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UNION TECHNIQUE DE L'ELECTRICITE

RDF 2000 : RELIABILITY DATA HANDBOOK

A universal model for reliability prediction of

Electronics components, PCBs and equipment

RECUEIL DE DONNEES DE FIABILITE : RDF 2000.

Modèle universel pour le calcul de la fiabilité prévisionnelle
des composants, cartes et équipements électroniques

FOREWORD

This present databook gives elements to calculate failure rate of mounted electronic components.

It made easier equipment reliability optimization studies, thanks to influence factors introduction.

This document replaces and cancels UTE C 80 - 810 (June 1997).

This present guide has been adopted on 07/03/2000 by the UTE board of directors.

SOMMAIRE

NOTE

This reliability calculation guide for electronic and optical card, is an important progress compared to older guides. Calculation models take directly into account the influence of the environment. The thermal cycling seen by cards, function of mission profiles undergone by the equipment, replace environment factor which is difficult to evaluate. These models can handle permanent working, on/off cycling and dormant applications. On the other hand, failure rate related to the component soldering, is henceforth included in component failure rate.

CONDITIONS OF USE

1. - INTRODUCTION

1.1. Theory of reliability predictions

Calculation of a reliability prediction for non-redundant equipment is the very first step in any complete reliability study concerning that equipment, and indeed, of any study of the reliability, availability, or safety of a system.

Reliability predictions are based on numerous assumptions, all of which need to be verified (choice of component family, for example).

A reliability study of an item entails not only verifying these assumptions, but also optimising its reliability (qualification of components and mounting processes, minimising of risk of external failure, etc).

A reliability prediction is essential, but no more so than research into the best possible reliability for least cost.

This handbook provides all the information needed to calculate electronic component and equipped printed circuit board failure rates: failures rates delivered include the influence of component mouting processes.

1.2. Structure of the handbook

The handbook is specifically designed as an aid to research into how to maximise equipment reliability, and to assist in the design of the equipment, by introducing various influencing factors (see also section 3.1.). In order to meet this objective, it is important that any reliability prediction should begin with the start of design (and then be finalised in accordance with section 5.4). Similarly, the choice of values for the influencing factors should not be automatic.

1.3. Data source

The reliability data contained in the handbook is taken mainly from field data concerning electronic equipment operating in three kinds of environment:

- «Ground; stationary; weather protected» (in other words: equipment for stationary use on the ground in weather protected locations, operating permanently or otherwise).

This applies mainly to telecommunications equipment and computer hardware.

- «Ground; stationary; non weather protected» (in other words: equipment for stationary use on the ground in non-weather protected locations).

This relates mainly to public payphones and GSM relays.

- «Airborne, Inhabited, Cargo» (in other words: equipment used in a plane, benign conditions).

This relates to on board calculators civilian planes.

- «Ground; non stationary; moderate» (in other words: equipment for non-stationary use on the ground in moderate conditions of use).

This concerns mainly on board automotive calculators and military mobile radio.

By processing the raw data (statistical processes, results based on geographic distribution, according to equipment type, etc), it has been possible to include various influencing factors and eliminate the main aberrant values. Other influencing factors are derived from the experience of experts (failure analyses, construction analyses, results of endurance tests).

The values adopted are those considered most probable at the present time (1992-1998).

This databook don't give any part count values, because mission profiles are needed to have credible values.

2. - ASSUMPTIONS ADOPTED FOR UTE C 80810

2.1. Nature of data

2.1.1. The reliability data in this handbook comprises failure rates and, for some (very few) component families, life expectancy.

Failure rates are assumed to be constant either for an unlimited period of operation (general case) or for limited periods: in these particular cases the laws governing failure rates versus time have not been adopted in the interests of simplicity.

Apart from a few exceptions (see section 2.1.3), the wear-out period is never reached by electronic components; in the same way it is accepted, again apart from some exceptions (see section 2.1.2), that the added risks of failure during the first few months of operation can be disregarded.

2.1.2. The infant mortality period

In practice, except for a few component families, the increased risk of failure during the first months of operation can be disregarded, because of the diversity of reasons for variations or uncertainty in the failure rate. This superficially simplistic hypothesis is in fact very realistic. It is confirmed by field data concerning the operation of equipment designed very carefully, with well chosen components (based on compatibility with use) and produced by a well controlled production system, as is generally the case for the components covered by this handbook.

