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

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National foreword

This British Standard is the UK implementation of EN 61709:2011. It is identical to IEC 61709:2011. It supersedes BS EN 61709:2000 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee DS/1, Dependability and value management.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Electric components - Reliability - Reference conditions for failure rates and stress models for conversion
(IEC 61709:2011)

Composants électriques -
Fiabilité -
Conditions de référence pour les taux de défaillance et modèles de contraintes pour la conversion
(CEI 61709:2011)

Elektrische Bauelemente -
Zuverlässigkeit -
Referenzbedingungen für Ausfallraten und Beanspruchungsmodelle zur Umrechnung
(IEC 61709:2011)

This European Standard was approved by CENELEC on 2011-07-29. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CENELEC
European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

The text of document 56/1422/FDIS, future edition 2 of IEC 61709, prepared by IEC TC 56, Dependability, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61709 on 2011-07-29.

This European Standard supersedes EN 61709:1998.

EN 61709:2011 includes the following significant technical changes with respect to EN 61709:1998:

– the addition of a number of component types and the updating of models for a large number of component types;

– the addition of annexes on reliability prediction, sources of failure rate data and component classification information.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2012-04-29
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2014-07-29

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61709:2011 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60300-3-2:2004	NOTE	Harmonized as EN 60300-3-2:2005 (not modified).
IEC 60721 series	NOTE	Harmonized in EN 60721 series.
IEC 61360 series	NOTE	Harmonized in EN 61360 series.
IEC 61360-1:2009	NOTE	Harmonized as EN 61360-1:2010 (not modified).
IEC 61360-4:2005	NOTE	Harmonized as EN 61360-4:2005 (not modified).
IEC 61649:2008	NOTE	Harmonized as EN 61649:2008 (not modified).
IEC 61703	NOTE	Harmonized as EN 61703.
IEC 62308	NOTE	Harmonized as EN 62308.
ISO 10303-11:1994	NOTE	Harmonized as EN ISO 10303-11:1995 (not modified).
ISO 10303-31	NOTE	Harmonized as EN ISO 10303-31.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application 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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-191	-	International Electrotechnical Vocabulary (IEV) - Chapter 191: Dependability and quality of service	-	-
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 weatherprotected locations	EN 60721-3-3	-
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	EN 60721-3-4	-
IEC 60721-3-5	-	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities - Section 5: Ground vehicle installations	EN 60721-3-5	-
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	EN 60721-3-7	-

CONTENTS

INTRODUCTION

This International Standard is intended for the reliability prediction of 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 standard 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 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.

This standard 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 standard also contains information on how to select the data that can be used in the presented models.

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

1 Scope

This International Standard gives guidance on how failure rate data can be employed for reliability prediction of electric components in equipment.

Reference conditions are numerical values of stresses that are typically 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 conditions. Failure rates stated at reference conditions allow 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 the failure rate data at these reference conditions to actual operating conditions when needed and this simplifies the prediction approach. Conversion of failure rate data is only permissible within the specified functional limits of the components.

This standard 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 International Standard then no additional information on the specified conditions is required.

This standard 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 standard assumes that the parts are being used within its useful life. The methods in this standard have a general application but are specifically applied to a selection of component types as defined in Clause 6 and Clause E.2.

2 Normative references

The following referenced documents are indispensable for the application 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 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 definitons

For the purpose of this document, the terms and definitions of IEC 60050-191, as well as the following terms and definitions apply.

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

[IEC 61360-1:2009, 2.18]

NOTE The term electric component includes the commonly used terms "electronic component", "electrical component" and "electro-mechanical component".

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 2 A failure of an item is an event that results in a fault in that item, which is a state.

3.1.3
failure mode
manner in which failure occurs

NOTE A failure mode may be defined by the function lost or the state transition that occurred.

3.1.4
instantaneous failure rate
failure rate

limit, if it exists, of the ratio of the conditional probability that the instant of a failure of a non-repairable item occurs within time interval (t, $t + \Delta t$) to Δt when Δt tends to zero, given that it has not failed 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 of 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 2 See IEC 61703.

NOTE 3 Other terms used for instantaneous failure rate are “hazard function”, “hazard rate” and “force of mortality” (abbreviation FOM).

NOTE 4 In this standard $\lambda(t)$ is assumed to be constant over time.

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

NOTE Stresses include electrical stress, temperature and environmental conditions

3.1.6
reference failure rate
failure rate stated under reference conditions given in this standard

NOTE 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 condition

[IEC 60050-151:2001, 151-16-02]

NOTE 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).

3.1.8
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.

3.1.9
component
constituent part of a device which cannot be physically divided into smaller parts without losing its particular function

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

3.1.10
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 Examples of equipment are a power transformer, the equipment of a substation, or measuring equipment.

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

3.1.11
useful life
time interval, from first use until user requirements are no longer met, due to economics or obsolescence

3.1.12
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 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.

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

3.1.13

virtual temperature

internal equivalent temperature (of a semiconductor device)

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

[IEC 60050-521: 2002, 521-05-14, modified]

3.1.14

virtual (equivalent) junction temperature

virtual temperature of the junction of a semiconductor device

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

NOTE The virtual temperature is not necessarily the highest temperature in the device.

3.2 Symbols

In this standard, the following symbols are used:

S	number of operating cycles per hour
E_a	activation energy of a failure process
I_op	operating current
I_rat	rated current
I_ref	reference current
P_op	operating power dissipation
P_rat	rated power dissipation
P_ref	reference power dissipation
$R(t_1,t_2)$	reliability between two times t_1 and t_2
R_th	thermal resistance
$R_\mathrm{th,amb}$	thermal resistance (to the environment)
S_ref	reference number of operating cycle per hour
T_amb	ambient temperature in Kelvin
T_0	reference ambient temperature in Kelvin
T_ref	reference temperature in Kelvin
U_op	operating voltage
U_rat	rated voltage
U_ref	reference voltage
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
ΔT	actual self-heating in degrees Celsius
ΔT_ref	reference self-heating 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;
θ_{op}	operating temperature in degrees Celsius
θ_0	reference ambient temperature in degrees Celsius
θ_{ref}	reference temperature in degrees Celsius
	– for capacitors the reference temperature of the capacitor;
	– for discrete semiconductors and optoelectronic components the reference junction temperature;
	– for inductors the reference temperature of the winding;
	– for ICs the reference virtual (equivalent) junction temperature;
	– for other electric components the reference temperature of the component;
	– for resistors the reference temperature of the resistor element.
λ_{f}	failure rate at full stress for an assembly:
λ_{p}	failure rate at part stress for an assembly;
λ_{i}	failure rate during time spent idle for an assembly;
$\lambda_{\mathrm{component}}$	failure rate of a component;
λ_{mode}	failure rate of a components failure mode;
λ_{S}	failure rate of a system;
λ	failure rate under operating conditions;
λ_{ref}	failure rate under reference conditions;
π_{I}	current dependence factor;
π_{ES}	electrical stress dependence factor;
π_{E}	environmental application factor;
π_{op}	stress factor for operating profile;
π_{S}	switching rate dependence factor;
π_{T}	temperature dependence factor;
π_{U}	voltage dependence factor.

