components under test. Where a component is available in a number of different values, for example resistors, capacitors, the values tested and the quantity of each value should be stated.
- A description of the characteristic measured, for example resistance, and the measuring conditions. Where the measurement conditions are specified by IEC or other specifications, then the specification number should be given.
- If more than one method of characteristic measurement is permissible then a description of the method used should be given. This description should contain all relevant details.
- The test start date, duration and measurement intervals should be stated.
- Where a delay exists between the cessation of the test and the commencement of measurements, then the time duration should be stated. The storage conditions during this delay should also be stated. Any conditioning stress applied to the components before measurement should also be stated.

J.5 Data on test failures

- The number of failures observed, categorized by test conditions and type of failure. Failure modes should be stated with percentage occurrence. Identified failure mechanisms should be stated with their associated activation energies and temperature ranges.
- The times at which the failures occurred or were verified.
- Special events during testing, for example events which might have affected the results.
- Complete data from tests should be presented whenever possible but if data from tests are discarded, these data and the reasons why they are not given in the presentation or results, should be given separately.
- Failure criteria for the components are normally defined by the requirements given by the specification to which reference is made in the test report. If failure criteria for the components are not given by the reference specification, they should be stated.
- Failure rate which can be assumed to be constant
  - The test time of components during which the failure rate is assumed to be constant should be indicated. Failure rates found will preferably be stated in failures per 10^9 hours of operation. The value of 60 % is often used as the upper confidence level for failure rates.
- Failure rate which cannot be assumed to be constant
  - The total test time can be divided into a number of separate periods and the results for each of these periods evaluated separately. The necessary time periods which have to be distinguished and the number of failures which occur during each time period should be given. If the results can be satisfactorily approximated by a mathematical function, it would be useful to present these functions, as well as the period during which they are applicable. In all cases, mean lifetime, failure distribution and the influence of derating should be stated. For life-limited components, an appropriate model should be suggested, for example Weibull distribution.

- Influence of stresses
    - As failure rates are dependent on the type and the intensity of stress, all failure rate data should be presented with the applied stress levels. Furthermore, it can be important to know the correlation between failure rate and stress (temperature, power, vibration, etc.) and, where possible, the activation energy of the failure mechanism should be supplied. Therefore, failure rate values obtained at different stress levels should be supplied separately.

Annex K
(informative)

Examples

K.1 Integrated circuit

For a bipolar random access memory device, the stated reference failure rate is $\lambda_{\text{ref}} = 10^{-7}\ \text{h}^{-1}$ at the virtual (equivalent) junction temperature of $\theta_{\text{ref}} = 75\ °\text{C}$ (based on the component ambient temperature of 40 °C and the reference self-heating of ΔT_{ref} of 35 °C).

What is the value of the failure rate at an ambient temperature of θ_{amb} = 65 °C and the self-heating of 35 °C?

Step (1): $\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}}$ for ICs from Equation (10).

Step (2): $\pi_{\text{T}} = 2{,}9$ follows from Table 14 with the virtual junction temperature under reference conditions $\theta_{\text{ref}} = 75\ °\text{C}\ (= 40\ °\text{C} + 35\ °\text{C})$, and the actual virtual junction temperature $\theta_{\text{op}} = \theta_{\text{amb}} + \Delta T_{\text{ref}} = 65\ °\text{C} + 35\ °\text{C} = 100\ °\text{C}$.

Step (3): Perform the calculation; the failure rate at $\theta_{\text{amb}} = 65\ °\text{C}$ is obtained as $\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} = 10^{-7}\text{h}^{-1} \times 2{,}9 = 2{,}9 \times 10^{-7}\text{h}^{-1} = 290\ \text{FIT}$ $\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} = 10^{-7}\ \text{h}^{-1} \times 2{,}9 = 290 \cdot 10^{-9}\ \text{h}^{-1}$.

K.2 Transistor

For a general-purpose transistor, the stated failure rate at the reference junction temperature $\theta_{\text{ref}} = 55\ °\text{C}$ and the reference voltage ratio $U_{\text{ref}}/U_{\text{rat}} = 0{,}5$ is given as $\lambda_{\text{ref}} = 2 \cdot 10^{-8}\ \text{h}^{-1}$. The operating voltage ratio is $U_{\text{op}}/U_{\text{rat}} = 0{,}8$.

What is the failure rate value at a junction temperature of $\theta_{\text{op}} = 90\ °\text{C}$?

Step (1): $\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}}$ for transistors from Equation (13).

Step (2): $\pi_{\text{U}} = 1{,}26$ follows from Table 21 for $U_{\text{op}}/U_{\text{rat}} = 0{,}8$.

Step (3): $\pi_{\text{T}} \approx 4{,}2$ follows from Table 23, with the reference junction temperature $\theta_{\text{ref}} = 55\ °\text{C}$, and the actual junction temperature $\theta_{\text{op}} = 90\ °\text{C}$.

Step (4): Perform the calculation, thus the failure rate at $\theta_{\text{op}} = 90\ °\text{C}$ and $U_{\text{op}}/U_{\text{rat}} = 0{,}8$ is obtained as:

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} = 2 \times 10^{-8}\text{h}^{-1} \times 1{,}26 \times 4{,}2 \approx 1{,}06 \times 10^{-7}\text{h}^{-1}$ ~~= 1,058×10⁻⁷ h⁻¹ ≈ 106 FIT.~~

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} = 2 \cdot 10^{-8}\ \text{h}^{-1} \times 1{,}26 \times 4{,}2 \approx 106 \cdot 10^{-9}\ \text{h}^{-1}$$

K.3 Capacitor

For a polypropylene film metal foil capacitor, the stated failure rate at the ambient temperature θ_{amb} of 50 °C and the reference voltage ratio of $U_{\text{ref}}/U_{\text{rat}} = 0{,}5$ is given as $\lambda = 3{,}5 \cdot 10^{-9}\ \text{h}^{-1}$.

What is the value of the failure rate at an ambient temperature of $\theta_{\text{amb}} = 60\,°\text{C}$ and an operating voltage ratio of $U_{\text{op}}/U_{\text{rat}} = 0{,}6$?

Step (1): $\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}}$ for capacitors from Equation (23)

Step (2): Conversion to reference condition:

$\pi_{\text{U}} = 1$ follows from Table 38 for $U_{\text{ref}}/U_{\text{rat}} = 0{,}5$.

$\pi_{\text{T}} = 1{,}8$ follows from Table 40 for $\theta_{\text{amb}} = \theta_{\text{op}} = 50\,°\text{C}$.

Perform the calculation, thus the failure rate at reference conditions of $\theta_{\text{ref}} = 40\,°\text{C}$ and $U_{\text{ref}}/U_{\text{rat}} = 0{,}5$ (see 9.1, Table 36) is obtained as

$$\lambda_{\text{ref}} = \lambda/(\pi_{\text{U}} \times \pi_{\text{T}}) = 3{,}5 \times 10^{-9}\text{h}^{-1}/(1 \times 1{,}8) = 1{,}94 \times 10^{-9}\text{h}^{-1}$$ ~~= 1,94 FIT~~

$$\lambda_{\text{ref}} = \frac{\lambda}{\pi_{\text{U}} \times \pi_{\text{T}}} = \frac{3{,}5 \cdot 10^{-9}\ \text{h}^{-1}}{1 \times 1{,}8} = 1{,}94 \cdot 10^{-9}\ \text{h}^{-1} .$$

Step (3): Conversion from reference to operating conditions:

$\pi_{\text{U}} = 1{,}5$ follows from Table 38 for $U_{\text{op}}/U_{\text{rat}} = 0{,}6$.

$\pi_{\text{T}} = 3{,}1$ follows from Table 40 for $\theta_{\text{op}} = 60\,°\text{C}$.

Perform the calculation, thus the failure rate at $\theta_{\text{op}} = 60\,°\text{C}$ and $U_{\text{op}}/U_{\text{rat}} = 0{,}6$ is obtained as

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} = 1{,}94 \times 10^{-9}\text{h}^{-1} \times 1{,}5 \times 3{,}1 \approx 9 \times 10^{-9}\text{h}^{-1}$$ ~~= 9 FIT~~

$$\lambda_{\text{op}} = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} = 1{,}94 \cdot 10^{-9}\ \text{h}^{-1} \times 1{,}5 \times 3{,}1 \approx 9 \cdot 10^{-9}\ \text{h}^{-1} .$$

K.4 Relay

A dust-tight general purpose relay with one normally open contact switches once per hour in stress region 4 (see 16.2.3, Figure 2) with motor load with alternating current ~~(a.c.)~~:

$\lambda_{\text{ref}} = 4 \times 10^{-9}\ \text{h}^{-1}$; $U = 220\ \text{V}$ AC, $I = 4\ \text{A}$, $I_{\text{rat}} = 16\ \text{A}$, ambient temperature $\theta_{\text{amb}} = 70\,°\text{C}$.

What is the value of the failure rate under these conditions?

Step (1): $\lambda = \lambda_{\text{ref}} \times \pi_{\text{ES}} \times \pi_{\text{S}} \times \pi_{\text{T}}$ for relays from Equation (32).

Step (2): $\pi_{\text{ES}} = 20$ follows from Table 53, stress region 4, inductive load.

Step (3): $\pi_{S} = 1$ follows from Table 51 and Equation (33) ~~one cycle per hour~~.

Step (4): $\pi_{\text{T}} = 1{,}8$ follows from Table 56 with $\theta_{\text{amb}} = 70\,°\text{C}$.

Step (5): Perform the calculation,
thus the failure rate, at the stated conditions is obtained as:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{ES}} \times \pi_{\text{S}} \times \pi_{\text{T}} = 4 \times 10^{-9}\text{h}^{-1} \times 20 \times 1 \times 1{,}8 = 1{,}44 \times 10^{-7}\text{h}^{-1}$$ ~~= 144 FIT~~

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{ES}} \times \pi_{\text{S}} \times \pi_{\text{T}} = 4 \cdot 10^{-9}\ \text{h}^{-1} \times 20 \times 1 \times 1{,}8 = 144 \cdot 10^{-9}\ \text{h}^{-1} .$$

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour
inside

Electric components – Reliability – Reference conditions for failure rates and stress models for conversion

Composants électriques – Fiabilité – Conditions de référence pour les taux de défaillance et modèles de contraintes pour la conversion

IEC 61709:2017-02(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTRIC COMPONENTS – RELIABILITY – REFERENCE CONDITIONS FOR FAILURE RATES AND STRESS MODELS FOR CONVERSION

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 61709 has been prepared by IEC technical committee 56: Dependability.

This third edition cancels and replaces the second edition, published in 2011. This edition constitutes a technical revision. This third edition is a merger of IEC 61709:2011 and IEC TR 62380:2004.

This edition includes the following significant technical changes with respect to the previous edition:

a) addition of 4.5 Components choice, 4.6 Reliability growth during the deployment phase of new equipment, 4.7 How to use this document, and of Clause 19 Printed circuit boards (PCB) and Clause 20 Hybrid circuits with respect to IEC TR 62380;
b) addition of failure modes of components in Annex A;

c) modification of Annex B, Thermal model for semiconductors, adopted and revised from IEC TR 62380;
d) modification of Annex D, Considerations on mission profile;
e) modification of Annex E, Useful life models, adopted and revised from IEC TR 62380;
f) revision of Annex F (former B.2.6.4), Physics of failure;
g) addition of Annex G (former Annex C), Considerations for the design of a data base on failure rates, complemented with parts of IEC 60319;
h) addition of Annex H, Potential sources of failure rate data and methods of selection;
i) addition of Annex J, Presentation of component reliability data, based on IEC 60319.

The text of this standard is based on the following documents:

FDIS	Report on voting
56/1714/FDIS	56/1721/RVD

Full information on the voting for the approval of this standard 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 stability 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

The contents of the corrigendum of October 2019 have been included in this copy.

INTRODUCTION

This document is intended for the reliability prediction of electric components as used in equipment and is aimed at organizations that have their own data and describes how to state and use that data in order to perform reliability predictions.

It can also be used to allow an organization to set up a failure rate database and describes the reference conditions for which field failure rates should be stated. The reference conditions adopted in this document are typical of the majority of applications of components in equipment however when components operate under other conditions the users may consider stating these conditions as their reference conditions.

Using the presented stress models allows extrapolation of failure rates from reference conditions to other operating conditions which in turn permits the prediction of failure rates at assembly level. This allows estimation of the effect of design changes or changes in the environmental conditions on component reliability. Reliability prediction is most useful in the early design phase of equipment. It can be used, for example, to identify potential reliability problems, the planning of logistic support strategies and the evaluation of designs.

The stress models contained herein are generic and are as simple as possible while still being comparable with more complex equations contained in other models. The predictions generated using this document have a wide range of prediction accuracy.

This document does not contain failure rates, but it describes how they can be stated and used. This approach allows a user to select the most relevant and up to date failure rates for the prediction from a source that they select. This document also contains information on how to select the data that can be used in the presented models.

The failure rates considered in this document are assumed to be constant, either for an unlimited period of operation (general case) or for limited periods. The limitation of life is called useful life and applies only for some few component families, reaching the wear-out failure period (during which the failure rate is increasing) within the normal period of use. It is hence assumed that during useful life, the failure rate can be considered constant for any practical use.

For the purposes of this document the term electric component includes the commonly used terms “electronic component”, “electrical component” and “electro-mechanical component”.

ELECTRIC COMPONENTS –
RELIABILITY –
REFERENCE CONDITIONS FOR FAILURE RATES AND STRESS MODELS FOR CONVERSION

1 Scope

This document gives guidance on the use of failure rate data for reliability prediction of electric components used in equipment.

The method presented in this document uses the concept of reference conditions which are the typical values of stresses that are observed by components in the majority of applications.

Reference conditions are useful since they provide a known standard basis from which failure rates can be modified to account for differences in environment from the environments taken as reference conditions. Each user can use the reference conditions defined in this document or use their own. When failure rates stated at reference conditions are used it allows realistic reliability predictions to be made in the early design phase.

The stress models described herein are generic and can be used as a basis for conversion of failure rate data given at these reference conditions to actual operating conditions when needed and this simplifies the prediction approach. Conversion of failure rate data is only possible within the specified functional limits of the components.

This document also gives guidance on how a database of component failure data can be constructed to provide failure rates that can be used with the included stress models. Reference conditions for failure rate data are specified, so that data from different sources can be compared on a uniform basis. If failure rate data are given in accordance with this document then additional information on the specified conditions can be dispensed with.

This document does not provide base failure rates for components – rather it provides models that allow failure rates obtained by other means to be converted from one operating condition to another operating condition.

The prediction methodology described in this document assumes that the parts are being used within its useful life. The methods in this document have a general application but are specifically applied to a selection of component types as defined in Clauses 6 to 20 and I.2.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-192:2015, *International electrotechnical vocabulary – Part 192: Dependability*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-192 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
electric component
component with conductive terminals through which voltages or currents may be applied or delivered

Note 1 to entry: The term electric component includes the commonly used terms “electronic component”, “electrical component” and “electro-mechanical component”.

[SOURCE: IEC 61360-1:2009, 2.18, modified — Existing note deleted and Note 1 to entry added]

3.1.2
Failure <of an item>
loss of ability to perform as required

Note 1 to entry: A failure of an item is an event that results in a fault of that item: see fault (IEC 60050-192:2015, 192-04-01).

Note 2 to entry: Qualifiers, such as catastrophic, critical, major, minor, marginal and insignificant, may be used to categorize failures according to the severity of consequences, the choice and definitions of severity criteria depending upon the field of application.

Note 3 to entry: Qualifiers, such as misuse, mishandling and weakness, may be used to categorize failures according to the cause of failure.

[SOURCE: IEC 60050-192:2015, 192-03-01]

3.1.3
failure mode
manner in which failure occurs

Note 1 to entry: A failure mode may be defined by the function lost or the state transition that occurred.

[SOURCE: IEC 60050-192:2015, 192-03-17]

3.1.4
instantaneous failure rate
failure rate
limit, if it exists, of the quotient of the conditional probability that the failure of a non-repairable item occurs within time interval $(t,\ t+\Delta t)$, by Δt, when Δt tends to zero, given that failure has not occurred within time interval $(0,\ t)$

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{1}{\Delta t} \frac{F(t+\Delta t) - F(t)}{R(t)} = \frac{f(t)}{R(t)}$$

where $F(t)$ and $f(t)$ are, respectively, the distribution function and the probability density at the failure instant, and where $R(t)$ is the reliability function, related to the reliability $R(t_1,\ t_2)$ by $R(t) = R(0,\ t)$.

Note 1 to entry: See IEC 61703, *Mathematical expressions for reliability, availability, maintainability and maintenance support terms*, for more detail.

Note 2 to entry: Other terms used for instantaneous failure rate are: “hazard function”; “hazard rate”; and “force of mortality” (abbreviation FOM).

Note 3 to entry: $\lambda(t)$ in this document is assumed to be constant over time unless explicitly stated otherwise.

[SOURCE: IEC 60050-192:2015, 192-05-06, modified — Note 3 to entry added]

3.1.5
reference conditions
stresses selected so as to correspond to the majority of applications and usage of components in equipment

Note 1 to entry: Stresses include electrical stress, temperature and environmental conditions.

3.1.6
reference failure rate
failure rate stated under reference conditions given in IEC 61709

Note 1 to entry: The reference failure rate is specific to the component, i.e. it includes the effect of complexity, technology of the casing, dependence on manufacturers and the manufacturing process, etc.

3.1.7
duty cycle
specified sequence of operating conditions

Note 1 to entry: The duty cycle states whether components are continuously or intermittently stressed during their operation. Continuous duty means operation for a long duration with constant or changing loads (e.g. process controls, telephone switch). Intermittent duty means operation with constant or changing loads during up state (e.g. numerical controls for machinery, road traffic signals).

[SOURCE: IEC 60050-151:2001, 151-16-02, modified — Note 1 to entry added]

3.1.8
operating state <of an item>
state of performing as required

Note 1 to entry: For a component it means that it is energized and/or connected to a load.

[SOURCE: IEC 60050-192:2015, 192-02-04, modified — Notes 1 and 2 to entry replaced with a new Note 1 to entry]

3.1.9
non-operating state <of an item>
state of not performing any required function

Note 1 to entry: The adjective “non-operating” designates an item in a non-operating state.

Note 2 to entry: A component may be in a non-operating state because of a failure or because it is in an idle state (IEC 60050-192:2015, 192-02-14), if it is not required to be in an up state, in a standby state (IEC 60050-192:2015, 192-02-10), during the required time or in an externally disabled time (IEC 60050-192:2015, 192-02-24), when the non operation is due to absence of external resources.

[SOURCE: IEC 60050-192:2015, 192-02-06, modified — Note 2 to entry added]

3.1.10
dormant state
state of being inactive, but capable of becoming active

Note 1 to entry: For a component it means that it is ready to be energized and/or connected to a load.

3.1.11
standby state <of an item>
non-operating up state during required time

[SOURCE: IEC 60050-192:2015, 192-02-10]

3.1.12
storage state
state of being placed at a specific facility, and under stated conditions, without being energized and/or connected to a load

Note 1 to entry: For example the storage state of a component is not assembled to a piece of equipment.

3.1.13
prediction
computation process used to obtain the predicted value of a quantity

[SOURCE: IEC 60050-192:2015, 192-11-01]

3.1.14
component
constituent part of a device which cannot be physically divided into smaller parts without losing its particular function

[SOURCE: IEC 60050-151:2001, 151-11-21]

3.1.15
equipment
single apparatus or set of devices or apparatuses, or the set of main devices of an installation, or all devices necessary to perform a specific task

Note 1 to entry: Examples of equipment are a power transformer, the equipment of a substation, measuring equipment.

[SOURCE: IEC 60050-151:2001, 151-11-25]

3.1.16
useful life <of an item>
time interval, from first use until user requirements are no longer met, due to economics of operation and maintenance, or obsolescence

Note 1 to entry: In this context, “first use” excludes testing activities prior to hand-over of the item to the end-user.

[SOURCE: IEC 60050-192:2015, 192-02-27]

3.1.17
drift
difference between the final value of a characteristic at the end of a specified period and the initial value, all other operating conditions being held constant

Note 1 to entry: The use of the term "drift" to refer to the immediate change of a characteristic in direct response to changed operating conditions (for example, temperature) is deprecated.

[SOURCE: IEC 60747-1:2006, 3.6.1]

3.1.18
virtual temperature <of a semiconductor device>
internal equivalent temperature
theoretical temperature which is based on a simplified representation of the thermal and electrical behaviour of the semiconductor device

Note 1 to entry: The virtual temperature is not necessarily the highest temperature in the device.

[SOURCE: IEC 60050-521:2002, 521-05-14, modified — Note 2 to entry deleted]

3.1.19
virtual (equivalent) junction temperature
virtual temperature of the junction of a semiconductor device

[SOURCE: IEC 60050-521:2002, 521-05-15]

3.1.20
ambient air temperature
the temperature, determined under prescribed conditions, of the air surrounding the complete device

Note 1 to entry: For devices installed inside an enclosure, it is the temperature of the air outside the enclosure.

[SOURCE: IEC TR 60943:1998, 1.3.1]

3.2 Symbols

In the normative part of this document, the following symbols are used. Other symbols are used and defined in the annexes.

Ea_1, Ea_2	activation energies of a failure process
A, C_i, k_0	constants
λ	failure rate under operating conditions
λ_{ref}	failure rate under reference conditions
$\lambda_{\mathrm{component}}$	failure rate of a component
λ_{mode}	failure rate of a component's failure mode
π_{I}	current dependence factor
π_{E}	environmental application factor
π_{ES}	electrical stress dependence factor
π_{S}	switching rate dependence factor
π_{T}	temperature dependence factor
π_{U}	voltage dependence factor
I_{op}	operating current
I_{rat}	rated current
I_{ref}	reference current
P_{op}	operating power dissipation
P_{ref}	reference power dissipation
P_{rat}	rated power dissipation
R_{th}	thermal resistance
$R_{\mathrm{th,\,amb}}$	thermal resistance (to the environment)
S	number of operating cycles per hour
S_{ref}	reference number of operating cycle per hour
U_{op}	operating voltage
U_{rat}	rated voltage
U_{ref}	reference voltage
ΔT	actual self-heating in degrees Celsius
ΔT_{ref}	reference self-heating in Kelvin
θ_0	reference ambient temperature in degrees Celsius
θ_{amb}	ambient temperature in degrees Celsius
T_0	reference ambient temperature in Kelvin
T_{amb}	ambient temperature in Kelvin
T_{op}	operating temperature in Kelvin

T_{ref} reference temperature in Kelvin

θ_{op} operating temperature in degrees Celsius

- for integrated circuits (ICs) the actual virtual (equivalent) junction temperature;
- for discrete semiconductors and optoelectronic components the actual junction temperature;
- for capacitors the actual capacitor temperature;
- for resistors the actual resistor element temperature;
- for inductors the actual winding temperature;
- for other electric components the actual ambient temperature;

θ_{ref} reference temperature in degrees Celsius

- for ICs the reference virtual (equivalent) junction temperature;
- for discrete semiconductors and optoelectronic components the reference junction temperature;
- for capacitors the reference temperature of the capacitor;
- for resistors the reference temperature of the resistor element.
- for inductors the reference temperature of the winding;
- for other electric components the reference temperature of the component;

4 Context and conditions

4.1 Failure modes and mechanisms

The characteristic preferred for reliability data of electric components is the (instantaneous) failure rate. It is to be noted that, although it is often generically defined as failure, the exact observed event that is measured is a failure mode.

In equipment a failure or functional loss is caused by a component failure where component failure mode is relevant to the application being carried out by the equipment.

It should be noted that a component has many features and only some may be used in the specific application. A function loss at the equipment level occurs only when there is a loss of the component feature that is used to support that function.

Furthermore a circuit requires the presence of component features according to what was defined by the designer; this may not encompass the total feature set of the component and may not use a particular feature to its full capacity as defined by the data sheet in terms of functional characteristics and ratings.

Handbooks usually define failure rate as an overall value, which includes all failure modes. This implies that component failure rate can be considered as the sum of the failure rates of all the modes, as follows:

$$\lambda_{\text{component}} = \sum_{i=1}^{n} \left(\lambda_{\text{mode}}\right)_i \tag{1}$$

where $\left(\lambda_{\text{mode}}\right)_i$ is the component failure rate in which the failure mode i occurs and n is the number of failure modes.

Failure modes are listed in Annex A.

A failure is related to a failure mechanism, which is the basic material behaviour that results in the failure. For integrated circuits more detailed description is presented in Annex F.

4.2 Thermal modelling

Temperature is a relevant factor affecting failure rate. It is in fact known that temperature and temperature change has an effect on component reliability. For temperature change see 4.4. The temperature effect is more significant for some families (active components and aluminium capacitors with non-solid electrolyte). The models adopted are those which give the effect of temperature on the predominating failure mechanisms (which are not normally the “wear-out” mechanisms).

Thermal modelling of components should then be as accurate as possible, in particular thermal resistance for semiconductors should be measured in order to allow accurate evaluation of the internal temperature.

When thermal resistance cannot be measured, thermal resistance models provided in Annex B can be used.

4.3 Mission profile consideration

4.3.1 General

During their life, components experience different conditions of use that represent the major factors affecting component reliability: the complex of these conditions is defined as mission profile.

The mission profile defines the required function and the environmental condition as a function of time. This will vary according to the type of operation that is undertaken. This operation may be continuous over time at a fixed level, continuous over time at a variable level or sporadic over time at either a fixed level or a variable level. In some cases switch on and switch off could be significant and of more importance than the steady state operational conditions. Careful consideration of the mission profile is needed in order to fully understand how it affects the component reliability.

The mission profile can be considered to be based on calendar time or on the time of actual operation or it can be cycle based (e.g. how many times an item is used).

More considerations on mission profile are detailed in Annex D.

4.3.2 Operating and non-operating conditions

A mission profile can be decomposed in several phases, on the basis of the typical use. The main classification of these phases is between operating and non-operating conditions. Although this document deals with components, the conditions of use usually refer to the assembly (equipment or system), and can be defined as follows when they refer to components.

- Operating: the component is assembled, powered or connected to a load and functioning at nominal conditions. See 3.1.8.
- Stand-by: the component is assembled, powered or connected to a load, but not functioning or functioning at conditions lower than nominal. See 3.1.11.
- Dormant: the component is assembled, but not powered or connected to a load. See 4.3.3.
- Storage: the component is not assembled, hence not powered or connected to a load. During storage components are packed stored in a warehouse. See 4.3.4

4.3.3 Dormancy

A component is considered dormant (i.e. in a dormant state) when it is inactive (it does not provide any of the required functions), but it is capable of becoming active and properly operating on demand (energized and/or connected to a load). To be considered dormant it is assumed that the component is assembled to a piece of equipment, but no power is applied.

Components that are dormant may fail, but usually the dormant failure rate is considerably lower than the operating failure rate, assuming that the piece of equipment is maintained within its specified conditions, when non-operating.

4.3.4 Storage

Components that are under storage conditions are not immune from failure, particularly when the storing conditions are different from those specified. However the stress models for environmental application factors in this document may not apply since they only deal with operating conditions. Different failure mechanisms may exist under storage conditions that have not been considered in the models. Furthermore the case where storage conditions change the failure rate when the item is active are not dealt with in this document.

Storage conditions should be treated separately from operating conditions. They may affect the components' failure behaviour in later life.

More information on storage can be found in IEC PAS 62435. Storage conditions should be defined and controlled, in order to ensure the reliability of the components stored.

4.4 Environmental conditions

The environment contributes to failure that occurs in the life of the equipment. As a consequence the duration and intensity of environmental stresses should be included in the operational model of the equipment.

A more severe environment may cause the failures to occur more frequently than one that is less severe. There will usually be several aspects of the environment that will be pertinent to a specific failure and all may need to be understood. The locality of the environment is also important, for example on an aircraft the in-cabin and on-engine environments are very different.

The environment may be described in terms of several types of parameters and their associated interactions.

IEC 60721-3-3 describes the environment in terms of:

- climatic conditions;
- special climatic conditions;
- biological conditions;
- chemically active substances;
- mechanically active substances;
- mechanical conditions (both static and dynamic).

All the above listed conditions are in general relevant to the equipment's reliability (e.g. failure rate) and it is reasonable to consider that the reliability of components, and therefore of the equipment, decreases as the environmental stress increases (see IEC 60721 (all parts) for a detailed quantitative description of the environmental parameters for each environment).

In this document it is assumed that the climatic and mechanical conditions are the most significant and this is also valid for many standard applications of components, but there may be situations where, for example, chemical conditions could result in a higher failure rate.

Other factors influencing the failure rate can be nuclear, ultraviolet, infrared and electromagnetic radiation, acoustics, altitude, software security, six degrees of freedom vibration, explosive atmosphere environments, item induced conditions, and hostile weapons effects for military items.

Estimated failure rates generated using the models in this document are valid only if the coldest part temperature of the considered component is over the dew point temperature.

In this document only the climatic and mechanical parameters are used to describe the effect of the reference environments on failure rates. However, temperature is treated separately in this document. For simplicity it has been chosen to address three basic environments, conventionally named E1, E2 and E3. These environments refer to general field usage situations, considering the specific values of the environmental parameters. These are defined in Table 1.

Table 1 – Basic environments

E1	**Stationary use at weather-protected locations**	The environment is highly insensitive to the weather outdoors and humidity is controlled within defined limits. This is typical of telecommunications and computer equipment placed in buildings. This includes office situations.
E2	**Stationary use at partially weather-protected or non-weather-protected locations**	The environment offers thermal and mechanical stresses directly influenced by natural environmental conditions. It is typical of equipment installed outdoors.
E3	**Portable and non-stationary use, ground vehicle installation**	The environment offers mechanical stresses and severe thermal gradients. It is typical of equipment mounted on vehicles or that are hand portable.

Table 2 shows the values of environmental parameters and their relationship to the classes indicated in the relevant IEC standards.

The effect of environment can be described as a change of failure rate, by applying an environmental application factor π_E (see Table 4). Note that π_E is a discrete factor since it is based on non-continuous data and summarizes a large number of different lower level factors.

It has to be noted, anyway, that most of the systems and equipment operate under controlled temperature and the effect of external environment is shielded by proper design decisions.

This document considers temperature cycle (operating times at different temperatures) in the mission profile, while rapid temperature changes are included in the environmental application factor, π_E (see 5.2.5).

The environmental application factors include all environmental parameters (excluding temperature, which has a specific model) such as rapid temperature changes, mechanical vibration, where no empirical models are available. The environmental application factors are used at equipment level.

Table 2 – Values of environmental parameters for basic environments

Environmental parameters	E1	E2	E3
	Stationary use at weather-protected locations	**Stationary use at partially weather-protected or non-weather-protected locations**	**Portable and non-stationary use, ground vehicle installation**
Temperature rate of change	$\leq$ 0,5° C/min	$>$ 0,5° C/min	$>$ 0,5° C/min
Stationary vibration, sinusoidal	2 Hz to 9 Hz $<$1,5 mm 9 Hz to 200 Hz $\leq$ 5 m/s^2	2 Hz to 9 Hz $\leq$3 mm 9 Hz to 200 Hz $\leq$ 10 m/s^2	2 Hz to 9 Hz $>$3 mm 9 Hz to 200 Hz $\geq$ 10 m/s^2 200 Hz to 500 Hz $\geq$15 m/s^2
Non-stationary vibration including shock	$\leq$ 70 m/s^2	$\leq$ 250 m/s^2	$>$ 250 m/s^2
IEC 60721-3-3 Classes	3K1 3K2 3K3 3K4 3K5 3K6 3M1 3M2 3M3	3K7 3K7L 3K8 3K8H 3K8L 3K9 3K10 3M4 3M5 3M6 3M7	-
IEC 60721-3-4 Classes	-	-	4K1 4K2 4K3 4K4 4K4H 4K4L
IEC 60721-3-5 Classes	-	-	5K1 5K2 5K3 5K4 5K4H 5K4L 5K5 5K6 5M1 5M2 5M3
IEC 60721-3-7 Classes	-	-	7K1 7K2 7K3 7K4 7K5
ETS 300 019-1-3 Classes	3.1-3.2-3.3	3.4-3.5	-
ETS 300 019-1-4 Classes	-	4.1-4.1E	-
ETS 300 019-1-8 Classes	8.1 and Note	-	-
ETS 300 019-1-5 Classes	-	-	5.1-5.2
ETS 300 019-1-7 Classes	-	-	7.1 – 7.2 – 7.3 – 7.3E

This document covers only the three environments for simplicity. The user can describe any environment using the same methodology and assess the proper environmental application effect π_E as described in 5.2.5.

4.5 Components choice

It is the responsibility of the manufacturer to ensure the life duration specified by the final user and that components used in equipment are compatible with the environment. Therefore, premature wear-out is assumed not to occur during the useful life period of the equipment in normal operating conditions, as prescribed by the final user.

However, some components may have a limited life duration, and so preventive maintenance has to be indicated to the final user. It is the responsibility of the component manufacturer to provide qualification and evaluation results of degradation mechanisms to the system manufacturer and to ensure that the appearance of wear-out mechanisms will be postponed beyond the useful life period of the equipment in normal operating conditions.

Good component and equipment reliability is not achieved without effort. Equipment reliability is built-in, starting from the initial design phases, by applying a rigorous quality assurance system, oriented toward improvement. This means that inadequate application of the rules for excellence in quality and reliability, taking into account the product type and its use and maintenance criticality, will affect reaching the objective.

Component failures, even those conventionally considered random, excluding wear-out and external causes, are due to manufacturing defects or misuse. These show their effects during operation.

Thus manufacturers and users have to adopt adequate preventive actions:

- qualification and control of the component manufacturing process;
- characterization and qualification of the components;
- acceptance tests;
- use of good design rules (thermal, electrical, mechanical).

This document does not describe quality levels since it does not consider quality levels lower than the best achievable set as design standards. Experience of poor quality cannot be considered in order to establish models, and waivers to the application of quality rules cannot be justified based on economic considerations when the total component/equipment cost, either of the manufacturer or of the user, is considered.

There are special applications such as space, avionics and submarine cables, where the impossibility – or at least the great difficulty – of performing maintenance, as well as for safety reasons, urge adoption of even more severe rules. These cases cannot be generalized and should be studied using specific experience with the equipment and the measures adopted (such as screening, burn-in, special quality assurance programmes).

Consequently, the equipment manufacturer has to choose component manufacturers who have the best "commercial practice" concerning quality, for example, those who comply with internationally recognized quality management systems, practise statistical process control and are approved under qualified manufacturing line approval (or able to be).

In these conditions, there are no longer any reasons to take into consideration quality factors, and the infant mortality period related to new component technology is neglected since only qualified production lines and stabilized ones are considered here.

When an equipment manufacturer uses a new component technology, and when such a manufacturer has not been able to justify the life duration in normal use conditions of its device, the equipment manufacturer has to undertake tests allowing justification of the life duration of this component to the final user.

4.6 Reliability growth during the deployment phase of new equipment

The models expounded in this document allow for calculating the failure rate of an electric item that is already in a mature production phase. However, prior to that, a newly developed item may have undergone some form of reliability growth process that is reflected by a decreasing failure rate during a more or less long period.

For instance, reliability growth is achieved by the correction of manufacturing issues such as the return of a process into control or the modification of a process to improve it. With respect to reliability growth in the field, it is the modifications to the item, its design, manufacturing or operation that lead to a more reliable item. For a comprehensive description of reliability processes and activities integrated into the product life cycle which contribute or provide for the product reliability growth, refer to IEC 61014.

A manufacturer should calibrate the reliability growth period according to its own experience. It was demonstrated experimentally on many electric items and with several manufacturers that the ratio between the failure rate during the starting period of deployment and the failure rate in the mature phase can be very different. Consequently, as soon as the observed failure rate during the beginning of the deployment of an electric item significantly exceeds the estimated value, a corrective action may have to be taken.

4.7 How to use this document

This document provides a method to convert failure rates from one set of operating conditions to another. To do this it uses the concept of failure rates at reference conditions and provides equations to convert them to other conditions.

Reference conditions are defined as the most common set of environmental and operating conditions for the user. For example if an organization has most of its equipment operating at 30ºC then it should state failure rates at this operating temperature and define it as the reference conditions. The reason the organization should choose the typical operating conditions as the reference conditions is so that when they collect field reliability data they do not have to make any adjustments to it to account for environmental differences before using it.

If an organization does not have a typical operating environment then they should decide to set the reference conditions at a level that is most appropriate for them, or they can use the reference conditions that are defined in this document in Clauses 6 to 20. In this case when they collect field data they may have to make adjustments to the data to bring it all to a set of reference conditions so that it can be combined and compared.

Many organizations will not have their own reliability data and so will need to use other sources of data. This document can then be used to convert the failure rates from operating conditions to reference conditions or vice versa.

NOTE For example if an organization wants to perform a prediction for an equipment at an operating temperature of 34 °C and the component being used are not covered by a single data source with some data coming from other multiple data handbooks then the base failure rates, which are stated at a particular and different level of environmental stress in each source, can be converted and combined using the equations in this document.

The equations in this document have been derived from empirical model fitting to field data and in some cases to the equations used in other standards and handbooks. This means that the equations here will give a generic fit to the data as is suitable in an international standard.

Figure 1 shows, for CMOS IC, a comparison of the temperature dependence of factors π_T stated in a number of prediction handbooks with the factor π_T stated in this document.

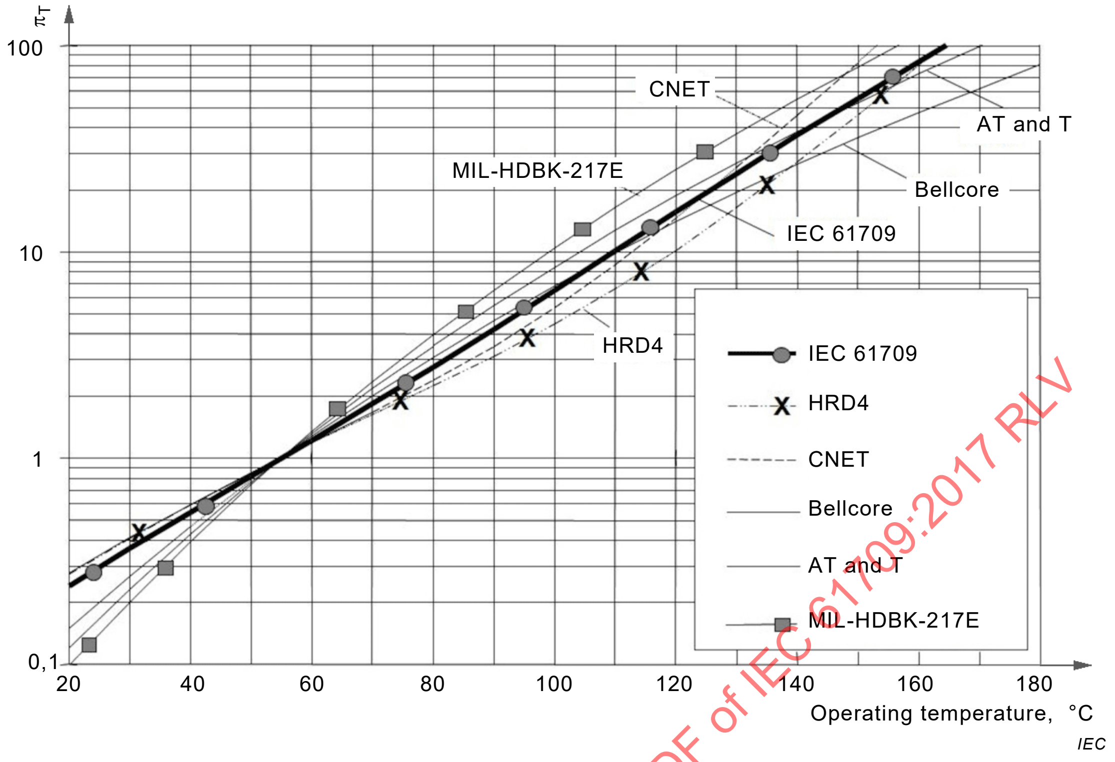


Figure 1 – Comparison of the temperature dependence of π_T for CMOS IC

Figure 1 demonstrates that the acceleration factors provided in this document are compatible with many acceleration factors given in prediction handbooks. The figure shows a fit to generic versions of the data from the prediction handbooks. The latest versions of the handbooks are detailed in H.5.3.

In order to use the equations given in this document then certain data will be required; this differs slightly by component type, but the most important data is a base failure rate stated at reference conditions. This can be obtained from field data (see IEC 60300-3-3, IEC 60300-3-5) or from manufacturer’s data or from other handbooks (see Annex H). If this data is not stated at reference conditions it can be converted to a reference condition by using the equations in this document. Knowledge of the operating environment at which the failure rate is stated is necessary in order to do this. When the failure rate is at reference conditions then it can be converted to other operating conditions using the equations contained in this document.

5 Generic reference conditions and stress models

5.1 Recommended generic reference conditions

Generic reference conditions are those values of environmental factors that are defined by an organization as being typical of the sorts of environment the organization's equipment is subjected to during normal operations. The factor could be any environmental factor the organization feels is relevant and apply to all component types.

This document, necessarily, takes a more limited view and defines the environmental factors of interest as being electrical stress, temperature and environmental conditions. Extensions to this set are not supported by this document.

Table 3 contains some recommendations that can be used by an organization unless they are not appropriate to the normal working conditions of that organization’s equipment. Any organization should choose conditions closest to their actual experience if they differ from those given in Table 3.

The values chosen represent the majority of component operating conditions.

Table 3 – Recommended reference conditions for environmental and mechanical stresses

Type of stress	Reference condition[a]
Ambient temperature[b]	θ_0 = 40 °C
Environmental condition	Environment E1 (see Table 1)
Special stresses	Not addressed in this document[c]

[a] The failure rates stated under these conditions apply only to components not damaged during transport and storage.

[b] The ambient temperature for the purposes of this document is the temperature of the medium next to the component during equipment operation, not taking into account any possible self-heating of the component. The surroundings of the component should be defined.

[c] Special stresses include wind, rain and snow, icing, drips, sprays or jets of water, dust (chemically active or not), effects of animal pests, corrosive gases, radioactive radiation, etc. These stresses may be significant contributors to failure however, as a general good practice; they should be addressed by design practices. There may be cases where their effect can be treated by applicable models. These stresses have such wide ranges of effects it would be inappropriate to address them in this document.

5.2 Generic stress models

5.2.1 General

Components may not always operate under the reference conditions. In such cases, operating conditions will result in failure rates different from those given for reference conditions. Therefore, models for stress factors, by which failure rates under reference conditions can be converted to values applying for operating conditions (actual ambient temperature and actual electrical stress on the components), and vice versa, may be required. In Clauses 6 to 20 specific stress models and values of π-factors for component categories are given and should be used for converting reference failure rates to field operational failure rates. π-factors are failure rate modifiers which are related to a specific stress or condition. They are a measure of the change of failure rate due to changes in that stress or condition. However, if more specific models are applicable for particular component types then these models should be used and their usage justified and reported.