2.1.3. Wear-out period

For the vast majority of components, the -wear-out period (during which failures take on a systematic character) is far removed from the periods of use (which range from 3 to 20 years).
There are, however, two cases in which the occurrence of wear-out failures should be taken into account (the failure rate of which increases with time).

a) For some families, if due care is not taken, the wear-out mechanisms may give rise to systematic failures after too short a period of time; metallization electromigration in active components, for example.

This risk needs to be eliminated by a good product design, and it is important to ensure this by qualification testing. In other words, it should not be taken into account for a prediction, and should be eliminated by qualification testing and by technical evaluation, which are, therefore, of critical importance.

b) For some (few) component families, the wear-out period is not far into the future. For these families, this handbook explains how to express the period for which the failure rate can be considered constant. This life expectancy is subject to influencing factors.

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

For these component families, it is important to ensure that the life expectancy given by the handbook is consistent with the intended use. If not, room for manoeuvring is fairly restricted: you can reduce the stresses, change the component family (or sub-family: for aluminium capacitors with non-solid electrolyte, there are several types characterised by different qualification tests).

You can also make provision for preventive maintenance.

Note: as before, and in the interests of simplicity, this handbook does not give the wear-out failure mathematical model (for which the failure rate increases over time), but a period during which the rate can be considered constant (in some cases the period at 10% of the cumulative failure rate).

2.2. Nature of failures

2.2.1. The data in this handbook covers intrinsic failures (apart from the few exceptions given in section 2.2.2).

In practice (see section 1.3), the raw reliability data has been processed to eliminate non-intrinsic component failures.

2.2.2. Special case of non-intrinsic residual failures due to electrical overloads.

There is, necessarily, a small proportion of non-intrinsic failures in the data, because it is impossible to detect all the non-intrinsic failures when they are residual.
Take, for example, the reliability of the components used in equipment located “at the heart” of a system, which is significantly better than that of the components located at the periphery (in other words connected to the external environment). It is understood that this is due to residual overloads, since the equipment is assumed adequately protected.

For the purpose of this handbook, we have therefore included an utilisation factor to take into account nonintrinsic residual failures due to the electrical environment for active components.

2.2.3. Other non-intrinsic failures

The other non-intrinsic failures (due to errors of design, choice, uses) are excluded from this handbook.

Errors of this kind should be avoided; hence they are not taken into for predictions. As a matter of fact, they are very largely independent of component family.

However, for some particular objectives, such as calculation of stocks of spare parts, it may be useful to include the risks of non-intrinsic residual failures due to design errors: some indications are given in section 4.3.

2.3. Large-scale integrated circuit, production date Influence.

Since the 90's, the reliability growth of components no longer occur, as in the70's and the 80's; thanks to fields failures returns data collections. This is particularly true for integrated circuits, and can be attributed to: generalisation of nitride based passivations, generalisation of dry etching and better planarization controls. However, the integration density for integrated circuits continues to grow at the same rate as in the past, at constant reliability figure. For this reason, and in order to takes into account the MOORE law, it is necessary to know the manufacturing year to calculate the failure rate of integrated circuits.

3. - INFLUENCING FACTORS

3.1. The component failure rate depends on a number of operational and environmental factors.

This is why, for each component family, the handbook gives a base failure rate value (normally a value which corresponds to the commonest internal temperature taken as a reference) multiplied by a number of influencing factors. This simplified, empirical expression takes account of the more significant influencing factors when it comes to conditions of use.

The main factors adopted are as follows:

a) Factors giving the influence of temperature (π_t, π_w)

It is now widely accepted that temperature has a moderate effect on component reliability. The effect is significant for some families (active components and aluminum capacitors with non-solid electrolyte). The models adopted are those which give the effect of temperature on the predominating failure mechanisms (which are not normally the “wear-out” mechanisms).

For semiconductors, we have applied an Arrhenius equation with activation energy of 0.3 to 0.4 electron volts.

For passive components, we have applied an Arrhenius equation with an activation energy of 0.15 to 0.4 electron volts.

Factor π_w for potentiometers gives the influence of load resistance on the temperature rise.

In the case of power dissipating components, we have given the thermal resistance (semiconductors) or the equation giving the internal temperature as a function of ambient temperature (resistors).

b) Factors giving the influence of special stresses:

Utilization factor π_u for thyristors, Zener diodes (operating permanently powered or otherwise).

Factor π_A for Aluminum liquid electrolyte capacitors giving the effect of current pulses.