4 Context and conditions

4.1 Failure modes

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 that 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:

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

where $(\lambda_{\text{mode}})_i$ 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.

4.2 Operating profile considerations

One of the major factors affecting component reliability is operating profile. 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 profile is needed in order to fully understand how it affects the component reliability.

The operating 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).

4.3 Storage conditions

Components that are under storage conditions are not immune from failure. However the stress models for environmental application factors in this standard 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.

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

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. 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 (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 the IEC 60721 series for a detailed quantitative descriptions of the environmental parameters for each environment).

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

Therefore, 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 standard and, for simplicity, it has 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.

Table 2 – Values of environmental parameters for basic environments

Basic environment	**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	≤ 0,5 °C/min	> 0,5 °C/min	> 0,5 °C/min

Basic environment	**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**
Stationary vibration, sinusoidal	2-9 Hz $<$1,5 mm 9-200 Hz $\le$ 5 m/s^2	2-9 Hz $\le$3 mm 9-200 Hz $\le$ 10 m/s^2	2-9 Hz $>$3 mm 9-200 Hz $\ge$ 10 m/s^2 200-500 Hz $\ge$15 m/s^2
Non-stationary vibration including shock	$\le$ 70 m/s^2	$\le$ 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 + 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 standard is written to contain only the three environments for the sake of simplicity. However 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.

5 Generic reference conditions and stress models

5.1 Recommended generic reference conditions

Generic reference conditions are those that apply to all component types. 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 recommendations in Table 3 should 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.

The values chosen represent the majority of component operating conditions. Any organization should choose conditions closer to their actual experience if they differ from that given in Table 3.

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 standard[c]

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

[b] For the purpose of this standard, the ambient temperature 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 standard.

5.2 Generic stress models

5.2.1 General

Components may not always operate under the reference conditions. In such cases, operational 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 Clause 6 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. The 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:

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

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.

NOTE When dealing with absolute values of voltage, as might be necessary for some component types, then the equation 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.

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. 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 ($E_{\mathrm{a1},}$ E_{a2}) is considered sufficient to model adequately 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 reference temperature, T_{ref}.

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

with the auxiliary variables

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

where, in Equations (5) and (6):

A	is a constant;
$E_{\mathrm{a1}}, E_{\mathrm{a2}}$	are activation energies in eV;
k_0	$= 8{,}616 \times 10^{-5}$ eV/K;
T_0	= 313 K;
T_{ref}	$= (\theta_{\mathrm{ref}} + 273)$ in K;
T_{op}	$= (\theta_{\mathrm{op}} + 273)$ 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} : reference capacitor temperature;

  θ_{op} : 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} : reference ambient temperature;

θ_{op} : actual ambient temperature.

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 environmental condition to another. The concept seems logical, but it bears some risk. For that reason, this standard 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 influence on the environmental application conditions will exist if the component is protected within the equipment. Whether an environmental application influence occurs depends therefore essentially on the equipment manufacturer. It is the duty of an organization to design for a specific environment. 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 solution is not to use this component in that environment.

The environmental application factor, π_{E}, should 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.

5.2.5.2 Dependence on switching rate π_{S}

This π-factor considers the number of operating cycles per hour, S, and only applies for relays.

a) $\pi_{\mathrm{S}} = 1$ for $0{,}01 < S < S_{\mathrm{ref}}$ (7)

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.

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

where

S is the number of operating cycles per hour;

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

5.2.5.3 Dependence on electrical stress π_{ES}

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

5.2.6 Other factors of influence

Other stress factors are given for individual types of components in Clause 6 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.

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

6.1 Integrated semiconductor circuits

6.1.1 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 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 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 k	70	
	No. of transistors > 50 k	90	
CMOS	No. of transistors ≤ 5 k	50	
	No. of transistors >5 k – 50 k	60	
	No. of transistors >50 k – 500 k	80	
	No. of transistors >500 k	90	
BICMOS		75	

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

Component		θ_{ref} °C	Note
Bipolar	TTL, -LS, -A(L)S, -F Logic	45	–
	Bus interface	55	
	TTL S Logic + bus interface	80	
	ECL 10 k 100 k 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 integrated circuits (IC)

Component		θ_{ref} °C	Note
Operational amplifiers, comparators and voltage monitors	Bipolar, BIFET CMOS	55 45	$U_{ref}/U_{rat} = 0{,}7$
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 k No. of transistors >50k – 50 M No. of transistors >50 M	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 k No. of transistors >5 k	70 80 80	

6.1.2 Stress factors

6.1.2.1 Models

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

$$\lambda = \lambda_{ref} \times \pi_U \times \pi_T \quad \text{for digital CMOS and bipolar analog ICs} \qquad (9)$$

$$\lambda = \lambda_{ref} \times \pi_T \quad \text{for all other ICs} \qquad (10)$$

The stress factors for voltage and temperature dependence are specified in 6.1.2.2 and 6.1.2.3, respectively.

6.1.2.2 Voltage dependence, factor π_U

The voltage dependence is only taken into account for digital CMOS and bipolar analog ICs, according to Equation (9). 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_{ref}/U_{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_{op}/U_{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

6.1.2.3 Temperature dependence, factor π_T

The relationship given in Equation (5) applies only up to the rated junction temperature. The constants A, E_{a1} and E_{a2} 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	E_{a1} eV	E_{a2} eV
ICs (except EPROM, OTPROM, EEPROM, EAROM)	0,9	0,3	0,7
EPROM, OPTROM, 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;

$$\theta_{op} = \theta_{amb} + P \times R_{th,amb} \quad \text{in degrees Celsius,} \tag{11}$$

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

$$\theta_{ref} = 40 + \Delta T_{ref} \quad \text{in degrees Celsius,} \tag{12}$$

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 5.6.1)	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

	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

6.2 Discrete semiconductors

6.2.1 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 be given when using other reference temperatures as 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 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
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
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_{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 ($\theta_{ref} = 40\ °C$).

[b] If used for stabilization, then the calculation shall 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	

6.2.2 Stress factors

6.2.2.1 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:

$$\lambda = \lambda_{ref} \times \pi_U \times \pi_T \quad \text{for transistors} \qquad (13)$$

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}}$ for diodes[1] and power semiconductors[2] (14)

The stress factors for voltage and temperature dependence are given in 6.2.2.3 and 6.2.2.4 respectively. Current may also be a significant factor.

6.2.2.3 Voltage dependence for transistors, factor π_{U}

The voltage dependence is only taken into account for transistors according to Equation (13). 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

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

Table 21 – Factor π_{U} for transistors

$U_{\text{op}}/U_{\text{rat}}$	≤ 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

6.2.2.4 Temperature dependence, factor π_{T}

The relationship given in Equation (5) applies only up to the maximum permissible junction temperature. The constants A, E_{a1} and E_{a2} 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	E_{a1} eV	E_{a2} 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

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

– and as a function of the junction temperature under reference conditions (see 6.2.1)

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

---

[1] General purpose diodes, Schottky diodes, voltage regulators and Zener diodes.

[2] Rectifier diodes, bridge diodes, thyristors, triacs and diacs.