The conversion of failure rates is only possible within the specified functional limits of the components.

The component failure rate under operating conditions is calculated as follows:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{I}} \times \pi_{\text{T}} \times \pi_{\text{E}} \times \pi_{\text{S}} \times \pi_{\text{ES}} \qquad (2)$$

where

λ_{ref} is the failure rate under reference conditions;

π_{U} is the voltage dependence factor;

π_{I} is the current dependence factor;

π_{T} is the temperature dependence factor;

π_{E} is the environmental application factor;

π_{S} is the switching rate dependence factor;

π_{ES} is the electrical stress dependence factor.

5.2.2 Stress factor for voltage dependence, π_U

$$\pi_\mathrm{U} = \exp\left\{ C_3 \left[\left(\frac{U_\mathrm{op}}{U_\mathrm{rat}} \right)^{C_2} - \left(\frac{U_\mathrm{ref}}{U_\mathrm{rat}} \right)^{C_2} \right] \right\} \tag{3}$$

where

U_op	is the operating voltage in V;
U_ref	is the reference voltage in V;
U_rat	is the rated voltage in V;
C_2 , C_3	are constants.

Equation (3) represents an empirical model to describe the voltage dependence of failure rates and is based on existing component reliability handbooks, existing component reliability data, and publicly available publications.

NOTE When dealing with absolute values of voltage as might be necessary for some component types then Equation 3 can be modified to $\pi_\mathrm{U} = \exp\left\{ C_1 \left(U_\mathrm{op}^{C_2} - U_\mathrm{ref}^{C_2} \right) \right\}$ where $C_1 = C_3 / U_\mathrm{rat}^{C_2}$.

5.2.3 Stress factor for current dependence, π_I

$$\pi_\mathrm{I} = \exp\left\{ C_4 \left[\left(\frac{I_\mathrm{op}}{I_\mathrm{rat}} \right)^{C_5} - \left(\frac{I_\mathrm{ref}}{I_\mathrm{rat}} \right)^{C_5} \right] \right\} \tag{4}$$

where

I_op	is the operating current in A;
I_ref	is the reference current in A;
I_rat	is the rated current in A;
C_4, C_5	are constants.

Equation (4) represents an empirical model to describe the current dependence of failure rates and is based on existing component reliability handbooks, existing component reliability data, and publicly available publications.

5.2.4 Stress factor for temperature dependence, π_T

$$\pi_\mathrm{T} = \exp\left[\frac{Ea_1}{k_0} \left(\frac{1}{T_\mathrm{ref}} - \frac{1}{T_\mathrm{op}} \right) \right] \tag{5}$$

Equation (5) is an empirical model based on the Arrhenius equation and it describes the temperature dependence of the failure rates. Ideally this computation should be made for each failure mode, however it is common practice to perform this calculation using an average of all activation energies for all failure modes or for the dominant failure mode only. It should be noted that in this latter case, the activation energy may also be a function of temperature since it is related to the different activation energies of the underlying failure modes. However this effect is commonly ignored.

In certain cases a more complex model using two activation energies is appropriate to fit the temperature dependence of failure rates. In such a case the following Equation (6) can be used. Use of the model with two activation energies (Ea_1, Ea_2) is considered sufficient to adequately model the temperature-failure rate relation. (This is sometimes known as competing risks; see JESD-85 for details.)

This extended Arrhenius equation is standardized to avoid temperature-dependent activation energies when changing the reference temperature, T_{ref}.

$$\pi_T = \frac{A \times \exp(Ea_1 \times z) + (1 - A) \times \exp(Ea_2 \times z)}{A \times \exp(Ea_1 \times z_{\text{ref}}) + (1 - A) \times \exp(Ea_2 \times z_{\text{ref}})} \tag{6}$$

with the auxiliary variables

$$z = \frac{1}{k_0}\left(\frac{1}{T_0} - \frac{1}{T_{\text{op}}}\right) \quad \text{and} \quad z_{\text{ref}} = \frac{1}{k_0}\left(\frac{1}{T_0} - \frac{1}{T_{\text{ref}}}\right) \quad \text{in (eV)}^{-1}$$

where in Equations (5) and (6):

A is a constant;

Ea_1, Ea_2 are activation energies in eV;

k_0 = 8,616 × 10^{-5} eV/K;

T_0 = 313 K;

T_{ref} $= (\theta_{\text{ref}} + 273)$ in K;

T_{op} $= (\theta_{\text{op}} + 273)$ in K.

The temperatures θ_{ref} and θ_{op} in degrees Celsius above are as follows;

- for ICs:
  θ_{ref} : reference virtual (equivalent) junction temperature;
  θ_{op} : actual virtual (equivalent) junction temperature;
- for discrete semiconductors and optoelectronic components:
  θ_{ref} : reference junction temperature;
  θ_{op} : actual junction temperature;
- for capacitors:
  θ_{ref} : average (*) reference capacitor temperature;
  θ_{op} : average (*) actual capacitor temperature;
- for resistors:
  θ_{ref} : average (*) reference temperature of the resistor element (for example, film);
  θ_{op} : average (*) actual temperature of the resistor element;
- for inductors:
  θ_{ref} : average (*) reference temperature of the winding;
  θ_{op} : average (*) actual temperature of the winding;
- for other electric components:

θ_{ref} : average (*) reference ambient temperature;

θ_{op} : average (*) actual ambient temperature;

NOTE (*) In this case average means “over the entire body of the component”.

5.2.5 Environmental application factor, π_{E}

Some data handbooks contain guidance on transferring a failure rate estimate from one general environmental condition to another. The concept is logical, but it carries some risk. For that reason, this document focuses more on situations where base failure rates are gathered from environment conditions which are similar to those applied to the component in practice.

The influence of environmental application conditions on the component depends essentially on the design of equipment; for example by using the equipment on ships or in the automotive field instead of in protected rooms (laboratory conditions), the influence on the environmental application conditions can be minimized, and in some cases can be removed entirely if the component is protected in some way within the equipment. Of course this will require some extra design effort and so may not be worth doing in all cases. Whether an environmental application influence occurs depends therefore essentially on the equipment manufacturer and it is the duty of an organization to design for a specific environment or if the impact of these stresses cannot be avoided, then specific studies are necessary for these pieces of equipment.

If the only failure rate data books available came from a source with very different environmental conditions, the need for an environmental application factor arises. To use such an environmental application factor means to assume that a more severe environment causes the activation of internal failure mechanisms in a predictable, more or less linear manner. There are situations where this assumption is wrong. When a component designed for ground equipment is used under severe shock and vibration conditions – these can destroy all components in a few hours – a π_{E}-factor could be calculated, but is not meaningful. The best practical solution should be to not use the component in that environment, but that is not always possible.

The environmental application factor, π_{E}, should therefore be handled with care.

Table 4 – Environmental application factor, π_{E}

Stationary use at weather-protected locations **E1**	**Stationary use at partially weather-protected or non-weather-protected locations** **E2**	**Portable and non-stationary use, ground vehicle installation** **E3**
1	2	4

NOTE Failure rate data books from a component supplier will often give guidance on how to transfer the failure rate to other operating and environmental conditions.

5.2.6 Dependence on switching rate, π_{S}

The factor π_{S} considers the number of operating cycles per hour, S, and only applies for relays in this document.

Factor π_{S} is not defined for $S < 0{,}01$.

a) $\pi_{\text{S}} = 1$ for $0{,}01 \leq S \leq S_{\text{ref}}$ (7)

b) $\pi_S = S/S_{ref}$ for $S > S_{ref}$ (8)

where

S is the number of operating cycles per hour;

S_{ref} is the reference number of operating cycles per hour.

NOTE The factor π_S can be as much as 100 for hermetically sealed contacts, normally closed, or non-sealed contacts, normally open under small loads.

5.2.7 Dependence on electrical stress, π_{ES}

This π-factor is only applicable to certain devices and is explained in detail in the related clauses.

5.2.8 Other factors of influence

Other stress factors are given for individual types of components in Clauses 6 to 20 where the dependence is known.

At present, no generally applicable conversion methods can be given for the dependence of the failure rate on humidity, air pressure, mechanical stress, etc.

Stress factors will have to be based on vendor/user history in similar applications or appropriate testing.

If the failure rate dependence of these types of stress is known, it should be considered.

If the dependence of the failure rate under these types of stress is unknown but is expected to be a function of these types of stress, appropriate studies may be necessary.

6 Integrated semiconductor circuits

6.1 Specific reference conditions

The following recommendations for reference temperatures given in Table 5 to Table 9 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment.

The reference self-heating, $\Delta T_{ref} = P_{ref} \times R_{th,amb}$, should be given when using reference temperatures other that those stated in the tables.

For any integrated circuit there are two thermal resistances generally considered; one between the junction and the case, and the other between the case and the environment. The thermal resistance, $R_{th,amb}$, above, should be the one that is most significant in the application under consideration.

When stating a failure rate for an ambient temperature of 40 °C, the reference power dissipation, P_{ref}, and the thermal resistance, $R_{th,amb}$, to the environment for which this value holds, should also be given.

Table 5 – Memory

Component			θ_{ref} °C	Note
Bipolar	RAM, FIFO	static	75	---
	PROM		75	
MOS, CMOS, BICMOS	RAM	dynamic	55	
	RAM, FIFO	static slow (≥ 30 ns) static fast (< 30 ns)	55	
	ROM mask		55	
	EPROM, OTPROM	UV erasable	55	
	FLASH		55	
	EEPROM, EAROM		55	

Table 6 – Microprocessors and peripherals, microcontrollers and signal processors

Component		θ_{ref} °C	Note
Bipolar		70	---
NMOS	No. of transistors ≤ 50 000	70	
	No. of transistors > 50 000	90	
CMOS	No. of transistors ≤ 5 000	50	
	No. of transistors > 5 000 to 50 000	60	
	No. of transistors > 50 000 to 500 000	80	
	No. of transistors > 500 000	90	
BICMOS		75	

Table 7 – Digital logic families and bus interfaces, bus driver and receiver circuits

Component			θ_{ref} °C	Reference voltage
Bipolar	TTL, -LS, -A(L)S, -F	Logic	45	---
	Bus interface		55	
	TTL S	Logic + bus interface	80	
	ECL	10 000 100 000 10(LV)E(L) / 100(LV)E(I)(P)	65 75 60	
CMOS	HCMOS, CMOS B, ACMOS (FCT, HC, A(U),C, LVX), (LVC, LCX, LV) (VCX, ALVC, AVC, AHC, VHC) Logic Analog switches, Bus interface		45	$U_{ref} = 5\,\text{V}$
	Bus interface	GTL(p)	50	
	Bus driver / receiver	RS422, RS423, RS485, CAN, etc. RS232, RS644/899, CML, etc. .	55	
BICMOS	Logic		45	
	Bus interface	ABT, BCT LVT, ALVT GTL(p) BTL, ETL	50 50 50 95	---
	Bus driver / receiver		55	

Table 8 – Analog ICs

Component		θ_{ref} °C	**Reference voltage ratio**
Operational amplifiers, comparators and voltage monitors	Bipolar, BIFET CMOS	55 45	$U_{\text{ref}}/U_{\text{rat}} = 0{,}7$
Reference elements	all technologies	45	---
Switch regulators	all technologies	55	
Power amplifiers and regulators (all technologies)	≤ 1 W > 1 W	70 90	
High frequency IC (> 100 MHz)			
HF modulator, demodulator PLL, VCO	bipolar CMOS, BICMOS	65 45	
Transmitter, receiver	bipolar CMOS, BICMOS	70 45	
Power amplifier / receiver	GaAs	80	

Table 9 – Application-specific ICs (ASICs)

Component		θ_{ref} °C	**Note**
ASICs, Full custom, Gate arrays, Telecom ICs, A/D-Converters			---
Bipolar	TTL	55	
	ECL	70	
	HV (> 50 V)	80	
NMOS		55	
CMOS, BICMOS	digital, analog / mixed No. of transistors ≤ 50 000 No. of transistors >50 000 to 50 × 10^6 No. of transistors >50 × 10^6	55 70 80	
	HV (> 50 V)	75	
Programmable ASICs (PLD) non erasable			
Bipolar	TTL	80	
	ECL	85	
CMOS	(anti-fuses)	80	
Programmable ASICs (PLD) erasable			
NMOS, CMOS	RAM basis	80	
	EPROM basis No. of transistors ≤ 5 000 EEPROM basis No. of transistors > 5 000 Flash-EPROM	70 80 80	

6.2 Specific stress models

6.2.1 General

The specific stress models are given for converting the failure rates between different conditions. These stress models contain constants, which are average values for the individual component types, from various manufacturers, determined from field experience and laboratory tests.

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} \qquad \text{for digital CMOS and bipolar analog ICs} \qquad (9)$$

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} \qquad \text{for all other ICs} \tag{10}$$

The stress factors for voltage and temperature dependence are specified in 6.2.2 and 6.2.3 respectively.

6.2.2 Voltage dependence, factor π_{U}

The voltage dependence is only taken into account for digital CMOS and bipolar analog ICs, according to Equation (3). The constants C_1, C_2 and C_3 given in Table 10 are used, unless other values are stated. The results are shown in Table 11 and Table 12.

Table 10 – Constants for voltage dependence

Integrated circuit	$U_{\text{ref}}/U_{\text{rat}}$	U_{ref}	C_1	C_2	C_3
Digital CMOS-family	–	5 V	0,1 V^{-1}	1	–
Analog	0,7	–	–	4,4	1,4

Table 11 – Factor π_{U} for digital CMOS-family ICs

U_{op} (V)	≤3	4	5	6	7	8	9	10	11	12	13	14	15
Factor π_{U}	0,8	0,9	1	1,1	1,2	1,3	1,5	1,6	1,8	2,0	2,2	2,5	2,7

Table 12 – Factor π_{U} for bipolar analog ICs

$U_{\text{op}}/U_{\text{rat}}$	≤0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
Factor π_{U}	0,75	0,77	0,80	0,87	1,0	1,3	1,8	3,0

6.2.3 Temperature dependence, factor π_{T}

The relationship given in Equation (6) applies only up to the rated junction temperature. The constants A, Ea_1 and Ea_2 given in Table 13 are used, unless other values have been stated. The results are shown in Table 14 and Table 15.

Table 13 – Constants for temperature dependence

	A	Ea_1 (eV)	Ea_2 (eV)
ICs (except EPROM, OTPROM, EEPROM, EAROM)	0,9	0,3	0,7
EPROM, OTPROM, EEPROM, EAROM	0,3	0,3	0,6

The factor π_{T} is obtained from Table 14 and Table 15:

- as a function of the actual virtual (equivalent) junction temperature;

$$\theta_{\text{op}} = \theta_{\text{amb}} + P_{\text{op}} \times R_{\text{th,amb}} \qquad \text{in degrees Celsius,} \tag{11}$$

- and as a function of the virtual (equivalent) junction temperature under reference conditions (see 6.1);

$$\theta_{\text{ref}} = 40 + \Delta T_{\text{ref}} \qquad \text{in degrees Celsius,} \tag{12}$$

where ΔT_{ref} is measured or calculated as $\Delta T_{\text{ref}} = P_{\text{ref}} \times R_{\text{th, amb}}$.

Table 14 – Factor π_T for ICs (without EPROM; FLASH-EPROM; OTPROM; EEPROM; EAROM)

θ_{ref} °C (see 6.1)	Factor π_T for θ_{op} °C																				
	≤25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**130**	**140**	**150**	**175**
40	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,3	4,1	5,1	6,3	7,7	9,6	12	18	28	44	67	102	275
45	0,44	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,4	4,1	5,1	6,3	7,8	9,7	15	23	36	55	83	225
50	0,36	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,2	2,8	3,4	4,2	5,2	6,4	8	12	19	29	45	68	184
55	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,3	2,8	3,4	4,2	5,3	6,5	10	16	24	37	56	150
60	0,24	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,3	2,8	3,5	4,3	5,3	8,2	13	20	30	46	123
65	0,2	0,24	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,9	2,3	2,8	3,5	4,4	6,7	10	16	24	37	100
70	0,16	0,2	0,24	0,3	0,37	0,45	0,54	0,67	0,82	1	1,2	1,5	1,9	2,3	2,9	3,6	5,5	8,5	13	20	30	82
75	0,13	0,16	0,2	0,24	0,3	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,3	2,9	4,5	6,9	11	16	25	67
80	0,11	0,13	0,16	0,2	0,24	0,29	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,3	3,6	5,69	8,6	13	20	54
85	0,087	0,11	0,13	0,16	0,2	0,24	0,29	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,9	4,5	7	11	16	44
90	0,07	0,086	0,11	0,13	0,16	0,19	0,24	0,29	0,35	0,43	0,53	0,66	0,81	1	1,2	1,5	2,4	3,7	5,6	8,7	13	36
95	0,057	0,07	0,085	0,1	0,13	0,16	0,19	0,23	0,29	0,35	0,43	0,53	0,65	0,81	1	1,2	1,9	3	4,6	7	11	29
100	0,046	0,056	0,069	0,084	0,1	0,13	0,15	0,19	0,23	0,28	0,35	0,43	0,53	0,65	0,81	1	1,5	2,4	3,7	5,6	8,5	23

Table 15 – Factor π_T for EPROM; FLASH-EPROM; OTPROM; EEPROM; EAROM

θ_{ref} °C (see 6.1)	Factor π_T for θ_{op} °C																				
	≤25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**130**	**140**	**150**	**175**
55	0,16	0,22	0,3	0,41	0,55	0,75	1	1,3	1,8	2,3	3,1	4,0	5,2	6,7	8,6	11	18	28	43	65	96	238

7 Discrete semiconductors

7.1 Specific reference conditions

The following recommendations for reference temperatures given in Table 16 to Table 19 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment.

The reference self-heating, $\Delta T_{\text{ref}} = P_{\text{ref}} \times R_{\text{th, amb}}$, should be given when using other reference temperatures than those stated in the tables. When stating a failure rate for an ambient temperature of 40 °C, the reference power dissipation, P_{ref}, and the thermal resistance, $R_{\text{th, amb}}$, to the environment for which this value holds, should also be given.

For discrete semiconductors there are two thermal resistances generally considered; one between the junction and the case, the other between the case and the environment. The thermal resistance, $R_{\text{th,amb}}$, above, should be the one that is most significant in the application under consideration.

Table 16 – Transistors common, low frequency

Component		θ_{ref} °C	Reference voltage ratio
Bipolar, universal	e.g. TO18, TO92, SOT(D)(3)23 or similar	55	$U_{\text{ref}}/U_{\text{rat}} = 0{,}5$
Transistor arrays		55	
Bipolar, low power	e.g. TO5, TO39, SOT223, SO8, SMA-SMC	85	
Bipolar, power	e.g. TO3, TO220, D(D)-Pack	100	
FET	junction MOS	55 55	
MOS power (SIPMOS)	e.g. TO3, TO220, D(D)-Pack	100	

Table 17 – Transistors, microwave, (e.g. RF > 800 MHz)

Component		θ_{ref} °C	Reference voltage ratio
Bipolar	wide band, small signal power	55 125	$U_{\text{ref}}/U_{\text{rat}} = 0{,}5$
GaAs FET	small signal low noise medium power high power	95 110 145	
MOSFET	wide band, small signal power	55 125	

Table 18 – Diodes

Component	θ_{ref} °C	Note
Universal diode (also with avalanche characteristics)	55	---
Schottky diode	55	
Limiting diode (suppressor diode)	40	
Zener diode ($P_{\text{tot}} < 1$ W) voltage protection[a]	40	
Zener diode, power stabilization[b]	100	
Reference diode	45	
Microwave diode, small signal detector diode capacitance diode mixer diode pin diode	45 45 70 55	
Microwave diode, power storage varactor gun diode impatt diode pin diode	100 160 180 100	
High-voltage rectifier diode	85	

[a] If applied for voltage protection the calculation can be made without accounting for self-heating ($\theta_{\text{ref}} = 40°\text{C}$).

[b] If used for stabilization then the calculation should take self-heating into account.

Table 19 – Power semiconductors

Component	θ_{ref} °C	Note
Rectifier diodes (also with avalanche characteristics)	70	----
Rectifier bridges	85	
Schottky diodes	85	
Thyristors	85	
Triacs, diacs	85	
Specialized and custom-made power semiconductors	consult manufacturer	

7.2 Specific stress models

7.2.1 General

The specific stress models are given for converting the failure rates between different conditions. These stress models contain constants which are average values for the individual component types from various manufacturers (determined from field experience and laboratory tests).

The failure rate under operating conditions, from Equation (2), is as follows:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} \qquad \text{for transistors} \tag{13}$$

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} \qquad \text{for diodes and power semiconductors} \tag{14}$$

NOTE 1 Diodes refer to general purpose diodes, Schottky diodes, voltage regulators and Zener diodes.

NOTE 2 Power semiconductors refer to rectifier diodes, bridge diodes, thyristors, triacs and diacs.

The stress factors for voltage and temperature dependence are given in 7.2.2 and 7.2.3 respectively. Current may also be a significant factor.

7.2.2 Voltage dependence for transistors, factor π_U

The voltage dependence is only taken into account for transistors according to Equation (3). The constants C_2 and C_3 given in Table 20 are used, unless other values are stated. The results are shown in Table 21.

Table 20 – Constants for voltage dependence of transistors

U_{ref}/U_{rat}	C_2	C_3
0,5	8,0	1,4

Table 21 – Factor π_U for transistors

U_{op}/U_{rat}	$\leq 0{,}6$	0,65	0,7	0,75	0,8	0,85	0,9	0,95	1
Factor π_U	1	1,04	1,08	1,14	1,26	1,46	1,82	2,52	4

7.2.3 Temperature dependence, factor π_T

The relationship given in Equation (6) applies only up to the maximum permissible junction temperature. The constants A, Ea_1 and Ea_2 given in Table 22 are used, unless other values have been stated. The results are shown in Table 23 and Table 24.

Table 22 – Constants for temperature dependence of discrete semiconductors

Component	A	Ea_1 (eV)	Ea_2 (eV)
Transistors, reference and microwave diodes	0,9	0,3	0,7
Diodes (without reference and microwave diodes) Power semiconductors [a]	1,0	0,4	–
[a] Rectifier diodes, bridge rectifiers, Schottky diodes, thyristors, triacs and diacs			

The factor π_T is obtained from Table 23 and Table 24:

– as a function of the actual junction temperature;

$$\theta_{op} = \theta_{amb} + P_{op} \times R_{th,amb} \quad \text{in degrees Celsius,} \qquad (15)$$

– and as a function of the junction temperature under reference conditions (see 7.1);

$$\theta_{ref} = 40 + \Delta T_{ref} \quad \text{in degrees Celsius,} \qquad (16)$$

where ΔT_{ref} is measured or calculated as $\Delta T_{ref} = P_{ref} \times R_{th,amb}$.

Table 23 – Factor π_T for transistors, reference and microwave diodes

θ_{ref} °C (see 7.1)	Factor π_T for θ_{op} °C																									
	≤ 25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**125**	**130**	**140**	**145**	**150**	**160**	**175**	**180**	**200**
40	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,3	4,1	5,1	6,3	7,7	9,6	12	18	28	35	44	67	83	102	153	275	332	689
45	0,44	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,4	4,1	5,1	6,3	7,8	9,7	15	23	29	36	55	68	83	125	225	272	563
55	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,3	2,8	3,4	4,2	5,3	6,5	10	16	19	24	37	45	56	84	150	182	377
70	0,16	0,2	0,24	0,3	0,37	0,45	0,54	0,67	0,82	1	1,2	1,5	1,9	2,3	2,9	3,6	5,5	8,5	11	13	20	25	30	46	82	99	206
85	0,087	0,11	0,13	0,16	0,2	0,24	0,29	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,9	4,5	5,6	7	11	13	16	24	44	53	110
95	0,057	0,07	0,085	0,10	0,13	0,16	0,19	0,23	0,29	0,35	0,43	0,53	0,65	0,81	1	1,2	1,9	3	3,7	4,6	7	8,6	11	16	29	35	72
100	0,046	0,056	0,069	0,084	0,1	0,13	0,15	0,19	0,23	0,28	0,35	0,43	0,53	0,65	0,81	1	1,5	2,4	3,0	3,7	5,6	6,9	8,5	13	23	28	58
110	0,03	0,036	0,045	0,055	0,067	0,081	0,099	0,12	0,15	0,18	0,22	0,28	0,34	0,42	0,52	0,65	1	1,5	1,9	2,4	3,6	4,5	5,6	8,3	15	18	38
125	0,015	0,019	0,023	0,028	0,035	0,043	0,052	0,063	0,078	0,095	0,12	0,14	0,18	0,22	0,27	0,34	0,52	0,81	1	1,2	1,9	2,3	2,9	4,3	7,8	9,4	20
145	0,0066	0,0081	0,0099	0,012	0,015	0,018	0,022	0,027	0,033	0,041	0,05	0,061	0,076	0,094	0,12	0,14	0,22	0,34	0,43	0,53	0,81	1	1,2	1,85	3,3	4,0	8,3
160	0,0035	0,0054	0,0044	0,0066	0,0080	0,0098	0,012	0,015	0,018	0,022	0,027	0,033	0,041	0,051	0,063	0,074	0,12	0,19	0,24	0,3	0,44	0,54	0,67	1	1,87	2,2	4,6
180	0,0016	0,0020	0,0025	0,0030	0,0037	0,0045	0,0055	0,0067	0,0082	0,01	0,012	0,015	0,019	0,023	0,029	0,036	0,055	0,085	0,11	0,13	0,2	0,25	0,31	0,46	0,83	1	2,1

Table 24 – Factor π_T for diodes (without reference and microwave diodes) and power semiconductors

θ_{ref} °C (see 7.1)	Factor π_T for θ_{op} °C																									
	≤25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**125**	**130**	**140**	**145**	**150**	**160**	**175**	**180**	**200**
40	0,47	0,61	0,79	1	1,3	1,6	2	2,4	3	3,7	4,4	5,4	6,5	7,7	9,2	11	15	20	24	27	36	41	47	61	87	98	151
55	0,24	0,31	0,4	0,51	0,64	0,80	1	1,2	1,5	1,9	2,3	2,7	3,3	3,9	4,7	5,5	7,6	10	12	14	18	21	24	31	44	50	77
70	0,13	0,17	0,21	0,27	0,35	0,43	0,54	0,67	0,82	1	1,2	1,5	1,8	2,1	2,5	3,0	4,1	5,6	6,5	7,5	9,9	11,3	13	17	24	27	41
85	0,074	0,095	0,12	0,16	0,2	0,25	0,31	0,38	0,46	0,57	0,69	0,83	1	1,2	1,4	1,7	2,3	3,2	3,7	4,3	5,6	6,4	7,3	9,5	14	15	23
100	0,044	0,056	0,072	0,092	0,12	0,15	0,18	0,22	0,28	0,34	0,41	0,49	0,59	0,71	0,84	1	1,4	1,9	2,2	2,5	3,3	3,8	4,4	5,6	8,0	9,0	14

8 Optoelectronic components

8.1 Specific reference conditions

The following recommendations for reference temperatures given in Table 25 to Table 29 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment.

The reference self-heating, $\Delta T_{\text{ref}} = P_{\text{ref}} \times R_{\text{th, amb}}$, should be given when using reference temperatures other than those stated in the tables.

When stating a failure rate for an ambient temperature of 40 °C, the reference power dissipation, P_{ref}, and the thermal resistance, $R_{\text{th,amb}}$, to the environment for which this value holds, should also be given.

For optoelectronic components there are two thermal resistances generally considered: one between the junction and the case, the other between the case and the environment. The thermal resistance, $R_{\text{th,amb}}$, above, should be the one that is most significant in the application under consideration.

Table 25 – Optoelectronic semiconductor signal receivers

Component	Reference junction temperature θ_{ref} °C	Reference voltage ratio
Phototransistor plastic and hermetically enclosed	45	$U_{\text{ref}} / U_{\text{rat}} = 0{,}5$
Photodiode (Si and Si PIN, InP, InP APD, Ge, Ge APD)	45	---
Photo element	45	
Detector module	40	
Solar component	40	

Table 26 – LEDs, IREDs, laser diodes and transmitter components

Component	Reference junction temperature θ_{ref} °C	Reference current ratio
LED visible light (radial and SMT, large power packages (> 100 mA DC))	45	$I_{\text{ref}} / I_{\text{rat}} = 0{,}5$
LED IRED ((Al)GaAs, InP)	75	
Laser diode (GaAs 880 nm, InP 1 300 nm, InP 1 500 nm)	75	---
Laser array, pump laser / pump laser cooled (GaAS 980 nm, InP 1 480 nm)	45	
Laser-transmitter modules	consult manufacturer	
Displays (LED)	55	
Displays (LCD, vacuum florescence)	consult manufacturer	
Semiconductor optical amplifier (SOA)	45	
Fibre (EDFA)	consult manufacturer	
Modulators (InP, LiNbO$_3$)	40	

Table 27 – Optocouplers and light barriers

Component		Reference junction temperature θ_{ref} °C	Note
Optocoupler	with bipolar output	55	---
	with FET output	65	
	with subsequent electronics	55	
	with subsequent power electronics	65	
Light barrier	with diode output / transistor output	55	
	with subsequent electronics	55	

Table 28 – Passive optical components

Component	Reference junction temperature θ_{ref} °C	Note
Optical waveguide connector (n-fold)	40	---
Optical fibre pigtail (one driver and one connector)	40	
Fibre	40	No temperature dependence to consider
Dispersion compensating fibre (DCF)	40	
Isolators	40	
Circulators	40	
Optical multiplexer, demultiplexer (thin film, arrayed-waveguide grating (AWG))	40	
Optical attenuators (fixed value, electromechanical)	40	
Switch (electromagnetical, MEMs)	40	
Coupler, splitter, filter (thin film, Bragg)	40	

Table 29 – Transceiver, transponder and optical sub-equipment

Component		Reference junction temperature θ_{ref} °C	Note
Transceiver, Transponder	SFF, SFP	40	---
	Xponder / Long haul tuneable	Consult manufacturer	
Optical spectrum analyzer (OPA, complex / OSA, complex)			
Active dispersion compensator			
Wavelength selective switch			
Wavelength blocker			
Ground trip current (GTC) interrupter (electro-mechanical)		40	No temperature dependence to consider

8.2 Specific stress models

8.2.1 General

The specific stress models are given for converting the failure rates between different conditions. These stress models contain constants. They are average values for the individual component types from various manufacturers (determined from field experience and laboratory tests).

The failure rate under operating conditions according to Equation (2) is:

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}}$ for phototransistors (17)

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}}$ for other optical semiconductor signal receivers, optocouplers and light barriers, optical waveguide connectors, optical fibre pigtails, transceivers, transponders (18)

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{I}} \times \pi_{\text{T}}$ for light-emitting diodes (LEDs) and infrared-emitting diodes (IREDs) (19)

$\lambda = \lambda_{\text{ref}}$ for other optical components (20)

The stress factors for voltage, current, and temperature dependence are given in 8.2.2 to 8.2.4.

8.2.2 Voltage dependence, factor π_{U}

The voltage dependence is only taken into account for phototransistors according to Equation (3). The constants C_2 and C_3 given in Table 30 are used, unless other values are stated. The results are shown in Table 31.

Table 30 – Constants for voltage dependence of phototransistors

$\frac{U_{\text{ref}}}{U_{\text{rat}}}$	C_2	C_3
0,5	8,0	1,4

Table 31 – Factor π_{U} for phototransistors

$\frac{U_{\text{op}}}{U_{\text{rat}}}$	**≤ 0,6**	**0,65**	**0,7**	**0,75**	**0,8**	**0,85**	**0,9**	**0,95**	**1**
Factor π_{U}	1	1,04	1,08	1,14	1,26	1,46	1,82	2,52	4

8.2.3 Current dependence, factor π_{I}

The current dependence is only taken into account for LEDs and IREDs, according to Equation (4). The constants C_4 and C_5 given in Table 32 are used, unless other values are stated. The results are shown in Table 33.

Table 32 – Constants for current dependence of LEDs and IREDs

$\frac{I_{\text{ref}}}{I_{\text{rat}}}$	C_4	C_5
0,5	1,4	8,0

Table 33 – Factor π_{I} for LEDs and IREDs

$\frac{I_{\text{op}}}{I_{\text{rat}}}$	**≤ 0,6**	**0,65**	**0,7**	**0,75**	**0,8**	**0,85**	**0,9**	**0,95**	**1**
Factor π_{I}	1	1,04	1,08	1,14	1,26	1,46	1,82	2,52	4

8.2.4 Temperature dependence, factor π_{T}

The relationship given in Equation (5) applies only up to the maximum permissible junction temperature. The values for the constant Ea_1 given in Table 34 are used, unless other values have been stated. The results are shown in Table 35.

Table 34 – Constants for temperature dependence of optoelectronic components

Component		Ea_1 (eV)
Optical semiconductor signal receiver	Si	0,3
	InP	0,7
	Ge	0,6
Light-emitting diodes (LED)		0,65
Infrared-emitting diodes (IRED)	(Al)GaAs	0,65
	InP	1,0
Semiconductor laser	GaAs	0,6
	InP	0,8
Optocoupler and light barriers		0,5
Optical waveguide connector; optical fibre pigtail		0,3
Transceiver, transponder		0,4

The factor π_{T} is obtained from Table 35:

– as a function of the actual junction temperature;

$$\theta_{\text{op}} = \theta_{\text{amb}} + P_{\text{op}} \times R_{\text{th,amb}} \quad \text{in degrees Celsius,} \qquad (21)$$

– and as a function of the junction temperature under reference conditions (see 8.1);

$$\theta_{\text{ref}} = 40 + \Delta T_{\text{ref}} \quad \text{in degrees Celsius,} \qquad (22)$$

where ΔT_{ref} is measured or calculated as $\Delta T_{\text{ref}} = P_{\text{ref}} \times R_{\text{th,amb}}$.

Table 35 – Factor π_T for optical components

Optical semiconductor signal receiver

	θ_{ref} °C	Factor π_T for θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Si	40	0,57	0,69	0,83	1	1,2	1,4	1,7	2	2,3	2,6	3,1	3,5	4	4,6	5,3	6
	45	0,48	0,58	0,7	0,84	1	1,2	1,4	1,6	1,9	2,2	2,6	3	3,4	3,9	4,4	5
InP	40	0,27	0,42	0,66	1	1,5	2,2	3,3	4,8	6,8	9,7	14	19	26	36	48	65
	45	0,18	0,28	0,44	0,66	1	1,5	2,2	3,2	4,5	6,4	9	13	17	24	32	43
Ge	40	0,33	0,48	0,7	1	1,4	2	2,8	3,8	5,2	7	9,4	12	16	21	28	36
	45	0,23	0,34	0,49	0,7	1	1,4	1,9	2,7	3,7	4,9	6,6	8,8	12	15	20	25

LED (visible light and IRED)

	θ_{ref} °C	Factor π_T for θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
(Al)GaAs	45	0,20	0,31	0,46	0,68	1	1,4	2,1	2,9	4,1	5,6	7,7	11	14	19	25	33
	55	0,099	0,15	0,22	0,33	0,49	0,7	1	1,4	2	2,7	3,7	5,1	6,9	9,2	12	16
	75	0,026	0,04	0,06	0,088	0,13	0,19	0,27	0,38	0,53	0,73	1	1,4	1,8	2,4	3,2	4,3
InP	75	0,004	0,007	0,013	0,024	0,043	0,076	0,13	0,22	0,37	0,62	1	1,6	2,5	4	6,1	9,3

Semiconductor laser

	θ_{ref} °C	Factor π_T for θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
GaAs	75	0,035	0,051	0,074	0,11	0,15	0,21	0,3	0,41	0,55	0,75	1	1,3	1,7	2,3	3	3,8
InP	75	0,035	0,051	0,074	0,11	0,15	0,21	0,3	0,41	0,55	0,75	1	1,3	1,7	2,3	3	3,8

Optocoupler and light barrier

	θ_{ref} °C	Factor π_T for θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
	55	0,17	0,23	0,32	0,43	0,57	0,76	1	1,3	1,7	2,2	2,8	3,5	4,4	5,5	6,8	8,5
	65	0,1	0,14	0,19	0,25	0,34	0,45	0,59	0,77	1	1,3	1,6	2,07	2,6	3,3	4,05	5,01

Optical waveguide connector; optical fibre pigtail; modulator; wavelength selective switch; wavelength blocker

	θ_{ref} °C	Factor π_T for θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
	40	0,57	0,69	0,83	1	1,2	1,4	1,7	2	2,3	2,6	3,1	3,5	4	4,6	5,3	6

Transceiver, transponder

	θ_{ref} °C	Factor π_T for θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
	40	0,47	0,61	0,79	1	1,3	1,6	2	2,4	3	3,7	4,4	5,4	6,5	7,7	9,2	11

9 Capacitors

9.1 Specific reference conditions

The recommendations for reference temperatures given in Table 36 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment.

Table 36 – Capacitors

Type of capacitor	**Reference capacitor temperature** θ_{ref} °C	**Reference voltage ratio**
Metal foil Polystyrol, polypropylene, polycarbonate, polyethylene terephthalate	40	50 % of rated voltage at 40 °C $U_{\text{ref}} / U_{\text{rat}} = 0{,}5$
Metallized film Polypropylene, polycarbonate, polyethylene terephthalate, acetyl cellulose		
Metallized paper (film)		
Mica		
Glass		
Acetyl cellulose		
Ceramic		
Deposited capacitors for hybrid circuits		
Tantalum electrolytic – non-solid electrolyte – solid electrolyte		
Aluminium electrolytic – non-solid electrolyte – solid and polymer electrolyte	40	80 % of rated voltage at 40 °C $U_{\text{ref}} / U_{\text{rat}} = 0{,}8$
Variable	40	----

9.2 Specific stress model

9.2.1 General

The failure rate under operating conditions according to Equation (2) is:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} \qquad (23)$$

NOTE Aluminium electrolytic components with non-solid electrolyte are electrochemical components with an especially wide technology range. Therefore the given constants and factors are just estimates of the values. More specific values can be given in the relevant component specifications or can be agreed upon between user and manufacturer.

The stress factors for voltage and temperature dependence are given in 9.2.2 and 9.2.3.

9.2.2 Voltage dependence, factor π_{U}

The voltage dependence is only taken into account for fixed capacitors, according to Equation (3).

For variable capacitors, $\pi_{\text{U}} = 1$.

The constants c_2 and c_3 given in Table 37 are used, unless other values are stated. The results are shown in Table 38.

Table 37 – Constants for voltage dependence of capacitors

Type of capacitor	$\frac{U_{ref}}{U_{rat}}$	c_2	c_3
Paper, metallized paper Metallized polypropylene film Metallized polyethylene terephthalate film Metallized cellulose acetate film	0,5	1,07	3,45
Polycarbonate film metal foil Metallized polycarbonate film	0,5	1,50	4,56
Polystyrene film Polyethylene terephthalate film metal foil Polypropylene film metal foil	0,5	1,29	4,0
Glass	0,5	1,11	4,33
Mica	0,5	1,12	2,98
Ceramic	0,5	1,0	4,0
Deposited capacitors for hybrid circuits	0,5	1,0	4,0
Aluminium electrolytic, non-solid electrolyte	0,8	1,0	1,36
Aluminium electrolytic, solid electrolyte	0,8	1,9	3,0
Tantalum electrolytic, non-solid electrolyte	0,5	1,0	1,05
Tantalum electrolytic, solid electrolyte	0,5	1,04	9,8

Table 38 – Factor π_U for capacitors

Type of capacitor	Factor π_U for U_{op}/U_{rat}									
	0,1	**0,2**	**0,3**	**0,4**	**0,5**	**0,6**	**0,7**	**0,8**	**0,9**	**1**
Paper, metallized paper Metallized polypropylene film Metallized polyethylene terephthalate film Metallized cellulose acetate film	0,26	0,36	0,50	0,71	1,0	1,40	2,0	2,9	4,2	6,1
Polycarbonate film metal foil Metallized polycarbonate film	0,23	0,30	0,42	0,63	1,0	1,7	2,9	5,2	9,8	19
Polystyrene film Polyethylene terephthalate film metal foil Polypropylene film metal foil	0,24	0,32	0,45	0,66	1,0	1,5	2,4	3,9	6,4	11
Glass	0,19	0,28	0,42	0,64	1,0	1,6	2,5	4,0	6,3	10
Mica	0,32	0,42	0,55	0,74	1,0	1,4	1,9	2,6	3,6	5
Ceramic	0,20	0,30	0,45	0,67	1,0	1,5	2,2	3,3	5,0	7,4
Deposited capacitors for hybrid circuits	0,20	0,30	0,45	0,67	1,0	1,5	2,2	3,3	5,0	7,4
Aluminium electrolytic, non-solid electrolyte	0,39	0,44	0,51	0,58	0,67	0,76	0,87	1,0	1,2	1,3
Aluminium electrolytic, solid electrolyte	0,15	0,16	0,19	0,24	0,31	0,44	0,64	1,0	1,6	2,8
Tantalum electrolytic, non-solid electrolyte	0,66	0,73	0,81	0,90	1,0	1,1	1,2	1,4	1,5	1,7
Tantalum electrolytic, solid electrolyte	0,021	0,054	0,14	0,37	1,0	2,7	7,4	20	56	154

9.2.3 Temperature dependence, factor π_T

The relationship given in Equation (6) applies only up to the maximum permissible component temperature. The constants A, Ea_1 and Ea_2 given in Table 39 are used, unless other values have been stated. The results are shown in Table 40.