Factor π_Y for relays (operating cycle rate).

Factor π_i for connectors (current intensity).

c) Factors giving the influence of applied voltage (π_S).

The influence of applied voltage is taken into account for transistors and optocouplers (voltage applied between input and output).

3.2. The life expectancy, when limited, is also influenced by certain factors (optocoupler operating current; temperature of aluminum capacitors with non-solid electrolyte; contact current for relays).

The life expectancy can be expressed as a number of cycles (power transistors, switches).

4. - HOW TO USE THE DATA

4.1. Calculation method

Given that the component failure rates are assumed constant, the failure rate of a non-redundant equipment can be obtained by adding together the failure rates of its individual components. In this handbook, the failure rates given for components include the effects of the mounting on a printed circuit board, but we have to add the failure rate of the naked PCB or hybrid.

Pages 21 and 22 of this handbook explain the method to be used to calculate the failure rate of a printed circuit board or a hybrid.

4.2. Reliability prediction results

The results of a reliability prediction are many and various, and not limited to failure rate: the following information is obtained:

- Failure rate (of component or equipment).

- Choice of technical construction for some components (choice of component family).

- Choice of conditions of use.

4.3. The failure rate can be used directly if the aim is to identify a reference base. Such is the case for many objectives described in section 5.

However, if the aim is to obtain an accurate estimate of stocks of spare parts, the result should be uprated to take account of non-intrinsic failures:

- unconfirmed failure phenomena (equipment, subsystem, identified as defective and found to be OK on repair).

- incorrect component usage, wrong choice of components for the first months of use of equipment of new design (period of improving reliability).

- incorrect maintenance, inappropriate use, human error, environmental attack.

- production process learning factor (component mounting process, etc).

The appropriate uprating factors cannot be given in this handbook: they depend on the prior experience of a company and how new the equipment production process is (for example, for unconfirmed failures, the uprating factor ranges from 10% to over 100% depending on newness).

4.4. In cases where conditions are not yet known default conditions can be assumed.

According to section 5.1, reliability prediction calculations should begin as early as possible, at the start of the equipment design phase, even if not all the applicable conditions can yet be known: in this case default values can be used provisionally, to help determine those conditions which are as yet unknown. These default values will then be gradually discarded as the definitive conditions are identified.

This method is far preferable to the simplified calculation method (for which all the values are replaced by default values, including those which are already known).

The calculations must therefore be prepared in such a way as to enable values to be modified easily.

5. - USES AND AIMS OF A RELIABILITY PREDICTION

5.1. A reliability prediction can be used as an aid to equipment design

The most beneficial use of a reliability prediction is as an aid to equipment designers, In this case, the help is based on determination of the stresses and factors influencing the reliability of each component (temperature, input voltage, technical construction of the components, etc). Predictions based on this handbook will lead the originators of a new design to choose the best conditions and the best component families, and to draw up component qualification or evaluation programmes.

If this important objective is to be met, it is essential for the reliability prediction to be begun at the very start of design, by the design originators, and then revised as required. The work should be carried out in close collaboration with the company's component quality experts.

5.2. A reliability prediction can be used to assess the potential of new equipment

The predicted reliability can be compared with the reliability objectives or stated requirements.

5.3. Predicted reliability values can be used as a basis for contractual reliability values

The contractual value of a failure rate must be determined on the basis of the predicted value; these two values will not necessarily be equal: a number of contractual values may be assumed depending on observation period or certain data may be modified provided it is justified. However, in all cases, the predicted value should be taken as the base.

5.4. Where used in conjunction with other characteristics of a project (electrical characteristics, weight, etc), the results of a reliability prediction can be used to compare different project solutions, as when evaluating proposals from tenderers. Comparisons of this kind are possible only if the data used is the same: hence the existence of a reliability data handbook.

5.5. The predicted failure rates for the individual items of a system are crucial when calculating system dependability and reparability.

5.6. Reliability predictions can be used as a basis for evaluating stocks of equipment and spare components required for maintenance (however, in this case, it is important to take account of probable non-intrinsic failures, as was explained in section 4.3). The purpose of a study of this kind is to optimise stocks of spare parts (avoid stock outages, but also avoid excessive and costly stocking levels).

5.7. Reliability predictions can be used as a benchmark for assessing results observed in operation. Indeed, observed results cannot be assessed effectively without a benchmark: mediocre reliability would be considered normal and there would be no attempt at improvement.