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

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

θ_{ref} °C (see 6.2.1)	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	,0066	,0081	,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	,0035	,0054	,0044	,0066	,0080	,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	,0016	,0020	,0025	,0030	,0037	,0045	,0055	,0067	,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 6.2.1)	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

6.3 Optoelectronic components

6.3.1 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 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 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
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
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 1480 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 tunable	Consult manufacturer	
Optical spectrum analyser (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

6.3.2 Stress factors

6.3.2.1 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:

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{u}} \times \pi_{\text{T}}$ for phototransistors (17)

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}}$ for other optical semiconductor signal receivers, (18)
optocouplers and light barriers,
optical waveguide connectors, optical fibre pigtails,

transceivers, transponders

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{I}} \times \pi_{\text{T}}$ 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 6.3.2.3 to 6.3.2.5.

6.3.2.3 Voltage dependence, factor π_{U}

The voltage dependence is only taken into account for phototransistors according to Equation (17). 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

6.3.2.4 Current dependence, factor π_{I}

The current dependence is only taken into account for LEDs and IREDs, according to Equation (19). 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

6.3.2.5 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 E_{a1} 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		E_{a1} 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

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

– and as a function of the junction temperature under reference conditions (see 6.3.1);

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

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

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	,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

6.4 Capacitors

6.4.1 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**
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		
Tantalum electrolytic – non-solid electrolyte – solid electrolyte		
Aluminium electrolytic non-solid electrolyte solid electrolyte	40	80 % of rated voltage at 40 °C $U_{\text{ref}} / U_{\text{rat}} = 0{,}8$
Variable	40	–

6.4.2 Stress factors

6.4.2.1 Model

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

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} \text{ [3]} \qquad (23)$$

The stress factors for voltage and temperature dependence are given in 6.4.2.2 and 6.4.2.3.

6.4.2.2 Voltage dependence, factor π_{U}

The voltage dependence is only taken into account for fixed capacitors, according to Equation (23).

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[3] 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 be given in the relevant component specifications or may be agreed upon between user and manufacturer.

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
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
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

6.4.2.3 Temperature dependence, factor π_T

The relationship given in Equation (6) applies only up to the maximum permissible component temperature. The constants A, E_{a1} and E_{a2} 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	E_{a1} eV	E_{a2} 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	–
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. Table 40 as a function of the actual capacitor temperature

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

where ΔT is the temperature change due to operating conditions;

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

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

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
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.

6.5 Resistors and resistor networks

6.5.1 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 be given when using other reference temperatures.

Table 41 – Resistors and resistor networks

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

6.5.2 Stress factors

6.5.2.1 Model

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 6.5.2.2.

6.5.2.2 Temperature dependence, factor π_{T}

The relationship given in Equation (6) applies only up to the maximum permissible resistor element temperature. The constants A, E_{a1} and E_{a2} 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	E_{a1} eV	E_{a2} 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 $\Delta T = P \times R_{\text{th,amb}} = (\theta_{\max} - 40) \times (P/P_{\text{rat}})$, 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);

$$\theta_{\text{ref}} = 40 + \Delta T_{\text{ref}} \quad \text{in degrees Celsius} \tag{28}$$

Table 43 – Factor π_T for resistors

Component	θ_{ref} °C (see 6.5.1)	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

6.6 Inductors, transformers and coils

6.6.1 Reference conditions

The recommendations for reference temperatures given in the 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 be given when using other reference temperatures.

Table 44 – Inductors, transformers and coils

Component		**Average reference winding temperature** θ_{ref} °C	**Note**
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	

6.6.2 Stress factors

6.6.2.1 Model

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 6.6.2.2.

6.6.2.2 Temperature dependence, factor π_T

The relationship given in Equation (6) applies only up to the maximum permissible winding temperature. The constants A, E_{a1} and E_{a2} 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	E_{a1} eV	E_{a2} 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

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

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);

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

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 6.6.1)	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

6.7 Microwave devices

6.7.1 Reference conditions

The reference conditions are given in the 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		

Component	Reference component temperature θ_{ref} °C	Note
Circulator		
Splitter/combiner		
Synthesizer		

6.7.2 Stress factors

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

6.8 Other passive components

6.8.1 Reference conditions

The reference conditions are given in the 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		

6.8.2 Stress factors

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

6.9 Electrical connections

6.9.1 Reference conditions

The reference conditions are given in the Table 49.

Table 49 – Electrical connections

Component	Conductor cross-section mm^2	θ_{ref} °C	Note
Solder (manual, machine)	–	40	50 % of rated current for the connected conductor $I_{\text{ref}} / I_{\text{rat}} = 0{,}5$
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		

6.9.2 Stress factors

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

6.10 Connectors and sockets

6.10.1 Reference conditions

The reference conditions are given in the Table 50.

Table 50 – Connectors and sockets

Component	θ_{ref} °C	Note
Plug-in contacts that shall 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 h.		

6.10.2 Stress factors

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

6.11 Relays

6.11.1 Reference conditions

The reference conditions are given in the Table 51.

Table 51 – Relays

Component	Electrical contact stress	θ_{ref} °C	Note
Low duty relays:	($0{,}5 < U \leq U_{\text{rat}}$) Va.c. and ($0 < I \leq 0{,}1$) A by resistive load	40	Operating current within the limits stated in the data sheet. Electrical contact stress (see stress regions in Figure 1)
General purpose relays:	($0 < U \leq 13$) V and ($0{,}1 < I \leq I_{\text{rat}}$) A by resistive load and a.c.		
Automotive relays:	($0 < U \leq 13$) V and ($0{,}1 < I \leq I_{\text{rat}}$) A by resistive load		
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.		

6.11.2 Stress factors

6.11.2.1 Model

The failure rate under operating conditions is:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{ES}} \times \pi_{\text{S}} \times \pi_{\text{T}} \tag{32}$$

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 6.11.2.3 and 6.11.2.4.

6.11.2.2 Dependence on switching rate, factor π_{S}

This factor considers the number of operating cycles per hour, S. According to Equations (7) and (8):

$\pi_{\text{S}} = 1$ for $S \leq 1$

$\pi_{\text{S}} = S$ for $S > 1$

6.11.2.3 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 1 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 stress profile should be considered (otherwise the higher stress factor should be applied).

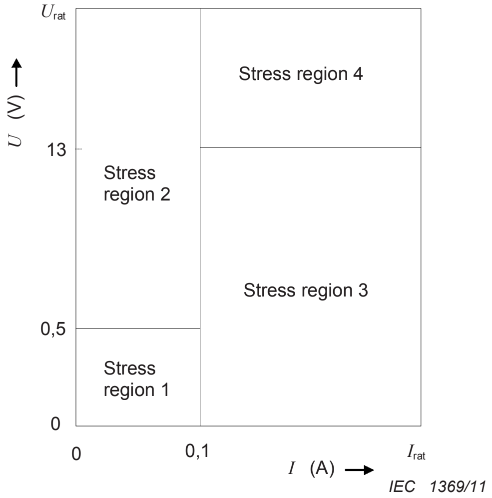

Figure 1 – Selection of stress regions in accordance with current and voltage-operating conditions

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

Stress region (see Figure 1)	**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 1)	**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	–	–
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 1)	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.