Table 39 – Constants for temperature dependence of capacitors

Type of capacitor	A	Ea_1 eV	Ea_2 eV
Paper Metallized paper Metallized polypropylene film Metallized polyethylene terephthalate film Metallized acetyl cellulose film Polyethylene terephthalate film metal foil Polypropylene film metal foil Polystyrene film metal foil Metallized paper film	0,999	0,5	1,59
Polycarbonate film metal foil, Metallized polycarbonate film	0,998	0,57	1,63
Glass, mica	0,86	0,27	0,84
Ceramic	1,0	0,35	–
Deposited capacitors for hybrid circuits	1,0	0,15	–
Aluminium electrolytic, non-solid electrolyte	0,87	0,5	0,95
Aluminium electrolytic, solid electrolyte	0,40	0,14	0
Tantalum electrolytic, non-solid electrolyte	0,35	0,54	0
Tantalum electrolytic, solid electrolyte	0,961	0,27	1,1
Variable	1,0	0,15	–

The factor π_T is obtained from Table 40:

– as a function of the actual capacitor temperature;

$$\theta_{op} = \theta_{amb} + \Delta T \quad \text{in degrees Celsius,} \tag{24}$$

where ΔT is the temperature change due to operating conditions;

– and as a function of the capacitor temperature under reference conditions (see Table 36);

$$\theta_{ref} = 40\,°C \tag{25}$$

Table 40 – Factor π_T for capacitors

Type of capacitor	**Capacitor temperature under reference conditions** θ_{ref} °C	**Factor π_T for θ_{op} °C**[a]													
		≤ 20	**30**	**40**	**50**	**60**	**70**	**80**	**85**	**90**	**100**	**105**	**110**	**120**	**125**
Paper, Metallized paper, Metallized polypropylene film, Metallized polyethylene terephthalate film, Metallized acetyl cellulose film, Polyethylene terephthalate film metal foil, Polypropylene film metal foil, Polystyrene film metal foil, Metallized paper film	40	0,28	0,54	1,0	1,8	3,1	5,2	9	12	16	33	49	77	210	350
Polycarbonate film metal foil, Metallized polycarbonate film	40	0,24	0,50	1,0	1,9	3,6	6,7	13	18	27	63	100	170	510	900
Glass, mica	40	0,45	0,67	1,0	1,5	2,5	4,2	7,5	10	-	-	-	-	-	-
Ceramic	40	0,41	0,65	1,0	1,5	2,2	3,1	4,4	5,1	6	8,1	9,3	11	14	16
Aluminium electrolytic, non-solid electrolyte	40	0,26	0,51	1,0	1,9	3,7	7,2	14	20	28	55	77	110	210	290
Deposited capacitors for hybrid circuits	40	0,68	0,83	1,0	1,2	1,4	1,6	1,9	2	2,2	2,5	2,6	2,8	3,1	3,3
Aluminium electrolytic, solid electrolyte	40	0,88	0,94	1,0	1,1	1,2	1,2	1,3	1,4	1,4	1,5	1,6	1,6	1,8	1,8
Tantalum electrolytic, non-solid electrolyte	40	0,74	0,83	1,0	1,3	1,8	2,7	4	5	-	-	-	-	-	-
Tantalum electrolytic, solid electrolyte	40	0,49	0,7	1,0	1,45	2,2	3,7	7	10	15	32	49	73	170	250
Variable	40	0,68	0,83	1,0	1,2	1,4	1,6	1,9	2	2,2	2,5	2,6	2,8	3,1	3,3

[a] The relationships given apply up to the rated capacitor temperature only.

10 Resistors and resistor networks

10.1 Specific reference conditions

The recommendations for reference resistor element temperatures given in Table 41 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment. The reference self-heating, ΔT_{ref}, should be given when using other reference temperatures.

Table 41 – Resistors and resistor networks

Component	**Reference resistor element temperature** θ_{ref} °C	**Reference power ratio**
Carbon film	55	50 % of rated power at 40 °C $P_{\text{ref}}/P_{\text{rat}} = 0{,}5$
Metal film	55	
Deposited thin film resistors for hybrid circuits	55	
Deposited thick film resistors for hybrid circuits	55	
Networks (film circuits) per resistor element	55	
Metal-oxide	85	
Wire-wound	85	
Variable	55	

10.2 Specific stress models

10.2.1 General

The failure rate under operating conditions according to Equation (2) is:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} \tag{26}$$

The stress factors for temperature dependence are given in 10.2.2.

10.2.2 Temperature dependence, factor π_{T}

The relationship given in Equation (6) applies only up to the maximum permissible resistor element temperature. The constants A, Ea_1 and Ea_2 given in Table 42 are used, unless other values have been stated. The results are shown in Table 43.

Table 42 – Constants for temperature dependence of resistors

A	Ea_1 eV	Ea_2 eV
0,873	0,16	0,44

The factor π_{T} is obtained from Table 43:

– as a function of the average actual temperature of the resistor element;

$$\theta_{\text{op}} = \theta_{\text{amb}} + \Delta T \quad \text{in degrees Celsius,} \tag{27}$$

where, $\Delta T = P_{\text{op}} \times R_{\text{th,amb}} = (\theta_{\max} - 40) \times (P_{\text{op}}/P_{\text{rat}})$ in degrees Celsius, is the temperature change due to operation (with $\theta_{\max}$ as maximum resistor element temperature);

– and as a function of the average temperature of the resistor element under reference conditions (see Table 41);

$$\theta_{\text{ref}} = 40 + \Delta T_{\text{ref}} \tag{28}$$

Table 43 – Factor π_T for resistors

Component	θ_{ref} °C (see 10.1)	**Factor π_T for θ_{op} °C**											
		≤ 25	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**125**
Resistors	55	0,49	0,56	0,71	0,89	1,1	1,4	1,8	2,2	2,8	3,6	4,6	5,1
	85	0,25	0,28	0,35	0,45	0,56	0,71	0,89	1,1	1,4	1,8	2,3	2,6

11 Inductors, transformers and coils

11.1 Reference conditions

The recommendations for reference temperatures given in Table 44 are based on a component ambient temperature of 40 °C and correspond to the majority of applications of components in equipment. The reference self-heating, ΔT_{ref}, should be given when using other reference temperatures.

Table 44 – Inductors, transformers and coils

Component		**Average reference winding temperature** θ_{ref} °C	**Reference power ratio**
Inductors for EMC applications	≤ 3A > 3A	60 85	50 % of rated power at 40 °C $P_{ref}/P_{rat} = 0{,}5$
Low frequency inductors and transformers	≤ 25 kHz	55	
High frequency inductors and transformers	> 25 kHz	55	
Mains transformers and transformers for switched-mode power supplies		85	

11.2 Specific stress model

11.2.1 General

The failure rate under operating conditions according to Equation (2) is:

$$\lambda = \lambda_{ref} \times \pi_T \tag{29}$$

The stress factors for temperature dependence are given in 11.2.2.

11.2.2 Temperature dependence, factor π_T

The relationship given in Equation (6) applies only up to the maximum permissible winding temperature. The constants A, Ea_1 and Ea_2 given in Table 45 are used, unless other values have been stated. The results are shown in Table 46.

Table 45 – Constants for temperature dependence of inductors, transformers and coils

A	Ea_1 eV	Ea_2 eV
0,996	0,06	1,13

The factor π_T is obtained from Table 46:

– as a function of the actual average winding temperature;

$$\theta_{op} = \theta_{amb} + \Delta T \quad \text{in degrees Celsius} \qquad (30)$$

where ΔT is the temperature change due to operating conditions;

– and as a function of the average winding temperature under reference conditions (see Table 44);

$$\theta_{ref} = 40 + \Delta T_{ref} \quad \text{in degrees Celsius} \qquad (31)$$

where ΔT_{ref} is measured or calculated at $0{,}5 \times P_{rat}$.

Table 46 – Factor π_T for inductors, transformers and coils

Component	θ_{ref} °C (see 11.1)	**Factor π_T for θ_{op} °C**												
		≤ 25	**30**	**40**	**50**	**60**	**70**	**80**	**85**	**90**	**100**	**110**	**120**	**125**
Inductors, transformers, coils	55	0,79	0,82	0,89	0,96	1,1	1,2	1,5	1,9	2,3	4,3	8,8	19	29
	60	0,75	0,78	0,84	0,91	1	1,1	1,5	1,8	2,2	4	8,4	18	27
	85	0,43	0,44	0,48	0,52	0,57	0,66	0,83	1	1,3	2,3	4,8	10	15

12 Microwave devices

12.1 Specific reference conditions

The reference conditions are given in Table 47.

Table 47 – Microwave devices

Component	**Reference component temperature** θ_{ref} °C	**Note**
Microwave elements	40	Temperature and electrical stress have no impact on the failure rates.
Coaxial and wave guides		
Load		
Attenuator fixed		
Attenuator variable		
Fixed elements		
Directional couplers		
Fixed stubs		
Cavities		
Variable elements		
Tuned stubs	40	
Tuned cavities		
Ferrite device (transmitter)		
Ferrite device (receiver)		
RF/microwave passives		
Filter		
Isolator		
Circulator		
Splitter/combiner		
Synthesizer		

12.2 Specific stress models

No models are currently known from experience in applying temperature and electrical stresses.

13 Other passive components

13.1 Specific reference conditions

The reference conditions are given in Table 48.

Table 48 – Other passive components

Component	Reference component temperature θ_{ref} °C	Note
Varistors	40	Temperature and electrical stress have no impact on the failure rates.
PTC thermistors, NTC thermistors		
Surge arresters		
Ceramic resonators		
Filters		
Surface wave filters (SAW), Surface wave oscillators (SAW-oscillators), voltage controlled oscillators (VCO)		
Piezoelectric components (transducers and sensors)		
Crystals		
Crystal oscillators: XO (clock), VCXO (voltage controlled), TCXO (temperature compensated), OCXO (oven controlled)		
Feed-through capacitors, feed-through filters		
Fuses		

13.2 Specific stress models

No models are currently known from experience in applying temperature and electrical stresses.

14 Electrical connections

14.1 Specific reference conditions

The reference conditions are given in Table 49.

Table 49 – Electrical connections

Component	**Conductor cross-section** mm^2	θ_{ref} °C	**Reference current ratio**
Solder (manual, machine)	-	40	50 % of rated current for the connected conductor $I_{ref} / I_{rat} = 0{,}5$
Wire bond for hybrid circuits (Al, Au)	-		
Wire-wrap	0,05 to 0,5		
Crimp (manual, machine)	0,05 to 300		
Termi-point	0,1 to 0,5		
Press in	0,3 to 2		
Insulation displacement	0,05 to 1		
Screw	0,5 to 16		
Clamp (elastic force)	0,5 to 16		

14.2 Specific stress models

No models are currently known from experience in applying temperature and electrical stresses.

15 Connectors and sockets

15.1 Reference conditions

The reference conditions are given in Table 50.

Table 50 – Connectors and sockets

Component	θ_{ref} °C	**Note**
Plug-in contacts that should be inserted without electrical load (gold or comparably corrosion-resistant, silver, tin, others) NOTE These also include connectors that can be inserted with a limited electrical load according to the data sheet.	40	Operating current within the limits stated in the data sheet
Plug-in contacts that are intended to be inserted under electrical load		
Coaxial plugs		
Time period: Up to the time interval that 90 % of the components survive. Duty cycle: For the electrical stress, the duty cycle is continuously or intermittently in operating state. Plugging frequency: ≤ 1 plugging cycle per 1 000 hours.		

15.2 Specific stress models

No models are currently known from experience in applying temperature and electrical stresses.

16 Relays

16.1 Reference conditions

Information contained in Clause 16 does not cover all today's relays technology.

The reference conditions are given in Table 51.

Table 51 – Relays

Component	**Electrical contact stress**	θ_{ref} °C	**Reference number of operating cycles per hour**
Low duty relays:	$(0{,}5 < U \leq U_{\text{rat}})$ V AC and $(0 < I \leq 0{,}1\ )$ A by resistive load	40	$\pi_{\text{S}} = 1$
General purpose relays:	$(\ 0 < U \leq 13)$ V and $(\ 0{,}1 < I \leq I_{\text{rat}})$ A by resistive load and AC		
Automotive relays:	$(\ 0 < U \leq 13)$ V and $(\ 0{,}1 < I \leq I_{\text{rat}})$ A by resistive load		
Operating current within the limits stated in the data sheet			
Electrical contact stress (See stress regions in 16.2.3, Figure 2)			
Time period:	Up to the time interval that 90 % of the relays survive.		
Duty cycle:	The duty cycle can be chosen within the limits set by the relay's specification (for coil and contact assembly).		
Operating cycles:	Up to the maximum number of operating cycles specified in the data sheet.		

16.2 Specific stress models

16.2.1 General

The failure rate under operating conditions is:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{ES}} \times \pi_{\text{S}} \times \pi_{\text{T}} \qquad (32)$$

where

π_{ES} is the electrical stress dependence factor;

π_{S} is the switching rate dependence factor;

π_{T} is the temperature dependence factor.

The values of the stress factors are given in 16.2.3 and 16.2.4.

16.2.2 Dependence on switching rate, factor π_{S}

The factor π_{S} considers the number of operating cycles per hour, S, according to Equations (7) and (8). Factor π_{S} is not defined for $S < 0{,}01$.

a) $\pi_{\text{S}} = 1$ for $0{,}01 \leq S \leq S_{\text{ref}}$ (33)

b) $\pi_{\text{S}} = S/S_{\text{ref}}$ for $S > S_{\text{ref}}$ (34)

where

S is the number of operating cycles per hour;

S_{ref} is the reference number of operating cycles per hour.

NOTE The factor π_{S} can be as much as 100 for hermetically sealed contacts, normally closed, or non-sealed contacts, normally open under small loads.

16.2.3 Dependence on electrical stress, factor π_{ES}

The factors π_{ES} given in Table 52 to Table 54 are based on the selection of the stress region in Figure 2 and the type of load.

Contacts where surge suppression is used can be treated like contacts under resistive load.

The rated current I_{rat} and the rated switching voltage U_{rat} are obtained from the relay detail specification of the individual relay type.

If different electrical stress conditions are used, a mission profile should be considered (otherwise the higher stress factor should be applied).

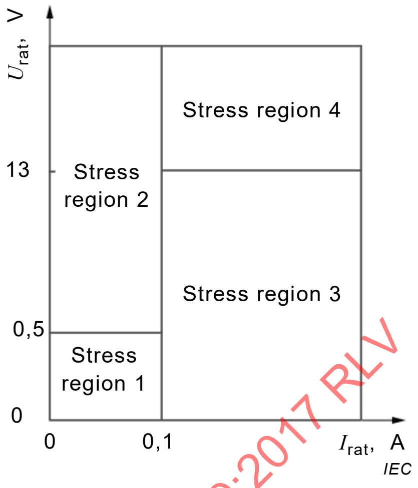


Figure 2 – Selection of stress regions in accordance with current and voltage-operating conditions

Table 52 – Factor π_{ES} for low current relays

Stress region (see Figure 2)	Factor π_{ES} for: Resistive load	Capacitive[a] and incandescent lamp load	Inductive load
1	2	2	–
2	1	8	8
3	2	20	40
4	8	40	–

[a] Maximum current peak (see relay detail specification) not to be exceeded.

Table 53 – Factor π_{ES} for general purpose relays

Stress region (see Figure 2)	Factor π_{ES} for: Resistive load DC	Resistive load AC	Capacitive[a] and incandescent lamp load DC	Capacitive[a] and incandescent lamp load AC	Inductive load DC	Inductive load AC
1 without Au-coating	50	50	2	1	–	–
1 with Au-coating	20	10	2	1	–	–
2	20	10	10	5	10	5
3	2	1	10	5	20	10
4	10	2	10	5	50	20

[a] Maximum current peak (see relay detail specification) not to be exceeded.

Table 54 – Factor π_{ES} for automotive relays

Stress region (see Figure 2)	Factor π_{ES} [a] for:		
	Resistive load	**Capacitive[b] and incandescent lamp load**	**Inductive load**
3	1	2 (1)	2 (1)
4	1	2 (1)	5 (1)

[a] Values in parentheses are valid for tungsten pre-contact.

[b] Maximum current peak (see relay detail specification) not to be exceeded.

16.2.4 Temperature dependence, factor π_T

The relationships given in Equations (5) and (6) apply only up to the maximum permissible component temperature. The formula constants A, Ea_1 and Ea_2 given in Table 55 are used, unless other values have been stated.

Table 55 – Constants for temperature dependence of relays

Supporting construction	A	Ea_1 eV	Ea_2 eV
Plastic	1,0	0,175	–
Metal, glass, ceramic	0,006	0,646	0

The calculated factors π_T are shown in Table 56 and are dependent on the ambient temperature, θ_{amb} .

Table 56 – Factor π_T for relays

Supporting construction	Factor π_T for the average ambient temperature θ_{amb} [a]			
	≤ 40 °C	70 °C	100 °C	125 °C
Plastic	1	1,8	2,8	4
Metal, glass, ceramic	1	1	1,3	2

[a] Valid only up to the maximum permissible ambient temperature according to the relay detail specification.

17 Switches and push-buttons

17.1 Specific reference conditions

The reference conditions are given in Table 57.

Table 57 – Switches and push-buttons

Component	Electrical contact stress	θ_{ref} °C	Note
Dip fix and encoding switches:	within the limits of the data sheet	---	Operating current within the limits stated in the data sheet Electrical contact stress (see stress regions in Figure 3)
Switches and push-buttons for light-current applications:	$(0{,}5 < U \leq U_{ref})$ V AC and $(0{,}1 < I \leq I_{ref})$ A by resistive load		
Switches and push-buttons for higher load:	$(0{,}5 < U \leq 13)$ V and $(0{,}1 < I \leq I_{ref})$ A by resistive load		
Time period:	Up to the time interval that 90 % of the switches and push-buttons survive.		
Duty cycle:	The duty cycle can be chosen within the limits set by the specification.		

17.2 Specific stress model

17.2.1 General

The failure rate under operating conditions is:

$$\lambda = \lambda_{ref} \times \pi_{ES} \tag{35}$$

where π_{ES} is the electrical stress dependence factor. The values of the stress factors are given in 17.2.2.

17.2.2 Dependence on electrical stress, factor π_{ES}

a) for dip fix, coding switches and foil push-buttons:

$\pi_{ES} = 1$

b) for other switches and push-buttons:

The factors π_{ES} given in Table 58 and Table 59 are based on the selection of the stress region in Figure 3 and the type of load.

The rated current I_{rat} and the rated switching voltage U_{rat} are obtained from the data sheet of the individual switches and push-button types.

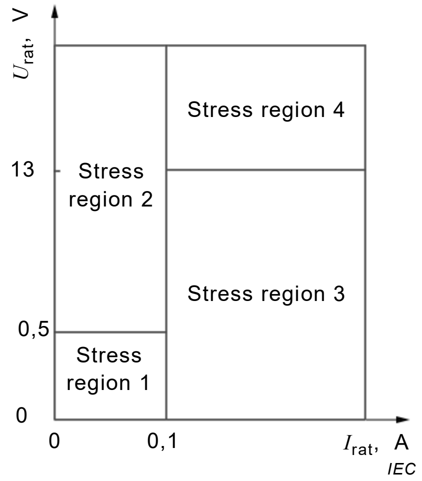


Figure 3 – Selection of stress regions in accordance with current and voltage-operating conditions

Table 58 – Factor π_{ES} for switches and push-buttons for low electrical stress

Stress region (see Figure 3)	Factor π_{ES} for:		
	Resistive load	Capacitive[a] and incandescent lamp load	Inductive load
1	2	2	–
2	1	8	8
3	2	20	40
4	8	40	–

[a] Maximum current peak (see data sheet) not to be exceeded.

Table 59 – Factor π_{ES} for switches and push-buttons for higher electrical stress

Stress region (see Figure 3)	Factor π_{ES} for:					
	Resistive load		Capacitive[a] and incandescent lamp load		Inductive load	
	DC	AC	DC	AC	DC	AC
1 Without Au-coating	50	50	2	1	–	–
1 With Au-coating	20	10	2	1	–	–
2	20	10	10	5	10	5
3	2	1	10	5	20	10
4	10	2	10	5	50	20

[a] Maximum current peak (see data sheet) not to be exceeded.

18 Signal and pilot lamps

18.1 Specific reference conditions

The reference conditions are given in Table 60.

Table 60 – Signal and pilot lamps

Component	Ambient temperature θ_{ref} °C	Note
Incandescent lamps	40	Rated voltage according to specifications
Glow lamps		
Time period: Up to the time interval that 93,5 % of the lamps survive. Duty cycle: The duty cycle is continuously in operating state; for intermittent operation the operating time is the sum of the periods alight.		

18.2 Specific stress model

18.2.1 General

The failure rate under operating conditions, as a function of the operating voltage, is calculated according to Equation (2) as follows:

$$\lambda = \lambda_{ref} \times \pi_U \tag{36}$$

18.2.2 Voltage dependence, factor π_U

The stress factor π_U for voltage dependence is given in Table 61.

Table 61 – Factor π_U for signal and pilot lamps

Type of lamp		**Factor π_U for U_{op}/U_{rat}**										
		≤ 0,70	**0,80**	**0,85**	**0,90**	**0,95**	**1,0**	**1,05**	**1,1**	**1,15**	**1,2**	**1,30**
Incandescent lamps	Signal and pilot lamps; railway-signalling lamps; low voltage traffic-light lamps	0,02	0,10	0,20	0,30	0,60	1,0	1,70	3,0	4,50	7,0	17,0
	Halogen lamps	–	–	–	–	0,60	1,0	1,7	3,0	–	–	–
	High voltage traffic-light lamps	–	–	–	–	0,60	1,0	2,0	4,0	–	–	–
Glow lamps	(with necessary series resistance)	–	–	–	0,5	0,7	1	1,3	1,6	2,0	–	–

NOTE 1 The failure rate, irrespective of construction and stress, may be higher for DC operation, higher ambient temperature, stress due to mechanical impact and electrical surges, or non-standard switching profiles.

NOTE 2 Consult the manufacturer for additional information.

19 Printed circuit boards (PCB)

Failures of PCBs should be taken into account in the stated failure rate for machine-soldered connections (see 14.1).

20 Hybrid circuits

A hybrid integrated circuit, hybrid microcircuit, or simply hybrid, is a miniaturized electronic circuit manufactured of individual devices, such as semiconductor devices (transistors and diodes) and passive components (resistors, inductors, transformers, and capacitors), bonded to a substrate or printed circuit board. A hybrid circuit is a circuit where two or more technologies are combined (SMD, ASIC and flexible circuit technology). Hybrid circuits have gradually become synonymous with circuits, where one of the methods used is thick film technology, whereby tracks and resistors are printed on a ceramic substrate.

A hybrid circuit is not considered a component in this document, in agreement with what is declared in its introduction and scope. In fact a hybrid is to be considered an assembly, also if miniaturized, but not an electric component.

Deposited capacitors and thick or thin film resistors are considered in the specific component clauses.

Annex A
(normative)

Failure modes of components

The failure mode is a description of what constitutes failure for a particular component type. There are generally three types of failure – complete, partial or degraded and drift – however most data handbooks do not make this distinction, giving a total failure rate of a component that represents failure in all modes.

However information on failure modes is useful since it is the rate of occurrence of failure modes that is observed. This information is also a useful input into reliability analysis, such as diagnostics coverage, and in safety analysis in order to calculate criticality of systems.

Annex A contains details on failure modes that are useful for this purpose. These modes are higher level, usually as perceived at circuit level, than the actual physical modes that they represent and will often include within them a number of lower level modes.

The data presented herein has been derived from a number of sources such as those listed in Annex H and in IEC TR 62380. The tables give a means of allocating estimated failure rate to specific failure modes when given a specific value for total failure rate.

For prediction purposes, component failure modes can be found in Table A.1 to Table A.7.

Table A.1 – Failure modes: ICs (digital)

Environment type	**Input/output fixed to 1** **Stuck at U_{cc}** %	**Input/output fixed to 0** **Stuck at ground** %	**Open circuit** %
Stationary use at weather-protected locations E1[a]	50	50	-
Stationary use at partially weather-protected or non-weather-protected locations E2[a] Portable and non-stationary use, ground vehicle installation E3[a]	5	5	90

NOTE For digital ICs the signal pins can be defined as inputs or outputs. When a failure occurs, for each input or output pin, there are three chances:

- – the (internal) failure caused the signal to be fixed at the logical level=1;
- – the (internal) failure caused the signal to be fixed at logical level=0;
- – the pin is no more internally connected.

The logical level=1, in terms of voltage, is usually the value of U_{cc} (positive supply voltage), while the logical level=0 is usually ground ($U = 0$).

Sometimes there are different voltages, hence it is more appropriate to speak in terms of stuck-at-1 or stuck-at-0 for the fixed signal at the failed pin.

For interface circuits, almost all defects are open circuits.

[a] See Table 1.

Table A.2 – Failure modes: transistors, diodes, optocouplers

		Short circuit %	Open circuit %	Drift %	Forward leakage current drift %
Transistors	Silicon	85	15		-
	GaAs	95	5		-
Diodes	Silicon	80	20		-
	GaAs	95	5		-
Zener diodes		70	20	10	
Thyristors		20	20		60
Optocouplers		10	50	40	-
Laser diodes		85	15	-	-

Table A.3 – Failure modes: LEDs

	Short circuit (forward degradation) %	Open circuit %	Optical coupling, or fibre %
Light emitting diode modules package type: with window	70	10	20
Light emitting diode modules package type: with fibre	40	10	50

Table A.4 – Failure modes: laser diodes and modules

	Diode failure %	Coupling failure %	Broken fibre %
Laser diodes modules 1,3 μm/1,55 μm modules	(degradation of the spectrum, current increase) 10	(high drop in output power) 90	-
Pump laser modules (0,98 μm 1,48 μm)	(high current increase) 90	(high drop in output power) 10	-
Modules (transmission) 0,85 μm modules (monomode fibre 9/125)	(no laser effect, degradation of the spectrum, current increase) 80	(high drop in output power) 10	(no output power) 10
Compact disks 0,85 μm modules (monomode fibre 9/125)	(no laser effect, degradation of the spectrum, current increase) 100	-	-

Table A.5 – Failure modes: photodiodes and receiver modules

	Short circuit (reverse degradation) %	Open circuit %	Coupling %
Photodiodes and receiver modules for telecommunications package type: with window	80	20	-
Photodiodes and receiver modules for telecommunications package type: with fibre	40	10	50

Table A.6 – Failure modes: capacitors

			Short circuit %	Open circuit %	Drift %
Ceramic	NPO-COG Fixed ceramic dielectric capacitors – Defined temperature coefficient – Class I		70	10	20
	X7R-X5R		90	10	-
	5ZU-Y5V-Y4T		90	10	-
	Feedthrough capacitors		70	30	-
Aluminium electrolytic	non-solid electrolyte	nominal voltage < 350 V	30	30	40
		nominal voltage > 350 V	50	-	50
	solid electrolyte		10	90	-
Tantalum electrolytic	non-solid electrolyte		80	20	-
	solid electrolyte		80	20	-
Metallized film			10	90	-
Mica			40	40	20
Variable ceramic capacitors, disks (dielectric ceramic)			40	10	50
Other technologies			10	90	-
Fixed plastic, paper, dielectric capacitors – Radio interference suppression capacitors (plastic, paper)			10	90	-
Thermistors with negative temperature coefficient (NTC)			70	10	20

Table A.7 – Failure modes: resistors, inductive devices, relays

		Open circuit %	Short circuit %	Drift %
Resistors	Carbon film	100	-	-
	Metal film	40	-	60
	High dissipation film resistors	100	0	
	Wire-wound	100	-	-
	Variable (non wirewound cermet potentiometer)	80	-	20
	Resistors network (surface mounting resistors and resistive array)	40	-	60
Inductive devices		80	20	-
Relays	General purpose	80	20	-
	Power relays	80	20	-
	Solid state relays	80	20	-
	Coaxial relays	80	20	-

Annex B
(informative)

Thermal model for semiconductors

B.1 Thermal model

This document defines the equipment ambient temperature θ_a as the average temperature around the equipment. According to IEC TR 60943 it is the air surrounding the complete device and, for devices installed inside an enclosure, it is the temperature of the air outside the enclosure.

Inside the equipment/system, there is a temperature distribution that depends on the position of the parts that dissipate power. Even if each unit in the equipment has its own temperature distribution (depending on the type of component and its position), a component ambient temperature θ_{ac} is conventionally defined, that is constant for all components in the unit, obtained by averaging the temperatures near each component. This hypothesis is generally valid for electronic units, although sometimes those that dissipate a lot of power in a single point should be excluded, in fact when a unit has areas with temperatures significantly different from θ_{ac}, for thermal modelling purposes they should be considered as two separate units.

More precisely, the component ambient temperature θ_{ac} is the temperature that would be found at the point where the component is installed supposing it could be removed (with or without heat sink). This is equivalent to supposing that there are no components that by themselves significantly influence the ambient temperature for nearby components. In other words, it is as if between each component and the others there would be a zone of separation that has a temperature equal to the component ambient temperature, that is a characteristic of the whole unit (see Figure B.1).

Situations that do not correspond to this hypothesis are handled by considering separately the parts of the unit as if they were thermally separate units, each with its own value of θ_{ac}.

Each unit inside the equipment therefore has its own thermal difference ($\Delta\theta_{a-ac}$) between the equipment ambient temperature and the component ambient temperature. This difference is assumed to be constant for each value of θ_a throughout the whole range of the latter in the range of temperatures considered normal for electric equipment, and depending on the power dissipated by the entire unit.

For all components of a unit:

$$\theta_{ac} = \theta_a + \Delta\theta_{a-ac} \tag{B.1}$$

where

θ_{ac} is the component ambient temperature (°C);

θ_a is the equipment ambient temperature (°C);

$\Delta\theta_{a-ac}$ is the difference between the equipment and component ambient temperatures (K).

In order to define or calculate the failure rate of the components, the component temperature also has to be evaluated:

$\theta_j = \theta_{ac} + \Delta\theta_{ac-j}$ junction temperature, for integrated circuits and semiconductors (B.2)

$\theta_{\text{c}} = \theta_{\text{ac}} + \Delta\theta_{\text{ac-c}}$ body temperature, for passive components subjected to dissipation (B.3)

In conclusion, the general thermal model can be summarized as:

$$\Delta\theta_{\text{ac-c}} = P \times R_{\text{th, ac-j}} \tag{B.4}$$

$$\Delta\theta_{\text{ac-c}} = P \times R_{\text{th, ac-c}} \tag{B.5}$$

where

P	is the component power dissipation;
$R_{\text{th, ac-j}}$	is the thermal resistance between component ambient temperature and junction temperature;
$R_{\text{th,ac-c}}$	is the thermal resistance between component ambient temperature and body temperature.

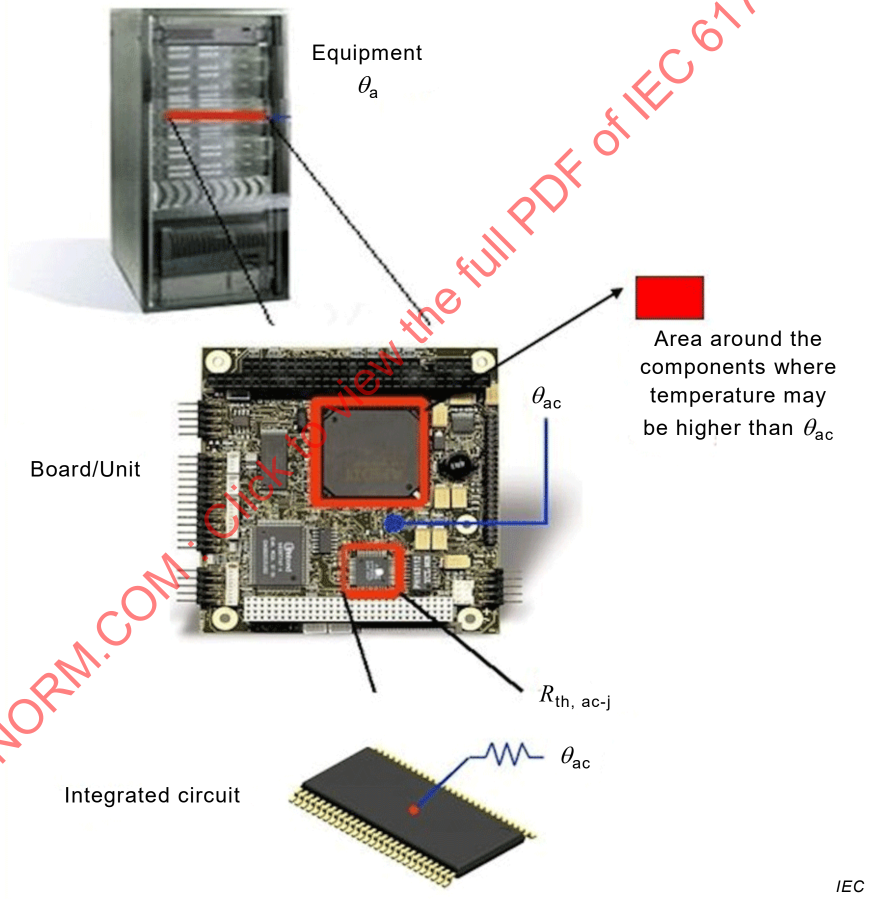


Figure B.1 – Temperatures inside equipment

B.2 Junction temperature calculation

When it is not possible to obtain the junction temperature value using the appropriate tools of the experimental thermal analysis the junction temperature value can be calculated as a function of the mean power dissipation P and of the device thermal resistance.

The simplified equation proposed here is sufficiently accurate for reliability calculations:

$$\theta_j = \theta_{\mathrm{ac}} + P \times R_{\mathrm{th,\,ac-j}} \quad \text{(B.6)}$$

$$\theta_{\mathrm{j}} = \theta_{\mathrm{case}} + P \times R_{\mathrm{th,\,c\text{-}j}} \quad \text{(B.7)}$$

where

θ_{j}	is the junction temperature (°C);
θ_{ac}	is the component ambient temperature (°C);
θ_{case}	is the case temperature (°C);
P	is the component power dissipation (W);
$R_{\mathrm{th,\,ac-j}}$	is the thermal resistance component ambient-junction (°C/W);
$R_{\mathrm{th,c-j}}$	is the junction-case thermal resistance (°C/W).

B.3 Thermal resistance evaluation

The preferred method is to take the thermal resistance value specified or published by the manufacturers (see Figure B.2).

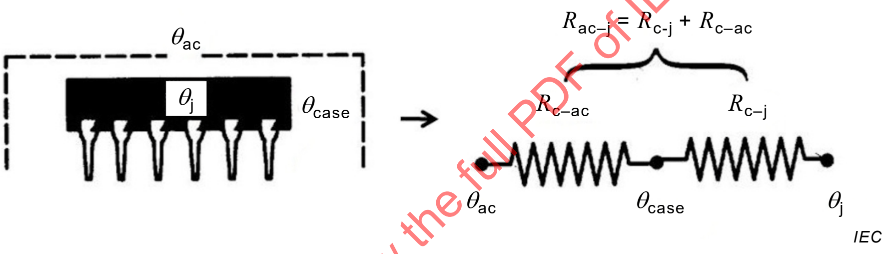


Figure B.2 – Thermal resistance model

If the device thermal resistance values are not directly available (measurements, manufacturer data), they can be calculated as a function of the package type, the pin number and the airflow factor.

Table B.1 – Thermal resistance as a function of package type, pin number and airflow factor

	$R_{\text{th, c-j}}$ °C/W	$R_{\text{th, ac-j}}$ °C/W
DIL package ceramic	$0{,}23\left(10+\dfrac{1520}{N+3}\right)$	$(0{,}23+0{,}66K)\left(10+\dfrac{1520}{N+3}\right)$
DIL package plastic	$0{,}33\left(10+\dfrac{1520}{N+3}\right)$	$(0{,}33+0{,}66K)\left(10+\dfrac{1520}{N+3}\right)$
PLCC package plastic	$0{,}28\left(15+\dfrac{1600}{N+3}\right)$	$(0{,}28+0{,}72K)\left(15+\dfrac{1600}{N+3}\right)$
SOJ and SOL package plastic	$0{,}28\left(15+\dfrac{1760}{N+3}\right)$	$(0{,}28+0{,}72K)\left(15+\dfrac{1760}{N+3}\right)$
PGA package ceramic	$0{,}33\left(10+\dfrac{1440}{N+3}\right)$	$(0{,}33+0{,}66K)\left(10+\dfrac{1440}{N+3}\right)$
QFP package plastic	$0{,}4\left(27+\dfrac{2260}{N+3}\right)$	$(0{,}4+0{,}6K)\left(27+\dfrac{2260}{N+3}\right)$
BGA package plastic	$0{,}4\left(6{,}6+\dfrac{1{,}1\times10^6}{N^2}\right)$	$(0{,}4+0{,}6K)\left(6{,}6+\dfrac{1{,}1\times10^6}{N^2}\right)$

where

N is the number of pins of the package;

K is the airflow factor given, according to the air velocity v in m/s, by the following equation

$$K=\frac{0{,}59\times v+1{,}11}{v+0{,}7} \tag{B.8}$$

where v is the air velocity in m/s. Typical values of v and K are given in Table B.2.

Table B.2 – Typical values of v are K

	v m/s	K
Natural convection	0,15	1,4
Slightly assisted cooling	0,5	1,2
Fan assisted cooling	1	1
Forced cooling	4	0,7

B.4 Power dissipation of an integrated circuit *P*

The power dissipation of an integrated circuit (where experimental values are not available) can be calculated considering its composing elements:

- a constant part from the direct current supply (P_{DC});
- a frequency dependent part (P_{f});
- duty cycle, for device with standby mode (P_{stby}).

P_{DC} and P_{f} calculation can be performed using Table B.3:

Table B.3 – Values of P_{DC} and P_f

Type		P_{DC} W	P_f W
MOS, Bipolar, ECL, GaAs		$U_{cc\ Nom}\ I_{cc\ Max}$	0
CMOS	ACT	$1{,}6\ 10^{-3}\ U_{cc\ Nom}\ N_1$	$U_{cc}^{\ 2} f_{op} 10^{-6}\ (C_{pd}N_2 + C_LN_3)$
	other	$U_{cc\ Nom}\ I_{cc\ Max}$ [a]	$U_{cc}^{\ 2} f_{op} 10^{-6}\ (C_{pd}N_2 + C_LN_3)$
	memories	$U_{cc\ Nom}\ I_{cc\ Max}$	0
BICMOS		$U_{cc\ Nom}\ I_{cc\ Max}$	$U_{cc}^{\ 2} f_{op} 10^{-6}\ (C_{pd}N_2 + C_LN_3)$

[a] Normally $P_f = 0$

where

$U_{cc\,Nom}$ is the nominal voltage (V)
(default value $U_{cc\,Nom}$ = 3 V, for BICMOS $U_{cc\,Nom}$ = 1 V to 1,8 V);

$I_{cc\,Max}$ is the maximum supply current (A);

f_{op} is the operation frequency (MHz);

C_L is the load capacitance (default value C_L = 50 pF);

C_{pd} is the power dissipation capacitance (pF);

N_1 is the number of inputs;

N_2 is the number of function elements;

N_3 is the number of outputs.

If a linear device has more than one current supply, P_{DC} is calculated separately for every supply and the values are summed.

The sum of P_{DC} and P_f, calculated in the conditions defined above, identifies the power dissipation in the worst case P_{WC} and it is a value representative of the values dispersion of different manufacturers and of different production lots.

For semi-custom integrated circuits (gate arrays and cell based), the power dissipation calculation is complex because the knowledge of the device internal composition is required, in relation to its use (registers, flip-flop and latches number).

The calculation has to be extended considering every case and it is convenient for these devices to define the maximum worst case power P_{fWC} as that one related to the maximum admitted operating frequency.

The worst case power value at the operating frequency is given by

$$P_{WC} = \frac{P_{fWC}\, f_{op} + P_{DC}(f_{max} - f_{op})}{f_{max}} \tag{B.9}$$

where

P_{fWC} is the worst case power dissipation at the maximum frequency (W);

P_{DC} is the DC power dissipation (W);

f_{op} is the operating frequency (MHz);

f_{max} is the maximum operating frequency (MHz);

f_{max} = 30 MHz (HC, HCT), f_{max} = 50 MHz (AC, ACT), f_{max} = 100 MHz (BICMOS).

A conventional value of the power dissipation P_{op} to be used in the junction temperature calculation is:

$$P_{op} = P_{WC} \frac{(P_{DC} + 3{,}5)}{3 \cdot P_{WC} + 5} \tag{B.10}$$

For devices with a standby mode, particularly memories, the power dissipation P_{av} is calculated considering the duty cycle:

$$P_{av} = P_{op} \frac{D}{100} + P_{stby} \frac{(100 - D)}{100} \tag{B.11}$$

where

P_{stby} is the standby power dissipation (W);

D is the duty cycle (%).

Annex C
(informative)

Failure rate prediction

C.1 General

Reliability predictions are conducted during the whole life cycle of equipment at various levels and degrees of detail, in order to evaluate, determine and improve the dependability of the equipment.

Successful reliability prediction of equipment generally requires a model that considers the structure of the equipment. The level of detail in that model will depend on the information available at the time (e.g. parts list, circuit diagram), and several reliability models are available depending on the problem (e.g. reliability block diagrams, fault tree analysis, state-space methods).

During the conceptual and early design phase, failure rate prediction is applicable to estimate equipment failure rate in order to check if reliability targets may be achieved and to help make decisions about the architecture for the product (e.g. use of redundancy, cooling).

Reliability prediction calculations should begin as early as possible, at the start of the equipment design phase, even if not all the applicable conditions can yet be known: in this case default values can be used provisionally, to help determine those conditions which are as yet unknown. These default values will then gradually be updated as the definitive conditions are identified.

This method is far preferable to the simplified calculation method (for which all the values are replaced by default values, including those, which are already known). The calculations should therefore be prepared in such a way as to enable values to be modified easily.

The procedures in this document can be used to carry out failure rate prediction at reference and operating conditions (prediction at reference conditions is also known as part count prediction which assumes an average stress on all components, while prediction at operating conditions, also known as part stress method takes the individual load on each component into account. The part count method is usually used in the early phase of the design, while part stress prediction is used later when the detailed design has been made. For part count prediction see C.2.4.2 and for part stress see C.2.4.3.).

C.2 Failure rate prediction for assemblies

C.2.1 General

Failure rate prediction is usually performed at assembly level. Predictions are useful for several important activities in the life cycle of equipment where they are used, in addition to many other important procedures, to ensure reliability goals.

Examples of such activities:

- assess whether reliability goals can be reached;
- identify and mitigate potential design weaknesses;
- compare alternative designs;
- evaluate designs;
- provide input data for higher level assembly dependability analysis;
- conduct cost calculations (e.g. life-cycle costs);

- establish objectives for reliability tests;
- plan logistic support strategies (e.g. spare parts and resources).

Failure rate prediction is often used in combination with other tools which can be used to improve the process of prediction by making it more representative of reality by allowing assembly structure and measures of importance to be introduced.

Failure rates to be used for spare parts provisioning and life-cycle costs calculation require particular attention. For these activities, failure rates should include all causes, even design errors, equipment and dependent (pattern) failures, to provide a realistic figure of what is happening or will happen in field during the operation phase of the life cycle. See also Annex F (database).

C.2.2 Assumptions and limitations

Failure rate predictions are based on the following assumptions, resulting from focussing on physical failures occurring at random over time.

Assumptions of failure rate predictions are as follows:

- the prediction model assumes that a failure of any component will lead to a failure of the assembly;
- component failures are treated as independent of each other; no distinction is made between complete, partial and drift failures;
- components are used within their specifications;
- design and manufacturing processes of the components and assembly under consideration are under control;
- failure rates are assumed to be constant either for an unlimited period of operation (general case) or for a given limited period of interest (e.g. useful life). Although this is known to be realistic for some components for others it is not. However the assumption greatly simplifies the task;
- apart from a few exceptions the wear-out failure period is never reached by electric components; in the same way it is accepted, again apart from some exceptions, that the added risks of failure during the first few months of operation can be disregarded.