Obviously we should not expect observations to mirror exactly the predicted reliability values, for a number of reasons:

- Predictions are based only on intrinsic reliability: they do not therefore take account of external overload conditions (however, according to section 2.2, they do take account of residual overloads).
- Predictions do not take account of design errors or incorrect use of components.
- Predictions do not take account of the risks involved in using lots of components with poor reliability.

These departures from reality, far from being a handicap are in fact an advantage: in practice, the differences can be used to reveal a lack of reliability and, following analysis, take a corrective action. This very important quality enhancement process is crucial when it comes to minimising the infant mortality period and correcting equipment design errors.

ENVIRONMENT INFLUENCE

1. GENERAL

Experience has shown that component reliability is heavily influenced by mechanical and climatic environment conditions, as well as by electrical environment conditions (residual overload).

This factor is therefore included in this handbook, based on observations and published values: for simplicity, climatic and mechanical environment conditions have been classified in ten or so environment types. However, the mission profile has to be taken into account (see paragraph 11), to determine estimated failure rate of components in the considered environment.

3. ENVIRONMENT TYPES DEFINED

The environment types are based on IEC 721-3 («classification of groups of environmental parameters and their severity»), with some simplifications, and the specification ETS 300 019 (ETSI specification: environmental conditions for telecommunications equipment).

Table 1 gives, for the various types of environment adopted for the purposes of this handbook, the following information:

- the short form designation adopted for this handbook.

- the complete designation (generally according to IEC 721-3).

- the main stresses included.

- some typical applications.

Table 2 quantifies the mechanical stresses (shock and vibration) for the main types of environment.

Tables 3 define the environmental conditions according to the presence and activity of chemical and mechanical substances (definitions given in table 3-b based on the conventions summarised in table 3a), and according to climatic conditions.

Table 1: Description and typical applications of the commonest types of environment

<table>
<tr><th colspan="3">Environment description</th><th rowspan="2">Description of the environment</th><th rowspan="2">Applications</th></tr>
<tr><th>Short form designation (adopted in the handbook)</th><th colspan="2">Complete designation</th></tr>
<tr><td>Ground; stationary; weather protected</td><td colspan="2">Equipment for stationary use on the <u>ground</u> in Weather protected locations</td><td>Controlled temperature and humidity, low stress good maintenance</td><td>Equipment in environmentally controlled premises</td></tr>
<tr><td rowspan="2">Ground; stationary non weather protected</td><td colspan="2">Equipment for stationary use on the ground; in non Weather protected locations</td><td>Some mechanical and climatic stresses (moderate) Average quality maintenance</td><td rowspan="2">Equipment located in premises with little or no environmental control:
- phone booths
- equipment in public buildings
- equipment in streets, stations, etc,
- equipment in industrial environments.</td></tr>
<tr><td colspan="3">important note: the phrase "non weather protected" (according to IEC 721.3) applies to the equipment and not to the components.
With regard to, the components (which are protected from the elements), the main difference from the type "ground; fixed; protected" lies in the absence of environmental control (humidity and temperature).</td></tr>
<tr><td>Ground; non stationary; benign</td><td colspan="2">Equipment for <u>non-stationary</u> use on the <u>ground</u>. in <u>benign</u> conditions</td><td>Mechanical stress is more severe than for "ground; stationary; non Weather protected" Sometimes difficult maintenance</td><td>Radiotelephones - Portable equipment on ground vehicles. Railway rolling Stock equipment</td></tr>
<tr><td>Ground; non stationary; severe</td><td colspan="2">Equipment for <u>non-stationary</u> use on the <u>ground</u>, in <u>severe</u> conditions</td><td>As for "ground; non stationary benign", but with more severe; mechanical stresses</td><td></td></tr>
<tr><td>Satellite; flight</td><td colspan="2">Used on board an orbiting satellite</td><td>Very low mechanical stresses</td><td></td></tr>
<tr><td>Satellite; launch</td><td colspan="2">Used on board a satellite During launch</td><td>Extremely severe shock
High amplitude vibration and high frequencies (up to 2 000 Hz)</td><td></td></tr>
<tr><td>Airborne; benign</td><td rowspan="4">Used in an aircraft in …</td><td>: benign conditions</td><td>Conditions similar to those of "ground; non-stationary; benign-, but with more intense vibration up to 2 000 Hz</td><td rowspan="6">Other applications (other than "aircraft" and "ship") are possible, provided that the stresses are comparable.</td></tr>
<tr><td>Airborne; moderate</td><td>: moderate conditions</td><td rowspan="3">The qualifying terms "moderate", "severe" and "extremely severe", are defined in table 2; they represent increasing levels of mechanical stresses.</td></tr>
<tr><td>Airborne; severe</td><td>: severe conditions</td></tr>
<tr><td>Airborne; extremely severe</td><td>: extremely severe conditions</td></tr>
<tr><td>Naval; benign</td><td rowspan="2">Used on board a ship in</td><td>benign conditions</td><td rowspan="2">Conditions similar to those of "ground; stationary; non- weather protected", but with more pronounced shock and vibration. The qualifying terms, "benign" and "severe" represent the mechanical stresses according to table 2.</td></tr>
<tr><td>Naval; severe</td><td>severe conditions</td></tr>
</table>