6.11.2.4 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, E_{a1} and E_{a2} given in Table 55 are used, unless other values have been stated.

Table 55 – Constants for temperature dependence of relays

Supporting construction	A	E_{a1} eV	E_{a2} 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 – Facteur 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.

6.12 Switches and push-buttons

6.12.1 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 6.12.2, Figure 2)
Switches and push-buttons for light-current applications:	$(0{,}5 < U \leq U_{\text{rat}})$ V a.c. and $(0{,}1 < I \leq I_{\text{rat}})$ A by resistive load		
Switches and push-buttons for higher load:	$(0{,}5 < U \leq 13)$ V and $(0{,}1 < I \leq I_{\text{rat}})$ 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.		

6.12.2 Stress factors

6.12.2.1 Model

The failure rate under operating conditions is:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{ES}} \tag{33}$$

where π_{ES} is the electrical stress dependence factor. The values of the stress factors are given in 6.12.2.2.

6.12.2.2 Dependence on electrical stress, 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 2 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.

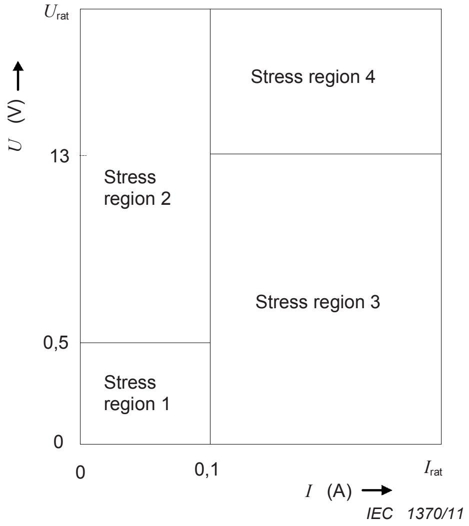

Figure 2 – Selection of stress regions in accordance with current and voltage-operating conditions

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

Stress region (see Figure 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 data sheet) not to be exceeded.

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

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
Without Au-coating	50	50	2	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.

6.13 Signal and pilot lamps

6.13.1 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.		

6.13.2 Stress factors

6.13.2.1 Model

The failure rate under operating conditions, as a function of the operating voltage, is calculated according to Equation (34) as follows:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \tag{34}$$

6.13.2.2 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 $U_{\text{op}}/U_{\text{rat}}$ =										
		≤ 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.												

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 and is a useful input into reliability analysis, such as diagnostics coverage, and in safety analysis in order to calculate criticality of systems.

This annex 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 Table D.1. 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.4.

Table A.1 – Failure modes – Integrated circuits (ICs)(digital)

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

Table A.2 – Failure modes – Transistors, diodes, optocouplers

Component		**Short-circuit** %	**Open circuit** %	**Drift** %
Transistors	Silicon	85	15	–
	GaAs	95	5	–
Diodes	Silicon	85	15	–
	GaAs	95	5	–
Optocouplers		10	50	40
Laser diodes		85	15	–

Table A.3 – Failure modes – Capacitors

Component			Short-circuit %	Open circuit %	Drift %
Ceramic	NPO-COG		70	10	20
	X7R-X5R		90	10	–
	5ZU-Y5V-Y4T		90	10	–
	Feedthrough capacitors		70	30	–
Aluminum 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			40	10	50
Other technologies			10	90	–

Table A.4 – Failure modes – Resistors, inductive devices, relays

Component		Open circuit %	Short-circuit %	Drift %
Resistors	Carbon film	100	–	–
	Metal film	40	–	60
	Wire-wound	100	–	-
	Variable	80	–	20
	Resistors network	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)

Failure rate prediction

B.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, etc.), and several reliability models are available depending on the problem (e.g. reliability block diagrams, fault tree analysis, state-space methods, etc.).

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, etc.).

The procedures in this standard can be used to carry out failure rate prediction at reference and operating conditions (parts count and parts stress method).

B.2 Failure rate prediction for assemblies

B.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 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 C (data base).

B.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. Although this is known to be realistic for some components for the majority it is not true, however the assumption greatly simplifies the task;
- 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.

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. Other models may need to be used to determine end-of-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.

B.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 profiles if necessary;
    - identify relevant environmental stresses;
    - select the data source according to the guidance given in Annex D;
    - 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.

B.2.4 Prediction models

B.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.

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

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

$$\lambda_{\mathrm{S}} = \sum_{i=1}^{n} \left(\lambda_{\mathrm{ref}}\right)_i \tag{B.1}$$

where

λ_{ref} is the 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.

B.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. 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:

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

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;
n is the number of components.

In Clause 6 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):

$$\lambda_{\text{op}} = \lambda \times \pi_{\text{op}} \tag{B.3}$$

with

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

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, $0 \leq W \leq 1$;

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, $0 \leq \rho \leq 1$; 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.

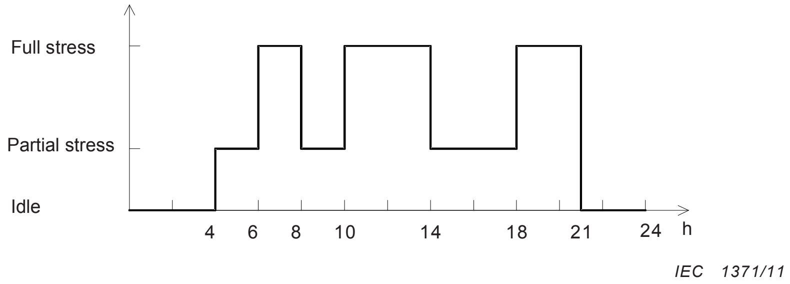

Figure B.1 – Stress profile

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.

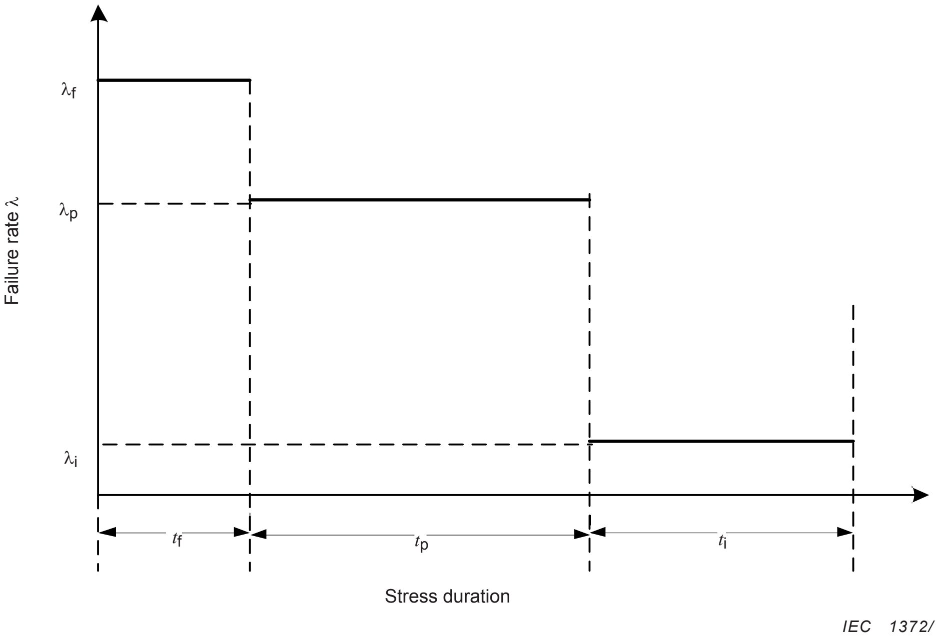

Figure B.2 – Averaging failure rates

B.2.6 Other methods of reliability prediction

B.2.6.1 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.