Limitations of failure rate predictions are as follows:

- they cannot provide proof that a reliability goal has been achieved;
- due to the statistical nature of the information available, prediction works best for large component and assembly counts;
- results are dependent on the trustworthiness of the source data;
- the assumption of constant component failure rates may not always be true; in such cases this method may lead to incorrect results and other models may need to be used to determine useful life;
- failure rate data and stress models may not exist for new component types;
- stresses that are not considered may predominate and influence the failure rate.

C.2.3 Process for failure rate prediction

The process for reliability prediction using failure rates consists of the following steps:

a) Define and understand the assembly to be analysed:
    - obtain information on structure, such as functional and reliability block diagrams, if available, in order to check if series assumption is valid;
    - obtain bill of materials;

  - obtain component specifications or data sheets for all components used in cases where parts stress analysis is to be carried out;
  - obtain circuit diagrams and schematic diagrams if needed;
  - define the boundaries from the assembly specifications and schematic diagrams;
  - identify the functions and specification of the assembly, in particular understanding what a failure is.

b) When carrying out failure rate prediction at operating conditions, obtain information on operating conditions for each component when different from stated reference conditions:
  - identify the operating temperatures;
  - determine the actual electrical stresses;
  - determine mission profiles if necessary;
  - identify relevant environmental stresses;
  - select the data source according to the guidance given in Annex H;
  - use the stress models as defined in 5.2;
  - sum up the component failure rates.

c) Document the results, justification for choices and any assumptions made:
  - no guidance on presentation of results is given since many organizations define their own report structure or use those predefined in commercial software;
  - the justification process for the data sources and methods used should be documented;
  - any assumptions made should be listed so that the validity of the prediction can be assessed.

C.2.4 Prediction models

C.2.4.1 General

The failure rate of the assembly is calculated by summing up the failure rates of each component in each category. This applies under the assumption that a failure of any component is assumed to lead to equipment failure otherwise known as a chain or series configuration.

The following models assume that the component failure rate under reference or operating conditions is constant. Justification for use of a constant failure rate assumption should be given. This may take the form of analyses of likely failure mechanisms, related failure distributions, etc.

C.2.4.2 Failure rate prediction at reference conditions

Prediction at reference conditions (also called part count prediction) allows a prediction at a very early stage in the design process and is therefore very useful for feasibility studies, comparing design options and prioritizing analytic activities. Further it allows regulatory authorities to evaluate a design for example for a SIL level (see IEC 61508) without detailed knowledge of the design.

If the time to failure is exponentially distributed over the considered time interval then the failure rate for an assembly in a series configuration under reference conditions is calculated as follows:

$$\lambda_{\mathrm{S,ref}} = \sum_{i=1}^{n} (\lambda_{\mathrm{ref}})_i \tag{C.1}$$

where

$\lambda_{\mathrm{S,ref}}$ is the failure rate of an assembly under reference conditions;

λ_{ref} is the component failure rate under reference conditions;

n is the number of components.

The reference conditions adopted are typical for the majority of applications of components in equipment. It is assumed that the failure rate used under reference conditions is specific to the component, i.e. it includes the effects of complexity, technology of the casing, different manufacturers and the manufacturing process, etc.

C.2.4.3 Failure rate prediction at operating conditions

Components may not always operate under the reference conditions. In such cases, the real operational conditions will result in failure rates different from those given for reference conditions (also called part stress prediction). Therefore, models for stress factors, by which failure rates under reference conditions can be converted to values applying for operating conditions (actual ambient temperature and actual electrical stress on the components), and vice versa, may be needed.

The failure rate for assemblies under operating conditions is calculated as follows:

$$\lambda_{\mathrm{S}} = \sum_{i=1}^{n} (\lambda)_i = \sum_{i=1}^{n} (\lambda_{\mathrm{ref}} \times \pi_{\mathrm{U}} \times \pi_{\mathrm{I}} \times \pi_{\mathrm{T}} \times \pi_{\mathrm{E}} \times \pi_{\mathrm{S}} \times \pi_{\mathrm{ES}})_i \tag{C.2}$$

where

λ_{ref} is the component failure rate under reference conditions;

π_{U} is the voltage dependence factor;

π_{I} is the current dependence factor;

π_{T} is the temperature dependence factor;

π_{E} is the environmental application factor;

π_{S} is the switching rate dependence factor;

π_{ES} is the electrical stress dependence factor;

n is the number of components.

In Clauses 6 to 20 specific stress models and values for component categories are given for the π-factors and should be used for converting reference failure rates to field operational failure rates. However, if more specific models are applicable for particular component types then these models should be used and their usage justified and documented.

Conversion of failure rates is only possible within the specified functional limits of the components.

C.2.5 Other methods of reliability prediction

C.2.5.1 Similarity analysis

Similarity analysis includes the use of in-service equipment performance data to compare newly designed equipment with predecessor equipment for predicting end item reliability when the uses and stresses are similar. The method of similarity analysis is described in IEC 62308.

C.2.5.2 Simulation

Simulation is an empirical approach to equipment modelling that can allow the building of real-world models and attempt to use them to predict what is likely to happen to equipment in the future. The underlying techniques used in this process involve random sampling from failure distributions, and representation of equipment structure using such techniques as mathematical models, reaction kinetics models and empirical models. These techniques allow the building of fairly realistic models of complex equipment that can be used to understand their failure behaviour under various operating conditions and predict what the reliability will be at some future time.

C.2.5.3 Testing

Failure rate data can also be obtained from tests. It can be from testing of equipment or components. Normally testing of equipment is carried out by the equipment manufacturer while testing of components is usually carried out by the component manufacturer.

The test conditions will seldom be the same as the reference conditions; often the test will be accelerated, i.e. with increased stresses compared to the reference conditions. In these cases the failure rate information has to be transformed to reference conditions using the equations given in Clauses 6 to 20. The failure rate should be estimated based on statistical models such as, for example, the exponential distribution, the Weibull distribution, the normal distribution or the lognormal distribution.

In many cases no failures will occur during the test and the manufacturer will then often state the failure rate as 60 % upper confidence limit. When comparing test data (or field data) coming from different samples a guide can be found in IEC 60300-3-5 and IEC 61710.

When reporting failure rates based on test, the test conditions should be listed together with the statistical estimation of the failure rates and any transformation from test conditions to reference conditions. The empirical factors used for this transformation should be justified.

Care should be taken that the stress in an accelerated test does not introduce failure modes that are not relevant for the use of the component.

C.2.5.4 Physics of failure

Physics of failure (PoF) is an approach to reliability prediction modelling where the goal is to use physical principles with appropriate failure probability density distributions to design for failure-free operation and/or specify reliability targets and to predict failure times for components. It uses knowledge of root-cause failure processes in an attempt to identify the "weakest link" of a design to ensure that the planned equipment life is exceeded by the design. The approach can also be used for new components made from new materials, technologies and processes if basic physical and stress information is available. This methodology addresses the useful life of a product (see Annex F).

C.2.6 Validity considerations of reliability models and predictions

To use any quantitative reliability prediction method it is necessary to be aware of its validity. Like all engineering models, the failure rate models are approximations of reality, and are based on the best field data that could be obtained for a wide variety of parts and equipment. This data is then analysed and adapted, with many simplifying assumptions, to create usable models. Then when a model is used, further assumptions for the design parameters such as stress and temperature are made.

Thus a reliability prediction for equipment should not be treated as an absolute value for its field failure rate. It is generally agreed that these predictions can be good when used for relative comparisons, such as comparing design alternatives, or comparing equipment. Note also that reliability predictions do not account for unsuitable design decisions, substandard quality control for purchased parts, bad workmanship, poor product level quality control, overstressed field operation, etc.

Arguments for the reliability models and predictions, as given in this document, are as follows:

- often reliance is placed on failure rate data gathered from a variety of sources representing average conditions, however the accuracy and validity of such data may be questionable;
- for new technology components, failure rate data may not be available for all components as even the most recently published data is inevitably out of date;
- while the failure rate models given may indicate that a low failure rate can be achieved through a reduction in a single stress, in practice other stresses may predominate and render single stress reductions alone ineffective in achieving high reliability;
- the methods provide only broad estimates of reliability;
- the assumption of constant failure rate during the useful life of an item is not always valid but such an assumption provides suitable values for comparative analysis.

C.3 Component considerations

C.3.1 Component model

In this document a component is considered to consist of the actual component itself (e.g. silicon die), the encapsulation (e.g. case) and connection points. How the connection points are attached to the circuit board, also called the attachment system (e.g. solder joint), are treated separately in Clause 14 and this means that failures in the attachment system should be treated as component failures when using this document.

It is assumed that any failure rate used under reference conditions is specific to the component, i.e. it includes the effect of component complexity, technology of the casing, materials used, component construction, manufacturers and the manufacturing process, etc.

Care should be taken when using failure rate data from some data sources since some sources include the attachment system in the component failure rates and some do not.

C.3.2 Components classification

Component identification is the most important element of any codification system because it establishes a unique identification for every component. The identification consists of the minimum data required to establish clearly the essential characteristics of the component, i.e. those characteristics that give it a unique character and differentiate it from all others. A number of component classification systems are briefly described in Annex I.

This document recommends the use of IEC 61360 (all parts) which provides a clear and unambiguous definition of characteristic properties of all elements of electrotechnical equipment from basic components to subassemblies and full equipment. This document only uses the component-related aspects of IEC 61360 (all parts). The component coding elements of IEC 61360 (all parts) are described in Annex I.

C.4 General consideration about failure rate

C.4.1 General

The failure rate of an electric component depends on many influences, such as operating phase, failure criterion, duration of stress, operating mode (continuous or intermittent), ambient temperature and temperature cycling rate, humidity, electrical stress, cyclical switching rate, mechanical stress, air pressure and special stresses. It should be noted that a failure rate value, without knowledge of the conditions under which it was observed or is to be expected, provides no real information. For this reason, the values of the relevant factors of influence should always be given when stating a failure rate. It is possible to state how the failure rate depends on some of these influences. This dependence applies only within the specified limit values of the components.

Estimated values of the failure rates can be derived either from life tests or from field data. These estimated failure rates only apply under the conditions that applied during the tests or field observation. The rules according to which such estimates are derived depend on the statistical distribution function applying, i.e. whether "constant failure rate period" (exponential distribution) or "early life and wear-out failure period" (for example, Weibull distribution) exist. If the distribution over time of the failures is known, and estimated values of the failure rate have been calculated, the result should be interpreted statistically.

The dimension of failure rates is the number of failures per unit time, but it is worth noting that the time measure can be replaced by cycles, number of operations, etc. depending on the component type. Generally component failure rates are given in one of two standard forms, either as number of failures per 10^6 h or in number of failures per 10^9 h.

C.4.2 General behaviour of the failure rate of components

The general behaviour of the failure rate can be modelled by the Weibull distribution (see IEC 61649:2008, Clause 8). Its shape parameter, β, models three periods in the lifecycle, which can be explained as follows:

a) Early life failure period ($\beta < 1$)

   For some components, at the start of the operating period, a higher failure rate is sometimes observed which decreases with time. Early life failures occur due to manufacturing processes and material weaknesses that do not result in failures in tests performed before shipping.

   There are a few components that will exhibit decreasing failure rate in use. This is usually due to problems in the component manufacturing process as well as to handling problems (ESD, mechanical damages, etc.). This document does not support prediction of these component types and if early life failures are still to be expected for a component, the beginning of the phase of constant failure rate should be specified.

   This document assumes constant failure rates hence it is assumed that any early life failures are removed by process control or by screening (see IEC 61163-2).

b) Constant failure rate period ($\beta = 1$)

   Here, as the term suggests, the failure rate is constant. In some cases this occurs because competing failure rates produce an averaging effect that make it appear as if the failure rate is constant when the underlying failure rates of the individual competing failure modes are not.

   Generally electric components operate in the constant failure rate phase (from end of early life failure period to start of wear-out failure period) and are dealt with in this document. This behaviour can be most easily modelled by the exponential distribution and procedures for verification of constant failure rate can be found in IEC 60605-6. For components showing limited variations of the failure rate within the useful life, for example electromechanical components showing wear-out, the assumption of constant failure rate can be maintained by using the average failure rate during the useful life.

c) Wear-out failure period ($\beta > 1$)

   This period shows an increasing failure rate due to the dominating effects of wear-out, ageing or fatigue (see also Annex F).

   This document assumes that for most components the failure rate is averaged for the time interval specified in the data sheet. Since this document only covers the useful life of the component, it is important to know when the useful life ends for a given component due to wear-out. Some suppliers define this point as where a certain percentage of failures have occurred (e.g. 10 %). Others define the end-of-life as being when the failure rate has increased by a certain factor (e.g. failure rate doubled).

This limitation to the useful life of the component is reasonable since for the vast majority of components, the wear-out failure period (during which failures take on a systematic character) is far away from the periods of use (which can typically range from 3 to 20 years).

There are three cases in which the occurrence of wear-out failures should be taken into account (the failure rate of which increases with time):

1) For some families, if due care is not taken, the wear-out mechanisms may give rise to systematic failures after too short a period of time: metallization electro-migration in active components, for example. This risk needs to be eliminated by a good product design, and it is important to ensure this by qualification testing. In other words, it should not be taken into account for a prediction, and should be eliminated by qualification testing and by technical evaluation, which are, therefore, of critical importance.
2) For some (very few) component families, the wear-out failure period is relatively short. For these families, this document explains how to express the period for which the failure rate can be considered constant. This useful life is subject to influencing factors. Such families include relays, aluminium capacitors (with non-solid electrolyte), laser diodes, optocouplers, power transistors in cyclic operation, connectors and switches and keyboards.
3) In some cases a component operates solely in the wear-out phase due to its physical or chemical nature. This group include chemically-based components, components where use is made of a physical degradation mechanism and nearly all components where there is a mechanical interaction. These component types will always be in the wear-out phase and so the failure rate will always be increasing. This can often be confirmed by Weibull analysis of failure data (see IEC 61649 for details).

The time points which separate these operating periods cannot be determined exactly. In general terms the time dependence curve for any single component type could be significantly different. When interpreting reliability figures it is important to determine the physical reality of failure modes and distributions.

For more details on these different phases refer to IEC 61649 and IEC 62308.

C.4.3 Expected values of failure rate

It is recommended to state failure rate data for components under environmental and operating conditions close to the conditions in field use. This results in the most relevant predictions. Therefore data from previous products and from field data from the organization doing the analysis is preferred.

Values determined from a life test with a single sample – or the confidence limits derived from it – often do not provide enough information. Therefore the resulting dispersions of the predicted values for modules and equipment may be too great.

Failure rate data, stated according to this document, should therefore be taken as statistical "expected values" for operation under the given reference conditions for the time period given and the total population, i.e. it is to be expected that in future use, under the conditions given, the averages obtained will be the values cited.

C.4.4 Sources of variation in failure rates

A failure rate generated from collecting data on equipment will be dependent upon all the circumstances under which the equipment operates. Consequently, the failure rate data should only be used for predictions on equipment in which the circumstances are similar. if the circumstances are different then the predicted failure rate will need to be adjusted.

Unfortunately, the circumstances of a data collection are rarely adequately described, Therefore, any data will be based on some explicit assumptions, some implicit assumptions, and some assumptions that are not addressed in this document.

It is important to appreciate that a failure rate is not an intrinsic and immutable property of a piece of equipment. An engineer involved either in collecting or using data should fully understand the factors that influence failure rate derivation and use.

Circumstances that can create variations in failure rates are:

- Component detail

  When collecting data, it is possible that information that is important to the differentiation of failure rate is lost. This is often the case when a taxonomy or categorization is used to group component types.

- Suitability for service

  Suitability for service is related to the quality of a component. When making a prediction the analyst should, wherever possible, try to assess the validity of the assumptions made for the particular situation and establish if the equipment represented by the data was properly fabricated, used appropriate materials of construction, was properly maintained, was operated within design conditions and was designed to appropriate standards.

- Failure mode combinations

  Great care therefore should be taken when using failure data to ensure that the definition of failure modes used to gather the failure data is the same as the definition of failure modes that are being expected and is not a mix of different failure mode definitions. This is of particular importance when handbook data or failure data provided by an external source is used. If the types of failure mode definition cannot be identified, then the outcome of any prediction may not match the actual observed behaviour. See 4.1 and Annex A for more details on failure modes.

- Maintenance

  The maintenance strategy for equipment will significantly affect both the number and severity of failures. An inadequate preventive maintenance programme will not prevent failures, a cursory routine inspection programme may detect some potential failures, and a full preventive maintenance programme may pick up potential failures as incipient failures rather than waiting until they occur.

Annex D
(informative)

Considerations on mission profile

D.1 General

Mission profile is defined as the complex of conditions of use experienced by components during their life.

The mission profile defines the required function and the environmental condition as a function of time. This will vary according to the type of operation that is undertaken. This operation may be continuous over time at a fixed level, continuous over time at a variable level or sporadic over time at either a fixed level or a variable level. In some cases switch on and switch off could be significant and of more importance than the steady state operational conditions. Careful consideration of the mission profile is needed in order to fully understand how it affects the component reliability.

The mission profile can be considered to be based on calendar time or on the time of actual operation or it can be cycle based (e.g. how many times an item is used).

The duration of stress (sum of rated operating times, and non-operating times) can affect the failure rate. A (maximum) time period of stress over which failure rate was observed should therefore always be included in a failure rate specification. This is the time in which the given constant failure rate can be expected to occur.

Mechanical stresses of components higher than those permitted by the component specification should be avoided by the appropriate equipment design. If higher stresses cannot be avoided, they should be taken into account when performing the equipment reliability prediction.

The conditions of use are usually referred to the assembly (equipment or system), then the mission profile is typically defined for the assembly (equipment or system) and conditions for components are derived from it.

D.2 Dormancy

Components are sometimes not continuously stressed during the operating time of the assembly. There can be breaks with no electrical stress during operating periods of the assembly, also indicated as dormancy. This can be taken into account by the stress factor for mission profile, π_{op} .

When the only variation on component conditions is dormancy, the failure rate for intermittent operation between an operating condition and a dormant condition is obtained using Equation (D.1)

$$\lambda_{\text{op}} = \lambda \times \pi_{\text{op}} \tag{D.1}$$

with

$$\pi_{\text{op}} = W + \rho \times (1 - W) \tag{D.2}$$

where

λ_{op} is the failure rate, when dormant conditions occur;

λ is the failure rate for the specific component:

- for failure rate predictions at reference conditions, $\lambda = \lambda_{\text{ref}}$;
- and for failure rate predictions at operating conditions, the failure rate according to the equation stated in 5.2.1 based on Equation (2);

π_{op} is the operating stress factor;

W is the ratio of operating time of component with stress to operating time of assembly, $0 \le W \le 1$;

ρ is a constant. This is the failure rate reduction factor from nominal operating conditions to dormant conditions (no electrical stress applied) and takes into account that even non-stressed components may fail, $0 \le \rho \le 1$; a typical assumption is $\rho = 0{,}1$ when no values are known from experience.

D.3 Mission profile

Sometimes during operation, a component is subjected to different stress levels, which imply different failure rates, since the failure rate depends on the stress.

For example, if a component is in operation 24 hours a day then it will, on average, fail more often in one year as the same component that is only in operation 12 hours a day, assuming that the operating conditions are similar. A failure rate prediction should consider those different stress levels. By consideration of stress duration and stress levels, the difference between predicted failure rates and the observed failure rates can be kept low.

The actual stresses occurring with alternating stress levels can be combined into one mission profile. A mission profile states the actual duration of stress levels during a defined calendar time, for example one day. Figure D.1 shows a possible mission profile over one day.

Stress levels refer to any of the applicable factors relevant to the specific component, in particular temperature and electrical stress, which directly influence component failure rate.

In Figure D.1 any of the indicated partial stress can be:

- a reduced operating temperature;
- a reduced electrical stress (stand-by);
- any reduced stress, specific for the considered component;
- different operation environment (different environmental application factor π_{E} values).

This document considers temperature cycle (operating times at different temperatures) in the mission profile, but in this context does not consider rapid temperature changes or humidity, which are included in the environmental application factor π_{E} (see 5.2.5).

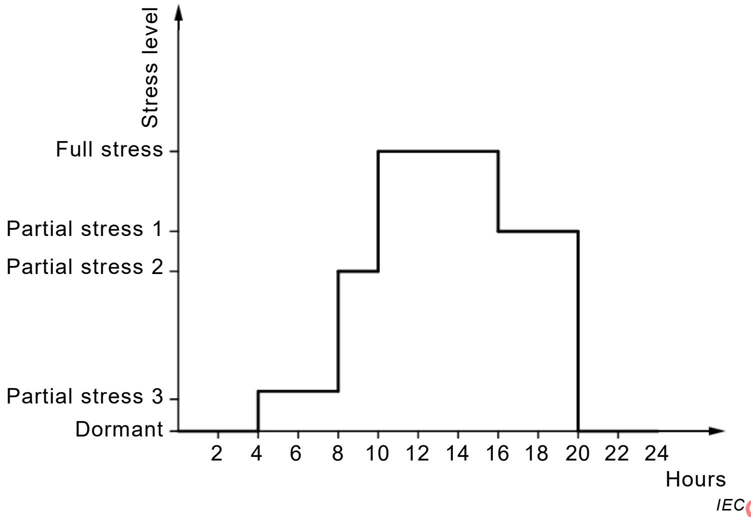


Figure D.1 – Mission profile

The failure rate for a mission profile, λ_{as}, as shown in Figure D.1 is the weighted average of the failure rates under different stress levels

$$\lambda_{\mathrm{as}} = \frac{1}{t_{\mathrm{f}} + \sum_{i=1}^{N} t_{\mathrm{p},i} + t_{\mathrm{d}}} \left(t_{\mathrm{f}} \lambda_{\mathrm{f}} + \sum_{i=1}^{N} t_{\mathrm{p},i} \lambda_{\mathrm{p},i} + t_{\mathrm{d}} \lambda_{\mathrm{d}} \right) \qquad \text{(D.3)}$$

with

$$\lambda_{\mathrm{d}} = \rho \times \lambda_{\mathrm{f}} \qquad \text{(D.4)}$$

where

t_{f} is the fraction of time with full (nominal) stress;

$t_{\mathrm{p},i}$ is the fraction of time with partial stress i;

t_{d} is the fraction of time at dormant conditions;

λ_{f} is the failure rate at full (nominal) stress;

$\lambda_{\mathrm{p},i}$ is the failure rate at partial stress i;

λ_{d} is the failure rate during dormancy;

ρ is the reduction factor from operating conditions to dormant conditions (no electrical stress applied); a typical assumption is $\rho = 0{,}1$ if no other information is available;

N is the number of stress levels.

D.4 Example of mission profile

The failure rate of assemblies is needed for the planning of stock holding. The assembly operates with an average daily operation time of 12 hours with full stress, six hours at partial stress with reduced failure rate and six hours dormant.

The following failure rates were predicted:

- $2\,400 \cdot 10^{-9}$ h^{-1} at full stress;
- $1\,400 \cdot 10^{-9}$ h^{-1} at partial stress;
- 10 % of failure rate at full stress is assumed for dormant state (see D.2).

The failure rate for alternating stress is as follows:

$$\lambda_{\mathrm{as}} = \frac{1}{t_{\mathrm{f}} + t_{\mathrm{p}} + t_i} \left(t_{\mathrm{f}} \lambda_{\mathrm{f}} + t_{\mathrm{p}} \lambda_{\mathrm{p}} + t_i \lambda_i \right) = \frac{1}{24} \left(12 \cdot 2\,400 + 6 \cdot 1400 + 6 \cdot 0{,}1 \cdot 2\,400 \right) \cdot 10^{-9}\ \mathrm{h}^{-1} = 1610\ \cdot 10^{-9}\ \mathrm{h}^{-1}$$

Annex E
(informative)

Useful life models

E.1 General

Failure rates dealt with in this document are assumed to be constant either for an unlimited period of operation (general case) or for limited periods. The limitation of useful life applies only for some few component families, reaching the wear-out failure period (during which failures take on a systematic character) within normal period of use.

For these families, Annex E gives useful life models taken from different sources, such as those listed in Annex H and in particular from IEC TR 62380, explaining how to express the period for which the failure rate can be considered constant. This useful life is subject to influencing factors and may be expressed either as a unit of time (normally hours) or as a number of cycles.

Such families include power transistors in cyclic operation, optocouplers, laser diodes, aluminium capacitors (with non-solid electrolyte), relays, switches, keyboards and connectors.

For these component families, it is important to ensure that the useful life given is consistent with the intended duration of use. If not, room for manoeuvring is fairly restricted: stresses can be reduced, or the component family can be changed (or the sub-family, for example with aluminium capacitors with non-solid electrolyte there are several types characterized by different qualification tests).

The operating time should not exceed the useful life value since beyond this time, the failure rate λ cannot be assumed to be constant.

E.2 Power transistors

The useful life of power transistors under cycling mode is given by a maximum number of cycles S. This number of cycles is limited to:

$$S = 10^{7} \times e^{-0{,}05\,\Delta T_{\mathrm{j}}} \tag{E.1}$$

with ΔT_{j} as junction temperature range.

E.3 Optocouplers

E.3.1 Useful life L

Depending factors for the useful life of optocouplers are the

- junction temperature θ_{j} expressed by factor L_0;
- input current I_{F} (operating and test condition) expressed by κ_0 and κ_2;
- transfer ratio m defined through final/initial transfer ratio expressed by κ_1;
- cumulative failure ratio (in percent) expressed by κ_3.

The useful life of the optocoupler in hours is given by

$$L = L_0 \times \kappa_0 \times \kappa_1 \times \kappa_2 \times \kappa_3 \qquad \text{(E.2)}$$

E.3.2 Factor L_0

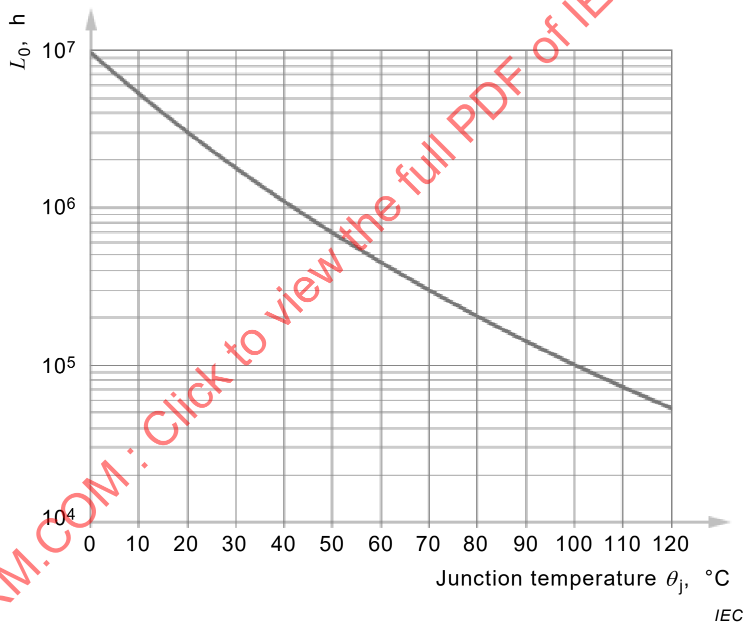
The factor L_0 which is a function of the junction temperature θ_j gives the useful life at reference conditions:

- operating input current I_F = 50 mA (κ_0 = 1);
- transfer ratio m = 0,5 (κ_1 = 1);
- test input current I_F = 1 mA (κ_2 = 1);
- cumulative failure ratio 10 % (κ_3 = 1).

and can be expressed by the following equation

$$L_0 = 0{,}4 \times \exp\left(\frac{4640}{\theta_j + 273}\right) \qquad \text{(E.3)}$$

or derived by the following graph



NOTE For moulded plastic optocouplers, the junction temperature is limited to 90 °C.

E.3.3 Factor κ_0

The factor κ_0 is giving the influence of the operating input current and is defined by

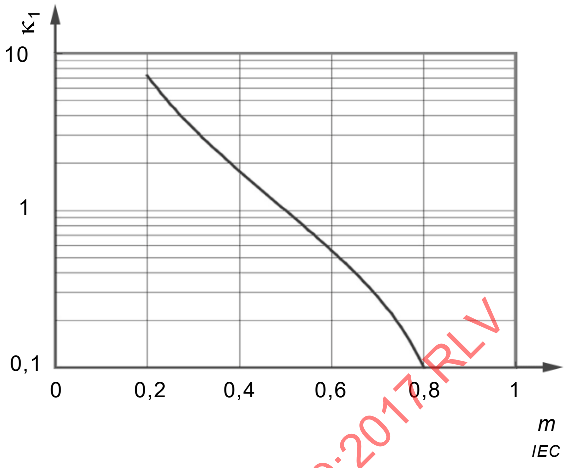
$$\kappa_0 = \frac{50}{\text{input current (operating, mA)}} \qquad \text{(E.4)}$$

E.3.4 Factor κ_1

The factor κ_1 is a function of the selected transfer ratio where

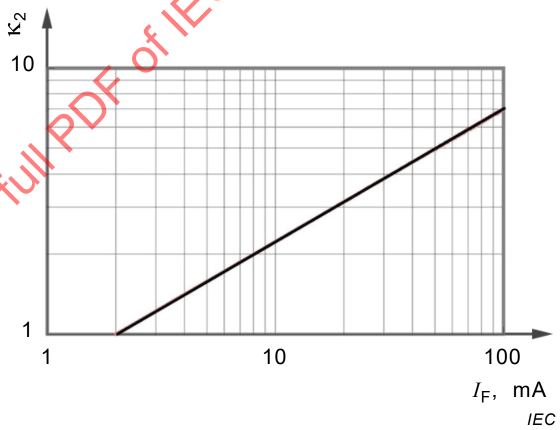
$$m = \frac{\text{Final transfer ratio}}{\text{Initial transfer ratio}}$$

and can be derived from the graph.



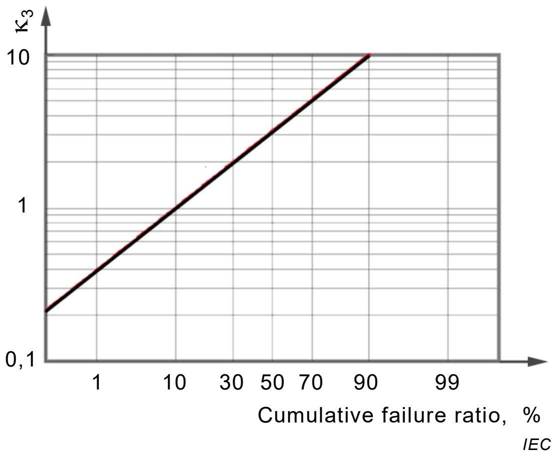
E.3.5 Factor κ_2

The factor κ_2 is a function of the current I_F measured at the transfer ratio (testing conditions) and can be derived from the graph.



E.3.6 Factor κ_3

The factor κ_3 depends on the cumulative failure ratio given in percent as shown in the graph.



E.4 LED and LED modules

E.4.1 Useful life L

Depending factors for useful life of light emitting diode[1] modules are the

- junction temperature θ_j expressed by factor L_0;
- operating input current expressed by κ_0;
- optical power ratio m defined through final/initial optical power expressed by κ_1;
- measurement current I_F expressed by κ_2;
- cumulative failure ratio (in percent) expressed by κ_3.

Useful life of LED and LED modules in hours is given by

$$L = L_0 \times \kappa_0 \times \kappa_1 \times \kappa_2 \times \kappa_3 \qquad \text{(E.5)}$$

E.4.2 Factor L_0

The factor L_0 which is a function of the junction temperature θ_j gives the useful life at the following reference conditions:

- operating input current I_F = 100 mA (κ_0 = 1);
- optical power ratio m = 0,5: (κ_1 = 1);
- optical power measuring current I_F = 100 mA (κ_2 = 1);
- cumulative failure ratio 10 % (κ_3 = 1).

and can be expressed by the following equations.

Diode type	**Factor L_0 expressed in hours**
0,85 µm diodes	$L_0 = 2{,}3 \cdot 10^5 \times \exp\left(7000 \times \left(\frac{1}{\theta_\mathrm{j} + 273} - \frac{1}{343}\right)\right)$ (E.6) (0,6 eV)
1,3 µm diodes	$L_0 = 8{,}7 \cdot 10^6 \times \exp\left(7000 \times \left(\frac{1}{\theta_\mathrm{j} + 273} - \frac{1}{343}\right)\right)$ (E.7) (0,6 eV)

or can be derived by the following graph.

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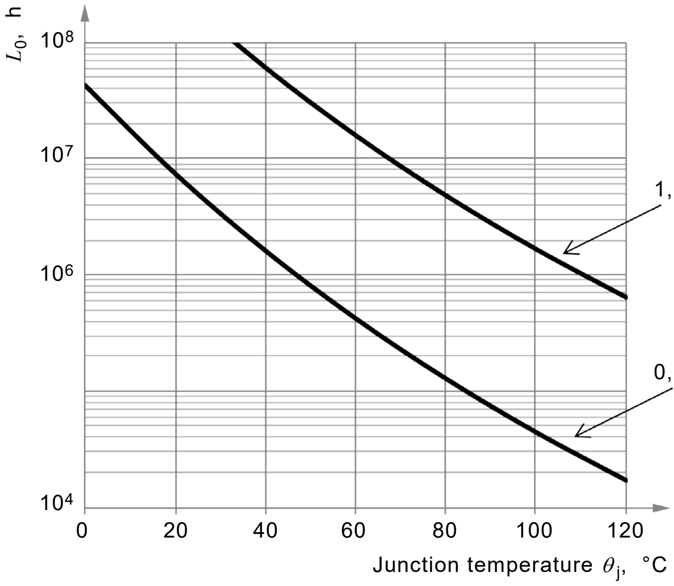
[1] According to IEC 62007.



IEC

E.4.3 Factor κ_0

The factor κ_0 gives the influence of the operating input current and is defined by

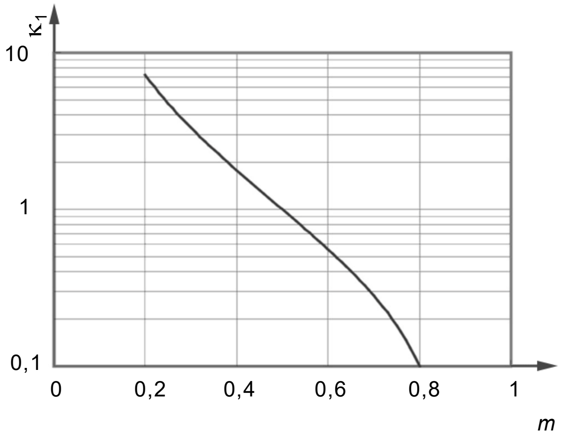
$$\kappa_0 = \frac{100}{\text{operating input current (mA)}} \tag{E.8}$$

E.4.4 Factor κ_1

The factor κ_1 is a function of the selected optical power ratio where

$$m = \frac{\text{final optical power}}{\text{initial optical power}}$$

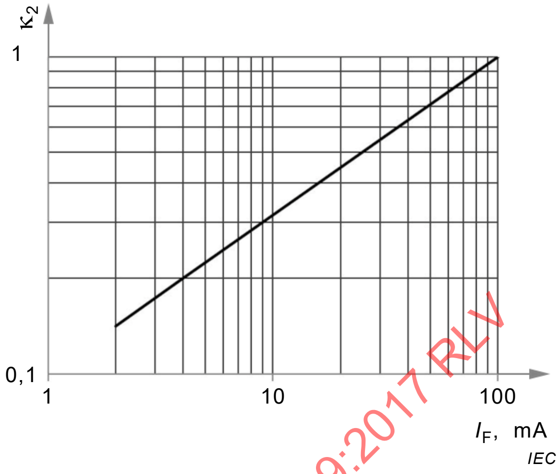
and can be derived from the graph.



IEC

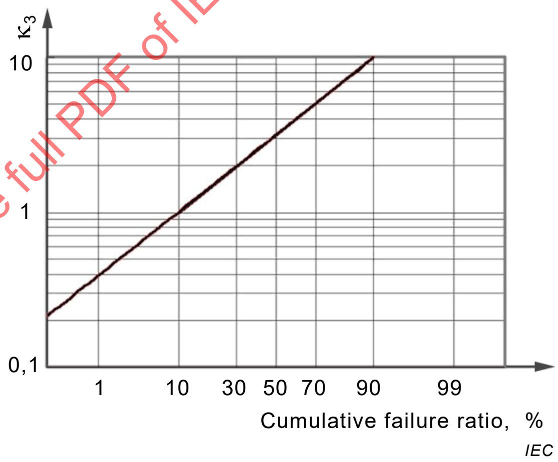
E.4.5 Factor κ_2

The factor κ_2 is a function of the optical power measuring current I_F and can be derived from the graph.



E.4.6 Factor κ_3

The factor κ_3 depends on the cumulative failure ratio given in percent as shown in the graph.



E.5 Aluminium, non-solid electrolyte capacitors

The main influencing factor for useful life L of non-solid electrolyte aluminium capacitors is the capacitor temperature θ_C in °C.

NOTE Other factors as applied voltage and ripple current to life are disregarded at this stage.

Useful life in hours is given by

$$L = QTD \times 2^{\left(\frac{\theta_M + 5 - \theta_C}{10}\right)} \tag{E.9}$$

where

QTD	is the qualification test duration in hours;
θ_M	is the maximum temperature of the climatic category in degrees Celsius;
$\theta_C = \theta_{ambient} + 5$	is the capacitor temperature in degrees Celsius.

The “qualification test duration” depends on the technology type and can also be denoted as “base lifetime” of the capacitor.

E.6 Relays

According to IEC technical committee 94 (All-or-nothing electrical relays) there are no general models for the useful life of relays.

Data on useful life can be obtained from data sheets or directly from manufacturers of the component type or, if not available, suitable life tests should be performed according to IEC 61810-2, IEC 61810-2-1 and IEC 61812-1.

E.7 Switches and keyboards

Failure rate of switches and keyboards is assumed to be constant but only within the specified number of switching cycles.

Examples for useful life limitation are given in Table E.1.

Table E.1 – Useful life limitations for switches and keyboards

Type	Limitations (cycles)
Toggle and push button switches	Between 20 000 and 100 000
Rotary switches	20 000
Keyboards	Between 500 000 and 1 000 000

E.8 Connectors

Useful life of connectors is limited. The number of mating/unmating cycles should not exceed the specified value (or the value given by the manufacturer).

Annex F
(informative)

Physics of failure

F.1 General

The physics of failure (PoF) approach proactively incorporates reliability into the design process by establishing a scientific basis for evaluating new materials, structures, and electronics technologies. Information to plan tests and screens, and to determine electrical and thermal-mechanical stress margins are identified by the approach.

The PoF approach encourages innovative, cost-effective design through the use of realistic reliability assessment and is an attempt to identify the "weakest link" of a design to ensure that the required equipment life and reliability is exceeded by the design.

The methodology generally ignores the issue of defects escaping from the manufacturing process and assumes that product reliability is strictly governed by the predicted life of the weakest link.

At the integrated circuit level for instance, example models address microcircuit die attach fatigue, bond wire flexure fatigue and die fatigue cracking. The models are very complex and require detailed device geometry information and materials properties. In general, the models are most useful in the early stages of designing devices but not at the assembly level when flexibility no longer exists to change device designs.

The PoF approach is not only a tool to allow better and more effective designs but it can be an aid for cost-effective approaches for improving the entire approach to building electronic systems. However an understanding of the PoF is necessary in applications which afford little opportunity for testing, or for reliability growth.

Reliability assessments based on PoF methods incorporate reliability into the design process with the intention that the system meets the user requirements. Predicting the reliability of electronics is a hard engineering task since there are too many factors, both controllable and uncontrollable, which cannot be readily identified, quantified, or combined into an all-inclusive and deterministic equation. However, some progress has been made to simplify the prediction process. For example software exists which will predict the fatigue life of solder joints, component leads, and plated through holes. This software is based on finite element analysis (FEA) and the results of such complex FEA of assemblies have become an integral part of the design process, and provide a more comprehensive reliability prediction process than was available in the past.

In PoF based prediction modelling a probabilistic mechanics based approach is used. The goal is to use PoF principles with appropriate failure probability density distributions to design for failure-free operation and predict times for components now available, as well as new components resulting from new materials, technologies and processes. The stress-margin approach, using models based on PoF analysis is used as an alternative to standard stress based approaches.

Much of the focus on PoF has been on the failure of integrated circuits and so a brief outline of failure mechanisms as a basis for a PoF approach is given in F.2.

Failure mechanisms details and models for many other device types can be found in such repositories as RIAC WARP.

F.2 Failure mechanisms of integrated circuits

The end of life period of an integrated circuit is supposed to appear far beyond the utilization period of the equipment. This assumption has to be assessed by a preliminary qualification.

The main observed failures in semiconductors are caused by thermomechanical constraints applied to components mounted on PCBs. The failure rate related to the humidity is insignificant (for active components, especially since the general use of nitride based passivation). Furthermore, in these studied environments no defect related to mechanical shocks or to vibrations or to chemical contamination has been observed. Consequently, these failure mechanisms have not been taken into account in the models.

The main failure mechanisms are listed in Table F.1.

Table F.1 – Failure mechanism for Integrated circuits

Type	Silicon technologies	GaAs technologies	Packages
Mechanisms	Electromigration Oxides ageing Hot electrons Charge gain and charge loss	Gate sink Ohmic contact degradation Gate and drain lagging Electromigration Thermal fatigue Purple plague	Thermal fatigue Purple plague

The integrated circuit model used in this document does not include the failure rate due to soft errors, when the function is fully retrievable without outside intervention, for example provoked by the creation of electron-hole pair by the passage of alpha particle emitted by the package materials. This failure rate due to soft errors may be of the same order of magnitude as the intrinsic failure rate, especially for dynamic memories.

For interface circuits, the integrated circuit models used in this document include a failure rate considered to be constant, due to external electrical influences. This failure rate depends on the electrical environment of the equipment, given that the equipment does have primary or secondary protections, depending on the state of the art of the period observed. (For the purposes of this document, interface circuits are taken to be circuits or devices connecting the equipment to the outside environment.)

Annex G
(informative)

Considerations for the design of a data base on failure rates

G.1 General

This document requires failure rates in order to be useful. These can be obtained from a number of sources the most useful of which would be field usage data, the second most useful would be test related data, most probably obtained from the component manufacturers.

The basic idea behind the information given in the following clauses is that there is a collection of reliability data, which is converted to input for the database, from where it can be retrieved by people or organizations in order to make failure rate calculations on the next higher level of aggregation.

G.2 Data collection acquisition – collection process

Guidance on data collection is given in IEC 60300-3-2.

G.3 Which data to collect and how to collect it

The use of failure data drives the way it should be collected. The final use should hence be clearly defined before setting up the data collection equipment as, once it is developed, it is very difficult and costly to make changes because some information is missing, which is vital for the end-user.

