

BS EN 61709:2011



BSI Standards Publication

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 It supersedes BS EN 61709:2000 which is withdrawn.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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EN 61709

August 2011

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Supersedes EN 61709:1998

English version

**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.

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CENELEC

European Committee for Electrotechnical Standardization
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Management Centre: Avenue Marnix 17, B - 1000 Brussels

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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.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
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	-

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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 definitions

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:

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

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
$R_{th,amb}$	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;
$\lambda_{component}$	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:

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

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	$\leq 0,5 \text{ }^{\circ}\text{C/min}$	$> 0,5 \text{ }^{\circ}\text{C/min}$	$> 0,5 \text{ }^{\circ}\text{C/min}$

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 ≤ 5 m/s ²	2-9 Hz ≤3 mm 9-200 Hz ≤ 10 m/s ²	2-9 Hz >3 mm 9-200 Hz ≥ 10 m/s ² 200-500 Hz ≥15 m/s ²
Non-stationary vibration including shock	≤ 70 m/s ²	≤ 250 m/s ²	> 250 m/s ²
IEC 60721-3-3 Classes	3K1 3K2 3K3 3K4 3K5 3K6 3M1 3M2 3M3	3K7 3K7L 3K8 3K8H 3K8L 3K9 3K10 3M4 3M5 3M6 3M7	–
IEC 60721-3-4 Classes	–	–	4K1 4K2 4K3 4K4 4K4H 4K4L
IEC 60721-3-5 Classes	–	–	5K1 5K2 5K3 5K4 5K4H 5K4L 5K5 5K6 5M1 5M2 5M3
IEC 60721-3-7 Classes	–	–	7K1 7K2 7K3 7K4 7K5
ETS 300 019-1-3 Classes	3.1; 3.2; 3.3	3.4; 3.5	–
ETS 300 019-1-4 Classes	–	4.1; 4.1E	–
ETS 300 019-1-8 Classes	8.1 + 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	$\theta_0 = 40\text{ °C}$
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:

$$\lambda = \lambda_{\text{ref}} \times \pi_U \times \pi_I \times \pi_T \times \pi_E \times \pi_S \times \pi_{\text{ES}} \quad (2)$$

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

$$\pi_U = \exp \left\{ C_3 \left[\left(\frac{U_{op}}{U_{rat}} \right)^{C_2} - \left(\frac{U_{ref}}{U_{rat}} \right)^{C_2} \right] \right\} \quad (3)$$

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 $\pi_U = \exp \left\{ C_1 \left(U_{op}^{C_2} - U_{ref}^{C_2} \right) \right\}$ where $C_1 = C_3 / U_{rat}^{C_2}$.

5.2.3 Stress factor for current dependence, π_I

$$\pi_I = \exp \left\{ C_4 \left[\left(\frac{I_{op}}{I_{rat}} \right)^{C_5} - \left(\frac{I_{ref}}{I_{rat}} \right)^{C_5} \right] \right\} \quad (4)$$

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

$$\pi_T = \exp \left[\frac{Ea_1}{k_0} \left(\frac{1}{T_{ref}} - \frac{1}{T_{op}} \right) \right] \quad (5)$$

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_{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} .

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

with the auxiliary variables

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

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

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

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

- for ICs:
 - θ_{ref} : reference virtual (equivalent) junction temperature;
 - θ_{op} : actual virtual (equivalent) junction temperature;
- for discrete semiconductors and optoelectronic components:
 - θ_{ref} : reference junction temperature;
 - θ_{op} : actual junction temperature;
- for capacitors:
 - θ_{ref} : 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	Stationary use at partially weather-protected or non-weather-protected locations	Portable and non-stationary use, ground vehicle installation
E1	E2	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.

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

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.

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

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 than 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, AC MOS (FCT, HC, A(U),C, LVX), (LVC, LCX, LV) (VCX, ALVC, AVC, AHC, VHC) Logic Analog switches, Bus interface	45	$U_{ref} = 5$ 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	
	Bus driver / receiver	95	
		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	70	
	> 1 W	90	
High frequency IC (> 100 MHz)			
HF modulator, demodulator PLL, VCO	Bipolar	65	
	CMOS, BICMOS	45	
Transmitter, receiver	Bipolar	70	
	CMOS, BICMOS	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	55	
		No. of transistors >50k – 50 M	70	
		No. of transistors >50 M	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	70	
		No. of transistors >5 k	80	
			80	

6.1.2 Stress factors

6.1.2.1 Models

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

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

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

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

Table 11– Factor π_U for digital CMOS-family ICs

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

Table 12 – Factor π_U for bipolar analog ICs

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

6.1.2.3 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;

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

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

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

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} ($^{\circ}\text{C}$)																							
	≤ 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	55	
MOS	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	95	
medium power	110	
high power	145	
MOSFET wide band, small signal power	55 125	