B.2.6.2 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.

B.2.6.3 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 Clause 6. 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 the manufacturer will 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 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.

B.2.6.4 Physics-of-failure

Physics-of-failure 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.

B.2.7 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 analyzed 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 standard, 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.

B.3 Component considerations

B.3.1 Component model

In this standard 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 and have their own clause and this means that failures in the attachment system should be treated as component failures when using this standard.

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 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.

B.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 E.

This standard recommends the use of the IEC 61360 series 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 standard only uses the component-related aspects of IEC 61360. The component coding elements of IEC 61360 are described in Annex E.

B.4 General consideration about failure rate

B.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 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 dimensions of failure rates is 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 failures per 10^6 h or in failures per 10^9 h. In the latter case the acronym FIT is often used.

B.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 Clause 8 of IEC 61649:2008). Its shape parameter, β, models three periods in the lifecycle, which can be simply explained as follows:

a) Early 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 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 standard does not support prediction of these component types and if early failures are still to be expected for a component, the beginning of the phase of constant failure rate should be specified.

This standard assumes constant failure rates hence it is assumed that any early 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 case this occurs because competing failure rate produce a averaging effect that make it appear as if the failure rate is constant when the underlying failure rates of the individual competing failure modes is not.

Generally electric components operate in the constant failure rate phase (from end of early-failure period to start of wear-out failure period) and are dealt with in this standard. 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.

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

This period shows an increasing rate of failures due to the dominating effects of wear-out, ageing or fatigue.

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).

This standard assumes that for these components the failure rate is averaged for the time interval specified in the data sheet. Since this standard 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).

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.

B.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 company 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 standard, 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.

B.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; and therefore, any data will be based on some explicit assumptions, some implicit assumptions, and some assumptions that are not addressed.

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 include:

- 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, 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 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 program will not prevent failures, a cursory routine inspection program may detect some potential failures, and a full preventive maintenance program may pick up potential failures as incipient failures rather than delaying until they occur.

Annex C
(informative)

Considerations for the design of a data base on failure rates

C.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.

The basic idea behind the information given in the following clauses is that there is a collection of dependability 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.

C.2 Data collection acquisition – Collection process

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

C.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 because 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:

- 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.

C.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.

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

C.5 Failure rate database attributes

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

Table C.1 – Reliability prediction database attributes

Categories of information	Detailed information	Purpose
Component identification	Manufacturer, Part number, Link to data sheet	To filter for component, product line and manufacturer
Component categorization	Component main category Technology Complexity Mechanical size Housing Thermal considerations Compliance issues – standards – certificates. Manufacturing specific information like hazardous substance issues, packaging, lot sizes, tests performed during manufacturing, etc.	To filter for similar items To filter for parts which fulfil certain regulative requirements. 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

Categories of information	Detailed information	Purpose
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 like upper, lower limit, probabilities, etc.	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 D
(informative)

Potential sources of failure rate data and methods of selection

D.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.

D.2 Data source selection

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

- user data;
- manufacturer 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 a data source cannot be found, a risk assessment should be performed to determine the necessity for obtaining further data, e.g. 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 case (as defined, for example, by DEF00-42-3).

D.3 User data

User data is that which has been produced by the company 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 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.

D.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 manufacturers 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.

D.5 Handbook reliability data

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, e.g. 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 D.1 provides information to the user concerning data sources for component failure rate determination. This list is not comprehensive, and is not intended to give a preference for sources. It remains up to the user to determine which data source is relevant for the application. Note that there are a number of handbooks and standards that describe reliability prediction, but only those that contain data are listed here.

Table D.1 – Sources of reliability data (in alphabetical order)

Data source	Short description	Location information
1. AT&T reliability manual	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	Available from most good book stores: Klinger, David J.,Yoshinao Nakada, and Maria A. Menendez, Editors, AT&T Reliability Manual, Van Nostrand Reinhold, 1990, ISBN:0442318480
2. Data collection for non electric reliability handbook. Volume 3, section 1, failure rate data (continued)	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	Available from National Technical information services. http://www.ntis.gov/search/product.aspx?ABBR=AD841108
3. Prediction of component failure rates for PSA on nuclear power plants 1982-1997	This document describes the revised component failure rate calculated by re-prediction on 49 Japanese light water reactors from 1982 to 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)
4. FIDES	FIDES is a new reliability data handbook (since January 2004) developed by a consortium of French industry under the supervision of the French DoD (DGA) . The FIDES methodology is based on physics of failures and is supported by the analysis of test data, field returns and existing modelling	Available on request at fides@innovation.net

Data source	Short description	Location information
5. Guidelines for Process Equipment Reliability Data - With Data Tables	This guideline was 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	Available from: Center for Chemical Process Safety/AIChE ISBN: 978-0-8169-0422-8 Electronic ISBN: 978-1-59124-568-1
6. HRD5: British Telecom Handbook of Reliability Data	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	The HRD5 method is available in a number of commercially available reliability software packages but the original handbook is no longer on sale
7. IEEE Gold book	The IEEE Gold book IEEE 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	Available from: IEEE Customer Service 445 Hoes Lane PO Box 1331 Piscataway, NJ 08855-1331, USA courrier électronique customer.service@ieee.org
8. IRPH:2003, Italtel Reliability Prediction Handbook	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	Available on request from: quality@italtel.it
9. MIL217Plus	Reliability Information Analysis Center (RIAC) replacement prediction methodology for MIL-HDBK-217, it supersedes PRISM	Available at: http://www.theriac.org/productsandservices/products/217plus/index.swn (checked 17/11/2008)
10. MIL-HDBK-217 MIL-HDBK-217F Reliability Prediction of Electronic Equipment	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	Available from the internet in a number of places, such as http://assist.daps.dla.mil/quicksearch (checked 17/11/2008) It is also incorporated within several commercially available reliability software packages