The prediction models are not intended to describe the physical behaviour of the components or explain their failure mechanisms, but to represent the best estimate based on observed data. They seek to represent what happens to equipment in real field conditions in the steady-state part of the life cycle.

When the final purpose for using failure models is to provide design objectives, data coming from the field should be suitably filtered in order to eliminate from the observed population those items that have not yet reached reliability maturity, i.e. items affected by equipment failures, design errors, or infant mortality.

When analysing field data that has come from testing and repair in repair centres, a specific topic to be carefully considered is diagnostics coverage. In fact, more than one component (or even a large number) may be removed during repair, and the percentage "no fault found" (NFF) may be above the generally accepted limit of around 20 %, which is considered to be the minimum that is normally achievable.

On the other hand, if the result is aimed at spare parts dimensioning (logistics), either at component or equipment level, other situations should be considered when deciding what data to collect:

- no fault found (NFF);
- imperfect diagnostics;
- incorrect use of components that lead to systematic failures;
- maintenance not correctly performed and human errors;
- external factors (electrical and environmental);
- the learning curve of manufacturing processes;

- the case where multiple components are removed to carry out a repair;
- the case when a component failure causes the failure of other components.

G.4 Calculation and decision making

Failure rates in the database are derived from all or some of the reported information. Ideally they are determined from the field while also taking test results from external sources into account and then adapting these to the reference conditions.

For data obtained from the field, all failures should be included that can be reproduced during the testing of the replaced equipment (e.g. subassemblies). The individual reasons for failures are not important here (e.g. manufacturing fault of a component, stress, external effects within the range of the specified values). Experience shows that in some of the rejected equipment no failures can be found. These pieces of equipment should be not considered for the determination of the failure rate. It can be necessary for users to take these NFF parts into account separately when planning spare-parts logistics.

For data obtained from test, the principles of IEC 60300-3-5 should be followed.

While confidence limits are of value for interval estimates of the data determined from tests, they are not reasonable for expected values.

G.5 Data descriptions

As a minimum any data base should contain information on the following.

1) Component identification and specification data
    a) Identification
    b) Component technology
2) Specification of component
    a) Electrical specification of component
    b) Environmental specification of component.
3) Component field related data
    a) Method of selection of monitored components
    b) Field conditions
    c) Data on failures during field operation
4) Component test related data
    a) Method of selection of test components
    b) Test conditions
    c) Data on failures during test

For a solely field failure database item 4 would be omitted, and for a test database item 3 would be omitted.

The following clauses outline the minimum recommended contents of these data items.

G.6 Identification of components

G.6.1 General

The information supplied to identify the components should be in accordance with the relevant IEC or internationally recognized management quality systems publications for the component type under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other component specifications should be used and the source of the specifications stated. As a minimum, the following information should be given. Only information applicable to a particular component type should be supplied.

Examples of the specific information required for different component types can be found in IEC 61360-4.

G.6.2 Component identification

- A description of the component type with sufficient details to uniquely identify the component type, for example N-channel V-MOS transistor. When available, specification numbers should be given.
- The component part number. If available, a universal part number, for example stock number, should be given; otherwise a part number specific to the component manufacturer may be given.
- Name of the manufacturer and place of manufacture. The purpose of these references is to allow access to more detailed information if required.
- The date of manufacture or lot number or other production batch related identification. This information will allow access to other components that were produced at the same time as the sample should a problem arise.
- The production status of the component, for example development sample, pre-production, standard production, mature technology.
- Information regarding compliance with other recognized standards should be given whenever possible.

G.6.3 Component technology

- A description of the basic component technology, for example metal film resistor.
- A general description of the production process, for example ion beam epitaxy.
- Packaging information, for example plastic, hermetic weld.
- Thermal resistance, for example Rthj-a, Rthj-c.
- Complexity of circuit.
- Method of termination, for example endcaps, DIL, SMD.

G.7 Specification of components

G.7.1 General

The information supplied to specify the components should be in accordance with the relevant IEC or internationally recognized management quality systems publications for the component type under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other component specifications should be used and the source of the specifications stated. As a minimum, the following information should be given.

G.7.2 Electrical specification of components

- Relevant information about ratings and characteristics should be supplied. These references taken from the applicable component specifications will depend on the type of test performed. For example, if power cycling tests are performed then the ratings for power dissipation should be given.
- Information should be given about any pre-test screening the components to be tested may have undergone. The results of such screening should be given.

G.7.3 Environmental specification of components

Information should be given regarding the maximum environmental conditions the components can withstand, for example temperature, humidity, acceleration.

G.8 Field related issues data

G.8.1 General

The field environmental conditions should be those described in the relevant IEC or internationally recognized management quality systems publications for the components in operation whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other specifications should be used and the source of the specifications stated. The following minimum information should be supplied.

G.8.2 Actual field conditions

- The source of the results, for example the quality assurance department of the manufacturer.
- A description of the field conditions used, for example the electrical, mechanical and environmental conditions. The field conditions should be identified by quoting the relevant IEC or other test specifications where possible.
- The number of components exposed to the field conditions. Where a component is available in a number of different values, for example resistors, capacitors, the values present and the quantity of each value should be stated.
- A description of the characteristic measured, for example resistance, and the measuring conditions. Where the measurement conditions are specified by IEC or other specifications, then the specification number should be given.
- If more than one method of characteristic measurement is permissible then a description of the method used should be given. This description should contain all relevant details.
- The operation start date, duration and measurement intervals should be stated.

G.8.3 Data on field failures

- The number of failures observed, categorized by environmental conditions and type of failure modes should be stated with percentage occurrence. Identified failure mechanisms should be stated with their associated activation energies and temperature ranges.
- The times at which the failures occurred or were verified.
- Special events during operation, for example events which might have affected the results.
- Complete data from operation should be presented whenever possible but if data from operations are discarded, these data and the reasons why they are not given in the presentation or results, should be given separately.
- Failure criteria for the components (for degradation failures as well as for catastrophic failures), are normally defined by the requirements given by the specification to which reference is made in the field report. If failure criteria for the components are not given by the reference specification, they should be stated.
- Failure rate which can be assumed to be constant.
- The operating time of components during which the failure rate is assumed to be constant should be indicated (i.e. useful life). Failure rates found will preferably be stated in failures per 10^9 h of operation. The value of 60 % is often used as the upper confidence level for failure rates.
- Failure rate which cannot be assumed to be constant.
  - The operating test time can be divided into a number of separate periods and the results for each of these periods evaluated separately. The necessary time periods which have to be distinguished and the number of failures which occur during each time period should be given. If the results can be satisfactorily approximated by a

mathematical function, it would be useful to present these functions, as well as the period during which they are applicable. In all cases, mean lifetime, failure distribution and the influence of derating should be stated. For life-limited components, an appropriate model should be suggested.

- Influence of stresses.
  - As failure rates are dependent on the type and the intensity of stress, all failure rate data should be presented with the applied stress levels. Furthermore, it can be important to know the correlation between failure rate and stress (temperature, power, vibration, etc.) and, where possible, the activation energy of the failure mechanism should be supplied. Therefore, failure rate values obtained at different stress levels should be supplied separately.

G.9 Test related issues data

G.9.1 General

The test and sampling conditions should be those described in the relevant IEC or internationally recognized management quality systems publications for the components under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other test specifications should be used and the source of the specifications stated. The following minimum information should be supplied.

G.9.2 Actual test conditions

- The source of the results, for example the quality assurance department of the manufacturer.
- A description of the test conditions used, for example the electrical, mechanical and environmental conditions. The test conditions should be identified by quoting the relevant IEC or other test specifications where possible.
- The number of components under test. Where a component is available in a number of different values, for example resistors, capacitors, the values tested and the quantity of each value should be stated.
- A description of the characteristic measured, for example resistance, and the measuring conditions. Where the measurement conditions are specified by IEC or other specifications, then the specification number should be given.
- If more than one method of characteristic measurement is permissible then a description of the method used should be given. This description should contain all relevant details.
- The test start date, duration and measurement intervals should be stated.
- Where a delay exists between the cessation of the test and the commencement of measurements, then the time duration should be stated. The storage conditions during this delay should also be stated. Any conditioning stress applied to the components before measurement should also be stated.

G.9.3 Data on test failures

- The number of failures observed, categorized by test conditions and type of failure modes should be stated with percentage occurrence. Identified failure mechanisms should be stated with their associated activation energies and temperature ranges.
- The times at which the failures occurred or were verified.
- Special events during testing, for example events which might have affected the results.
- Complete data from tests should be presented whenever possible but if data from tests are discarded, these data and the reasons why they are not given in the presentation or results, should be given separately.
- Failure criteria for the components (for degradation failures as well as for catastrophic failures), are normally defined by the requirements given by the specification to which reference is made in the test report. If failure criteria for the components are not given by the reference specification, they should be stated.

- Failure rate which can be assumed to be constant.
  - The test time of components during which the failure rate is assumed to be constant should be indicated (i.e. useful life). Failure rates found will preferably be stated in failures per 10^9 h of operation. The value of 60 % is often used as the upper confidence level for failure rates.
- Failure rate which cannot be assumed to be constant.
  - The total test time can be divided into a number of separate periods and the results for each of these periods evaluated separately. The necessary time periods which have to be distinguished and the number of failures which occur during each time period should be given. If the results can be satisfactorily approximated by a mathematical function, it would be useful to present these functions, as well as the period during which they are applicable. In all cases, mean lifetime, failure distribution and the influence of derating should be stated. For life-limited components, an appropriate model should be suggested.
- Influence of stresses.
  - As failure rates are dependent on the type and the intensity of stress, all failure rate data should be presented with the applied stress levels. Furthermore, it can be important to know the correlation between failure rate and stress (temperature, power, vibration, etc.) and, where possible, the activation energy of the failure mechanism should be supplied. Therefore, failure rate values obtained at different stress levels should be supplied separately.

G.10 Failure rate database attributes

Table G.1 describes some of the attributes of a database suitable for reliability prediction.

Table G.1 – Reliability prediction database attributes

Categories of information	Detailed information	Purpose
Component identification	Manufacturer Part No Link to datasheet	To filter for component, product line and manufacturer
Component categorization	Component main category Technology Complexity Mechanical size Housing Thermal considerations	To filter for similar items.
	Compliance issues – standards – certificates	To filter for parts which fulfil certain regulative requirements.
	Manufacturing specific information like hazardous substance issues, packaging, lot sizes, tests performed during manufacturing, etc.	To allow for checking against manufacturing issues, which could be rejection criteria.
Usage categorization	Function/Purpose Environmental conditions	To filter for specific types of application of the part, which cause a certain set of electrical stress.
(Reference) Failure rate		To state the failure rate applicable to the reference conditions given.
(Reference) Conditions		To state the conditions applicable to the reference failure rate given.
Stress model	π-factors applicable and their mathematical combination	To determine how to convert failure rates from reference conditions to application operating conditions.
Information related to elements of the stress model	Parameters, formulae or tables necessary to determine the value of the relevant π-factor	To determine the values for the π-factors.
Data considered for calculation of the failure rate or reference to the detailed calculation	Reference to detailed calculation. Component hours	To retrieve the full story. To estimate the relevance and credibility of the data.
Confidence interval (if any)	Data such as upper, lower limit, probabilities	To estimate the accuracy of the failure rate given.
Further information concerning the data forming the basis for the failure rate	Age of data Component hours Failures Confidence limit and related data	
Originator information	Originator of the calculation Date of issue Date of storage in database	To ensure traceability.

Annex H
(informative)

Potential sources of failure rate data and methods of selection

H.1 General

When performing reliability prediction, it is advisable to use current reliable sources of field data whenever they are available and applicable as long as they are valid for the equipment. Annex H gives some guidance on how to select appropriate sources.

H.2 Data source selection

Data should be obtained from the following sources in the given order of preference:

- user data;
- manufacturer's data;
- handbook data.

If user data is available for the prediction then it should be used. If no user data is available then the manufacturer’s data should be examined and, if judged suitable, used. If no manufacturer’s data is available then handbook data or other data should be examined and, if judged suitable, used.

If no data source can be found, a risk assessment should be performed to determine the necessity tasks for obtaining further data, for example by a reliability test programme, whether to use expert judgement or whether to accept the fact that data is not available for the particular component under consideration.

In all cases however, in order to ensure that work is technically correct, it is necessary to present justification for the choices made while the work is performed. It is normally necessary to justify the use of reliability prediction as a valid reliability technique before justifying the actual method and data sources used. In order to justify the use of the technique, in this case reliability prediction, there are a number of considerations that need to be made:

- if reliability prediction is the only way to perform the task or generate information then the justification should say why this is the only way;
- if reliability prediction is not the only way, yet it is the best way, then the justification should say why this is the best way;
- if reliability prediction is not the only way nor the best way then the justification should specify why it is being used.

Once reliability prediction is justified then the actual prediction methodology (parts count or parts stress or some hybrid) should be justified. This is carried out in the same manner as the justification for prediction:

- if method “X” is the only way to perform the prediction then the justification should say why this is the only way;
- if method “X” is not the only way to perform the prediction, yet it is the best way, then the justification should say why this is the best way;
- if method “X” is not the only way nor the best way then the justification should specify why it is being used.

Once the methodology is justified, the data sources used as input data should be justified. This is done in the same manner as above.

The justification should be recorded so that the decisions made during the process can be defended at some later date. The justification information can be used along with the results of a prediction as part of any dependability case (as defined, for example, in IEC 62741).

H.3 User data

User data is that which has been produced by the organization performing the prediction for the sole purpose of deriving reliability information about components that can be obtained in no other way. Data can be, for instance, from in house testing, user field experience, lessons learned, or expert judgement.

If user data is available, check whether data is collected and presented in accordance with applicable standards and a detailed review of data collection and analysis processes should be made. IEC 60300-3-2 and IEC 60300-3-5 are available guides to these processes.

For field data the following should be reviewed: data collection procedures, relevance of failures, and analysis techniques. Data required to quantify the prediction model is obtained from sources such as warranty records, customer maintenance records, component suppliers, or expert elicitation from design or field service engineers. If field failure rate data has been collected then the conditions (environmental and functional stresses) for which the values are valid should also be stated.

For test data the following should be reviewed: tests and tests conditions applied to the components, lot sampling, number of lots, manufacturing, testing period, and failure analysis. When using failure rates that have been determined under laboratory test conditions a distinction should be made in the way in which failure rates are obtained, since in most cases, the failure criteria applicable to the test are not directly transferable to field applications and it is therefore advisable to use field data wherever it is available and applicable.

The failure rates stated should be understood as expected values for the stated time interval and the entirety of lots, and they should be operated under the stated conditions, i.e. it is to be expected that in future use under the given conditions the stated values will, on average, be obtained. Confidence limits for expected values of components are not reasonable because they only apply for estimated failure rates based on life tests.

H.4 Manufacturer's data

Manufacturer's data is that which is supplied by the manufacturer based on tests of a particular component.

If manufacturer's data is available, check whether data is collected and presented in accordance with applicable standards and a detailed review of data collection and analysis processes should be made. IEC 60300-3-2 and IEC 60300-3-5 are available guides to these processes.

For manufacturer's data the following should be reviewed: tests and tests conditions applied to the components, lot sampling, number of lots, manufacturing and testing period, and failure analysis.

If a manufacturer's stated values originate from accelerated tests with high stresses and have been converted to normal levels of stress for a long period through undifferentiated use of conversion factors, they may deviate from the values observed in operation. Due to the different procedures used to determine failure rates by the manufacturer (e.g. worst case tolerance) and by the user (e.g. function maintained despite parameter changes, fault propagation law), more favourable values may be obtained.

H.5 Handbook reliability data

H.5.1 General

Failure rate data of components are published in several reliability handbooks. Usually the data published is component data obtained from equipment in specific applications, for example telephone exchanges. In some cases the source of the data is unspecified and may not be obtained from field data. Due to this reason, failure rate predictions often differ significantly from field observations and can often lead to misleading conclusions.

Table H.2 provides information to the user concerning data sources for component failure rate determination. This list is not comprehensive and not necessarily maintained up to date, and is not intended to give a preference for sources. It remains up to the user to determine which data source is relevant for their application. Note that there are a number of handbooks and standards that describe reliability prediction, but only those that contain data are listed here. This information is given for the convenience of users of this document and does not constitute an endorsement by the IEC.

H.5.2 Using handbook data with this document

The following steps are recommended:

Step (1) Select an appropriate handbook (see H.5.3);

Step (2) Define reference conditions, for example those stated in this document (see Clauses 6 to 20);

Step (3) Determine the failure rate with these conditions.

Example:

For a general-purpose transistor, the failure rate at reference conditions should be determined. Results are given in Table H.1.

Step (1) Select a Handbook, e.g. MIL-HDBK-217F, 1995 (it serves here only as an example)

Step (2) Define reference conditions (see 7.1)

Reference junction temperature: $\theta_{\text{ref}} = 55\,°\text{C}$,

Voltage ratio: $U_{\text{ref}}/U_{\text{rat}} = 0{,}5$ (U_{ref} is 50 % of rated voltage)

Step (3) Determine failure rate at reference conditions (e.g. from MIL-HDBK-217F:1995, Clause 6.6)

$$\lambda_{\text{p}} = \lambda_{\text{b}} \times \pi_{\text{T}} \times \pi_{\text{R}} \times \pi_{\text{S}} \times \pi_{\text{Q}} \times \pi_{\text{E}}$$

$$\lambda_b = 0{,}18 \cdot 10^{-6}\ \text{h}^{-1}$$

$$\pi_{\text{T}} = 1{,}9 \text{ for } \theta_{\text{ref}} = 55\,°\text{C}$$

$$\pi_{\text{R}} = 0{,}43 \text{ for rated power} < 0{,}1\ \text{W}$$

$$\pi_{\text{S}} = 0{,}21 \text{ for } V_{\text{S}} \equiv U_{\text{ref}}/U_{\text{rat}} = 0{,}5$$

$$\pi_{\text{Q}} = 1,\ \pi_{\text{E}} = 1$$

$$\lambda_{\text{ref}} \equiv \lambda_{\text{p}} = 0{,}18 \cdot 10^{-6}\ \text{h} \times 1{,}9 \times 0{,}43 \times 0{,}21 \times 1 \times 1 \approx 30{,}9 \cdot 10^{-9}\ \text{h}^{-1}$$

Table H.1 – Result of calculation for transistors common, low frequency

Component	θ_{ref} °C	$U_{\text{ref}}/U_{\text{rat}}$	λ_{ref}
Bipolar, universal e.g. TO18, TO92, SOT(D)(3)23 or similar	55	0,5	$30{,}9 \cdot 10^{-9}$ h^{-1}
Transistor arrays	55		
Bipolar, low power e.g. TO5, TO39, SOT223, SO8, SMA-SMC	85		
Bipolar, power e.g. TO3, TO220, D(D)-Pack	100		
FET junction MOS	55 55		
MOS power (SIPMOS) e.g. TO3, TO220, D(D)-Pack	100		

H.5.3 List of available handbooks

Table H.2 – Sources of reliability data (in alphabetical order)

Data source	Short description
1. AT&T Reliability manual Klinger, David J.,Yoshinao Nakada, and Maria A. Menendez, Editors, AT&T Reliability Manual, Van Nostrand Reinhold, 1990, ISBN:0442318480	The AT&T reliability manual outlines prediction models and contains component failure data. The main prediction models include a decreasing hazard rate model for early life failures, which is modelled using Weibull data, and a steady- state hazard rate model using constant failure rate data. In this respect the handbook is unique.
2. Prediction of component failure rates for PSA on nuclear power plants 1982-1997 Available as a paper: “Prediction of component failure rates for PSA on nuclear power plants 1982-1997”. Author; KIRIMOTO YOSHIHIRO (Cent. Res. Inst. of Electr. Power Ind., Nucl. Inf. Center) MATSUZAKI AKIHIRO(Cent. Res. Inst. of Electr. Power Ind., Nucl. Inf. Center) SASAKI ATSUSHI(Cent. Res. Inst. of Electr. Power Ind., Nucl. Inf. Center) Journal title; Denryoku Chuo Kenkyujo Genshiryoku Joho Senta Hokoku Journal Code:L2958A VOL.;NO.P00001;PAGE.104P(2001)	This document describes the revised component failure rate calculated by re-prediction on 49 Japanese light water reactors from 1982 to 1997.
3. FIDES Available on the internet	FIDES is a reliability data handbook developed by a consortium of French industry under the supervision of the French Department of Defense (DGA). The FIDES methodology is based on physics of failures and is supported by the analysis of test data, field returns and existing modelling
4. Guidelines for process equipment reliability data – With data tables Available from Center for Chemical Process Safety/AIChE ISBN: 978-0-8169-0422-8 Electronic ISBN: 978-1-59124-568-1.	These guidelines were written to provide process safety practitioners and their managers with the information required to estimate statistical failure rates for pumps, valves, heat exchangers, instruments and other chemical process equipment. The failure rates are essential for making a chemical process risk analysis to predict the risk of various process and facility scenarios.
5. HRD5: British Telecom Handbook of reliability data This method is available in a number of commercial reliability software packages.	HRD5 is a reliability standard developed by British Telecommunications plc that also provides models for a wide range of components. In general, HRD5 is similar to CNET 93, but provides simpler models and requires fewer data parameters for analysis.

Data source	Short description
6. IEEE 493-2007 Available from IEEE Customer Service	The IEEE book with recommended practice for the design of reliable, industrial and commercial power equipment provides data concerning equipment reliability used in industrial and commercial power distribution equipment.
7. IRPH 2003: Italtel Reliability prediction Handbook Available from Italtel spa - Italy	The Italtel prediction handbook was first published in 1993 as the result of collaboration among many European organizations and companies, in particular a study group involving British Telecom, Italtel and CNET. The result of these studies lead to the publication of three virtually identical Handbooks, by CNET (RDF 93), Italtel (IRPH 93) and British Telecom (HRD 5). IRPH 2003 adopts the failure rate models of IEC 61709 (1996), with some simplifications to make them easier to use. Reference failure rates are mainly derived from field data and based on a collaboration with Siemens.
8. HDBK-217Plus Available on the internet	Reliability Information Analysis Center (RIAC) replacement prediction methodology for MIL-HDBK-217
9. MIL-HDBK-217 MIL-HDBK-217F Reliability prediction of electronic equipment Available on the internet	MIL-HDBK-217, Reliability prediction of electronic equipment, has been the mainstay of reliability predictions for about 40 years.
10. NPRD 2016 Available on the internet	NPRD 2016 data provides failure rates for a wide variety of items, including mechanical and electro-mechanical parts and assemblies. The document provides detailed failure rate data on over 25 000 parts for numerous part categories grouped by environment and quality level.
11. NSWC-11 Handbook of reliability prediction procedures for mechanical equipment. Available on the internet	This handbook, developed by the Naval Surface Warfare Center – Carderock Division provides failure rate models for fundamental classes of mechanical components.
12. Offshore and onshore reliability data (OREDA) Available from Oreda	The handbooks contain reliability data from offshore equipment compiled in a form that can easily be used for various safety, reliability and maintenance analysis.
13. UTE C80-810 Available from AFNOR	This handbook is known as UTE C80-810 Reliability data handbook. This handbook covers most of the same components as MIL-HDBK-217. This handbook was originally named RDF.
14. Reliability data for safety instrumented equipment PDS data handbook, 2006 Edition Available on the internet	Reliability data dossiers for field devices (sensors, valves) and control logic (electronics) are presented, including data for subsea equipment.
15. Failure Mode/Mechanism Distributions FMD-2016 Available on the internet	FMD-2016 Databook contains field failure mode and mechanism distribution data on a variety of electrical, mechanical, and electromechanical parts and assemblies.
16. Safety Equipment Reliability Handbook - 4th Edition Available from ISA (International Society of Automation)	This publication contains information on failure rates, failure mode distributions, diagnostic detection capability, and common cause susceptibility. This handbook was created to supply that information in a format specific to safety integrity verification. The data is formatted such that it can be directly used in safety verifications and to allow for easy comparison of equipment items or designs.
17. Siemens SN 29500 Available from Siemens AG Corporate Technology	The Siemens SN 29500 failure rates of components and expected values method was developed by Siemens AG for use of Siemens and Siemens associates as a uniform basis for reliability prediction. SN 29500 is based on IEC 61709 and states failure rates under reference conditions as described in this document.

Data source	**Short description**
18. TELCORDIA SR-332 This method is available in a number of commercial reliability software packages.	The SR–332, Reliability prediction procedure for electronic equipment, documents the recommended methods for predicting device and unit hardware reliability.
19. Various software	Many pieces of reliability software contain reliability data. In many cases this is data taken from one of the above sources but in some cases the data is unique to the software.

Annex I
(informative)

Overview of component classification

I.1 General

Component identification is the most important element of any codification system because it establishes a unique identification for every item of supply. The identification consists of the minimum data required to establish clearly the essential characteristics of the item, i.e. those characteristics that give it a unique character and differentiate it from all others. Annex I gives a brief overview of the generic component description standards which may be encountered. Unfortunately it is not possible to give a translation table between these descriptions and the one used in this document.

This document recommends the use of the IEC 61360 standards to define the component type. This component tree is described in Table I.1 and will allow users of the IEC 61360 descriptions to find component models easily in this document.

I.2 The IEC 61360 system

This document provides a basis for the clear and unambiguous definition of characteristic properties (data element types) of all elements of electrotechnical equipment from basic components to subassemblies and full equipment. Although originally conceived in the context of providing a basis for the exchange of information on electric components, it may be used in areas outside the original conception such as assemblies of components and electrotechnical equipment and sub-equipment.

It provides for establishing a classification hierarchy and the allocation of applicable and relevant properties to each of the classes so established in order to describe fully the characteristics of objects belonging to that class and hence it facilitates the exchange of data describing electrotechnical equipment through a defined structure in order for the information to be exchanged in a computer-sensible form.

The part of IEC 61360 that is of interest is IEC 61360-4 which provides the IEC reference collection of classes and associated characteristic properties for electric components and materials used in electrotechnical equipment. Table I.1 contains the classification tree for IEC 61360-4 cross-referenced against the relevant clause in this document. In cases where no such data exists in this document, the clause is noted as “N/A” (not available). Where this document contains lower level detail in terms of component types than in IEC 61360-4, then the clause will have “+” noted beside it.

In Table I.1 below, the headings L1 to L5 represent the descriptive level tags given in IEC 61360-4. Each level tag adds another layer of description to the component type. Note that for completeness each of these descriptions should have the terms “IECREF:CO:EE” for “IEC reference collection, Components, Electric-Electronic” or “IECREF:CO:EM” for “IEC reference collection, Components, Electromechanical” placed in front of it. Hence the full code for a “fixed air capacitor” would be “IECREF:CO:EE:CAP:FIX:AIR”.

Note also that only the component categories are listed in Table I.1, the geometric data has been omitted.

Table I.1 – Classification tree (IEC 61360-4)

Component description	**IEC 61360-4 classification tree**					**Clause in this document**
	L1	**L2**	**L3**	**L4**	**L5**	
ELECTRIC COMPONENTS						
Amplifier	AMP					6+
Amplifier, low frequency	AMP	LF				6+
Amplifier, low frequency power	AMP	LF	PWA			6+
Amplifier, low frequency voltage	AMP	LF	VTA			6+
Amplifier, low frequency voltage differential	AMP	LF	VTA	DFA		6+
Amplifier, low frequency voltage differential AC-coupled	AMP	LF	VTA	DFA	ACA	6+
Amplifier, low frequency voltage differential DC-coupled	AMP	LF	VTA	DFA	OPA	6+
Amplifier, low frequency voltage single sided	AMP	LF	VTA	SSA		6+
Amplifier, radio frequency	AMP	RF				6+
Amplifier, wide band	AMP	WB				6+
Antenna	ANT					N/A
Antenna, capacitive (whip)	ANT	CAP				N/A
Antenna, inductive (ferroceptor)	ANY	IND				N/A
Antenna, resistive (tuned dipole)	ANY	RES				N/A
Battery	BAT					N/A
Battery, primary	BAT	PRI				N/A
Battery, secondary	BAT	SEC				N/A
Capacitor	CAP					9+
Capacitor, fixed	CAP	FIX				9+
Capacitor, fixed air	CAP	FIX	AIR			9+
Capacitor, fixed ceramic	CAP	FIX	CER			9+
Capacitor, fixed ceramic, class 1	CAP	FIX	CER	CL1		9+
Capacitor, fixed ceramic, class 2	CAP	FIX	CER	CL2		9+
Capacitor, fixed, electrolytic	CAP	FIX	ELC			9+
Capacitor, fixed electrolytic with solid tantalum electrolyte	CAP	FIX	ELC	STAN		9+
Capacitor, fixed electrolytic with non-solid tantalum electrolyte	CAP	FIX	ELC	NTAN		9+
Capacitor, fixed electrolytic with solid aluminium electrolyte	CAP	FIX	ELC	SAL		9+
Capacitor, fixed electrolytic with non-solid aluminium electrolyte	CAP	FIX	ELC	NAL		9+
Capacitor, fixed, film	CAP	FIX	FLM			9+
Capacitor, fixed, glass	CAP	FIX	GLS			9+
Capacitor, fixed, mica	CAP	FIX	MIC			9+
Capacitor, fixed, multilayer	CAP	FIX	MLAY			9+
Capacitor, fixed, paper	CAP	FIX	PAP			9+

Component description	IEC 61360-4 classification tree					Clause in this document
	L1	L2	L3	L4	L5	
Capacitor, variable	CAP	VAR				9+
Conductor	CND					N/A
Conductor, bare	CND	BAR				N/A
Conductor, insulated	CND	INS				N/A
Conductor, insulated, cable	CND	INS	CBL			N/A
Conductor, insulated, cable, power	CND	INS	CBL	POW		N/A
Conductor, insulated, cable, signal	CND	INS	CBL	SIG		N/A
Conductor, insulated, cable, signal, low frequency	CND	INS	CBL	SIG	LF	N/A
Conductor, insulated, cable signal, high frequency	CND	INS	CBL	SIG	HF	N/A
Conductor, insulated, insulated wire (single conductor)	CND	INS	IWR			N/A
Delay line	DEL					N/A
Diode device	DID					7+
Diode device, bridge rectifier	DID	BRI				7+
Diode device, diode	DID	DIO				7+
Diode device, diode, break over diode	DID	DIO	BOD			7+
Diode device, diode, rectifier diode	DID	DIO	REC			7+
Diode device, diode, signal diode	DID	DIO	SIG			7+
Diode device, diode, stabilizer diode	DID	DIO	STB			7+
Diode device, diode, stabilizer diode, current regulator	DID	DIO	STB	CUR		7+
Diode device, diode, stabilizer diode, voltage reference	DID	DIO	STB	REF		7+
Diode device, diode, stabilizer diode, voltage regulator	DID	DIO	STB	REG		7+
Diode device, diode, stabilizer diode, stabistor	DID	DIO	STB	STA		7+
Diode device, diode, stabilizer diode, transient suppressor	DID	DIO	STB	SUP		7+
Diode device, diode, variable	DID	DIO				7+
Diode device, voltage multiplier	DID	VMP				7+
Fibre optics	FIBOPTIC					8+
Fibre optics, links	FIBOPTIC	LINKS				8+
Fibre optics, connectors	FIBOPTIC	CONN				8+
Fibre optics, switched	FIBOPTIC	SWI				8+
Fibre optics, branches	FIBOPTIC	BRA				8+
Fibre optics, couplers/splitters	FIBOPTIC	COUP				8+
Fibre optics, attenuators	FIBOPTIC	ATT				8+
Fibre optics, detectors	FIBOPTIC	DET				8+
Fibre optics, isolators	FIBOPTIC	ISOL				8+
Fibre optics, networks	FIBOPTIC	NETW				8+
Fibre optics, light sources	FIBOPTIC	SOURC				8+
Fibre optics, modulators	FIBOPTIC	MOD				8+

Component description	**IEC 61360-4 classification tree**					**Clause in this document**
	L1	**L2**	**L3**	**L4**	**L5**	
Fibre optics, transmitters/receivers	FIBOPTIC	TXRX				8+
Fibre optics, waveguides	FIBOPTIC	WG				8+
Fibre optics, cables	FIBOPTIC	CAB				8+
Fibre optics, filters	FIBOPTIC	FIL				8+
Fibre optics, lens	FIBOPTIC	LENS				8+
Filter	FIL					12
IC	IC					6+
IC, analog/digital	IC	AD				6+
IC, analog	IC	ANA				6+
IC, digital	IC	DIG				6+
IC, digital, combinational sequential interface (CSI)	IC	DIG	CSI			6+
IC, digital, microcontroller	IC	DIG	MUC			6+
IC, digital, microprocessor	IC	DIG	MUP			6+
IC, digital, programmable logic device (PLD)	IC	DIG	PLD			6+
IC, digital, storage	IC	DIG	STO			6+
IC, digital, storage, CAM	IC	DIG	STO	CAM		6+
IC, digital, storage, CCD	IC	DIG	STO	CCD		6+
IC, digital, storage, RAM	IC	DIG	STO	RAM		6+
IC, digital, storage, RAM, dynamic	IC	DIG	STO	RAM	DRAM	6+
IC, digital, storage, RAM, static	IC	DIG	STO	RAM	SRAM	6+
IC, digital, storage, ROM	IC	DIG	STO	ROM		6+
IC, digital, storage, register	IC	DIG	STO	REG		6+
IC, periodic/DC	IC	PER				6+
Inductor	IND					11+
Inductor, fixed	IND	FIX				11+
Inductor, fixed, deflection units	IND	FIX	DFL			11+
Inductor, fixed, choke	IND	FIX	CHOKE			11+
Inductor, fixed, coil	IND	FIX	COIL			11+
Inductor, fixed, linearity control unit	IND	FIX	LININUT			11+
Inductor, fixed, antenna inductors	IND	FIX	ANT			11+
Inductor, fixed, solenoids	IND	FIX	SOL			11+
Inductor, variable	IND	VAR				11+
Lamp	LAM					18+
LCD	LCD					8+
Microwave components	MIC					12+
Optoelectronic device	OPT					8+
Optoelectronic device, image pickup device	OPT	IMAGE				8+
Optoelectronic device, photocoupler	OPT	PHC				8+
Optoelectronic device, photoemmiter	OPT	PHE				8+

Component description	IEC 61360-4 classification tree					Clause in this document
	L1	L2	L3	L4	L5	
Optoelectronic device, photoemmiter, infrared emitting diode	OPT	PHE	IRD			8+
Optoelectronic device, photoemmiter, LASER	OPT	PHE	LAS			8+
Optoelectronic device, photoemmiter, LED	OPT	PHE	LED			8+
Optoelectronic device, photosensor	OPT	PHS				8+
Optoelectronic device, photosensor, infrared	OPT	PHS	IR			8+
Optoelectronic device, photosensor, ultraviolet	OPT	PHS	U			8+
Optoelectronic device, photosensor, visible radiation	OPT	PHS	VIS			8+
Oscillator	OSC					13+
Piezoelectric device	PE					13+
Printed wiring circuit	PWC					N/A
Resistor	RES					10+
Resistor, fixed	RES	FIX				10+
Resistor, fixed, linear	RES	FIX	LIN			10+
Resistor, fixed, linear, resistor network	RES	FIX	LIN	MUL		10+
Resistor, fixed, linear, single	RES	FIX	LIN	SIN		10+
Resistor, fixed, linear, single, chip	RES	FIX	LIN	SIN	CHIP	10+
Resistor, fixed, linear, single, fusing	RES	FIX	LIN	SIN	FUS	10+
Resistor, fixed, linear, single, low power	RES	FIX	LIN	SIN	LP	10+
Resistor, fixed, linear, single, precision	RES	FIX	LIN	SIN	PREC	10+
Resistor, fixed, linear, single, power	RES	FIX	LIN	SIN	PWR	10+
Resistor, fixed, linear, single, PTC	RES	FIX	LIN	SIN	THERM	10+
Resistor, fixed, non-linear	RES	FIX	NLN			10+
Resistor, fixed, non-linear, light dependent	RES	FIX	NLN	LDR		10+
Resistor, fixed, non-linear, thermistor	RES	FIX	NLN	TDR		10+
Resistor, fixed, non-linear, thermistor, NTC	RES	FIX	NLN	TDR	NTC	10+
Resistor, fixed, non-linear, thermistor, PTC	RES	FIX	NLN	TDR	PTC	10+
Resistor, fixed, non-linear, varistor	RES	FIX	NLN	VDR		10+
Resistor, variable	RES	VAR				10+
Resistor, variable, potentiometer	RES	VAR	POT			10+
Resistor, variable, potentiometer, preset	RES	VAR	POT	PRESET		10+
Resistor, variable, potentiometer, rotary precision	RES	VAR	POT	PRECROT		10+
Resistor, variable, potentiometer, slide	RES	VAR	POT	SLIDE		10+

Component description	IEC 61360-4 classification tree					Clause in this document
	L1	L2	L3	L4	L5	
Resistor, variable, potentiometer, low power rotary	RES	VAR	POT	LPROT		10+
Resistor, variable, potentiometer, power rotary	RES	VAR	POT	PWRPROT		10+
Resistor, variable, two terminal	RES	VAR	TT			10+
Resonator	RESON					13+
Sensor	SEN					N/A
Sensor, relative humidity	SEN	HUM				N/A
Sensor, light	SEN	LGT				N/A
Sensor, magnetic field strength	SEN	MGN				N/A
Sensor, nuclear	SEN	NCL				N/A
Sensor, pressure	SEN	PRS				N/A
Sensor, proximity	SEN	PRX				N/A
Sensor, temperature	SEN	TMP				N/A
Spark gaps	SPARK					N/A
Spark gaps, air	SPARK	AIR				N/A
Spark gaps, gas filled	SPARK	GAS				N/A
Transformers	TFM					11+
Transformers, power	TFM	POW				11+
Transformers, power, fixed	TFM	POW	FIX			11+
Transformers, power, variable	TFM	POW	VAR			11+
Transformers, signal	TFM	SIG				11+
Transformers, signal, fixed	TFM	SIG	FIX			11+
Transformers, signal, variable	TFM	SIG	VAR			11+
Transistors	TRA					7+
Transistors, bipolar	TRA	BIP				7+
Transistors, bipolar, power	TRA	BIP	POW			7+
Transistors, bipolar, power, low frequency	TRA	BIP	POW	LF		7+
Transistors, bipolar, power, high frequency	TRA	BIP	POW	HF		7+
Transistors, bipolar, signal	TRA	BIP	SIG			7+
Transistors, bipolar, signal, low frequency	TRA	BIP	SIG	LF		7+
Transistors, bipolar, signal, high frequency	TRA	BIP	SIG	HF		7+
Transistors, FET	TRA	FET				7+
Transistors, FET, power	TRA	FET	POW			7+
Transistors, FET, power, low frequency	TRA	FET	POW	LF		7+
Transistors, FET, power, high frequency	TRA	FET	POW	HF		7+
Transistors, FET, small signal	TRA	FET	SIG			7+
Trigger device	TRG					7+
Trigger device, DIAC	TRG	DIA				7+
Trigger device, thyristor	TRG	THY				7+
Trigger device, thyristor, fast turn off	TRG	THY	FTO			7+
Trigger device, thyristor, gate turn off	TRG	THY	GTO			7+

Component description	**IEC 61360-4 classification tree**					**Clause in this document**
	L1	**L2**	**L3**	**L4**	**L5**	
Trigger device, thyristor, reverse blocking	TRG	THY	RVB			7+
Trigger device, TRIAC	TRG	TRI				7+
Tubes	TUB					N/A
Tubes, CRT	TUB	CRT				N/A
Tubes, CRT, colour display	TUB	CRT	COL			N/A
Tubes, CRT, monochrome display	TUB	CRT	MCR			N/A
Tubes, gas filled	TUB	GAS				N/A
Tubes, photo sensitive	TUB	PHO				N/A
Tubes, space charge controlled	TUB	SCC				N/A
Tubes, space charge wave	TUB	SCW				N/A
Tuner	TUN					N/A
ELECTROMECHANICAL COMPONENTS						
Connector	CON					14+
Connector, circular	CON	CIRC				14+
Connector, IC	CON	IC				14+
Connector, plug and jack	CON	JACK				14+
Connector, plug and jack, plug assembly	CON	JACK	ASSY			14+
Connector, plug and jack, complex jack boards	CON	JACK	CMPLX			14+
Connector, plug and jack, concentric type	CON	JACK	CONC			14+
Connector, plug and jack, concentric type, jack	CON	JACK	CONC	JACK		14+
Connector, plug and jack, concentric type, multiple	CON	JACK	CONC	MULT		14+
Connector, plug and jack, concentric type, plug	CON	JACK	CONC	PLUG		14+
Connector, plug and jack, pin type	CON	JACK	PIN			14+
Connector, plug and jack, pin type, jack	CON	JACK	PIN	JACK		14+
Connector, plug and jack, pin type, multiple jack	CON	JACK	PIN	MULT		14+
Connector, plug and jack, pin type, plug	CON	JACK	PIN	PLUG		14+
Connector, plug and jack, pin type, shielded jack	CON	JACK	PIN	SHLD		14+
Connector, plug and jack, D.C. power type	CON	JACK	PWR			14+
Connector, plug and jack, D.C. power type, car	CON	JACK	PWR	CAR		14+
Connector, plug and jack, D.C. power type, jack	CON	JACK	PWR	JACK		14+
Connector, plug and jack, D.C. power type, plug	CON	JACK	PWR	PLUG		14+
Connector, modular	CON	MOD				14+
Connector, printed circuit board	CON	PCB				14+
Connector, rectangular	CON	RECT				14+

Component description	IEC 61360-4 classification tree					Clause in this document
	L1	L2	L3	L4	L5	
Connector, radio frequency	CON	RF				14+
Connector, sockets	CON	SOCK				14+
Connector, sockets, antenna feeder	CON	SOCK	ANT			14+
Connector, sockets, fuse holder	CON	SOCK	FUSE			14+
Connector, sockets, IC	CON	SOCK	IC			14+
Connector, sockets, light	CON	SOCK	LIGHT			14+
Connector, sockets, PCB	CON	SOCK	PCB			14+
Connector, sockets, power socket	CON	SOCK	PWR			14+
Connector, sockets, signal socket	CON	SOCK	SIG			14+
Connector, sockets, transistor	CON	SOCK	TRA			14+
Connector, sockets, tube	CON	SOCK	TUBE			14+
Connector, sockets, quartz crystal	CON	SOCK	XTAL			14+
Connector, terminals	CON	TERM				14+
Connector, terminals, array	CON	TERM	ARRY			14+
Connector, terminals, board	CON	TERM	BRD			14+
Connector, terminals, rod	CON	TERM	ROD			14+
Connector, terminals, small	CON	TERM	SM			14+
Connector part	CONPART					14+
Connector part, contact	CONPART	CONTACT				14+
Connector part, accessories	CONPART	ACCY				14+
Connector part, tool	CONPART	TOOL				14+
Connector part, shell	CONPART	SHELL				14+
Connector part, insert	CONPART	INSERT				14+
Fuse	FUS					13+
Fuse, current activated	FUS	CUR				13+
Fuse, thermally activated	FUS	TERM				13+
Loudspeaker	LSP					N/A
Loudspeaker, electromagnetic	LSP	ELM				N/A
Loudspeaker, electrostatic	LSP	ELS				N/A
Loudspeaker, ionic	LSP	ION				N/A
Loudspeaker, magnetodynamic	LSP	MGD				N/A
Loudspeaker, magnetostrictive	LSP	MGS				N/A
Loudspeaker, moving conductor	LSP	MVC				N/A
Loudspeaker, piezoelectric	LSP	PXE				N/A
Loudspeaker, pneumatic	LSP	PNM				N/A
Microphone	MIC					N/A
Motor	MOT					N/A
Motor, linear	MOT	LIN				N/A
Motor, linear, AC	MOT	LIN	AC			N/A
Motor, linear, DC	MOT	LIN	DC			N/A
Motor, linear, step	MOT	LIN	STP			N/A
Motor, linear, universal	MOT	LIN	UNI			N/A
Motor, rotational	MOT	ROT				N/A

Component description	IEC 61360-4 classification tree					Clause in this document
	L1	L2	L3	L4	L5	
Motor, rotational, AC	MOT	ROT	AC			N/A
Motor, rotational, DC	MOT	ROT	DC			N/A
Motor, rotational, step	MOT	ROT	STP			N/A
Motor, rotational, universal	MOT	ROT	UNI			N/A
Relay	REL					16+
Switch	SWI					17+
Switch, mechanical	SWI	MEC				17+
Switch, reed	SWI	REE				17+
Switch, thermostatic	SWI	THE				17+
MAGNETIC PARTS						
Hard magnetic part	HRD					N/A
Soft magnetic part	SFT					N/A

I.3 Other systems

I.3.1 General

This information is given for the convenience of users of this document and does not constitute an endorsement by the IEC.