VIBRATIONS											SHOCKS
Accelerations m/s^2	Frequencies Some Hz up to the above frequency. (Hz)	50	100	200	200	300	300	500	1000	2000	peak acceleration m/s^2
		22	11	6	11	6	11	2,3	6	0,5	Duration ms
1	200	Ground stationary Weather-protected									
10	200			Ground stationary Non weather protected							
20	200		← Naval ; benign →								
20	500		← Ground ; non stationary ; benign →								
20	2000		Airborne ; benign								
30	500						← Ground; non stationary; severe →				
30	2000		Airborne; moderate								
50	200		← Naval severe →								
80	2000				Airborne; severe						
150	2000				Airborne; extremely severe					Satellite launch	

Table2: Mechanical conditions according to the environment: characteristic shocks and vibrations.

Table 3-a : Definition of concentration classes used in Table 3b for active substances

Table 3-a-1: Mechanically active substances

Designation of classes used in Table 3-b	Sand	Dust		Examples of type of environment
	(Mg/M3)	(Mg/M3)	(Mg/M2 h)	
Negligible	0	0,01	0,4	Naval; benign
Low	30	0,2	1,5	Ground; weather protected
Moderate	300	0,4	1,5	Ground; non weather protected
High	3000	4	40	Ground; non stationary; severe

Table 3-a-2: Chemically active substances

Designation of classes used in Table 3-b	Salt mist	$S0_2$	H_2S	Cl	$N0_2$	Examples of type of environment
		(proportion in 10^{-9})				
Low	(low)*	30	7	7	50	Ground; weather protected
Moderate	(moderate)*	100	70	70	300	Ground; non weather protected
High	(high)*	400	400	70	500	Naval; severe
** No figure has been published						

Table 3-b: Typical conditions for each environment type according to Table 1 (mechanically and chemically active substances and climatic conditions)

	Active substances concentration (classes according to Tables 3-a)			Relative humidity %	Mean temperature °C	Rapid changes of Temperature : qualitative estimation of temperature range
	Mechanically active substances	Chemically active substances				
		Gaseous substances	Fluid substances			
	Concentration class 3ccording to Table 3-a-1	Concentration class according to Table 3-a-2	Concentration class without exact figures			
Ground; stationary; weather protected	low	low	negligible	40 to 70	+5 to +45	negligible
Ground; stationary; non weather protected	moderate	moderate	negligible	5 to 100	-40 to +45	low
Ground; non stationary; benign	moderate	moderate	negligible	5 to 100*	-40 to +45	low
Airborne; benign	low	low	negligible	510 100	-40 to +45	low
Airborne; moderate	low	low	negligible	5 to 100	-40 to +45	low
Naval; benign	very low	low	negligible	5 to 100	-40 to +45	low
Ground; non stationary; severe	high	moderate	low	5 to 100	-40 to +70	moderate
Airborne; severe	high	moderate	high	5to-100	-65 to +85	high
Naval; severe	moderate	high	high	10 to 100	-40 to +70	high
Airborne; extremely severe	high	moderate	high	5 to 100	-65 to +85	high
Satellite; launch	low	moderate	low	0 to 50	-40 to +20	high
Satellite ; Orbit	very low	moderate	low	0	-40 à +65	moderate
* 40 to 70 on board trains (railway equipment)						

3.- ELECTRICAL ENVIRONMENT CONDITIONS

Reliability is also heavily dependent on electrical environment conditions (voltage and current overloads). This applies in particular to a component connected to interface circuits between an electronic circuit board and the outside environment (another equipment, especially if remotely located).