Data source	Short description	Location information
11. NPRD-95	NPRD-95 data provides failure rates for a wide variety of items, including mechanical and electromechanical 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	Available from: Reliability Analysis Center 201 Mill Street Rome, NY 13440-6916 USA
12. NSWC-94/L07 - Handbook of reliability prediction procedures for mechanical equipment.	This handbook, developed by the Naval Surface Warfare Center – Carderock Division provides failure rate models for fundamental classes of mechanical components	Available from: http://www.stormingmedia.co.uk
13. OREDA:2002	The 4th edition of the OREDA - Handbook was released in October 2002 containing OREDA® Phase IV (1993-96) and Phase V (1997-00) data. The handbooks contain reliability data on offshore equipment compiled in a form that can easily be used for various safety, reliability and maintenance analyses	Available from: Det Norske Veritas Veritasveien 1 N-1322 Høvik NORWAY Att.: ENENO753 http://www.dnv.com
14. PRISM (RAC / EPRD)	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	Available from: http://src.alionscience.com/prism
15. RDF:2003	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	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
16. IEC/TR 62380 – Reliability data handbook — Universal model for reliability prediction of electronics components, PCBs and equipment	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	Available from: IEC standards stockist
17. Reliability data for safety instrumented equipment PDS data handbook, 2006 Edition	Reliability data dossiers for field devices (sensors, valves) and control logic (electronics) are presented, including data for subsea equipment	Available from: Sydvest, Trondheim, Norway E-mail: post@sydvest.com http://www.sydvest.com
18. Reliability failure rate/mode handbook, section 3.1, integrated circuit failure rates	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	Available from: RIAC, 6000 Flanagan Road, Suite 3, Utica NY 13502-1348 Phone: 315.351.4200 Toll free: 877.363.RIAC (7422)

Data source	Short description	Location information
19. Safety equipment reliability handbook, 2nd edition	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	Available from: ISA http://www.isa.org
20. Siemens SN 29500	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 standard	The standard is available on request
22. TELCORDIA SR-332	The SR–332, Reliability prediction procedure for electronic equipment, documents the recommended methods for predicting device and unit hardware reliability	Available from: Telcordia Technologies, Inc. 8 Corporate Place, PYA 3A-184 Piscataway, NJ 08854-4156 USA The Telcordia SR–332 is incorporated within several commercially available reliability software packages
22. 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	Various sources

Annex E
(informative)

Overview of component classification

E.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. This annex 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 standard.

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

E.2 The IEC 61360 system

This standard 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 electro-technical equipment through a defined structure in order for the information to be exchanged in a computer-sensible form.

The particular IEC 61360 standard 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 electro-technical equipment. Table E.1 contains the classification tree for IEC 61360-4, cross-referenced against the relevant clause in this standard. In cases where no such data exists in this standard, the clause is noted as “N/A” (not available). Where this standard contains lower level detail in terms of component types than in IEC 61360-4, then the clause will have “+” noted beside it.

In Table E.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 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 E.1, the geometric data has been omitted.

Table E.1 – Classification tree (IEC 61360)

Component description	**IEC 61360-4 classification tree**					**Clause in this standard**
	L1	**L2**	**L3**	**L4**	**L5**	
ELECTRIC COMPONENTS						
Amplifier	AMP					6.1+
Amplifier, low frequency	AMP	LF				6.1
Amplifier, low frequency power	AMP	LF	PWA			6.1
Amplifier, low frequency voltage	AMP	LF	VTA			6.1
Amplifier, low frequency voltage differential	AMP	LF	VTA	DFA		6.1
Amplifier, low frequency voltage differential AC-coupled	AMP	LF	VTA	DFA	ACA	6.1
Amplifier, low frequency voltage differential DC-coupled	AMP	LF	VTA	DFA	OPA	6.1
Amplifier, low frequency voltage single sided	AMP	LF	VTA	SSA		6.1
Amplifier, radio frequency	AMP	RF				6.1
Amplifier, wide band	AMP	WB				6.1
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					6.4+
Capacitor, fixed	CAP	FIX				6.4
Capacitor, fixed air	CAP	FIX	AIR			6.4
Capacitor, fixed ceramic	CAP	FIX	CER			6.4
Capacitor, fixed ceramic, class 1	CAP	FIX	CER	CL1		6.4
Capacitor, fixed ceramic, class 2	CAP	FIX	CER	CL2		6.4
Capacitor, fixed, electrolytic	CAP	FIX	ELC			6.4
Capacitor, fixed electrolytic with solid tantalum electrolyte	CAP	FIX	ELC	STAN		6.4
Capacitor, fixed electrolytic with non-solid tantalum electrolyte	CAP	FIX	ELC	NTAN		6.4
Capacitor, fixed electrolytic with solid aluminium electrolyte	CAP	FIX	ELC	SAL		6.4

Component description	**IEC 61360-4 classification tree**					**Clause in this standard**
	L1	**L2**	**L3**	**L4**	**L5**	
Capacitor, fixed electrolytic with non-solid aluminium electrolyte	CAP	FIX	ELC	NAL		6.4
Capacitor, fixed, film	CAP	FIX	FLM			6.4
Capacitor, fixed, glass	CAP	FIX	GLS			6.4
Capacitor, fixed, mica	CAP	FIX	MIC			6.4
Capacitor, fixed, multilayer	CAP	FIX	MLAY			6.4
Capacitor, fixed, paper	CAP	FIX	PAP			6.4
Capacitor, variable	CAP	VAR				6.4
Conductor	CND					6.9+
Conductor, bare	CND	BAR				6.9
Conductor, insulated	CND	INS				6.9
Conductor, insulated, cable	CND	INS	CBL			6.9
Conductor, insulated, cable, power	CND	INS	CBL	POW		6.9
Conductor, insulated, cable, signal	CND	INS	CBL	SIG		6.9
Conductor, insulated, cable, signal, low frequency	CND	INS	CBL	SIG	LF	6.9
Conductor, insulated, cable signal, high frequency	CND	INS	CBL	SIG	HF	6.9
Conductor, insulated, insulated wire (single conductor)	CND	INS	IWR			6.9
Delay line	DEL					N/A
Diode device	DID					6.2+
Diode device, bridge rectifier	DID	BRI				6.2
Diode device, diode	DID	DIO				6.2
Diode device, diode, break over diode	DID	DIO	BOD			6.2
Diode device, diode, rectifier diode	DID	DIO	REC			6.2
Diode device, diode, signal diode	DID	DIO	SIG			6.2
Diode device, diode, stabilizer diode	DID	DIO	STB			6.2
Diode device, diode, stabilizer diode, current regulator	DID	DIO	STB	CUR		6.2
Diode device, diode, stabilizer diode, voltage reference	DID	DIO	STB	REF		6.2
Diode device, diode, stabilizer diode, voltage regulator	DID	DIO	STB	REG		6.2
Diode device, diode, stabilizer diode, stabistor	DID	DIO	STB	STA		6.2