I.3.2 NATO stock numbers

The NATO Codification System (NCS) has been in place since the mid-1950s. It provides standards for the use of common stock identification equipment throughout the NATO alliance. The NCS identification process is based on the "item of supply" concept, a term which refers to an item required for acquisition in order to satisfy a logistics need. It can consist of one or many "items of production" (i.e. a product of a specific manufacturer) having equivalent "fundamental characteristics". The NCS provides NATO countries with uniform and common equipment for the identification, classification, and stock numbering of items of supply.

I.3.3 UNSPSC codes

The United Nations Standard Products and Services Code® (UNSPSC®) provides an open, global multi-sector standard for efficient, accurate classification of products and services. This code is used to classify all products and services. It was jointly developed by the United Nations Development Programme (UNDP) and Dun & Bradstreet Corporation (D & B) in 1998.

I.3.4 STEP/EXPRESS

STEP (Standard for the Exchange of Product data) is the colloquial term for ISO 10303-31:1994 and is targeted at the exchange of data describing a product between computer aided engineering equipment (e.g. CAD, CAM), and also long-term retention of such data.

EXPRESS is the language used within STEP to formally define the semantics of the data. It is a lexical object information modelling language and is defined in ISO 10303-11:2004. EXPRESS is used in many other activities outside STEP.

I.3.5 IECQ

IECQ is a body that awards qualification of various different types to the manufacturers of components. In order to do this it specifies the standards (called blank detail specifications) that a component should meet. Each of these standards has a number and components of that particular quality are often called by the number of the relevant standard.

I.3.6 ECALS

The computer readable standard dictionary of semiconductor devices and general electronic components (usually referred to as the "ECALS Dictionary") was developed by the standardization project of the ECALS steering committee of the Japan Electronic and Information Technology Industries Association (JEITA). It is based on the standard developed in the ECALS-2 project on development of a global supply chain foundation for semiconductors and electronic components, one of the advanced information development experimental tasks of the Ministry of International Trade and Industry (MITI) of Japan through the Information-Technology Promotion Agency of Japan. For harmonization with standards, the ECALS Dictionary has been developed pursuant and with reference to IEC 61360 (all parts) and to ISO 13584 (all parts) to the greatest possible extent.

I.3.7 ISO 13584

ISO 13584 is not a series of standards that defines electric components per se, it comprises however a series of standards for the computer-sensible representation and exchange of part library data. The objective is to provide a mechanism capable of transferring parts library data, independent of any application which uses a parts library data base. The nature of this description makes it suitable not only for the exchange of files containing parts, but also as a basis for implementing and sharing databases of parts library data.

I.3.8 MIL specifications

A United States defence standard, often called a military standard, "MIL-STD", or "MIL-SPEC", is used to help achieve standardization objectives by the U.S. Department of Defence. According to the Government Accountability Office (GAO), military specifications "describe the physical and/or operational characteristics of a product", while military standards detail the processes and materials to be used to make the product. The GAO acknowledges, however, that the terms are often used interchangeably.

The MIL-SPEC documents define various component types, for instance MIL-C-18312 describes fixed capacitors with a metallized paper-plastic, or plastic film dielectric, for use in direct current application and packaged in a hermetically sealed metal case. In many organizations the component types become known by the MIL specification number (in this case, 18312).

Annex J
(informative)

Presentation of component reliability data

J.1 General

This document requires failure rates in order to be useful. As has already been explained (see H.5.3) these can be obtained from a number of sources, the most useful of which would be from field operation data. The second best sources is to obtain the data from component manufacturers and Annex J outlines how this data should be presented for use with this document. It is most likely that this form of manufacture data will be derived from tests.

Annex J outlines the content of a report generated by the component manufacturer and describes the data that should be contained within it. This is based on the standard IEC 60319 and replaces guidance previously provided by that standard.

It is essential for component manufacturers to present reliability data for users in order to make decisions on use as well as predict failure rates and risks. It is essential that the component manufacturers provide summary data on reliability characteristics and factors affecting the failure rate prediction of the components in the component data sheets. It is essential that this is provided in a concise fashion. It should not be necessary for users to look at several documents to get the basic data. In order to be concise, detailed reliability test data should be provided separately if required.

As a minimum any manufacturer’s data report should contain information on the following:

1) Component identification and specification data
    a) Identification
    b) Component technology
2) Specification of component
    a) Electrical specification of component
    b) Environmental specification of component
3) Component test related data
    a) Method of selection of test components
    b) Test conditions
    c) Data on failures during test

The following clauses outline the minimum recommended contents of these data items.

J.2 Identification of components

J.2.1 General

The information supplied to identify the components should be in accordance with the relevant IEC or internationally recognized management quality systems publications for the component type under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other component specifications should be used and the source of the specifications stated. As a minimum, the following information should be given. Only information applicable to a particular component type should be supplied.

Examples of the specific information required for different component types can be found in IEC 61360-4.

J.2.2 Component identification

- A description of the component type with sufficient details to uniquely identify the component type, for example N-channel V-MOS transistor. When available, specification numbers should be given.
- The component part number. If available, a universal part number, for example stock number, should be given; otherwise a part number specific to the component manufacturer may be given.
- Name of the manufacturer and place of manufacture. The purpose of these references is to allow access to more detailed information if required.
- The date of manufacture or lot number or other production batch related identification.
- The production status of the component, for example development sample, pre-production, standard production, mature technology.
- Information regarding compliance with other recognized standards should be given whenever possible.

J.2.3 Component technology

- A description of the basic component technology, for example metal film resistor.
- A general description of the production process, for example ion beam epitaxy.
- Packaging information, for example plastic, hermetic weld.
- Thermal resistance, for example $R_{\text{thj-a}}$, $R_{\text{thj-c}}$.
- Complexity of circuit.
- Method of termination, for example end caps, DIL, SMD.

J.3 Specification of components

J.3.1 General

The information supplied to specify the components should be in accordance with the relevant IEC or internationally recognized management quality systems publications for the component type under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other component specifications should be used and the source of the specifications stated. As a minimum, the following information should be given.

J.3.2 Electrical specification of components

- Relevant information about ratings and characteristics should be supplied. These references taken from the applicable component specifications will depend on the type of test performed. For example, if power cycling tests are performed then the ratings for power dissipation should be given.
- Information should be given about any pre-test screening the components to be tested may have undergone. The results of such screening should be given.

J.3.3 Environmental specification of components

Information should be given regarding the maximum environmental conditions the components can withstand, for example temperature, humidity, acceleration.

J.4 Test related issues data

J.4.1 General

The test and sampling conditions should be those described in the relevant IEC or internationally recognized management quality systems publications for the components under test whenever possible. If IEC or internationally recognized management quality systems publications are not available, then other test specifications should be used and the source of the specifications stated. The following minimum information should be supplied.

Data obtained from reliability tests should be presented using graphical methods whenever possible.

J.4.2 Actual test conditions

- The source of the results, for example the quality assurance department of the manufacturer.
- A description of the test conditions used, for example the electrical, mechanical and environmental conditions. The test conditions should be identified by quoting the relevant test specifications where possible.
- The number of components under test. Where a component is available in a number of different values, for example resistors, capacitors, the values tested and the quantity of each value should be stated.
- A description of the characteristic measured, for example resistance, and the measuring conditions. Where the measurement conditions are specified by IEC or other specifications, then the specification number should be given.
- If more than one method of characteristic measurement is permissible then a description of the method used should be given. This description should contain all relevant details.
- The test start date, duration and measurement intervals should be stated.
- Where a delay exists between the cessation of the test and the commencement of measurements, then the time duration should be stated. The storage conditions during this delay should also be stated. Any conditioning stress applied to the components before measurement should also be stated.

J.5 Data on test failures

- The number of failures observed, categorized by test conditions and type of failure. Failure modes should be stated with percentage occurrence. Identified failure mechanisms should be stated with their associated activation energies and temperature ranges.
- The times at which the failures occurred or were verified.
- Special events during testing, for example events which might have affected the results.
- Complete data from tests should be presented whenever possible but if data from tests are discarded, these data and the reasons why they are not given in the presentation or results, should be given separately.
- Failure criteria for the components are normally defined by the requirements given by the specification to which reference is made in the test report. If failure criteria for the components are not given by the reference specification, they should be stated.
- Failure rate which can be assumed to be constant
  - The test time of components during which the failure rate is assumed to be constant should be indicated. Failure rates found will preferably be stated in failures per 10^9 hours of operation. The value of 60 % is often used as the upper confidence level for failure rates.
- Failure rate which cannot be assumed to be constant
  - The total test time can be divided into a number of separate periods and the results for each of these periods evaluated separately. The necessary time periods which have to be distinguished and the number of failures which occur during each time period should be given. If the results can be satisfactorily approximated by a mathematical function, it would be useful to present these functions, as well as the period during which they are applicable. In all cases, mean lifetime, failure distribution and the influence of derating should be stated. For life-limited components, an appropriate model should be suggested, for example Weibull distribution.
- Influence of stresses

- As failure rates are dependent on the type and the intensity of stress, all failure rate data should be presented with the applied stress levels. Furthermore, it can be important to know the correlation between failure rate and stress (temperature, power, vibration, etc.) and, where possible, the activation energy of the failure mechanism should be supplied. Therefore, failure rate values obtained at different stress levels should be supplied separately.

Annex K
(informative)

Examples

K.1 Integrated circuit

For a bipolar random access memory device, the stated reference failure rate is $\lambda_{\text{ref}} = 10^{-7}\ \text{h}^{-1}$ at the virtual (equivalent) junction temperature of $\theta_{\text{ref}} = 75\ ^\circ\text{C}$ (based on the component ambient temperature of 40 °C and the reference self-heating of ΔT_{ref} of 35 °C).

What is the value of the failure rate at an ambient temperature of θ_{amb} = 65 °C and the self-heating of 35 °C?

Step (1): $\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}}$ for ICs from Equation (10).

Step (2): $\pi_{\text{T}} = 2{,}9$ follows from Table 14 with the virtual junction temperature under reference conditions $\theta_{\text{ref}} = 75\ ^\circ\text{C}\ (= 40\ ^\circ\text{C} + 35\ ^\circ\text{C})$, and the actual virtual junction temperature $\theta_{\text{op}} = \theta_{\text{amb}} + \Delta T_{\text{ref}} = 65\ ^\circ\text{C} + 35\ ^\circ\text{C} = 100\ ^\circ\text{C}$.

Step (3): Perform the calculation; the failure rate at $\theta_{\text{amb}} = 65\ ^\circ\text{C}$ is obtained as $\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} = 10^{-7}\ \text{h}^{-1} \times 2{,}9 = 290 \cdot 10^{-9}\ \text{h}^{-1}$.

K.2 Transistor

For a general-purpose transistor, the stated failure rate at the reference junction temperature $\theta_{\text{ref}} = 55\ ^\circ\text{C}$ and the reference voltage ratio $U_{\text{ref}}/U_{\text{rat}} = 0{,}5$ is given as $\lambda_{\text{ref}} = 2 \cdot 10^{-8}\ \text{h}^{-1}$. The operating voltage ratio is $U_{\text{op}}/U_{\text{rat}} = 0{,}8$.

What is the failure rate value at a junction temperature of $\theta_{\text{op}} = 90\ ^\circ\text{C}$?

Step (1): $\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}}$ for transistors from Equation (13).

Step (2): $\pi_{\text{U}} = 1{,}26$ follows from Table 21 for $U_{\text{op}}/U_{\text{rat}} = 0{,}8$.

Step (3): $\pi_{\text{T}} \approx 4{,}2$ follows from Table 23, with the reference junction temperature $\theta_{\text{ref}} = 55\ ^\circ\text{C}$, and the actual junction temperature $\theta_{\text{op}} = 90\ ^\circ\text{C}$.

Step (4): Perform the calculation, thus the failure rate at $\theta_{\text{op}} = 90\ ^\circ\text{C}$ and $U_{\text{op}}/U_{\text{rat}} = 0{,}8$ is obtained as:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} = 2 \cdot 10^{-8}\ \text{h}^{-1} \times 1{,}26 \times 4{,}2 \approx 106 \cdot 10^{-9}\ \text{h}^{-1}$$

K.3 Capacitor

For a polypropylene film metal foil capacitor, the stated failure rate at the ambient temperature θ_{amb} of 50 °C and the reference voltage ratio of $U_{\text{ref}}/U_{\text{rat}} = 0{,}5$ is given as $\lambda = 3{,}5 \cdot 10^{-9}\ \text{h}^{-1}$.

What is the value of the failure rate at an ambient temperature of $\theta_{\text{amb}} = 60\ ^\circ\text{C}$ and an operating voltage ratio of $U_{\text{op}}/U_{\text{rat}} = 0{,}6$?

Step (1): $\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}}$ for capacitors from Equation (23)

Step (2): Conversion to reference condition:

$\pi_{\text{U}} = 1$ follows from Table 38 for $U_{\text{ref}} / U_{\text{rat}} = 0{,}5$.

$\pi_{\text{T}} = 1{,}8$ follows from Table 40 for $\theta_{\text{amb}} = \theta_{\text{op}} = 50\ °\text{C}$.

Perform the calculation, thus the failure rate at reference conditions of $\theta_{\text{ref}} = 40\ °\text{C}$ and $U_{\text{ref}} / U_{\text{rat}} = 0{,}5$ (see 9.1, Table 36) is obtained as

$$\lambda_{\text{ref}} = \frac{\lambda}{\pi_{\text{U}} \times \pi_{\text{T}}} = \frac{3{,}5 \cdot 10^{-9}\ \text{h}^{-1}}{1 \times 1{,}8} = 1{,}94 \cdot 10^{-9}\ \text{h}^{-1}.$$

Step (3): Conversion from reference to operating conditions:

$\pi_{\text{U}} = 1{,}5$ follows from Table 38 for $U_{\text{op}} / U_{\text{rat}} = 0{,}6$.

$\pi_{\text{T}} = 3{,}1$ follows from Table 40 for $\theta_{\text{op}} = 60\ °\text{C}$.

Perform the calculation, thus the failure rate at $\theta_{\text{op}} = 60\ °\text{C}$ and $U_{\text{op}} / U_{\text{rat}} = 0{,}6$ is obtained as

$$\lambda_{\text{op}} = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} = 1{,}94 \cdot 10^{-9}\ \text{h}^{-1} \times 1{,}5 \times 3{,}1 \approx 9 \cdot 10^{-9}\ \text{h}^{-1}.$$

K.4 Relay

A dust-tight general purpose relay with one normally open contact switches once per hour in stress region 4 (see 16.2.3, Figure 2) with motor load with alternating current:

$\lambda_{\text{ref}} = 4 \times 10^{-9}\,\text{h}^{-1}$; $U = 220\ \text{V}$ AC, $I = 4\ \text{A}$, $I_{\text{rat}} = 16\ \text{A}$, ambient temperature $\theta_{\text{amb}} = 70\ °\text{C}$.

What is the value of the failure rate under these conditions?

Step (1): $\lambda = \lambda_{\text{ref}} \times \pi_{\text{ES}} \times \pi_{\text{S}} \times \pi_{\text{T}}$ for relays from Equation (32).

Step (2): $\pi_{\text{ES}} = 20$ follows from Table 53, stress region 4, inductive load.

Step (3): $\pi_S = 1$ follows from Table 51 and Equation (33).

Step (4): $\pi_{\text{T}} = 1{,}8$ follows from Table 56 with $\theta_{\text{amb}} = 70\ °\text{C}$.

Step (5): Perform the calculation,
thus the failure rate, at the stated conditions is obtained as:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{ES}} \times \pi_{\text{S}} \times \pi_{\text{T}} = 4 \cdot 10^{-9}\ \text{h}^{-1} \times 20 \times 1 \times 1{,}8 = 144 \cdot 10^{-9}\ \text{h}^{-1}.$$

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

COMPOSANTS ÉLECTRIQUES –
FIABILITÉ –
CONDITIONS DE RÉFÉRENCE POUR LES TAUX DE DÉFAILLANCE ET MODÈLES DE CONTRAINTES POUR LA CONVERSION

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Cette troisième édition annule et remplace la deuxième édition, parue en 2011. Cette édition constitue une révision technique. Cette troisième édition constitue une fusion entre l'IEC 61709:2011 et l'IEC TR 62380:2004.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) ajout de 4.5 Choix des composants, 4.6 Croissance de la fiabilité pendant la phase de déploiement du nouvel équipement, 4.7 Méthode d'utilisation du présent document et de l'Article 19 Circuits imprimés (PCB) et de l' Article 20 Circuits hybrides par rapport à l'IEC TR 62380;

b) ajout des modes de défaillance des composants à l'Annexe A;

c) modification de l'Annexe B, Modèle thermique pour semiconducteurs, adoptée de l'IEC TR 62380 et révisée;

d) modification de l'Annexe D, Considérations sur le profil de mission;

e) modification de l'Annexe E, Modèles de durée de vie, adoptée de l'IEC TR 62380 et révisée;

f) révision de l'Annexe F (ancien Paragraphe B.2.6.4), Physique de défaillance;

g) ajout de l'Annexe G (ancienne Annexe C), Considérations sur la conception d'une base de données de taux de défaillance, complétée par des parties de l'IEC 60319;

h) Ajout de l'Annexe H, Sources potentielles de données de taux de défaillance et méthodes de sélection;

i) Ajout de l'Annexe J, Présentation des données de fiabilité des composants, d'après l'IEC 60319.

Le texte de cette norme est issu des documents suivants:

FDIS	Rapport de vote
56/1714/FDIS	56/1721/RVD

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Le contenu du corrigendum d'octobre 2019 a été pris en considération dans cet exemplaire.

INTRODUCTION

Le présent document est destiné aux prévisions de fiabilité des composants électriques utilisés dans les équipements et s'adresse aux organismes qui disposent de leurs propres données. Il décrit par ailleurs les méthodes pour établir et utiliser ces données afin de réaliser des prévisions de fiabilité.

Le présent document peut également permettre à un organisme d'établir une base de données de taux de défaillance et de décrire les conditions de référence pour lesquelles il convient d'établir des taux de défaillance en exploitation. Les conditions de référence adoptées dans le présent document sont typiques de la plupart des applications de composants dans des équipements. Toutefois, lorsque les composants sont utilisés dans d'autres conditions, les utilisateurs peuvent vouloir déclarer ces conditions comme leurs conditions de référence.

L'application des modèles de contraintes présentés permet d'extrapoler les taux de défaillance des conditions de référence à d'autres conditions de fonctionnement qui, à leur tour, permettent de prévoir les taux de défaillance à l'étape de la fabrication. Ceci permet d'estimer l'effet des modifications de conception ou des changements observés dans les conditions d'environnement sur la fiabilité des composants. La prévision de fiabilité se révèle très utile dans la première phase de conception des matériels. Elle peut servir, par exemple, à mettre en évidence de possibles défauts de fiabilité, à mettre au point les principes de logistique de maintenance et à évaluer des conceptions.

Les modèles de contraintes exposés dans le présent document sont génériques et aussi simples que possible, tout en pouvant toujours être comparés aux équations plus complexes propres à d'autres modèles. Les prévisions générées à l’aide du présent document affichent un niveau d'exactitude élevé.

Le présent document ne présente pas de taux de défaillance, mais décrit les méthodes qui permettent de les établir et de les utiliser. Cette approche permet à un utilisateur de choisir les taux de défaillance les plus appropriés et actualisés à partir desquels il peut établir des prévisions à partir d'une source de son choix. Le présent document apporte également des informations sur la méthode de sélection des données pouvant être utilisées dans les modèles présentés.

Il est fait l'hypothèse que les taux de défaillance envisagés dans le présent document sont constants, soit pendant une période de fonctionnement illimitée (cas général), soit pendant des périodes limitées. La limitation de la vie est appelée durée de vie utile et s'applique uniquement à certaines familles de composants qui atteignent la période de défaillance par usure (au cours de laquelle le taux de défaillance augmente) pendant la période normale d'utilisation. Par conséquent, il est fait l'hypothèse que pendant la durée de vie, le taux de défaillance peut être considéré comme constant pour une utilisation pratique quelconque.

Pour les besoins du présent document, le terme composant électrique inclut les termes "composant électronique", "composant électrique" et "composant électromécanique" couramment utilisés.

COMPOSANTS ÉLECTRIQUES –
FIABILITÉ –
CONDITIONS DE RÉFÉRENCE POUR LES TAUX DE DÉFAILLANCE ET MODÈLES DE CONTRAINTES POUR LA CONVERSION

1 Domaine d'application

Le présent document donne des recommandations concernant l'utilisation des données de taux de défaillance pour les prévisions de fiabilité de composants électriques utilisés dans les équipements.

La méthode exposée dans le présent document utilise le concept des conditions de référence, qui sont les valeurs typiques des contraintes observées sur les composants dans la plupart des applications.

Les conditions de référence sont utiles dans la mesure où elles fournissent une base normalisée connue à partir de laquelle les taux de défaillance peuvent être modifiés afin de prendre en compte les différences observées dans l'environnement en fonction des environnements pris comme conditions de référence. Chaque utilisateur peut appliquer les conditions de référence définies dans le présent document ou bien appliquer ses propres conditions de référence. Lorsque les taux de défaillance indiqués dans les conditions de référence sont utilisés, cela permet de réaliser des prévisions de fiabilité réalistes dès la première phase de conception.

Les modèles de contraintes décrits dans le présent document sont génériques et peuvent être utilisés comme base de conversion des données de taux de défaillance dans ces conditions de référence, dans des conditions de fonctionnement réelles si nécessaire, ce qui simplifie l'approche prévisionnelle. La conversion des données de taux de défaillance n'est possible que dans les limites de fonctionnement spécifiées pour les composants.

Le présent document donne également des recommandations concernant les méthodes pour constituer une base de données de taux de défaillance des composants afin que les taux fournis puissent être employés avec les modèles de contraintes fournis. Les conditions de référence pour les données de taux de défaillance sont définies, de façon à permettre de comparer, dans des conditions uniformes, des données d'origines différentes. Si les données de taux de défaillance sont fournies conformément au présent document, il est possible de se dispenser d'information supplémentaire sur les conditions définies

Le présent document ne fournit pas des taux de défaillance de base pour les composants; elle fournit en revanche des modèles qui permettent de convertir les taux de défaillance obtenus par d'autres moyens d’une condition de fonctionnement à l’autre.

La méthodologie de prévision décrite dans le présent document pose comme hypothèse l'utilisation des éléments au cours de leur durée de vie. Les méthodes décrites dans le présent document ont une application générale, mais s’appliquent spécifiquement à une sélection de types de composants définis de l’Article 6 à l’Article 20 et en I.2.

2 Références normatives

Les documents suivants cités dans le texte constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l’édition citée s’applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60050-192:2015, *Vocabulaire Électrotechnique International – Partie 192: Sûreté de fonctionnement*

3 Termes, définitions et symboles

3.1 Termes et définitions

Pour les besoins du présent document, les termes et définitions de l'IEC 60050-192 ainsi que les suivants, s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1.1
composant électrique
composant doté de terminaisons conductrices à travers lesquelles on peut appliquer des tensions ou injecter des courants

Note 1 à l'article: Le terme composant électrique inclut les termes "composant électronique", "composant électrique" et "composant électromécanique" couramment utilisés.

[SOURCE: IEC 61360-1:2009, 2.18, modifiée — La note existante a été supprimée et la Note 1 à l'article a été ajoutée]

3.1.2
défaillance <d'une entité>
perte de l'aptitude à fonctionner tel que requis

Note 1 à l'article: La défaillance d'une entité est un événement qui provoque une panne de cette entité: voir panne (IEC 60050-192:2015, 192-04-01).

Note 2 à l'article: Des qualificatifs tels que catastrophique, critique, majeur, mineur, marginal et non significative peuvent être utilisés pour classer les défaillances en fonction de la gravité des conséquences, selon des critères de gravité dont le choix et les définitions dépendent du domaine d'application.

Note 3 à l'article: Des compléments tels que "par mauvais emploi", "par fausse manœuvre" et "par fragilité" peuvent être utilisés pour classer les défaillances selon leur cause.

[SOURCE: IEC 60050-192:2015, 192-03-01]

3.1.3
mode de défaillance
manière selon laquelle une défaillance se produit

Note 1 à l'article: Un mode de défaillance peut être défini par la fonction perdue ou par la transition d'état qui s'est produite.

[SOURCE: IEC 60050-192:2015, 192-03-17]

3.1.4
taux instantané de défaillance
taux de défaillance
limite, si elle existe, du quotient par Δt de la probabilité conditionnelle pour que la défaillance d'une entité non réparable soit comprise dans l'intervalle de temps $(t, t + \Delta t)$, lorsque Δt tend vers zéro, en supposant qu'une défaillance ne se soit pas produite dans l'intervalle de temps $(0, t)$

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{1}{\Delta t} \frac{F(t+\Delta t) - F(t)}{R(t)} = \frac{f(t)}{R(t)}$$

où $F(t)$ et $f(t)$ sont, respectivement, la fonction de répartition et la densité de probabilité à l'instant de la défaillance, et où $R(t)$ est la fonction de fiabilité, liée à la fiabilité $R(t_1, t_2)$ par la relation $R(t) = R(0, t)$.

Note 1 à l'article: Voir l'IEC 61703, *Expressions mathématiques pour les termes de fiabilité, de disponibilité, de maintenabilité et de logistique de maintenance*, pour plus de détails.

Note 2 à l'article: D'autres termes sont utilisés pour désigner le taux instantané de défaillance: "fonction de risque", "taux de risque" et "taux instantané de mortalité" (abréviation FOM - force of mortality).

Note 3 à l'article: Dans le présent document, il est fait l'hypothèse que $\lambda(t)$ est constant dans la durée, sauf indication contraire explicite.

[SOURCE: IEC 60050-192:2015, 192-05-06, modifiée — La Note 3 à l'article a été ajoutée]

3.1.5
conditions de référence
contraintes sélectionnées de manière à correspondre à la plupart des applications et utilisations de composants dans des équipements

Note 1 à l'article: Les contraintes incluent les contraintes électriques, la température et les conditions d'environnement.

3.1.6
taux de défaillance de référence
taux de défaillance établi dans les conditions de référence données dans l'IEC 61709

Note 1 à l'article: Le taux de défaillance de référence est spécifique au composant, c'est-à-dire qu'il tient compte des effets de la complexité, du type de boîtier, de l'influence des fabricants et du procédé de fabrication, etc.

3.1.7
cycle de service
séquence spécifiée de conditions de fonctionnement

Note 1 à l'article: Le cycle de service précise si les composants subissent des contraintes de façon permanente ou intermittente pendant leur utilisation. Le service continu désigne une utilisation de longue durée avec des charges constantes ou variables (par exemple, commandes de procédés, commutateur téléphonique). Le service intermittent désigne une utilisation avec des charges constantes ou variables pendant l'état actif (par exemple, commandes numériques de machines, feux de signalisation routiers).

[SOURCE: IEC 60050-151:2001, 151-16-02, modifiée — La Note 1 à l'article a été ajoutée]

3.1.8
état de fonctionnement <d'une entité>
état dans lequel le fonctionnement est tel que requis

Note 1 à l'article: Pour un composant, cela signifie qu'il est sous tension et/ou connecté à une charge.

[SOURCE: IEC 60050-192:2015, 192-02-04, modifiée — Les Notes 1 et 2 à l'article ont été remplacées par une nouvelle Note 1 à l'article]

3.1.9
état de non-fonctionnement <d'une entité>
état ne permettant pas de réaliser une fonction requise quelconque

Note 1 à l'article: Le terme "en non-fonctionnement" qualifie une entité dans un état de non-fonctionnement.

Note 2 à l'article: Un composant peut être dans un état de non-fonctionnement en raison d'une défaillance ou parce qu'il se trouve dans un état vacant (IEC 60050-192:2015, 192-02-14), s'il n'est pas exigé qu'il soit dans un état de disponibilité, dans une période d'attente (IEC 60050-192:2015, 192-02-10) pendant la durée exigée ou dans un temps d'incapacité externe (IEC 60050-192:2015,192-02-24), lorsque le non-fonctionnement est dû à l'absence de ressources externes.

[SOURCE: IEC 60050-192:2015, 192-02-06, modifiée — La Note 2 à l'article a été ajoutée]

3.1.10
état dormant
état d'une entité inactive capable de devenir active

Note 1 à l'article: Pour un composant, cela signifie qu'il est prêt à être mis sous tension et/ou connecté à une charge.

3.1.11
attente <d'une entité>
état de disponibilité et de non-fonctionnement pendant une période requise

[SOURCE: IEC 60050-192:2015, 192-02-10]

3.1.12
état de stockage
état d'un composant placé dans une installation spécifique selon des conditions définies, sans être mis sous tension et/ou connecté à une charge

Note 1 à l'article: Par exemple, l'état de stockage d'un composant n'est pas assemblé à une partie de l'équipement.

3.1.13
prévision
processus de calcul permettant d'obtenir la valeur prévue d'une grandeur

[SOURCE: IEC 60050-192:2015, 192-11-01]

3.1.14
composant
partie constitutive d'un dispositif ne pouvant être fractionnée matériellement sans perdre sa fonction particulière

[SOURCE: IEC 60050-151:2001, 151-11-21]

3.1.15
équipement, matériel
appareil unique ou ensemble de dispositifs ou appareils, ou ensemble des dispositifs principaux d'une installation, ou ensemble des dispositifs nécessaires à l'accomplissement d'une tâche particulière

Note 1 à l'article: Des exemples d'équipement ou de matériel sont un transformateur de puissance, l'équipement d'une sous-station, un équipement de mesure.

[SOURCE: IEC 60050-151:2001, 151-11-25]

3.1.16
vie utile <d'une entité>
intervalle de temps depuis la première utilisation jusqu'à ce que les besoins de l'utilisateur ne soient plus satisfaits à cause des coûts de fonctionnement et de maintenance ou pour obsolescence

Note 1 à l'article: La première utilisation exclut, dans ce contexte, les essais préalables à la livraison de l'entité à l'utilisateur final

[SOURCE: IEC 60050-192:2015, 192-02-27]

3.1.17
dérive
différence entre la valeur finale d'une caractéristique à la fin d'une période spécifiée et la valeur initiale, toutes les autres conditions de fonctionnement étant maintenues constantes

Note 1 à l'article: L'emploi du terme "dérive" pour faire référence à la variation immédiate d'une caractéristique en réponse directe à des conditions de fonctionnement modifiées (par exemple, température) est déconseillé.

[SOURCE: IEC 60747-1:2006, 3.6.1]

3.1.18
température virtuelle<d’un dispositif à semiconducteurs>
température équivalente interne
température théorique basée sur une représentation simplifiée du comportement thermique et électrique d’un dispositif à semiconducteurs

Note 1 à l'article: La température virtuelle n'est pas nécessairement la température la plus élevée du dispositif.

[SOURCE: IEC 60050-521:2002, 521-05-14, modifiée — La Note 2 à l'article a été supprimée]

3.1.19
température virtuelle (équivalente) de jonction
température virtuelle de la jonction d’un dispositif à semiconducteurs

[SOURCE: IEC 60050-521:2002, 521-05-15]

3.1.20
température de l'air ambiant
température de l'air environnant un appareil complet, et définie suivant des conditions prescrites

Note 1 à l'article: Pour les appareils installés à l'intérieur d'une enveloppe, c'est la température de l'air à l'extérieur de l'enveloppe.

[SOURCE: IEC TR 60943:1998, 1.3.1]

3.2 Symboles

Dans la partie normative du présent document, les symboles suivants sont utilisés. D’autres symboles sont utilisés et définis dans les annexes.

Ea_1, Ea_2	énergies d'activation d'un processus de défaillance
A, C_i, k_0	constantes
λ	taux de défaillance dans les conditions de fonctionnement
λ_ref	taux de défaillance dans les conditions de référence
$\lambda_\mathrm{composant}$	taux de défaillance d'un composant
λ_mode	taux de défaillance relatif à un mode de défaillance d'un composant
π_I	facteur traduisant l'influence du courant
π_E	facteur traduisant l'influence de l’environnement
π_ES	facteur traduisant l'influence des contraintes électriques
π_S	facteur traduisant l'influence de la fréquence de manœuvre
π_T	facteur traduisant l'influence de la température
π_U	facteur traduisant l'influence de la tension
I_op	courant de fonctionnement

I_{rat}	courant assigné
I_{ref}	courant de référence
P_{op}	puissance dissipée en fonctionnement
P_{ref}	puissance dissipée de référence
P_{rat}	puissance dissipée assignée
R_{th}	résistance thermique
$R_{\mathrm{th,\,amb}}$	résistance thermique (dans l'environnement)
S	nombre de cycles de manœuvres par heure
S_{ref}	nombre de référence de cycles de manœuvres par heure
U_{op}	tension de fonctionnement
U_{rat}	tension assignée
U_{ref}	tension de référence
ΔT	autoéchauffement réel en degrés Celsius
ΔT_{ref}	autoéchauffement de référence en Kelvin
θ_0	température ambiante de référence en degrés Celsius
θ_{amb}	température ambiante en degrés Celsius
T_0	température ambiante de référence en Kelvin
T_{amb}	température ambiante en Kelvin
T_{op}	température de fonctionnement en Kelvin
T_{ref}	température de référence en Kelvin
θ_{op}	température de fonctionnement en degrés Celsius – pour les circuits intégrés, la température virtuelle (équivalente) réelle de jonction; – pour les composants discrets à semiconducteurs et les composants optoélectroniques, la température réelle de jonction; – pour les condensateurs, la température réelle du condensateur; – pour les résistances, la température réelle de l'élément de résistance; – pour les inductances, la température réelle de l'enroulement; – pour les autres composants électriques, la température ambiante réelle;
θ_{ref}	température de référence en degrés Celsius – pour les circuits intégrés, la température virtuelle (équivalente) de jonction de référence; – pour les composants discrets à semiconducteurs et les composants optoélectroniques, la température de jonction de référence; – pour les condensateurs, la température de référence du condensateur; – pour les résistances, la température de référence de l'élément de résistance; – pour les inductances, la température de référence de l'enroulement; – pour les autres composants électriques, la température de référence du composant.

4 Contexte et conditions

4.1 Modes de défaillance et mécanismes

La caractéristique préférentielle comme donnée de fiabilité de composants électriques est le taux (instantané) de défaillance. Il doit être noté que, bien qu'il soit souvent défini de manière générique comme une défaillance, l'événement exact observé qui est mesuré est un mode de défaillance.

Une défaillance ou une perte de fonction d'un équipement est provoquée par le mode de défaillance d'un composant lorsque ce mode de défaillance touche l'application exécutée par l'équipement.

Il convient de noter qu'un composant comporte de nombreuses caractéristiques, dont seulement certaines peuvent être utilisées dans l'application spécifique. Une perte de fonction au niveau de l'équipement se produit uniquement lors de la perte de la caractéristique du composant permettant cette fonction.

Par ailleurs, un circuit exige l'existence de caractéristiques de composants selon ce qui a été défini par le concepteur, ce qui peut ne pas englober la totalité des caractéristiques du composant et peut ne pas utiliser une caractéristique particulière à sa capacité maximale, telle que définie par la fiche technique en ce qui concerne les caractéristiques fonctionnelles et assignées.

Les recueils définissent habituellement le taux de défaillance comme une valeur globale qui inclut tous les modes de défaillance. Ceci signifie que le taux de défaillance d'un composant peut être exprimé comme la somme des taux de défaillance de tous les modes, comme suit:

$$\lambda_{\text{composant}} = \sum_{i=1}^{n} \left(\lambda_{\text{mode}}\right)_i \qquad (1)$$

où $\left(\lambda_{\text{mode}}\right)_i$ est le taux de défaillance du composant auquel se produit le mode de défaillance i et n est le nombre de modes de défaillance.

Les modes de défaillance sont énumérés à l'Annexe A.

Une défaillance est associée à un mécanisme de défaillance, qui est le comportement de base du matériau à l'origine de la défaillance. Des informations plus détaillées concernant les circuits intégrés sont fournies à l'Annexe F.

4.2 Modélisation thermique

La température est un facteur ayant une influence importante sur le taux de défaillance. Il est bien connu que la température et les variations de température ont un effet sur la fiabilité des composants. Pour obtenir des informations concernant les variations de température, voir 4.4. L’effet de la température est plus marqué pour certaines familles (composants actifs et condensateurs à l'aluminium à électrolyte non solide). Les modèles adoptés sont ceux qui associent l'effet de la température aux mécanismes de défaillance prédominants (qui ne sont pas les mécanismes d'"usure" normaux).

Par conséquent, il convient que la modélisation thermique des composants soit aussi exacte que possible, et il convient en particulier de mesurer la résistance thermique des semiconducteurs de façon à pouvoir évaluer avec exactitude la température interne.

Lorsque la résistance thermique ne peut pas être mesurée, les modèles de résistance thermique présentés à l'Annexe B peuvent être utilisés.

4.3 Considérations relatives au profil de mission

4.3.1 Généralités

Au cours de leur vie, les composants sont soumis à différentes conditions d'utilisation, qui constituent les principaux facteurs affectant leur fiabilité: l'ensemble de ces conditions est défini comme le profil de mission.

Le profil de mission définit la fonction exigée et la condition d'environnement en fonction du temps. Il varie selon le type de fonctionnement appliqué. Ce fonctionnement peut être continu dans la durée à un niveau fixe, continu dans la durée à un niveau variable ou sporadique dans la durée à un niveau fixe ou variable. Dans certains cas, les mises sous tension et hors tension peuvent être significatives et se révéler plus importantes que les conditions de fonctionnement de régime permanent. Une attention toute particulière au profil de mission est nécessaire pour bien comprendre son influence sur la fiabilité des composants.

Le profil de mission peut être défini en fonction de la durée calendaire ou de la durée d'exploitation réelle. Il peut également être basé sur les cycles (par exemple, nombre d'utilisations d'une entité).

Une description plus détaillée du profil de mission est fournie à l'Annexe D.

4.3.2 Conditions de fonctionnement et de non-fonctionnement

Un profil de mission peut être décomposé en plusieurs phases sur la base de l'utilisation typique. Ces phases sont classées selon deux catégories principales: les conditions de fonctionnement et les conditions de non-fonctionnement. Bien que le présent document traite des composants, les conditions d'utilisation font habituellement référence à l’ensemble (équipement ou système) et peuvent être définies comme suit lorsqu'elles font référence aux composants.

- Fonctionnement: le composant est assemblé, mis sous tension ou connecté à une charge et fonctionne dans les conditions nominales. Voir 3.1.8.
- Attente: le composant est assemblé, mis sous tension ou connecté à une charge, mais ne fonctionne pas ou fonctionne dans des conditions inférieures aux conditions nominales. Voir 3.1.11.
- Dormant: le composant est assemblé mais n'est pas mis sous tension ni connecté à une charge. Voir 4.3.3.
- Stockage: le composant n'est pas assemblé, par conséquent il n'est pas mis sous tension ni connecté à une charge. Pendant le stockage, les composants sont emballés et conservés dans un entrepôt. Voir 4.3.4.

4.3.3 Dormance

Un composant est réputé dormant (c'est-à-dire, à l’état dormant) lorsqu'il est inactif (il ne réalise aucune des fonctions exigées), mais capable de devenir actif et de fonctionner correctement sur demande (sous tension et/ou connecté à une charge). Le composant est censé être à l’état dormant lorsqu’il est intégré dans un équipement sans être mis sous tension.

Les composants dormants peuvent subir des défaillances, mais le taux de défaillance à l'état dormant est généralement beaucoup plus faible que le taux de défaillance à l'état de fonctionnement, en partant du principe que l'équipement est maintenu dans ses conditions spécifiques à l'état de non-fonctionnement.

4.3.4 Stockage

Les composants soumis aux conditions de stockage ne sont pas protégés contre la défaillance, en particulier lorsque ces conditions sont différentes de celles spécifiées.

Toutefois, les modèles de contraintes relatifs aux facteurs d'environnement définis dans le présent document peuvent ne pas s'appliquer dans la mesure où ils traitent uniquement des conditions de fonctionnement. Des mécanismes de défaillance différents non pris en compte dans les modèles peuvent exister dans des conditions de stockage. De plus, l'aspect selon lequel les conditions de stockage modifient le taux de défaillance lorsque l'entité est active n'est pas couvert par le présent document.

Il convient de traiter les conditions de stockage séparément des conditions de fonctionnement. Elles peuvent affecter le comportement vis-à-vis d’une défaillance des composants au cours de la durée de vie ultérieure.

Des informations supplémentaires concernant le stockage peuvent être consultées dans l'IEC PAS 62435. Il convient de définir et de contrôler les conditions de stockage afin de garantir la fiabilité des composants stockés.

4.4 Conditions d’environnement

L'environnement contribue aux défaillances qui se produisent au cours de la durée de vie de l'équipement. Il convient par conséquent d'intégrer la durée et l'intensité des contraintes d’environnement au modèle d'exploitation de l'équipement.