First priority is to protect the exposed components appropriately (by a system of protection comprising components designed to resist overload conditions). However, it is often found that the reliability of exposed and protected components does not match that of components located “at the heart” of an equipment. We have therefore included electrical environment conditions for the active components (bearing in mind that we are concerned with the effect of residual overloads after a protection system.

We might equally have applied the influence of the electrical environment for other families (some passive components).

4 - VALIDITY MODEL ACCORDING TO ENVIRONMENT

Failures Analysis undertaken on field failed active devices, during the period 92 to 98, have shown that:
- For the "ground; stationary; weather protected" environment, there is no package related defects, neither coming from the mounting process.
- For "ground; stationary; non-weather protected", "ground non-stationary; severe" and "airborne benign" environments, the main observed defects are caused to thermomechanical constraints applied on components mounted on PCBs. The failure rate related to the humidity is insignificant (for active components, especially since the generalisation of the nitride based passivations). Furthermore, in these studied environments no defect related to, mechanical shocks, neither to vibrations nor to chemical contamination has been observed. Consequently, these failure mechanisms have not been taken into account in the models.

Therefore, to use correctly these models, it is necessary to make appropriate qualification tests, to verify these hypotheses for the considered environment. Plastic encapsulated devices are in most of the described environments in this document insensitive to shocks and vibrations.

Furthermore, for the "ground; stationary; non weather protected", it is necessary to insure that there is no condensation on cold parts of the equipment (especially for equipment having a stand by mode), and also there is no streaming on the equipment itself, to avoid any corrosion phenomenon.

5 - COMPONENTS CHOICE

It is the responsibility of the manufacturer to guarantee the life duration specified by the final user and that components used in equipment, are compatible with the environment. Therefore, premature usury phenomena must not occur, during the useful life period of the equipment in normal utilisation conditions prescribed by the final user (cf. section 2.1.3). However some components may have limited life duration, but a preventive maintenance has to be indicated to the final user (cf. section 2.1.3).

It is the responsibility of the component manufacturer to provide qualification and evaluation results of degradation mechanisms to the manufacturer, to insure that the appearance of usury mechanisms will be postponed beyond the useful life period of the equipment in normal utilisation conditions, prescribed by the final user.

Consequently, equipment manufacturer has to choose components manufacturers who have the best "commercial practice" concerning quality, those who are ISO 9000 certified, practice the statistical process control, and are under qualified manufacture line approval (or able to be).

In these conditions, there are no longer any reasons to take into consideration quality factors, and the infant mortality period related to new components technologies is neglected. We only consider qualified productions lines and stabilised one.