Component description	**IEC 61360-4 classification tree**					**Clause in this standard**
	L1	**L2**	**L3**	**L4**	**L5**	
Diode device, diode, stabilizer diode, transient suppressor	DID	DIO	STB	SUP		6.2
Diode device, diode, variable	DID	DIO				6.2
Diode device, voltage multiplier	DID	VMP				6.2
Fibre optics	FIBOPTIC					6.3+
Fibre optics, links	FIBOPTIC	LINKS				6.3
Fibre optics, connectors	FIBOPTIC	CONN				6.3
Fibre optics, switched	FIBOPTIC	SWI				6.3
Fibre optics, branches	FIBOPTIC	BRA				6.3
Fibre optics, couplers/splitters	FIBOPTIC	COUP				6.3
Fibre optics, attenuators	FIBOPTIC	ATT				6.3
Fibre optics, detectors	FIBOPTIC	DET				6.3
Fibre optics, isolators	FIBOPTIC	ISOL				6.3
Fibre optics, networks	FIBOPTIC	NETW				6.3
Fibre optics, light sources	FIBOPTIC	SOURC				6.3
Fibre optics, modulators	FIBOPTIC	MOD				6.3
Fibre optics, transmitters/receivers	FIBOPTIC	TXRX				6.3
Fibre optics, waveguides	FIBOPTIC	WG				6.3
Fibre optics, cables	FIBOPTIC	CAB				6.3
Fibre optics, filters	FIBOPTIC	FIL				6.3
Fibre optics, lens	FIBOPTIC	LENS				6.3
Filter	FIL					6.7
IC	IC					6.1+
IC, analog/digital	IC	AD				6.1
IC, analog	IC	ANA				6.1
IC, digital	IC	DIG				6.1
IC, digital, combinational sequential interface (CSI)	IC	DIG	CSI			6.1
IC, digital, microcontroller	IC	DIG	MUC			6.1
IC, digital, microprocessor	IC	DIG	MUP			6.1
IC, digital, programmable logic device (PLD)	IC	DIG	PLD			6.1
IC, digital, storage	IC	DIG	STO			6.1
IC, digital, storage, CAM	IC	DIG	STO	CAM		6.1
IC, digital, storage, CCD	IC	DIG	STO	CCD		6.1
IC, digital, storage, RAM	IC	DIG	STO	RAM		6.1
IC, digital, storage, RAM, dynamic	IC	DIG	STO	RAM	DRAM	6.1

Component description	**IEC 61360-4 classification tree**					**Clause in this standard**
	L1	**L2**	**L3**	**L4**	**L5**	
IC, digital, storage, RAM, static	IC	DIG	STO	RAM	SRAM	6.1
IC, digital, storage, ROM	IC	DIG	STO	ROM		6.1
IC, digital, storage, register	IC	DIG	STO	REG		6.1
IC, periodic/DC	IC	PER				6.1
Inductor	IND					6.7+
Inductor, fixed	IND	FIX				6.7
Inductor, fixed, deflection units	IND	FIX	DFL			6.7
Inductor, fixed, choke	IND	FIX	CHOKE			6.7
Inductor, fixed, coil	IND	FIX	COIL			6.7
Inductor, fixed, linearity control unit	IND	FIX	LININUT			6.7
Inductor, fixed, antenna inductors	IND	FIX	ANT			6.7
Inductor, fixed, solenoids	IND	FiX	SOL			6.7
Inductor, variable	IND	VAR				6.7
Lamp	LAM					6.13
LCD	LCD					6.3
Microwave components	MIC					6.7
Optoelectronic device	OPT					6.3
Optoelectronic device, image pickup device	OPT	IMAGE				6.3
Optoelectronic device, photocoupler	OPT	PHC				6.3
Optoelectronic device, photoemmiter	OPT	PHE				6.3
Optoelectronic device, photoemmiter, infrared emitting diode	OPT	PHE	IRD			6.3
Optoelectronic device, photoemmiter, LASER	OPT	PHE	LAS			6.3
Optoelectronic device, photoemmiter, LED	OPT	PHE	LED			6.3
Optoelectronic device, photosensor	OPT	PHS				6.3
Optoelectronic device, photosensor, infrared	OPT	PHS	IR			6.3
Optoelectronic device, photosensor, ultraviolet	OPT	PHS	U			6.3
Optoelectronic device, photosensor, visible radiation	OPT	PHS	VIS			6.3
Oscillator	OSC					6.8
Piezoelectric device	PE					6.8
Printed wiring circuit	PWC					N/A
Resistor	RES					6.5
Resistor, fixed	RES	FIX				6.5

Component description	IEC 61360-4 classification tree					Clause in this standard
	L1	L2	L3	L4	L5	
Resistor, fixed,linear	RES	FIX	LIN			6.5
Resistor, fixed, linear, resistor network	RES	FIX	LIN	MUL		6.5
Resistor, fixed, linear, single	RES	FIX	LIN	SIN		6.5
Resistor, fixed, linear, single, chip	RES	FIX	LIN	SIN	CHIP	6.5
Resistor, fixed, linear, single, fusing	RES	FIX	LIN	SIN	FUS	6.5
Resistor, fixed, linear, single, low power	RES	FIX	LIN	SIN	LP	6.5
Resistor, fixed, linear, single, precision	RES	FIX	LIN	SIN	PREC	6.5
Resistor, fixed, linear, single, power	RES	FIX	LIN	SIN	PWR	6.5
Resistor, fixed, linear, single, PTC	RES	FIX	LIN	SIN	THERM	6.5
Resistor, fixed, non-linear	RES	FIX	NLN			6.5
Resistor, fixed, non-linear, light dependent	RES	FIX	NLN	LDR		6.5
Resistor, fixed, non-linear, thermistor	RES	FIX	NLN	TDR		6.5
Resistor, fixed, non-linear, thermistor, NTC	RES	FIX	NLN	TDR	NTC	6.5
Resistor, fixed, non-linear, thermistor, PTC	RES	FIX	NLN	TDR	PTC	6.5
Resistor, fixed, non-linear, varistor	RES	FIX	NLN	VDR		6.5
Resistor, variable	RES	VAR				6.5
Resistor, variable, potentiometer	RES	VAR	POT			6.5
Resistor, variable, potentiometer, preset	RES	VAR	POT	PRESET		6.5
Resistor, variable, potentiometer, rotary precision	RES	VAR	POT	PRECROT		6.5
Resistor, variable, potentiometer, slide	RES	VAR	POT	SLIDE		6.5
Resistor, variable, potentiometer, low power rotary	RES	VAR	POT	LPROT		6.5
Resistor, variable, potentiometer, power rotary	RES	VAR	POT	PWRPROT		6.5
Resistor, variable, two terminal	RES	VAR	TT			6.5
Resonator	RESON					6.8
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

Component description	IEC 61360-4 classification tree					Clause in this standard
	L1	L2	L3	L4	L5	
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					6.7
Transformers, power	TFM	POW				6.7
Transformers, power, fixed	TFM	POW	FIX			6.7
Transformers, power, variable	TFM	POW	VAR			6.7
Transformers, signal	TFM	SIG				6.7
Transformers, signal, fixed	TFM	SIG	FIX			6.7
Transformers, signal, variable	TFM	SIG	VAR			6.7
Transistors	TRA					6.2
Transistors, bipolar	TRA	BIP				6.2
Transistors, bipolar, power	TRA	BIP	POW			6.2
Transistors, bipolar, power, low frequency	TRA	BIP	POW	LF		6.2
Transistors, bipolar, power, high frequency	TRA	BIP	POW	HF		6.2
Transistors, bipolar, signal	TRA	BIP	SIG			6.2
Transistors, bipolar, signal, low frequency	TRA	BIP	SIG	LF		6.2
Transistors, bipolar, signal, high frequency	TRA	BIP	SIG	HF		6.2
Transistors, FET	TRA	FET				6.2
Transistors, FET, power	TRA	FET	POW			6.2
Transistors, FET, power, low frequency	TRA	FET	POW	LF		6.2
Transistors, FET, power, high frequency	TRA	FET	POW	HF		6.2
Transistors, FET, small signal	TRA	FET	SIG			6.2
Trigger device	TRG					6.2
Trigger device, DIAC	TRG	DIA				6.2
Trigger device, thyristor	TRG	THY				6.2
Trigger device, thyristor, fast turn off	TRG	THY	FTO			6.2
Trigger device, thyristor, gate turn off	TRG	THY	GTO			6.2
Trigger device, thyristor, reverse blocking	TRG	THY	RVB			6.2
Trigger device, TRIAC	TRG	TRI				6.2