Un environnement plus sévère peut générer des défaillances plus fréquentes qu'un environnement moins sévère. Plusieurs aspects environnementaux sont généralement associés à une défaillance spécifique et il peut être nécessaire de tous les comprendre. La localisation de l’environnement étudié a également son importance: par exemple, dans un aéronef, l'environnement du poste de pilotage et l'environnement des moteurs sont très différents.

L'environnement peut être décrit à partir de plusieurs types de paramètres et de leurs interactions associées.

L'IEC 60721-3-3 décrit l'environnement en termes de:

- conditions climatiques;
- conditions climatiques spéciales;
- conditions biologiques;
- substances chimiquement actives;
- substances mécaniquement actives;
- conditions mécaniques (tant statiques que dynamiques).

Toutes les conditions énumérées ci-dessus sont généralement pertinentes pour la fiabilité des équipements (par exemple, taux de défaillance), et il est raisonnable de considérer que la fiabilité des composants, et par conséquent de l’équipement, diminue proportionnellement à l'augmentation de la contrainte environnementale (voir l'IEC 60721 (toutes les parties) pour une description quantitative détaillée des agents environnementaux pour chaque environnement concerné).

Le présent document pose l’hypothèse que les conditions climatiques et mécaniques sont les plus importantes, cette hypothèse étant également valable pour de nombreuses applications types de composants. Il peut toutefois y avoir des situations dans lesquelles, par exemple, des conditions chimiques peuvent générer un taux de défaillance plus élevé.

Ces phénomènes peuvent également être observés pour les conditions particulières suivantes: rayonnement nucléaire, ultraviolet, infrarouge et électromagnétique, l’acoustique, l'altitude, la sûreté logicielle, les vibrations six degrés de liberté, les atmosphères explosives, les conditions induites par l'entité et les effets nuisibles des armes pour les équipements militaires.

Les taux de défaillance estimés générés en utilisant les modèles du présent document ne sont valides que si la température de la partie la plus froide du composant étudié est supérieure à la température de point de rosée.

Dans le présent document, seuls les agents climatiques et les paramètres mécaniques sont utilisés pour décrire l'effet des environnements de référence sur les taux de défaillance. Toutefois, la température est traitée séparément dans le présent document. Pour des raisons de simplicité, il a été décidé de traiter trois environnements de base, désignés par convention E1, E2 et E3. Ces environnements font référence aux situations d'utilisation réelle générales, compte tenu des valeurs spécifiques des agents environnementaux. Ceux-ci sont définis dans le Tableau 1 .

Tableau 1 – Environnements de base

E1	**Utilisation à poste fixe, protégé contre les intempéries**	L'environnement est insensible dans une large mesure aux conditions climatiques et l'humidité est contrôlée dans des limites définies. Cet environnement est typique des équipements de télécommunications et du matériel informatique situés dans des bâtiments. Il comprend l'environnement des bureaux.
E2	**Utilisation à poste fixe, protégé partiellement ou non protégé contre les intempéries**	L'environnement est soumis à des contraintes thermiques et mécaniques influencées directement par les conditions naturelles. Cet environnement est typique des équipements installés à l'extérieur.
E3	**Utilisation à poste mobile et non fixe, installation sur véhicules au sol**	L'environnement est soumis à des contraintes mécaniques et à des gradients thermiques élevés. Cet environnement est typique des équipements montés sur véhicules ou portatifs.

Le Tableau 2 donne les valeurs des agents environnementaux et leur relation avec les classes indiquées dans les normes IEC correspondantes.

L'effet de l'environnement peut être décrit comme une variation du taux de défaillance, en utilisant un facteur d'environnement π_E (voir Tableau 4). Noter que π_E est un facteur discret dans la mesure où il est basé sur des données non continues et où il synthétise un grand nombre de facteurs de niveau inférieur différents.

Dans tous les cas, il doit être noté que la plupart des systèmes et des équipements fonctionnent sous une température contrôlée et que l'effet de l'environnement extérieur est limité par des décisions de conception appropriées.

Le présent document tient compte du cycle de température (temps de fonctionnement à différentes températures) dans le profil de mission, alors que les variations rapides de température sont incluses dans le facteur d'environnement π_E (voir 5.2.5).

Les facteurs d'environnement comprennent tous les agents environnementaux (à l'exclusion de la température, qui a un modèle spécifique) tels que les variations rapides de température, les vibrations mécaniques, pour lesquels il n'existe aucun modèle empirique. Les facteurs d'environnement sont utilisés au niveau de l'équipement.

Tableau 2 – Valeurs des agents environnementaux pour des environnements de base

Agents environnementaux	E1	E2	E3
	Utilisation à poste fixe, protégé contre les intempéries	**Utilisation à poste fixe, protégé partiellement ou non protégé contre les intempéries**	**Utilisation à poste mobile et non fixe, installation sur véhicules au sol**
Vitesse de variation de la température	≤ 0,5° C/min	> 0,5° C/min	> 0,5° C/min
Vibrations stationnaires, sinusoïdales	2 Hz à 9 Hz <1,5 mm 9 Hz à 200 Hz ≤ 5 m/s^2	2 Hz à 9 Hz ≤3 mm 9 Hz à 200 Hz ≤ 10 m/s^2	2 Hz à 9 Hz >3 mm 9 Hz à 200 Hz ≥ 10 m/s^2 200 Hz à 500 Hz ≥15 m/s^2
Vibrations non stationnaires, y compris les chocs	≤ 70 m/s^2	≤ 250 m/s^2	> 250 m/s^2
Classes de l'IEC 60721-3-3	3K1 3K2 3K3 3K4 3K5 3K6 3M1 3M2 3M3	3K7 3K7L 3K8 3K8H 3K8L 3K9 3K10 3M4 3M5 3M6 3M7	-
Classes de l'IEC 60721-3-4	-	-	4K1 4K2 4K3 4K4 4K4H 4K4L
Classes de l'IEC 60721-3-5	-	-	5K1 5K2 5K3 5K4 5K4H 5K4L 5K5 5K6 5M1 5M2 5M3
Classes de l'IEC 60721-3-7	-	-	7K1 7K2 7K3 7K4 7K5
Classes ETS 300 019-1-3	3.1-3.2-3.3	3.4-3.5	-
Classes ETS 300 019-1-4	-	4.1-4.1E	-
Classes ETS 300 019-1-8	8.1 et Note	-	-
Classes ETS 300 019-1-5	-	-	5.1-5.2
Classes ETS 300 019-1-7	-	-	7.1 – 7.2 – 7.3 – 7.3E

Pour des raisons de simplicité, le présent document ne traite que des trois environnements concernés. L'utilisateur peut décrire tout environnement avec la même méthodologie et évaluer l'effet de l'environnement d'application approprié π_E décrit en 5.2.5.

4.5 Choix des composants

Il incombe au fabricant de garantir la durée de vie spécifiée par l'utilisateur final et de s'assurer que les composants utilisés dans l'équipement sont compatibles avec l'environnement. Par conséquent, l'usure prématurée n'est pas censée apparaître pendant la durée de vie utile de l'équipement dans les conditions normales de fonctionnement, comme cela est spécifié par l'utilisateur final.

Toutefois, dans la mesure où certains composants peuvent avoir une durée de vie limitée, une maintenance préventive doit être indiquée à l'utilisateur final. Le fabricant du composant est tenu de communiquer les résultats de qualification et d'évaluation des mécanismes de dégradation au fabricant du système et de veiller à ce que l'apparition des mécanismes d'usure soit reportée au-delà de la durée de vie utile de l'équipement dans les conditions normales de fonctionnement.

Une fiabilité optimale des composants et des équipements n'est pas obtenue sans effort. La fiabilité de l'équipement est intégrée, dès les premières phases de conception, en appliquant un système d'assurance qualité rigoureux orienté vers l'amélioration. À l'inverse, une application inappropriée des règles d'excellence en matière de qualité et de fiabilité, en tenant compte du type de produit et de sa criticité d'utilisation et de maintenance, compromet l'atteinte de l'objectif.

Les défaillances des composants, même celles convenues comme aléatoires, à l'exclusion de l'usure et des causes externes, sont dues à des défauts de fabrication ou à un mauvais usage. Leurs effets se manifestent pendant le fonctionnement.

Par conséquent, les fabricants et les utilisateurs doivent adopter des mesures préventives appropriées:

- qualification et maîtrise du procédé de fabrication des composants;
- caractérisation et qualification des composants;
- essais d'acceptation;
- utilisation de bonnes règles de conception (thermique, électrique, mécanique).

Le présent document ne décrit pas les niveaux de qualité dans la mesure où il ne tient pas compte des niveaux de qualité inférieurs aux meilleurs niveaux de qualité possible définis comme des normes de conception. L'expérience d'une mauvaise qualité ne peut pas être prise en compte dans l'élaboration des modèles, et les dispenses d'application des règles de qualité ne peuvent pas être justifiées sur la base de considérations d’ordre économique lorsque le coût total du composant ou de l'équipement appartenant au fabricant ou à l'utilisateur est étudié.

Dans certaines applications spéciales, comme l'espace, l'avionique et les câbles sous-marins, l'incapacité – ou du moins la grande difficulté – à exécuter des opérations de maintenance incite, autant que pour des raisons de sécurité, à adopter des règles encore plus strictes. Ces situations ne peuvent pas être généralisées et il convient de les étudier sur la base d'une expérience spécifique avec l'équipement et des mesures adoptées (telles que des programmes de déverminage, de rodage ou d'assurance qualité spéciaux).

Par conséquent, le fabricant de l'équipement doit choisir les fabricants de composants qui ont les meilleures "pratiques commerciales" en termes de qualité, par exemple, ceux qui se conforment aux systèmes de management de la qualité internationalement reconnus, mettent en œuvre le contrôle statistique de fabrication et sont sous agrément de savoir-faire ou ligne de fabrication qualifiée (ou susceptible de l’être).

Dans ces conditions, il n'y a plus aucune raison de tenir compte des facteurs de qualité. De même la période de défaillance précoce associée aux nouvelles technologies de production des composants est ignorée dans la mesure où seules les lignes de fabrication qualifiées et celles qui sont stabilisées sont envisagées ici.

Lorsque le fabricant d'un équipement a recours à une nouvelle technologie de production d'un composant mais qu'il n'est pas en mesure de justifier la durée de vie de son dispositif dans les conditions d'utilisation normale, il doit réaliser des essais pour justifier la durée de vie de ce composant à l'utilisateur final.

4.6 Croissance de la fiabilité pendant la phase de déploiement du nouvel équipement

Les modèles présentés dans le présent document permettent de calculer le taux de défaillance d'une entité électrique qui se trouve déjà dans une phase de production avancée. Toutefois, une nouvelle entité peut au préalable avoir été soumise à un certain processus de croissance de la fiabilité, qui se manifeste par une baisse du taux de défaillance pendant une période plus ou moins longue.

Par exemple, la croissance de la fiabilité est obtenue en remédiant aux problèmes de fabrication, tels que le retour d'un procédé au stade de contrôle ou la modification d'un procédé à des fins d'amélioration. En ce qui concerne la croissance de la fiabilité en exploitation, les modifications apportées à l'entité, sa conception, sa fabrication ou son fonctionnement permettent d'obtenir une entité plus fiable. Pour une description complète des processus et activités de fiabilité intégrés au cycle de vie du produit qui contribuent à ou assurent la croissance de la fiabilité du produit, voir l'IEC 61014.

Il convient que le fabricant adapte la période de croissance de la fiabilité à sa propre expérience. L'expérience a démontré que pour de nombreuses entités électriques et en présence de plusieurs fabricants, le rapport entre le taux de défaillance au début de la période de déploiement et le taux de défaillance dans la phase avancée peut être très différent. Par conséquent, dès que le taux de défaillance observé au début du déploiement d'une entité électrique dépasse de façon significative la valeur estimée, une action corrective peut devoir être prise.

4.7 Méthode d'utilisation du présent document

Le présent document expose une méthode de conversion des taux de défaillance d'un ensemble de conditions de fonctionnement à un autre. À cette fin, elle utilise le concept des taux de défaillance aux conditions de référence et propose des équations pour les convertir à d'autres conditions.

Les conditions de référence sont définies comme l'ensemble le plus courant de conditions d'environnement et de fonctionnement pour l'utilisateur. Par exemple, si la grande majorité des équipements d'un organisme fonctionnent à 30 °C, il convient alors que l'organisme établisse les taux de défaillance à cette température de fonctionnement et la définisse comme la condition de référence. Il convient que l'organisme choisisse les conditions typiques de fonctionnement comme conditions de référence de sorte qu'il n'ait pas besoin d'ajuster les données de fiabilité qu'il recueille en exploitation pour tenir compte des différences environnementales avant leur utilisation.

Si un organisme ne dispose pas d'un environnement opérationnel type, il convient qu'il définisse les conditions de référence au niveau le plus approprié. Il peut également appliquer les conditions de référence définies des Articles 6 à 20 dans le présent document. Dans ce cas, il peut devoir adapter les données d'exploitation recueillies dans un ensemble de conditions de référence pour ainsi pouvoir les associer et les comparer.

De nombreux organismes ne disposent pas de leurs propres données de fiabilité, il est donc nécessaire qu'ils utilisent d'autres sources de données. Le présent document peut alors être utilisé pour convertir les taux de défaillance obtenus dans des conditions de fonctionnement aux conditions de référence et inversement.

NOTE Par exemple, si un organisme souhaite réaliser une prévision pour un équipement à une température de fonctionnement de 34 °C et que le composant utilisé n'est pas couvert par une seule source de données avec certaines données provenant de plusieurs autres recueils de données, alors les taux de défaillance de base, qui sont établis à un niveau particulier et différent de contrainte environnementale dans chaque source, peuvent être convertis et associés au moyen des équations fournies dans le présent document.

Les équations fournies dans le présent document ont été déterminées à partir d'un modèle empirique ajusté aux données d'exploitation et, dans certains cas, aux équations utilisées dans d'autres normes et recueils. Il s'agit donc dans le cas présent d'équations qui offrent un ajustement générique aux données selon les conventions d'une norme internationale.

La Figure 1 représente, pour les circuits intégrés CMOS, une comparaison des facteurs π_T traduisant l'influence de la température mentionnés dans un certain nombre de recueils de prévision avec le facteur π_T établi dans le présent document.

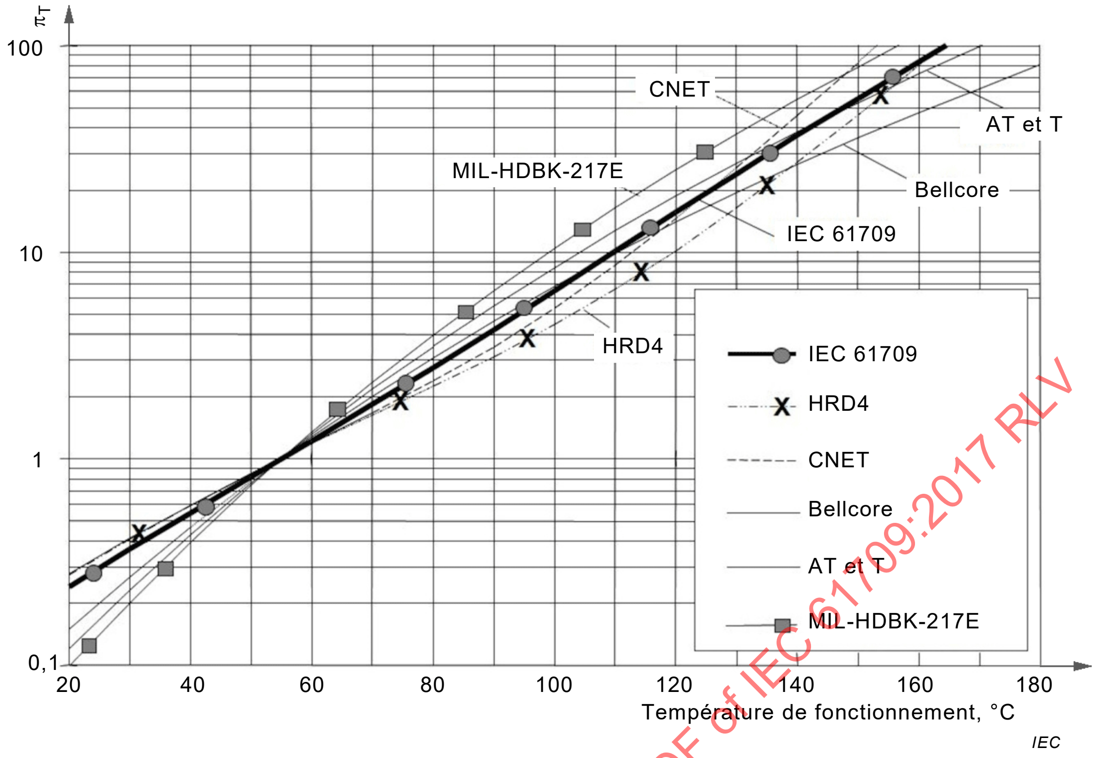

Figure 1 – Comparaison des facteurs π_T traduisant l'influence de la température pour les circuits intégrés CMOS

La Figure 1 démontre que les facteurs d'accélération spécifiés dans le présent document sont compatibles avec de nombreux facteurs d'accélération donnés dans les recueils de prévision. La figure indique une adéquation aux versions génériques des données provenant des recueils de prévision. Les dernières versions des recueils sont détaillées en H.5.3.

Certaines données sont exigées pour appliquer les équations données dans le présent document. Ces données sont légèrement différentes selon le type de composant, mais les données les plus importantes portent sur un taux de défaillance de base établi aux conditions de référence. Celles-ci peuvent être obtenues à partir des données d'exploitation (voir l'IEC 60300-3-3 et l'IEC 60300-3-5), des données du fabricant ou d'autres recueils (voir l'Annexe H). Si ces données ne sont pas établies aux conditions de référence, elles peuvent être converties à une condition de référence en utilisant les équations du présent document. Pour ce faire, il est nécessaire de connaître l'environnement opérationnel dans lequel le taux de défaillance est établi. Lorsque le taux de défaillance est établi aux conditions de référence, il peut ensuite être converti à d'autres conditions de fonctionnement en utilisant les équations du présent document.

5 Conditions de référence et modèles de contraintes génériques

5.1 Conditions de référence génériques recommandées

Les conditions de référence génériques sont les valeurs des facteurs d'environnement définies par un organisme comme étant propres aux types d'environnement auxquels l'équipement de l'organisme est soumis pendant le fonctionnement normal. Le facteur peut être n'importe quel facteur d'environnement jugé pertinent par l'organisme et s'appliquer à tous les types de composants.

Inévitablement, le présent document limite les possibilités et définit les facteurs d'environnement d'intérêt comme étant la contrainte électrique, la température et les conditions d'environnement. Les autres facteurs ne sont pas couverts par le présent document.

Le Tableau 3 présente certaines recommandations qu'un organisme peut utiliser à moins qu'elles ne soient pas appropriées aux conditions normales de fonctionnement des équipements de cet organisme. Il convient que tout organisme choisisse les conditions les plus représentatives de son expérience réelle si ces conditions diffèrent de celles indiquées dans le Tableau 3.

Les valeurs choisies représentent la plupart des conditions de fonctionnement des composants.

Tableau 3 – Conditions de référence recommandées pour les contraintes environnementales et mécaniques

Type de contrainte	Condition de référence[a]
Température ambiante[b]	θ_0 = 40 °C
Condition d'environnement	Environnement E1 (voir Tableau 1)
Contraintes spéciales	Non traité dans le présent document[c]

[a] Les taux de défaillance donnés dans ces conditions s'appliquent uniquement à des composants qui n'ont pas été endommagés pendant le transport et le stockage.

[b] Pour les besoins du présent document, la température ambiante est la température du milieu environnant le composant au cours du fonctionnement de l'équipement, en ne tenant pas compte de tout autoéchauffement potentiel du composant. Il convient de définir le milieu environnant du composant.

[c] Les contraintes spéciales comprennent le vent, la pluie et la neige, la formation de givre, les ruissellements, les pulvérisations ou jets d'eau, la poussière (chimiquement active ou non), les effets des animaux nuisibles, les gaz corrosifs, les rayonnements radioactifs, etc. Ces contraintes peuvent constituer des éléments importants qui contribuent aux défaillances; toutefois, dans la mesure où elles constituent une bonne pratique générale, il convient de les traiter par des méthodes de conception. Leur effet peut dans certains cas être traité par des modèles applicables. Les effets de ces contraintes sont si étendus qu'il serait inapproprié de les traiter dans le présent document.

5.2 Modèles de contraintes génériques

5.2.1 Généralités

Les composants peuvent ne pas toujours fonctionner dans les conditions de référence. Dans ces cas, les taux de défaillance observés dans les conditions de fonctionnement sont différents de ceux donnés pour les conditions de référence. Il peut donc être exigé d'utiliser des modèles pour les facteurs de contrainte permettant de convertir les taux de défaillance observés dans les conditions de référence en valeurs de taux de défaillance applicables dans les conditions de fonctionnement (température ambiante réelle et contraintes électriques réelles appliquées aux composants) et inversement. Les Articles 6 à 20 décrivent les modèles de contrainte et les valeurs des facteurs π spécifiques applicables aux catégories de composants, et qu'il convient d'utiliser pour convertir les taux de défaillance de référence en taux de défaillance en exploitation. Les facteurs π sont des modificateurs de taux de défaillance associés à une contrainte ou une condition spécifique. Ces facteurs constituent une mesure de l'évolution du taux de défaillance provoquée par les variations de la contrainte ou de la condition concernée. Cependant, si des modèles plus spécifiques s'appliquent à des types particuliers de composants, il convient alors de s'en servir et de justifier et consigner leur utilisation.

La conversion des taux de défaillance n'est possible que dans les limites de fonctionnement spécifiées pour les composants.

Le taux de défaillance des composants dans les conditions de fonctionnement se calcule comme suit:

$$\lambda = \lambda_{\mathrm{ref}} \times \pi_{\mathrm{U}} \times \pi_{\mathrm{I}} \times \pi_{\mathrm{T}} \times \pi_{\mathrm{E}} \times \pi_{\mathrm{S}} \times \pi_{\mathrm{ES}} \qquad (2)$$

où

λ_{ref}	est le taux de défaillance dans les conditions de référence;
π_{U}	est le facteur traduisant l'influence de la tension;
π_{I}	est le facteur traduisant l'influence du courant;
π_{T}	est le facteur traduisant l'influence de la température;
π_{E}	est le facteur traduisant l'influence de l'environnement;
π_{S}	est le facteur traduisant l'influence de la fréquence de manœuvre;
π_{ES}	est le facteur traduisant l'influence des contraintes électriques.

5.2.2 Facteur de contrainte applicable à l'influence de la tension, π_{U}

$$\pi_{\mathrm{U}} = \exp\left\{ C_3 \left[\left(\frac{U_{\mathrm{op}}}{U_{\mathrm{rat}}} \right)^{C_2} - \left(\frac{U_{\mathrm{ref}}}{U_{\mathrm{rat}}} \right)^{C_2} \right] \right\} \qquad (3)$$

où

U_{op}	est la tension de fonctionnement en V;
U_{ref}	est la tension de référence en V;
U_{rat}	est la tension assignée en V;
C_2, C_3	sont des constantes.

L'Équation (3) représente un modèle empirique permettant de décrire l'influence de la tension sur les taux de défaillance. Elle est basée sur les recueils actuels de fiabilité des composants, les données actuelles de fiabilité des composants et les publications accessibles au public.

NOTE Lorsque des tensions absolues, qui peuvent se révéler nécessaires pour certains types de composants, sont appliquées, l'Equation 3 peut alors être modifiée en $\pi_{\mathrm{U}} = \exp\left\{ C_1 \left(U_{\mathrm{op}}^{C_2} - U_{\mathrm{ref}}^{C_2} \right) \right\}$ où $C_1 = C_3 / U_{\mathrm{rat}}^{C_2}$.

5.2.3 Facteur de contrainte applicable à l'influence du courant, π_{I}

$$\pi_{\mathrm{I}} = \exp\left\{ C_4 \left[\left(\frac{I_{\mathrm{op}}}{I_{\mathrm{rat}}} \right)^{C_5} - \left(\frac{I_{\mathrm{ref}}}{I_{\mathrm{rat}}} \right)^{C_5} \right] \right\} \qquad (4)$$

où

I_{op}	est le courant de fonctionnement en A;
I_{ref}	est le courant de référence en A;
I_{rat}	est le courant assigné en A;
C_4, C_5	sont des constantes.

L'Équation (4) représente un modèle empirique permettant de décrire l'influence du courant sur les taux de défaillance. Elle est basée sur les recueils actuels de fiabilité des composants, les données actuelles de fiabilité des composants et les publications accessibles au public.

5.2.4 Facteur de contrainte applicable à l'influence de la température, π_T

$$\pi_\mathrm{T} = \exp\left[\frac{Ea_1}{k_0}\left(\frac{1}{T_\mathrm{ref}} - \frac{1}{T_\mathrm{op}}\right)\right] \qquad (5)$$

L'Équation (5) est un modèle empirique basé sur l'équation d'Arrhénius qui décrit l'influence de la température sur les taux de défaillance. En théorie, il convient d'effectuer ce calcul pour chaque mode de défaillance. La pratique courante consiste toutefois à effectuer ce calcul en utilisant la moyenne de toutes les énergies d'activation pour tous les modes de défaillance ou pour le mode de défaillance prédominant uniquement. Il convient de noter que l'énergie d'activation peut dans ce dernier cas être fonction également de la température dans la mesure où elle est liée aux différentes énergies d'activation des modes de défaillance sous-jacents. Cet effet est toutefois généralement ignoré.

Dans certains cas, un modèle plus complexe utilisant deux énergies d'activation est adapté à l'influence de la température sur les taux de défaillance. Dans une telle situation, l'Équation (6) suivante peut être appliquée. L'utilisation du modèle avec deux énergies d'activation (Ea_1, Ea_2) est suffisante pour une modélisation adéquate de la relation température-taux de défaillance. (Cette relation est parfois désignée sous l'appellation "risques concurrentiels"; voir JESD-85 pour des informations détaillées.)

Cette équation d'Arrhénius étendue est normalisée pour éviter l'utilisation d'énergies d'activation elles-mêmes fonctions de la température, en cas de variation de la température de référence T_ref.

$$\pi_T = \frac{A \times \exp(Ea_1 \times z) + (1-A) \times \exp(Ea_2 \times z)}{A \times \exp(Ea_1 \times z_\mathrm{ref}) + (1-A) \times \exp(Ea_2 \times z_\mathrm{ref})} \qquad (6)$$

avec les variables auxiliaires

$$z = \frac{1}{k_0}\left(\frac{1}{T_0} - \frac{1}{T_\mathrm{op}}\right) \text{ et } z_\mathrm{ref} = \frac{1}{k_0}\left(\frac{1}{T_0} - \frac{1}{T_\mathrm{ref}}\right) \text{ en (eV)}^{-1}$$

où, dans les Équations (5) et (6):

A	est une constante;
Ea_1, Ea_2	sont les énergies d'activation en eV;
k_0	$= 8{,}616 \times 10^{-5}$ eV/K;
T_0	= 313 K;
T_ref	$= (\theta_\mathrm{ref} + 273)$ en K;
T_op	$= (\theta_\mathrm{op} + 273)$ en K.

Les températures θ_ref et θ_op en degrés Celsius, susmentionnées, sont les suivantes:

- pour les circuits intégrés:

  θ_ref : température virtuelle (équivalente) de jonction de référence;

  θ_op : température virtuelle (équivalente) de jonction réelle;

- pour les composants discrets à semiconducteurs et les composants optoélectroniques:

θ_{ref} : température de jonction de référence;

θ_{op} : température de jonction réelle;

- pour les condensateurs:

  θ_{ref} : température moyenne (*) de référence du condensateur;

  θ_{op} : température moyenne (*) réelle du condensateur;

- pour les résistances:

  θ_{ref} : température moyenne (*) de référence de l'élément de résistance (par exemple, film);

  θ_{op} : température moyenne (*) réelle de l'élément de résistance;

- pour les inductances:

  θ_{ref} : température moyenne (*) de référence de l'enroulement;

  θ_{op} : température moyenne (*) réelle de l'enroulement;

- pour les autres composants électriques:

  θ_{ref} : température ambiante moyenne (*) de référence;

  θ_{op} : température ambiante moyenne (*) réelle;

NOTE (*) Dans ce cas, moyenne signifie "sur le corps entier du composant".

5.2.5 Facteur d'environnement, π_{E}

Certains recueils de données fournissent des lignes directrices concernant le transfert de l'estimation d'un taux de défaillance d'une condition d'environnement générale à une autre. Le concept est logique, mais comporte un certain risque. C'est la raison pour laquelle le présent document se concentre davantage sur des situations pour lesquelles les taux de défaillance de base sont obtenus de conditions d'environnement analogues à celles appliquées dans la pratique au composant.

L'influence des conditions d'environnement sur le composant dépend essentiellement de la conception de l'équipement. Par exemple, l'utilisation de l'équipement à bord de navires ou dans le secteur automobile, et non dans des locaux protégés (conditions de laboratoire) permet de réduire le plus possible l'influence des conditions d'environnement, et peut dans certains cas la supprimer entièrement si le composant est protégé d'une façon ou d'une autre dans l'équipement. Ceci nécessite de toute évidence de porter une plus grande attention à la conception ce qui, dans certains cas, peut ne pas se révéler utile. L'influence effective ou non de l'environnement d'application dépend par conséquent essentiellement du fabricant de l'équipement. La conception d'un environnement spécifique relève de la responsabilité d'un organisme. Si l'influence de ces contraintes ne peut être évitée, des études spécifiques se révèlent alors nécessaires pour ces équipements.

La question de la nécessité d'appliquer un facteur d'environnement se pose uniquement si les données de taux de défaillance disponibles dans les recueils proviennent d'une source soumise à des conditions d'environnement très différentes. L'utilisation d'un tel facteur d'environnement repose sur l'hypothèse selon laquelle l'existence d'un environnement plus sévère contribue à l'activation de mécanismes de défaillance interne d'une manière prévisible et plus ou moins linéaire. Cette hypothèse est inexacte pour certaines situations. L'utilisation d'un composant conçu pour un équipement au sol dans des conditions de choc et de vibrations sévères – ce qui peut détruire tous les composants en quelques heures – peut entraîner le calcul d'un facteur π_{E}, toutefois non significatif. Dans la meilleure pratique, il convient donc de ne pas utiliser ce composant dans l'environnement concerné, mais cela n'est pas toujours possible.

Il convient, par conséquent, d'utiliser le facteur d’environnement π_{E} avec prudence.

Tableau 4 – Facteur d'environnement, π_{E}

Utilisation à poste fixe, protégé contre les intempéries E1	Utilisation à poste fixe, protégé partiellement ou non protégé contre les intempéries E2	Utilisation à poste mobile et non fixe, installation sur véhicules au sol E3
1	2	4

NOTE Les recueils de données de taux de défaillance communiqués par le fournisseur d'un composant donnent souvent des lignes directrices concernant la méthode de transfert du taux de défaillance à d'autres conditions de fonctionnement et d'environnement.

5.2.6 Influence de la fréquence de manœuvre, π_{S}

Le facteur π_{S} prend en compte le nombre de cycles de manœuvres par heure, S, et s'applique uniquement aux relais décrits dans le présent document.

Le facteur π_{S} n'est pas défini pour $S < 0{,}01$.

a) $\pi_{\text{S}} = 1$ pour $0{,}01 \leq S \leq S_{\text{ref}}$ (7)

b) $\pi_{\text{S}} = S/S_{\text{ref}}$ pour $S > S_{\text{ref}}$ (8)

où

S est le nombre de cycles de manœuvres par heure;

S_{ref} est le nombre de référence de cycles de manœuvres par heure.

NOTE Le facteur π_{S} peut atteindre 100 pour des contacts étanches, normalement fermés, ou pour des contacts non scellés, normalement ouverts avec de faibles charges.

5.2.7 Influence des contraintes électriques, π_{ES}

Ce facteur π de contrainte s'applique uniquement à certains dispositifs, il est décrit en détail dans les articles associés.

5.2.8 Autres facteurs d'influence

D'autres facteurs de contrainte sont fournis pour chaque type de composants dans les Articles 6 à 20 lorsque l'influence est connue.

Il n'existe actuellement aucune méthode de conversion d'application générale pour l'influence de l'humidité, la pression atmosphérique, la contrainte mécanique, etc. sur le taux de défaillance.

Les facteurs de contrainte doivent être basés sur l'expérience du fournisseur/de l’utilisateur dans des applications analogues ou des essais appropriés.

Si l'influence de ces types de contraintes sur le taux de défaillance est connue, il convient d'en tenir compte.

Si l'influence de ces types de contraintes sur le taux de défaillance n'est pas connue, mais est censée dépendre de ces derniers, des études appropriées en la matière peuvent se révéler nécessaires.

6 Circuits intégrés à semiconducteurs

6.1 Conditions de référence spécifiques

Les recommandations suivantes applicables aux températures de référence données du Tableau 5 au Tableau 9 sont fondées sur une température ambiante de composant de 40 °C et correspondent à la plupart des applications de composants dans des équipements.

Il convient d'indiquer l'autoéchauffement de référence, $\Delta T_{\mathrm{ref}} = P_{\mathrm{ref}} \times R_{\mathrm{th,\,amb}}$, lorsque des températures de référence autres que celles indiquées dans les tableaux sont utilisées.

Pour tout circuit intégré, deux résistances thermiques sont généralement prises en considération; l'une étant située entre la jonction et le boîtier, et l'autre entre le boîtier et le milieu environnant. Il convient que la résistance thermique, $R_{\mathrm{th,amb}}$, mentionnée ci-dessus, soit la résistance la plus significative dans l'application à l'étude.

Lorsqu'un taux de défaillance est spécifié pour une température ambiante de 40 °C, il convient également d'indiquer la puissance dissipée de référence, P_{ref}, et la résistance thermique, $R_{\mathrm{th,amb}}$, vers l'environnement pour lequel cette valeur s'applique.

Tableau 5 – Mémoire

Composant			θ_{ref} °C	Note
Bipolaire	RAM, FIFO	statique	75	---
	PROM		75	
MOS, CMOS, BICMOS	RAM	dynamique	55	
	RAM, FIFO	statique lente (≥ 30 ns) statique rapide (< 30 ns)	55	
	masque ROM		55	
	EPROM, OTPROM	UV effaçable	55	
	FLASH		55	
	EEPROM, EAROM		55	

Tableau 6 – Microprocesseurs et périphériques, microcontrôleurs et processeurs de signaux

Composant		θ_{ref} °C	Note
Bipolaire		70	---
NMOS	Nombre de transistors ≤ 50 000	70	
	Nombre de transistors > 50 000	90	
CMOS	Nombre de transistors ≤ 5 000	50	
	Nombre de transistors > 5 000 à 50 000	60	
	Nombre de transistors > 50 000 à 500 000	80	
	Nombre de transistors > 500 000	90	
BICMOS		75	

Tableau 7 – Familles logiques numériques et interfaces de bus, circuit de commande et circuit récepteur de bus

Composant			θ_{ref} °C	Tension de référence
Bipolaire	TTL, -LS, -A(L)S, -F	Logique	45	---
	Interface bus		55	
	TTL S	Logique + interface bus	80	
	ECL	10 000 100 000 10(LV)E(L) / 100(LV)E(I)(P)	65 75 60	
CMOS	HCMOS, CMOS B, ACMOS (FCT, HC, A(U),C, LVX), (LVC, LCX, LV) (VCX, ALVC, AVC, AHC, VHC) Commutateurs logiques et analogiques, Interface bus		45	$U_{ref} = 5\,V$
	Interface bus	GTL(p)	50	
	Circuit de commande / récepteur de bus	RS422, RS423, RS485, CAN, etc. RS232, RS644/899, CML, etc. .	55	
BICMOS	Logique		45	
	Interface bus	ABT, BCT LVT, ALVT GTL(p) BTL, ETL	50 50 50 95	---
	Circuit de commande / récepteur de bus		55	

Tableau 8 – Circuits intégrés analogiques

Composant		θ_{ref} °C	Rapport de tension de référence
Amplificateurs opérationnels, comparateurs et régulateurs de tension	Bipolaire, BIFET CMOS	55 45	$U_{ref}/U_{rat} = 0{,}7$
Éléments de référence	toutes technologies	45	---
Régulateurs à commutateur	toutes technologies	55	
Amplificateurs et régulateurs de puissance (toutes technologies)	≤ 1 W > 1 W	70 90	
CI haute fréquence (> 100 MHz)			
Modulateur HF, démodulateur PLL, VCO	bipolaire CMOS, BICMOS	65 45	
Émetteur, récepteur	bipolaire CMOS, BICMOS	70 45	
Amplificateur / récepteur de puissance	GaAs	80	

Tableau 9 – Circuits intégrés spécifiques (ASIC)

Composant		θ_{ref} °C	Note
ASIC, Circuits intégrés personnalisés, Circuits intégrés prédiffusés, Circuits intégrés de télécommunication, Convertisseurs A/N			---
Bipolaire	TTL	55	
	ECL	70	
	HV (> 50 V)	80	
NMOS		55	
CMOS, BICMOS	numérique, analogique / mixte Nombre de transistors ≤ 50 k	55	
	Nombre de transistors > 50 000 à 50 × 10^6	70	
	Nombre de transistors > 50 × 10^6	80	
	HV (> 50 V)	75	
ASIC programmables (PLD - réseau logique programmable) non effaçables			
Bipolaire	TTL	80	
	ECL	85	
CMOS	(anti-fusibles)	80	
ASIC programmables (PLD - réseau logique programmable) effaçables			
NMOS, CMOS	Base RAM	80	
	Base EPROM Nombre de transistors ≤ 5 000 Base EEPROM Nombre de transistors > 5 000 Flash-EPROM	70 80 80	

6.2 Modèles de contraintes spécifiques

6.2.1 Généralités

Les modèles de contraintes spécifiques sont fournis pour convertir les taux de défaillance entre différentes conditions. Ces modèles de contraintes comportent des constantes qui sont des valeurs moyennes pour chaque type de composant provenant de différents fabricants, déterminées lors de l'exploitation et au cours d'essais en laboratoire.

$$\lambda = \lambda_{\mathrm{ref}} \times \pi_{\mathrm{U}} \times \pi_{\mathrm{T}} \quad \text{pour les circuits intégrés numériques CMOS et les circuits intégrés bipolaires analogiques} \tag{9}$$

$$\lambda = \lambda_{\mathrm{ref}} \times \pi_{\mathrm{T}} \quad \text{pour tous les autres circuits intégrés (CI)} \tag{10}$$

Les facteurs de contrainte traduisant l'influence de la tension et de la température sont donnés en 6.2.2 et 6.2.3 respectivement.

6.2.2 Influence de la tension, facteur π_{U}

Selon l'Équation (3), l'influence de la tension n'est prise en compte que pour les circuits intégrés numériques CMOS et les circuits intégrés bipolaires analogiques. Les constantes C_1, C_2 et C_3 données dans le Tableau 10 sont utilisées, à moins que d'autres valeurs ne soient indiquées. Les résultats sont présentés dans le Tableau 11 et le Tableau 12.

Tableau 10 – Constantes pour l'influence de la tension

Circuit intégré	$U_{\text{ref}}/U_{\text{rat}}$	U_{ref}	C_1	C_2	C_3
Famille numérique CMOS	–	5 V	0,1 V^{-1}	1	–
Analogique	0,7	–	–	4,4	1,4

Tableau 11 – Facteur π_U pour les circuits intégrés numériques CMOS

U_{op} (V)	≤3	4	5	6	7	8	9	10	11	12	13	14	15
Facteur π_U	0,8	0,9	1	1,1	1,2	1,3	1,5	1,6	1,8	2,0	2,2	2,5	2,7

Tableau 12 – Facteur π_U pour les circuits intégrés analogiques bipolaires

$U_{\text{op}}/U_{\text{rat}}$	≤0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
Facteur π_U	0,75	0,77	0,80	0,87	1,0	1,3	1,8	3,0

6.2.3 Influence de la température, facteur π_T

La relation donnée par l'Équation (6) ne s'applique qu'à des températures inférieures ou égales à la température de jonction assignée. Les constantes A, Ea_1 et Ea_2 données dans le Tableau 13 sont utilisées, à moins que d'autres valeurs ne soient indiquées. Les résultats sont présentés dans le Tableau 14 et le Tableau 15.

Tableau 13 – Constantes pour l'influence de la température

	A	Ea_1 (eV)	Ea_2 (eV)
Circuits intégrés (sauf EPROM, OTPROM, EEPROM, EAROM)	0,9	0,3	0,7
EPROM, OTPROM, EEPROM, EAROM	0,3	0,3	0,6

Le facteur π_T est obtenu à partir du Tableau 14 et du Tableau 15 en fonction:

- de la température virtuelle (équivalente) réelle de jonction;

$$\theta_{\text{op}} = \theta_{\text{amb}} + P_{\text{op}} \times R_{\text{th,amb}} \quad \text{en degrés Celsius,} \tag{11}$$

- et de la température virtuelle (équivalente) de jonction dans les conditions de référence (voir 6.1);

$$\theta_{\text{ref}} = 40 + \Delta T_{\text{ref}} \quad \text{en degrés Celsius,} \tag{12}$$

où ΔT_{ref} est mesuré ou calculé sous la forme $\Delta T_{\text{ref}} = P_{\text{ref}} \times R_{\text{th, amb}}$.

Tableau 14 – Facteur π_T pour les circuits intégrés (sauf mémoire EPROM, FLASH-EPROM, OTPROM, EEPROM, EAROM)

θ_{ref} °C (voir 6.1)	Facteur π_T pour θ_{op} °C																				
	≤25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**130**	**140**	**150**	**175**
40	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,3	4,1	5,1	6,3	7,7	9,6	12	18	28	44	67	102	275
45	0,44	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,4	4,1	5,1	6,3	7,8	9,7	15	23	36	55	83	225
50	0,36	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,2	2,8	3,4	4,2	5,2	6,4	8	12	19	29	45	68	184
55	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,3	2,8	3,4	4,2	5,3	6,5	10	16	24	37	56	150
60	0,24	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,3	2,8	3,5	4,3	5,3	8,2	13	20	30	46	123
65	0,2	0,24	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,9	2,3	2,8	3,5	4,4	6,7	10	16	24	37	100
70	0,16	0,2	0,24	0,3	0,37	0,45	0,54	0,67	0,82	1	1,2	1,5	1,9	2,3	2,9	3,6	5,5	8,5	13	20	30	82
75	0,13	0,16	0,2	0,24	0,3	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,3	2,9	4,5	6,9	11	16	25	67
80	0,11	0,13	0,16	0,2	0,24	0,29	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,3	3,6	5,69	8,6	13	20	54
85	0,087	0,11	0,13	0,16	0,2	0,24	0,29	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,9	4,5	7	11	16	44
90	0,07	0,086	0,11	0,13	0,16	0,19	0,24	0,29	0,35	0,43	0,53	0,66	0,81	1	1,2	1,5	2,4	3,7	5,6	8,7	13	36
95	0,057	0,07	0,085	0,1	0,13	0,16	0,19	0,23	0,29	0,35	0,43	0,53	0,65	0,81	1	1,2	1,9	3	4,6	7	11	29
100	0,046	0,056	0,069	0,084	0,1	0,13	0,15	0,19	0,23	0,28	0,35	0,43	0,53	0,65	0,81	1	1,5	2,4	3,7	5,6	8,5	23

Tableau 15 – Facteur π_T pour mémoires EPROM, FLASH-EPROM, OTPROM, EEPROM, EAROM

θ_{ref} °C (voir 6.1)	Facteur π_T pour θ_{op} °C																				
	≤25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**130**	**140**	**150**	**175**
55	0,16	0,22	0,3	0,41	0,55	0,75	1	1,3	1,8	2,3	3,1	4,0	5,2	6,7	8,6	11	18	28	43	65	96	238

7 Composants discrets à semiconducteurs

7.1 Conditions de référence spécifiques

Les recommandations suivantes applicables aux températures de référence données du Tableau 16 au Tableau 19 sont fondées sur une température ambiante de composant de 40 °C et correspondent à la plupart des applications de composants dans des équipements.