Component description	**IEC 61360-4 classification tree**					**Clause in this standard**
	L1	**L2**	**L3**	**L4**	**L5**	
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					6.1
Connector, circular	CON	CIRC				6.1
Connector, IC	CON	IC				6.1
Connector, plug and jack	CON	JACK				6.1
Connector, plug and jack, plug assembly	CON	JACK	ASSY			6.1
Connector, plug and jack, complex jack boards	CON	JACK	CMPLX			6.1
Connector, plug and jack, concentric type	CON	JACK	CONC			6.1
Connector, plug and jack, concentric type, jack	CON	JACK	CONC	JACK		6.1
Connector, plug and jack, concentric type, multiple	CON	JACK	CONC	MULT		6.1
Connector, plug and jack, concentric type, plug	CON	JACK	CONC	PLUG		6.1
Connector, plug and jack, pin type	CON	JACK	PIN			6.1
Connector, plug and jack, pin type, jack	CON	JACK	PIN	JACK		6.1
Connector, plug and jack, pin type, multiple jack	CON	JACK	PIN	MULT		6.1
Connector, plug and jack, pin type, plug	CON	JACK	PIN	PLUG		6.1
Connector, plug and jack, pin type, shielded jack	CON	JACK	PIN	SHLD		6.1
Connector, plug and jack, D.C. power type	CON	JACK	PWR			6.1
Connector, plug and jack, D.C. power type, car	CON	JACK	PWR	CAR		6.1

Component description	IEC 61360-4 classification tree					Clause in this standard
	L1	L2	L3	L4	L5	
Connector, plug and jack, D.C. power type, jack	CON	JACK	PWR	JACK		6.1
Connector, plug and jack, D.C. power type, plug	CON	JACK	PWR	PLUG		6.1
Connector, modular	CON	MOD				6.1
Connector, printed circuit board	CON	PCB				6.1
Connector, rectangular	CON	RECT				6.1
Connector, radio frequency	CON	RF				6.1
Connector, sockets	CON	SOCK				6.1
Connector, sockets, antenna feeder	CON	SOCK	ANT			6.1
Connector, sockets, fuse holder	CON	SOCK	FUSE			6.1
Connector, sockets, IC	CON	SOCK	IC			6.1
Connector, sockets, light	CON	SOCK	LIGHT			6.1
Connector, sockets, PCB	CON	SOCK	PCB			6.1
Connector, sockets, power socket	CON	SOCK	PWR			6.1
Connector, sockets, signal socket	CON	SOCK	SIG			6.1
Connector, sockets, transistor	CON	SOCK	TRA			6.1
Connector, sockets, tube	CON	SOCK	TUBE			6.1
Connector, sockets, quartz crystal	CON	SOCK	XTAL			6.1
Connector, terminals	CON	TERM				6.1
Connector, terminals, array	CON	TERM	ARRY			6.1
Connector, terminals, board	CON	TERM	BRD			6.1
Connector, terminals, rod	CON	TERM	ROD			6.1
Connector, terminals, small	CON	TERM	SM			6.1
Connector part	CONPART					6.1
Connector part, contact	CONPART	CONTACT				6.1
Connector part, accessories	CONPART	ACCY				6.1
Connector part, tool	CONPART	TOOL				6.1
Connector part, shell	CONPART	SHELL				6.1
Connector part, insert	CONPART	INSERT				6.1
Fuse	FUS					6.8
Fuse, current activated	FUS	CUR				6.8
Fuse, thermally activated	FUS	TERM				6.8

Component description	IEC 61360-4 classification tree					Clause in this standard
	L1	L2	L3	L4	L5	
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
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					6.11
Switch	SWI					6.12
Switch, mechanical	SWI	MEC				6.12
Switch, reed	SWI	REE				6.12
Switch, thermostatic	SWI	THE				6.12
MAGNETIC PARTS						
Hard magnetic part	HRD					N/A
Soft magnetic part	SFT					N/A

E.3 Other systems

E.3.1 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.

E.3.2 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.

E.3.3 STEP/EXPRESS

STEP (Standard for the Exchange of Product data) is the colloquial term for ISO 10303-31. 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, etc.), 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.

E.3.4 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 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.

E.3.5 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 the IEC 61360 and ISO 13584 series to the greatest possible extent.

E.3.6 ISO 13584

ISO 13584 is not a standard 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.

E.3.7 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 F
(informative)

Examples

F.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:
$\lambda = \lambda_{\text{ref}} \times \pi_{\text{T}} = 10^{-7}\text{h}^{-1} \times 2{,}9 = 2{,}9 \times 10^{-7}\text{h}^{-1} = 290\ \text{FIT}$.

F.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 $\lambda_{\text{ref}} = 2 \times 10^{-8}\ \text{h}^{-1}$.

The operating voltage ratio, $U_{\text{op}}/U_{\text{rat}} = 0{,}8$.

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:

$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} = 2 \times 10^{-8}\text{h}^{-1} \times 1{,}26 \times 4{,}2 \approx 1{,}06 \times 10^{-7}\text{h}^{-1} = 1{,}058 \times 10^{-7}\ \text{h}^{-1} \approx 106\ \text{FIT}$.

F.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 $\lambda = 3{,}5 \times 10^{-9}\text{h}^{-1}$.

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 Table 36) is obtained as:

$$\lambda_{\text{ref}} = \lambda/(\pi_{\text{U}} \times \pi_{\text{T}}) = 3{,}5 \times 10^{-9}\text{h}^{-1}/(1 \times 1{,}8) = 1{,}94 \times 10^{-9}\text{h}^{-1} = 1{,}94 \text{ FIT}$$

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:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{U}} \times \pi_{\text{T}} = 1{,}94 \times 10^{-9}\text{h}^{-1} \times 1{,}5 \times 3{,}1 \approx 9 \times 10^{-9}\text{h}^{-1} = 9 \text{ FIT}$$

F.4 Relay

A dust-tight general purpose relay with one normally open contact switches once per hour in stress region 4 (see Figure 1) with motor load with alternating current (a.c.):

$\lambda_{\text{ref}} = 4 \times 10^{-9}\text{h}^{-1}$; $U = 220\text{ V}$, $I = 4\text{ A}$, $I_{\text{rat}} = 16\text{ A}$, 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): $\pi_{\text{S}} = 1$ follows from Equation (7), 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:

$$\lambda = \lambda_{\text{ref}} \times \pi_{\text{ES}} \times \pi_{\text{S}} \times \pi_{\text{T}} = 4 \times 10^{-9}\text{h}^{-1} \times 20 \times 1 \times 1{,}8 = 1{,}44 \times 10^{-7}\text{h}^{-1} = 144 \text{ FIT}$$

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