Il convient d'indiquer l'autoéchauffement de référence, $\Delta T_{\text{ref}} = P_{\text{ref}} \times R_{\text{th, amb}}$, lorsque des températures de référence autres que celles indiquées dans les tableaux sont utilisées. Lorsqu'un taux de défaillance est spécifié pour une température ambiante de 40 °C, il convient également d'indiquer la puissance dissipée de référence, P_{ref}, et la résistance thermique, $R_{\text{th, amb}}$, vers l'environnement pour lequel cette valeur s'applique.

Pour les composants discrets à semiconducteurs, deux résistances thermiques sont généralement prises en considération; l'une étant située entre la jonction et le boîtier, l'autre entre le boîtier et le milieu environnant. Il convient que la résistance thermique, $R_{\text{th,amb}}$, mentionnée ci-dessus, soit la résistance la plus significative dans l'application à l'étude.

Tableau 16 – Transistors communs, à basse fréquence

Composant		θ_{ref} °C	Rapport de tension de référence
Bipolaire, universel analogue	par exemple TO18, TO92, SOT(D)(3)23 ou	55	$U_{\text{ref}}/U_{\text{rat}} = 0{,}5$
Réseaux de transistors		55	
Bipolaire, à faible puissance SMA-SMC	par exemple TO5, TO39, SOT223, SO8,	85	
Bipolaire, à puissance	par exemple TO3, TO220, D(D)-Pack	100	
FET	jonction MOS	55 55	
Puissance MOS (SIPMOS)	par exemple TO3, TO220, D(D)-Pack	100	

Tableau 17 – Transistors, hyperfréquences (par exemple RF > 800 MHz)

Composant		θ_{ref} °C	Rapport de tension de référence
Bipolaire	large bande, faible puissance de signal	55 125	$U_{\text{ref}}/U_{\text{rat}} = 0{,}5$
GaAs FET	faible signal, faible bruit, puissance moyenne puissance élevée	95 110 145	
MOSFET	large bande, faible puissance de signal	55 125	

Tableau 18 – Diodes

Composant	θ_{ref} °C	Note
Diode universelle (également avec caractéristiques à avalanche)	55	---
Diodes Schottky	55	
Diode limiteur de tension (diode de suppression de tension)	40	
Diode Zener ($P_{\text{tot}} < 1$ W) protection contre les surtensions[a]	40	
Diode Zener, puissance stabilisation[b]	100	
Diode de référence	45	
Diode pour hyperfréquences, à faible puissance de signal diode détectrice diode à condensateurs diode mélangeuse Diode PIN	45 45 70 55	
Diode pour hyperfréquences, puissance varicap diode gun diode impatt Diode PIN	100 160 180 100	
Diode de redressement haute tension	85	

[a] S'il est appliqué pour la protection contre les surtensions, le calcul peut être effectué sans tenir compte de l'autoéchauffement ($\theta_{\text{ref}} = 40$°C).

[b] S'il est utilisé pour la stabilisation, il convient alors que le calcul tienne compte de l'autoéchauffement.

Tableau 19 – Semiconducteurs de puissance

Composant	θ_{ref} °C	Note
Diodes de redressement (également avec caractéristiques à avalanche)	70	----
Ponts de redressement	85	
Diodes Schottky	85	
Thyristors	85	
Triacs, diacs	85	
Semiconducteurs de puissance spécialisés et personnalisés	consulter le fabricant	

7.2 Modèles de contraintes spécifiques

7.2.1 Généralités

Les modèles de contraintes spécifiques sont fournis pour convertir les taux de défaillance entre différentes conditions. Ces modèles de contraintes comportent des constantes qui sont des valeurs moyennes pour chaque type de composant provenant de différents fabricants (ces valeurs sont déterminées lors de l'exploitation et au cours d'essais en laboratoire).

Le taux de défaillance dans les conditions de fonctionnement est donné par les expressions suivantes, d'après l'Équation (2):

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} \qquad \text{pour les transistors} \qquad (13)$$

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} \qquad \text{pour les diodes et les semiconducteurs de puissance} \qquad (14)$$

NOTE 1 Les diodes font référence aux diodes d'usage général, aux diodes Schottky, aux diodes régulatrices de tension et aux diodes Zener.

NOTE 2 Les semiconducteurs de puissance font référence aux diodes de redressement, aux ponts de diodes, aux thyristors, aux triacs et aux diacs.

Les facteurs de contrainte traduisant l'influence de la tension et de la température sont donnés en 7.2.2 et 7.2.3 respectivement. Le courant peut aussi avoir une influence importante.

7.2.2 Influence de la tension pour les transistors, facteur π_U

L'influence de la tension est prise en compte uniquement pour les transistors selon l'Équation (3). Les constantes C_2 et C_3 données dans le Tableau 20 sont utilisées, à moins que d'autres valeurs ne soient indiquées. Les résultats sont présentés dans le Tableau 21.

Tableau 20 – Constantes pour l'influence de la tension pour les transistors

U_{ref}/U_{rat}	C_2	C_3
0,5	8,0	1,4

Tableau 21 – Facteur π_U pour les transistors

U_{op}/U_{rat}	$\leq 0,6$	0,65	0,7	0,75	0,8	0,85	0,9	0,95	1
Facteur π_U	1	1,04	1,08	1,14	1,26	1,46	1,82	2,52	4

7.2.3 Influence de la température, facteur π_T

La relation donnée par l'Équation (6) ne s'applique qu'à des températures inférieures ou égales à la température de jonction maximale admissible. Les constantes A, Ea_1 et Ea_2 données dans le Tableau 22 sont utilisées, à moins que d'autres valeurs ne soient indiquées. Les résultats sont présentés dans le Tableau 23 et le Tableau 24.

Tableau 22 – Constantes pour l'influence de la température pour les composants discrets à semiconducteurs

Composant	A	Ea_1 (eV)	Ea_2 (eV)
Transistors, diodes de référence et diodes pour hyperfréquences	0,9	0,3	0,7
Diodes (à l'exception des diodes de référence et diodes pour hyperfréquences) Semiconducteurs de puissance[a]	1,0	0,4	–

[a] Diodes de redressement, ponts de redressement, diodes Schottky, thyristors, triacs et diacs

Le facteur π_T est obtenu à partir du Tableau 23 et du Tableau 24 en fonction:

– de la température réelle de jonction;

$$\theta_{op} = \theta_{amb} + P_{op} \times R_{th,amb} \quad \text{en degrés Celsius,} \tag{15}$$

– et de la température de jonction dans les conditions de référence (voir 7.1);

$$\theta_{ref} = 40 + \Delta T_{ref} \quad \text{en degrés Celsius,} \tag{16}$$

où ΔT_{ref} est mesuré ou calculé sous la forme $\Delta T_{ref} = P_{ref} \times R_{th,\,amb}$.

Tableau 23 – Facteur π_T pour les transistors, les diodes de référence et les diodes pour hyperfréquences

θ_{ref} °C (voir 7.1)	Facteur π_T pour θ_{op} °C																									
	≤ 25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**125**	**130**	**140**	**145**	**150**	**160**	**175**	**180**	**200**
40	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,3	4,1	5,1	6,3	7,7	9,6	12	18	28	35	44	67	83	102	153	275	332	689
45	0,44	0,54	0,67	0,82	1	1,2	1,5	1,8	2,2	2,7	3,4	4,1	5,1	6,3	7,8	9,7	15	23	29	36	55	68	83	125	225	272	563
55	0,3	0,37	0,45	0,55	0,67	0,82	1	1,2	1,5	1,8	2,3	2,8	3,4	4,2	5,3	6,5	10	16	19	24	37	45	56	84	150	182	377
70	0,16	0,2	0,24	0,3	0,37	0,45	0,54	0,67	0,82	1	1,2	1,5	1,9	2,3	2,9	3,6	5,5	8,5	11	13	20	25	30	46	82	99	206
85	0,087	0,11	0,13	0,16	0,2	0,24	0,29	0,36	0,44	0,54	0,66	0,81	1	1,2	1,5	1,9	2,9	4,5	5,6	7	11	13	16	24	44	53	110
95	0,057	0,07	0,085	0,10	0,13	0,16	0,19	0,23	0,29	0,35	0,43	0,53	0,65	0,81	1	1,2	1,9	3	3,7	4,6	7	8,6	11	16	29	35	72
100	0,046	0,056	0,069	0,084	0,1	0,13	0,15	0,19	0,23	0,28	0,35	0,43	0,53	0,65	0,81	1	1,5	2,4	3,0	3,7	5,6	6,9	8,5	13	23	28	58
110	0,03	0,036	0,045	0,055	0,067	0,081	0,099	0,12	0,15	0,18	0,22	0,28	0,34	0,42	0,52	0,65	1	1,5	1,9	2,4	3,6	4,5	5,6	8,3	15	18	38
125	0,015	0,019	0,023	0,028	0,035	0,043	0,052	0,063	0,078	0,095	0,12	0,14	0,18	0,22	0,27	0,34	0,52	0,81	1	1,2	1,9	2,3	2,9	4,3	7,8	9,4	20
145	0,0066	0,0081	0,0099	0,012	0,015	0,018	0,022	0,027	0,033	0,041	0,05	0,061	0,076	0,094	0,12	0,14	0,22	0,34	0,43	0,53	0,81	1	1,2	1,85	3,3	4,0	8,3
160	0,0035	0,0054	0,0044	0,0066	0,0080	0,0098	0,012	0,015	0,018	0,022	0,027	0,033	0,041	0,051	0,063	0,074	0,12	0,19	0,24	0,3	0,44	0,54	0,67	1	1,87	2,2	4,6
180	0,0016	0,0020	0,0025	0,0030	0,0037	0,0045	0,0055	0,0067	0,0082	0,01	0,012	0,015	0,019	0,023	0,029	0,036	0,055	0,085	0,11	0,13	0,2	0,25	0,31	0,46	0,83	1	2,1

Tableau 24 – Facteur π_T pour les diodes (sauf les diodes de référence et les diodes pour hyperfréquences) et les semiconducteurs de puissance

θ_{ref} °C (voir 7.1)	Facteur π_T pour θ_{op} °C																									
	≤25	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**125**	**130**	**140**	**145**	**150**	**160**	**175**	**180**	**200**
40	0,47	0,61	0,79	1	1,3	1,6	2	2,4	3	3,7	4,4	5,4	6,5	7,7	9,2	11	15	20	24	27	36	41	47	61	87	98	151
55	0,24	0,31	0,4	0,51	0,64	0,80	1	1,2	1,5	1,9	2,3	2,7	3,3	3,9	4,7	5,5	7,6	10	12	14	18	21	24	31	44	50	77
70	0,13	0,17	0,21	0,27	0,35	0,43	0,54	0,67	0,82	1	1,2	1,5	1,8	2,1	2,5	3,0	4,1	5,6	6,5	7,5	9,9	11,3	13	17	24	27	41
85	0,074	0,095	0,12	0,16	0,2	0,25	0,31	0,38	0,46	0,57	0,69	0,83	1	1,2	1,4	1,7	2,3	3,2	3,7	4,3	5,6	6,4	7,3	9,5	14	15	23
100	0,044	0,056	0,072	0,092	0,12	0,15	0,18	0,22	0,28	0,34	0,41	0,49	0,59	0,71	0,84	1	1,4	1,9	2,2	2,5	3,3	3,8	4,4	5,6	8,0	9,0	14

8 Composants optoélectroniques

8.1 Conditions de référence spécifiques

Les recommandations suivantes applicables aux températures de référence données du Tableau 25 au Tableau 29 sont fondées sur une température ambiante de composant de 40 °C et correspondent à la plupart des applications de composants dans des équipements.

Il convient d'indiquer l'autoéchauffement de référence, $\Delta T_{\mathrm{ref}} = P_{\mathrm{ref}} \times R_{\mathrm{th,\,amb}}$ lorsque des températures de référence autres que celles indiquées dans les tableaux sont utilisées.

Lorsqu'un taux de défaillance est spécifié pour une température ambiante de 40 °C, il convient également d'indiquer la puissance dissipée de référence, P_{ref}, et la résistance thermique, $R_{\mathrm{th,amb}}$, vers l'environnement pour lequel cette valeur s'applique.

Pour les composants optoélectroniques, deux résistances thermiques sont généralement prises en considération: l'une étant située entre la jonction et le boîtier, l'autre entre le boîtier et le milieu environnant. Il convient que la résistance thermique, $R_{\mathrm{th,amb}}$, mentionnée ci-dessus, soit la résistance la plus significative dans l'application à l'étude.

Tableau 25 – Récepteurs de signaux optoélectroniques à semiconducteurs

Composant	Température de jonction de référence θ_{ref} °C	Rapport de tension de référence
Phototransistor plastique et à boîtier hermétique	45	$U_{\mathrm{ref}}/U_{\mathrm{rat}} = 0{,}5$
Photodiode (Si et Si PIN, InP, Inp APD, Ge, Ge APD)	45	---
Photoélément	45	
Module détecteur	40	
Composant solaire	40	

Tableau 26 – LED (diodes électroluminescentes), IRED (diodes infrarouges), diodes laser et composants d’émetteurs

Composant	**Température de jonction de référence** θ_{ref} °C	**Rapport de courant de référence**
LED (diode électroluminescente) en lumière visible (radiale et SMT, dispositifs de puissance de grande taille (> 100 mA courant continu))	45	$I_{\text{ref}} / I_{\text{rat}} = 0{,}5$
IRED (infrarouge) LED ((Al)GaAs, InP)	75	
Diode laser (GaAs 880 nm, InP 1 300 nm, InP 1 500 nm)	75	---
Réseau de diodes laser, laser à pompe / laser à pompe refroidi (GaAS 980 nm, InP 1 480 nm)	45	
Modules émetteurs à laser	consulter le fabricant	
Affichages (LED)	55	
Affichages (à cristaux liquides, électroluminescents)	consulter le fabricant	
Amplificateur optique à semiconducteur (SOA)	45	
Fibre (EDFA)	consulter le fabricant	
Modulateurs (InP, LiNbO$_3$)	40	

Tableau 27 – Optocoupleurs et barrières photoélectriques

Composant		**Température de jonction de référence** θ_{ref} °C	**Note**
Optocoupleur	avec sortie bipolaire	55	---
	avec sortie FET	65	
	avec électronique ultérieure	55	
	avec électronique de puissance ultérieure	65	
Barrière photoélectrique	avec sortie de diode / transistor	55	
	avec électronique ultérieure	55	

Tableau 28 – Composants optiques passifs

Composant	**Température de jonction de référence** θ_{ref} °C	**Note**
Connecteur à guide d'ondes optique (ordre n)	40	---
Fibre amorce (un pilote et un connecteur)	40	
Fibre	40	Aucune influence de la température à prendre en compte
Fibre de compensation de dispersion (DCF)	40	
Isolateurs	40	
Circulateurs	40	
Multiplexeur optique, démultiplexeur optique (couche mince, réseau sélectif planaire (AWG))	40	
Affaiblisseurs optiques (valeur fixe, électromécanique)	40	

Composant	Température de jonction de référence θ_{ref} °C	Note
Commutateur (électromagnétique, MEM)	40	
Coupleur, séparateur, filtre (couche mince, Bragg)	40	

Tableau 29 – Émetteur-récepteur, transpondeur et sous-équipement optique

Composant		Température de jonction de référence θ_{ref} °C	Note
Émetteur-récepteur, Transpondeur	SFF, SFP	40	---
	Xpondeur / longue distance, accordable	Consulter le fabricant	
Analyseur de spectre optique (OPA, complexe / OSA, complexe)			
Compensateur à dispersion active			
Commutateur sélectif de longueur d'onde			
Dispositif de blocage de longueur d'onde			
Courant de fuite à la terre (GTC) (électromécanique)		40	Aucune influence de la température à prendre en compte

8.2 Modèles de contraintes spécifiques

8.2.1 Généralités

Les modèles de contraintes spécifiques sont fournis pour convertir les taux de défaillance entre différentes conditions. Ces modèles de contraintes comportent des constantes. Celles-ci sont des valeurs moyennes pour chaque type de composant provenant de différents fabricants (ces valeurs sont déterminées lors de l'exploitation et au cours d'essais en laboratoire).

Le taux de défaillance dans les conditions de fonctionnement est donné par l’expression suivante, d'après l'Équation (2):

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}}$ pour les phototransistors (17)

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}}$ pour les autres récepteurs de signaux optiques à semiconducteurs, optocoupleurs et barrières photoélectriques,
connecteurs à guide d'ondes optique, fibres amorces, émetteurs-récepteurs, transpondeurs (18)

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{I}} \times \pi_{\text{T}}$ pour les diodes électroluminescentes (LED) et diodes infrarouges (IRED) (19)

$\lambda = \lambda_{\text{ref}}$ pour les autres composants optiques (20)

Les facteurs de contrainte pour l'influence de la tension, du courant et de la température sont donnés de 8.2.2 à 8.2.4.

8.2.2 Influence de la tension, facteur π_U

L'influence de la tension est prise en compte uniquement pour les phototransistors, selon l'Équation (3). Les constantes C_2 et C_3 données dans le Tableau 30 sont utilisées, à moins que d'autres valeurs ne soient indiquées. Les résultats sont présentés dans le Tableau 31.

Tableau 30 – Constantes pour l'influence de la tension sur les phototransistors

$\frac{U_{ref}}{U_{rat}}$	C_2	C_3
0,5	8,0	1,4

Tableau 31 – Facteur π_U pour les phototransistors

$\frac{U_{op}}{U_{rat}}$	**≤ 0,6**	**0,65**	**0,7**	**0,75**	**0,8**	**0,85**	**0,9**	**0,95**	**1**
Facteur π_U	1	1,04	1,08	1,14	1,26	1,46	1,82	2,52	4

8.2.3 Influence du courant, facteur π_I

L'influence du courant est prise en compte uniquement pour les diodes électroluminescentes (LED) et infrarouges (IRED), selon l'Équation (4). Les constantes C_4 et C_5 données dans le Tableau 32 sont utilisées, à moins que d'autres valeurs ne soient indiquées. Les résultats sont présentés dans le Tableau 33.

Tableau 32 – Constantes pour l'influence du courant sur les LED et IRED

$\frac{I_{ref}}{I_{rat}}$	C_4	C_5
0,5	1,4	8,0

Tableau 33 – Facteur π_I pour les LED et les IRED

$\frac{I_{op}}{I_{rat}}$	**≤ 0,6**	**0,65**	**0,7**	**0,75**	**0,8**	**0,85**	**0,9**	**0,95**	**1**
Facteur π_I	1	1,04	1,08	1,14	1,26	1,46	1,82	2,52	4

8.2.4 Influence de la température, facteur π_T

La relation donnée par l'Équation (5) ne s'applique qu'à des températures inférieures ou égales à la température de jonction maximale admissible. Les valeurs de la constante Ea_1 données dans le Tableau 34 sont utilisées, à moins que d'autres valeurs ne soient indiquées. Les résultats sont présentés dans le Tableau 35.

Tableau 34 – Constantes pour l'influence de la température sur les composants optoélectroniques

Composant		Ea_1 (eV)
Récepteur de signaux optiques à semiconducteurs	Si	0,3
	InP	0,7
	Ge	0,6
Diodes électroluminescentes (LED)		0,65
Diodes infrarouges (IRED)	(Al)GaAs	0,65
	InP	1,0
Laser semiconducteur	GaAs	0,6
	InP	0,8
Optocoupleur et barrières photoélectriques		0,5
Connecteur à guide d'ondes optique; fibre amorce		0,3
Émetteur-récepteur, transpondeur		0,4

Le facteur π_T est obtenu à partir du Tableau 35 en fonction:

– de la température réelle de jonction;

$$\theta_{op} = \theta_{amb} + P_{op} \times R_{th,amb} \quad \text{en degrés Celsius,} \tag{21}$$

– et de la température de jonction dans les conditions de référence (voir 8.1);

$$\theta_{ref} = 40 + \Delta T_{ref} \quad \text{en degrés Celsius,} \tag{22}$$

où ΔT_{ref} est mesuré ou calculé sous la forme $\Delta T_{ref} = P_{ref} \times R_{th,amb}$.

Tableau 35 – Facteur π_T pour les composants optiques

Récepteur de signaux optiques à semiconducteurs

	θ_{ref} °C	Facteur π_T pour θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Si	40	0,57	0,69	0,83	1	1,2	1,4	1,7	2	2,3	2,6	3,1	3,5	4	4,6	5,3	6
	45	0,48	0,58	0,7	0,84	1	1,2	1,4	1,6	1,9	2,2	2,6	3	3,4	3,9	4,4	5
InP	40	0,27	0,42	0,66	1	1,5	2,2	3,3	4,8	6,8	9,7	14	19	26	36	48	65
	45	0,18	0,28	0,44	0,66	1	1,5	2,2	3,2	4,5	6,4	9	13	17	24	32	43
Ge	40	0,33	0,48	0,7	1	1,4	2	2,8	3,8	5,2	7	9,4	12	16	21	28	36
	45	0,23	0,34	0,49	0,7	1	1,4	1,9	2,7	3,7	4,9	6,6	8,8	12	15	20	25

LED (lumière visible et IRED)

	θ_{ref} °C	Facteur π_T pour θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
(Al)GaAs	45	0,20	0,31	0,46	0,68	1	1,4	2,1	2,9	4,1	5,6	7,7	11	14	19	25	33
	55	0,099	0,15	0,22	0,33	0,49	0,7	1	1,4	2	2,7	3,7	5,1	6,9	9,2	12	16
	75	0,026	0,04	0,06	0,088	0,13	0,19	0,27	0,38	0,53	0,73	1	1,4	1,8	2,4	3,2	4,3
InP	75	0,004	0,007	0,013	0,024	0,043	0,076	0,13	0,22	0,37	0,62	1	1,6	2,5	4	6,1	9,3

Laser semiconducteur

	θ_{ref} °C	Facteur π_T pour θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
GaAs	75	0,035	0,051	0,074	0,11	0,15	0,21	0,3	0,41	0,55	0,75	1	1,3	1,7	2,3	3	3,8
InP	75	0,035	0,051	0,074	0,11	0,15	0,21	0,3	0,41	0,55	0,75	1	1,3	1,7	2,3	3	3,8

Optocoupleur et barrière photoélectrique

	θ_{ref} °C	Facteur π_T pour θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
	55	0,17	0,23	0,32	0,43	0,57	0,76	1	1,3	1,7	2,2	2,8	3,5	4,4	5,5	6,8	8,5
	65	0,1	0,14	0,19	0,25	0,34	0,45	0,59	0,77	1	1,3	1,6	2,07	2,6	3,3	4,05	5,01

Connecteur à guide d'ondes optique; fibre amorce; modulateurs; commutateur sélectif de longueur d'onde; dispositif de blocage de longueur d'onde

	θ_{ref} °C	Facteur π_T pour θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
	40	0,57	0,69	0,83	1	1,2	1,4	1,7	2	2,3	2,6	3,1	3,5	4	4,6	5,3	6

Émetteur-récepteur, transpondeur

	θ_{ref} °C	Facteur π_T pour θ_{op} °C															
		≤ 25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
	40	0,47	0,61	0,79	1	1,3	1,6	2	2,4	3	3,7	4,4	5,4	6,5	7,7	9,2	11

9 Condensateurs

9.1 Conditions de référence spécifiques

Les recommandations applicables aux températures de référence données dans le Tableau 36 sont fondées sur une température ambiante de composant de 40 °C et correspondent à la plupart des applications de composants dans des équipements.

Tableau 36 – Condensateurs

Type de condensateur	**Température de référence des condensateurs** θ_{ref} °C	**Rapport de tension de référence**
Feuille métallique Polystyrol, polypropylène, polycarbonate, polyéthylène téréphtalate	40	50 % de la tension assignée à 40 °C $U_{\text{ref}} / U_{\text{rat}} = 0{,}5$
Film métallisé Polypropylène, polycarbonate, polyéthylène téréphtalate, acétate de cellulose		
Papier métallisé (film)		
Mica		
Verre		
Acétate de cellulose		
Céramique		
Condensateurs par dépôt pour circuits hybrides		
Électrolytique au tantale - électrolyte non solide - électrolyte solide		
Électrolytique à l'aluminium - électrolyte non solide - électrolyte polymère solide	40	80 % de la tension assignée à 40 °C $U_{\text{ref}} / U_{\text{rat}} = 0{,}8$
Variable	40	----

9.2 Modèle de contrainte spécifique

9.2.1 Généralités

Le taux de défaillance dans les conditions de fonctionnement est donné par l'expression suivante, d'après l'Équation (2):

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} \qquad (23)$$

NOTE Les composants électrolytiques à l'aluminium à électrolyte non solide sont des composants électrochimiques appartenant à un vaste domaine technologique. Par conséquent, les constantes et facteurs donnés ne sont que des estimations des valeurs. Des valeurs plus spécifiques peuvent être fournies dans les spécifications de composants correspondantes ou peuvent être convenues entre l'utilisateur et le fabricant.

Les facteurs de contrainte traduisant l'influence de la tension et de la température sont donnés en 9.2.2 et 9.2.3.

9.2.2 Influence de la tension, facteur π_U

L'influence de la tension est prise en compte uniquement pour les condensateurs fixes, selon l'Équation (3).

Pour les condensateurs variables, $\pi_\mathrm{U} = 1$.

Les constantes C_2 et C_3 données dans le Tableau 37 sont utilisées, à moins que d'autres valeurs ne soient indiquées. Les résultats sont présentés dans le Tableau 38.

Tableau 37 – Constantes pour l'influence de la tension sur les condensateurs

Type de condensateur	$\frac{U_\mathrm{ref}}{U_\mathrm{rat}}$	C_2	C_3
Papier, papier métallisé Film de polypropylène métallisé Film de polytéréphtalate d'éthylène métallisé Film d'acétate de cellulose métallisé	0,5	1,07	3,45
Film de polycarbonate à armatures à feuilles métalliques Film de polycarbonate métallisé	0,5	1,50	4,56
Film de polystyrène Film de polytéréphtalate d'éthylène à armatures à feuilles métalliques Film de polypropylène à armatures à feuilles métalliques	0,5	1,29	4,0
Verre	0,5	1,11	4,33
Mica	0,5	1,12	2,98
Céramique	0,5	1,0	4,0
Condensateurs par dépôt pour circuits hybrides	0,5	1,0	4,0
Électrolytique à l'aluminium, électrolyte non solide	0,8	1,0	1,36
Électrolytique à l'aluminium, électrolyte solide	0,8	1,9	3,0
Électrolytique au tantale, électrolyte non solide	0,5	1,0	1,05
Électrolytique au tantale, électrolyte solide	0,5	1,04	9,8

Tableau 38 – Facteur π_U pour les condensateurs

Type de condensateur	**Facteur π_U pour U_{op}/U_{rat}**									
	0,1	**0,2**	**0,3**	**0,4**	**0,5**	**0,6**	**0,7**	**0,8**	**0,9**	**1**
Papier, papier métallisé Film de polypropylène métallisé Film de polytéréphtalate d'éthylène métallisé Film d'acétate de cellulose métallisé	0,26	0,36	0,50	0,71	1,0	1,40	2,0	2,9	4,2	6,1
Film de polycarbonate à armatures à feuilles métalliques Film de polycarbonate métallisé	0,23	0,30	0,42	0,63	1,0	1,7	2,9	5,2	9,8	19
Film de polystyrène Film de polytéréphtalate d'éthylène à armatures à feuilles métalliques Film de polypropylène à armatures à feuilles métalliques	0,24	0,32	0,45	0,66	1,0	1,5	2,4	3,9	6,4	11
Verre	0,19	0,28	0,42	0,64	1,0	1,6	2,5	4,0	6,3	10
Mica	0,32	0,42	0,55	0,74	1,0	1,4	1,9	2,6	3,6	5
Céramique	0,20	0,30	0,45	0,67	1,0	1,5	2,2	3,3	5,0	7,4
Condensateurs par dépôt pour circuits hybrides	0,20	0,30	0,45	0,67	1,0	1,5	2,2	3,3	5,0	7,4
Électrolytique à l'aluminium, électrolyte non solide	0,39	0,44	0,51	0,58	0,67	0,76	0,87	1,0	1,2	1,3
Électrolytique à l'aluminium, électrolyte solide	0,15	0,16	0,19	0,24	0,31	0,44	0,64	1,0	1,6	2,8
Électrolytique au tantale, électrolyte non solide	0,66	0,73	0,81	0,90	1,0	1,1	1,2	1,4	1,5	1,7
Électrolytique au tantale, électrolyte solide	0,021	0,054	0,14	0,37	1,0	2,7	7,4	20	56	154

9.2.3 Influence de la température, facteur π_T

La relation donnée par l'Équation (6) ne s'applique qu'à des températures inférieures ou égales à la température de composant maximale admissible. Les constantes A, Ea_1 et Ea_2 données dans le Tableau 39 sont utilisées, à moins que d'autres valeurs ne soient indiquées. Les résultats sont présentés dans le Tableau 40.

Tableau 39 – Constantes pour l'influence de la température sur les condensateurs

Type de condensateur	A	Ea_1 eV	Ea_2 eV
Papier Papier métallisé Film de polypropylène métallisé Film de polytéréphtalate d'éthylène métallisé Film d'acétate de cellulose métallisé Film de polytéréphtalate d'éthylène à armatures à feuilles métalliques Film de polypropylène à armatures à feuilles métalliques Film de polystyrène à armatures à feuilles métalliques Film de papier métallisé	0,999	0,5	1,59
Film de polycarbonate à armatures à feuilles métalliques, Film de polycarbonate métallisé	0,998	0,57	1,63
Verre, mica	0,86	0,27	0,84
Céramique	1,0	0,35	–
Condensateurs par dépôt pour circuits hybrides	1,0	0,15	–
Électrolytique à l'aluminium, électrolyte non solide	0,87	0,5	0,95
Électrolytique à l'aluminium, électrolyte solide	0,40	0,14	0
Électrolytique au tantale, électrolyte non solide	0,35	0,54	0
Électrolytique au tantale, électrolyte solide	0,961	0,27	1,1
Variable	1,0	0,15	–

Le facteur π_T est obtenu à partir du Tableau 40 en fonction:

– de la température réelle du condensateur;

$$\theta_{op} = \theta_{amb} + \Delta T \quad \text{en degrés Celsius,} \tag{24}$$

où ΔT est la variation de température due aux conditions de fonctionnement;

– et de la température du condensateur dans les conditions de référence (voir Tableau 36);

$$\theta_{ref} = 40\,°C \tag{25}$$

Tableau 40 – Facteur π_T pour les condensateurs

Type de condensateur	Température du condensateur dans les conditions de référence θ_{ref} °C	Facteur π_T pour θ_{op} °C[a]													
		≤ 20	30	40	50	60	70	80	85	90	100	105	110	120	125
Papier, Papier métallisé, Film de polypropylène métallisé, Film de polytéréphtalate d'éthylène métallisé, Film d'acétate de cellulose métallisé, Film de polytéréphtalate d'éthylène à armatures à feuilles métalliques, Film de polypropylène à armatures à feuilles métalliques, Film de polystyrène à armatures à feuilles métalliques, Film de papier métallisé	40	0,28	0,54	1,0	1,8	3,1	5,2	9	12	16	33	49	77	210	350
Film de polycarbonate à armatures à feuilles métalliques, Film de polycarbonate métallisé	40	0,24	0,50	1,0	1,9	3,6	6,7	13	18	27	63	100	170	510	900
Verre, mica	40	0,45	0,67	1,0	1,5	2,5	4,2	7,5	10	-	-	-	-	-	-
Céramique	40	0,41	0,65	1,0	1,5	2,2	3,1	4,4	5,1	6	8,1	9,3	11	14	16
Électrolytique à l'aluminium, électrolyte non solide	40	0,26	0,51	1,0	1,9	3,7	7,2	14	20	28	55	77	110	210	290
Condensateurs par dépôt pour circuits hybrides	40	0,68	0,83	1,0	1,2	1,4	1,6	1,9	2	2,2	2,5	2,6	2,8	3,1	3,3
Électrolytique à l'aluminium, électrolyte solide	40	0,88	0,94	1,0	1,1	1,2	1,2	1,3	1,4	1,4	1,5	1,6	1,6	1,8	1,8
Électrolytique au tantale, électrolyte non solide	40	0,74	0,83	1,0	1,3	1,8	2,7	4	5	-	-	-	-	-	-
Électrolytique au tantale, électrolyte solide	40	0,49	0,7	1,0	1,45	2,2	3,7	7	10	15	32	49	73	170	250
Variable	40	0,68	0,83	1,0	1,2	1,4	1,6	1,9	2	2,2	2,5	2,6	2,8	3,1	3,3

[a] Les relations indiquées s'appliquent uniquement à des températures inférieures ou égales à la température assignée du condensateur.

10 Résistances et réseaux de résistances

10.1 Conditions de référence spécifiques

Les recommandations applicables aux températures de référence de l'élément de résistance données dans le Tableau 41 sont fondées sur une température ambiante de composant de 40 °C et correspondent à la plupart des applications de composants dans des équipements. Il convient d'indiquer l'autoéchauffement de référence, ΔT_{ref}, lorsque d'autres températures de référence sont utilisées.

Tableau 41 – Résistances et réseaux de résistances

Composant	Température de référence de l'élément de résistance θ_{ref} °C	Rapport de puissance de référence
Couche de carbone	55	50 % de la puissance assignée à 40 °C $P_{\text{ref}}/P_{\text{rat}} = 0{,}5$
Film métallique	55	
Résistances à couche mince pour circuits hybrides	55	
Résistances à couche épaisse pour circuits hybrides	55	
Réseaux (circuits de film) par élément de résistance	55	
Oxyde métallique	85	
Bobinage	85	
Variable	55	

10.2 Modèles de contraintes spécifiques

10.2.1 Généralités

Le taux de défaillance dans les conditions de fonctionnement est donné par l'expression suivante, d'après l'Équation (2):

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} \qquad (26)$$

Les facteurs de contrainte pour l'influence de la température sont donnés en 10.2.2.

10.2.2 Influence de la température, facteur π_{T}

La relation donnée par l'Équation (6) ne s'applique qu'à des températures inférieures ou égales à la température de l'élément de résistance maximale admissible. Les constantes A, Ea_1 et Ea_2 données dans le Tableau 42 sont utilisées, à moins que d'autres valeurs ne soient indiquées. Les résultats sont présentés dans le Tableau 43.

Tableau 42 – Constantes pour l'influence de la température sur les résistances

A	***Ea*₁** eV	***Ea*₂** eV
0,873	0,16	0,44

Le facteur π_{T} est obtenu à partir du Tableau 43 en fonction:

- de la température moyenne réelle de l'élément de résistance;

  $$\theta_{\text{op}} = \theta_{\text{amb}} + \Delta T \quad \text{en degrés Celsius,} \qquad (27)$$

  où, $\Delta T = P_{\text{op}} \times R_{\text{th,amb}} = (\theta_{\max} - 40) \times (P_{\text{op}}/P_{\text{rat}})$ est la variation de température, en degrés Celsius, due au fonctionnement (avec $\theta_{\max}$ comme température maximale de l'élément de résistance);

- et de la température moyenne de l'élément de résistance dans les conditions de référence (voir Tableau 41);

  $$\theta_{\text{ref}} = 40 + \Delta T_{\text{ref}} \qquad (28)$$

Tableau 43 – Facteur π_T pour les résistances

Composant	θ_{ref} °C (voir 10.1)	**Facteur π_T pour θ_{op}** °C											
		≤ 25	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**125**
Résistances	55	0,49	0,56	0,71	0,89	1,1	1,4	1,8	2,2	2,8	3,6	4,6	5,1
	85	0,25	0,28	0,35	0,45	0,56	0,71	0,89	1,1	1,4	1,8	2,3	2,6

11 Inductances, transformateurs et bobines

11.1 Conditions de référence

Les recommandations applicables aux températures de référence données dans le Tableau 44 sont fondées sur une température ambiante de composant de 40 °C et correspondent à la plupart des applications de composants dans des équipements. Il convient d'indiquer l'autoéchauffement de référence, ΔT_{ref} , lorsque d'autres températures de référence sont utilisées.

Tableau 44 – Inductances, transformateurs et bobines

Composant		**Température de référence moyenne de l'enroulement** θ_{ref} °C	**Rapport de puissance de référence**
Inductances pour applications CEM	≤ 3A > 3A	60 85	50 % de la puissance assignée à 40 °C $P_{ref}/P_{rat} = 0{,}5$
Inductances et transformateurs basse fréquence	≤ 25 kHz	55	
Inductances et transformateurs haute fréquence	> 25 kHz	55	
Transformateurs secteur et transformateurs pour alimentations à découpage		85	

11.2 Modèle de contrainte spécifique

11.2.1 Généralités

Le taux de défaillance dans les conditions de fonctionnement est donné par l'expression suivante, d'après l'Équation (2):

$$\lambda = \lambda_{ref} \times \pi_T \qquad (29)$$

Les facteurs de contrainte pour l'influence de la température sont donnés en 11.2.2.

11.2.2 Influence de la température, facteur π_T

La relation donnée par l'Équation (6) ne s'applique qu'à des températures inférieures ou égales à la température maximale admissible de l'enroulement. Les constantes A, Ea_1 et Ea_2 données dans le Tableau 45 sont utilisées, à moins que d'autres valeurs ne soient indiquées. Les résultats sont présentés dans le Tableau 46.

Tableau 45 – Constantes pour l'influence de la température sur les inductances, transformateurs et bobines

A	Ea_1 eV	Ea_2 eV
0,996	0,06	1,13

Le facteur π_T est obtenu à partir du Tableau 46 en fonction:

– de la température moyenne réelle de l'enroulement;

$\theta_{op} = \theta_{amb} + \Delta T$ en degrés Celsius (30)

où ΔT est la variation de température due aux conditions de fonctionnement;

– et de la température moyenne de l'enroulement dans les conditions de référence (voir Tableau 44);

$\theta_{ref} = 40 + \Delta T_{ref}$ en degrés Celsius (31)

où ΔT_{ref} est mesuré ou calculé à $0{,}5 \times P_{rat}$.

Tableau 46 – Facteur π_T pour les inductances, transformateurs et bobines

Composant	θ_{ref} °C (voir 11.1)		**Facteur π_T pour θ_{op}** °C											
		≤ 25	**30**	**40**	**50**	**60**	**70**	**80**	**85**	**90**	**100**	**110**	**120**	**125**
Inductances, transformateurs, bobines	55	0,79	0,82	0,89	0,96	1,1	1,2	1,5	1,9	2,3	4,3	8,8	19	29
	60	0,75	0,78	0,84	0,91	1	1,1	1,5	1,8	2,2	4	8,4	18	27
	85	0,43	0,44	0,48	0,52	0,57	0,66	0,83	1	1,3	2,3	4,8	10	15

12 Dispositifs pour hyperfréquences

12.1 Conditions de référence spécifiques

Les conditions de référence sont indiquées dans le Tableau 47.

Tableau 47 – Dispositifs pour hyperfréquences

Composant	**Température de référence du composant** θ_{ref} °C	**Note**
Éléments pour hyperfréquences	40	Aucune incidence de la température et des contraintes électriques sur les taux de défaillance.
Guides coaxiaux et guides d'ondes		
Charge		
Affaiblisseur fixe		
Affaiblisseur variable		
Éléments fixes		
Coupleurs directifs		
Embases fixes		
Cavités		
Éléments variables		
Embases accordées	40	
Cavités accordées		
Dispositif avec ferrites (émetteur)		
Dispositif avec ferrites (récepteur)		
Composants passifs à fréquences radioélectriques/pour hyperfréquences		
Filtre		
Isolateur		
Circulateur		
Séparateur/combinateur		
Synthétiseur		

12.2 Modèles de contraintes spécifiques

L'application réelle des contraintes de température et électriques n'a produit jusqu'à présent aucun modèle.

13 Autres composants passifs

13.1 Conditions de référence spécifiques

Les conditions de référence sont indiquées dans le Tableau 48.

Tableau 48 – Autres composants passifs

Composant	Température de référence du composant θ_{ref} °C	Note
Varistances	40	Aucune incidence de la température et des contraintes électriques sur les taux de défaillance.
Thermistances à coefficient de température positif (CTP), thermistances à coefficient de température négatif (CTN)		
Parafoudres		
Résonateurs céramiques		
Filtres		
Filtres d'ondes de surface (SAW), oscillateurs d'ondes de surface (oscillateurs SAW), oscillateurs commandés en tension (OCT)		
Composants piézoélectriques (transducteurs et capteurs)		
Quartz		
Oscillateurs à quartz: XO (horloge), VCXO (commandé par une tension), PCT (compensé en température), OCXO (à enceinte à température régulée)		
Condensateurs de traversée, filtres de traversée		
Fusibles		

13.2 Modèles de contraintes spécifiques

L'application réelle des contraintes de température et électriques n'a produit jusqu’à présent aucun modèle.

14 Connexions électriques

14.1 Conditions de référence spécifiques

Les conditions de référence sont indiquées dans le Tableau 49.

Tableau 49 – Connexions électriques

Composant	Section de conducteur mm^2	θ_{ref} °C	Rapport de courant de référence
Brasure (manuelle, mécanique)	-	40	50 % du courant assigné pour le conducteur connecté $I_{\text{ref}} / I_{\text{rat}} = 0{,}5$
Soudure de fils pour circuits hybrides (Al, Au)	-		
Connexion enroulée	0,05 à 0,5		
Sertissure (manuelle, mécanique)	0,05 à 300		
Fusion par point	0,1 à 0,5		
Compression	0,3 à 2		
Dénudage	0,05 à 1		
Vis	0,5 à 16		
Pince (force élastique)	0,5 à 16		

14.2 Modèles de contraintes spécifiques

L'application réelle des contraintes de température et électriques n'a produit jusqu’à présent aucun modèle.