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

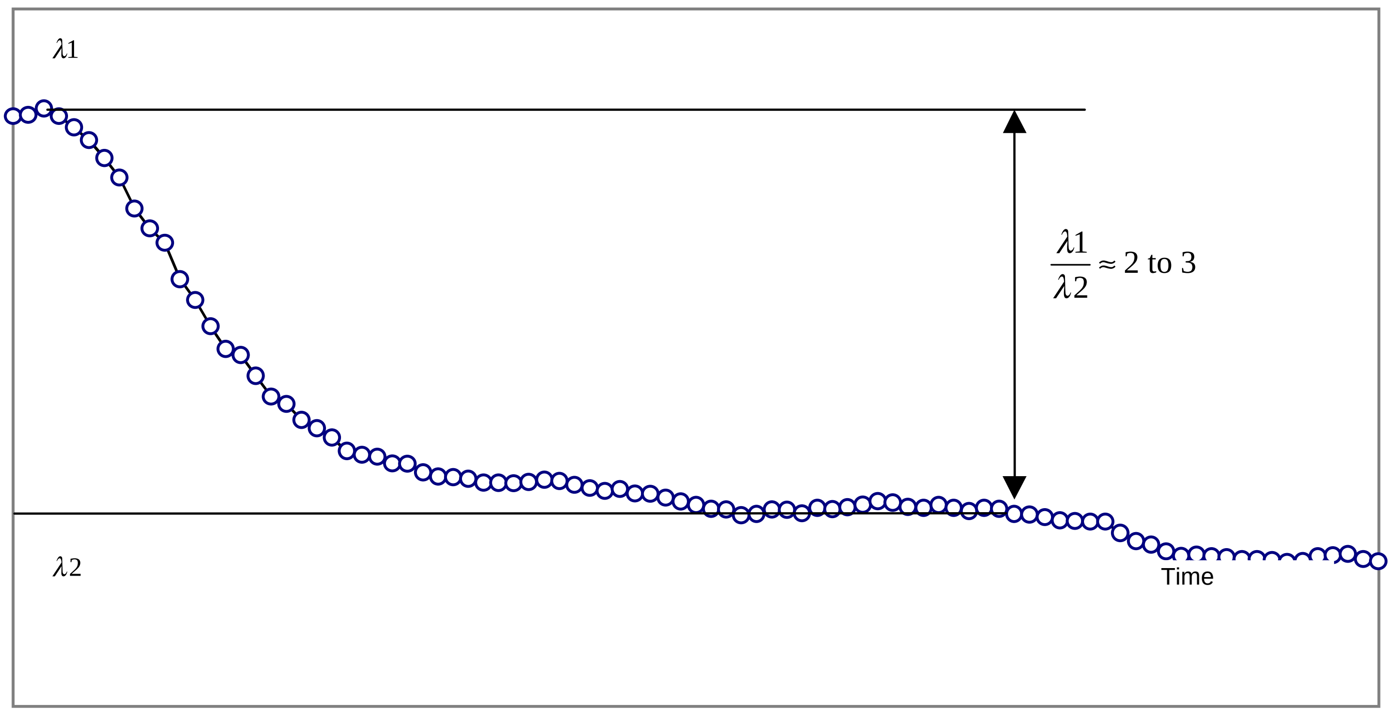
6 - LEARNING DURING THE DEPLOYMENT PHASE OF A NEW EQUIPMENT

Models retained in this document allow calculation of a reliability objective to reach, for an electronic card in its stabilised production phase. However, the operational reliability follow up of a newly developed electronic card, function of its deployment in the field, shows that there is a more or less long learning period, according to the improvement of the components implementation on the PCB and the components choice rectification for those having problem in the field (see figure here after).

Each manufacturer has to calibrate its learning period according to its own experience. However experimentally, on many electronic cards and several manufacturers, the ratio between the failure rate during the starting period of deployment and the one in the stabilised period, is between 2 and 3.

Consequently, as soon as the observed failure rate (out of non-defective removed cards: NDF) during the beginning of the deployment of an electronic card exceeds three time the estimated calculated value, a corrective action has to be taken.

Time dependant failure rate of a new electronic printed circuit board



7. - MISSION PROFILE

Estimated reliability calculation of equipment has to be done according to its field use conditions. They are defined by the mission profile.

A mission profile has to be decomposed in several homogeneous working phases, on the basis of a typical year of use. Following phases are to be considered:
- On/off working phases with various average outside temperatures seen by the equipment.
- Permanent-working phases with various average outside temperature swings seen by the equipment.
- Storage or dormant phases mode with various average outside temperature swings seen by the equipment.

The time quantity, to take into account on a field return from an equipment population, for a reliability calculation is therefore, the number of calendar hours of the installed population of this equipment, including working as well as storage or dormant hours.

Parameters necessary to define the mission profile of equipment are following:

- $(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the ith phase of the mission profile.
- $(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled (or the one of the component considered as the most critical for reliability, during the ith phase of the mission profile).
- τ_i : annual ratio of times for the PCB, in permanent working mode with supply, and at the $(t_{ac})_i$ temperature.
- τ_{on} : total annual ratio of time for the PCB, in permanent working mode with supply ($\tau_{on} = \sum_{i=1}^{y} \tau_i$).
- τ_{off} : total annual ratio of time for the PCB, in non working or storage/dormant modes. ($\tau_{on} + \tau_{off} = 1$).
- n_i : annual number of thermal cycles seen by the components of the PCB, corresponding to the ith phase of the mission profile with an average swing ΔT_i .
- ΔT_i : average swing of the thermal variation seen by the components of the PCB, corresponding to the ith phase of the mission profile.

For an on/off phase we have the following relation : $\Delta T_i = \left[\frac{\Delta T_j}{3} + (t_{ac})_i\right] - (t_{ae})_i$

With ΔT_j : increase of the internal temperature of the component as compare to t_{ac} , during a τ_{on} phase (This is the junction temperature increase for an integrated circuit or a discrete device ; this is the surface temperature increase for a passive device). Only the third of its value has to be taken into account for ΔT_i calculation, taking into account the fact that, thermomechanical stresses induce defects at the solder joint of the components, but also at the wire bounding of the die. The temperature to be taken into account is therefore a compromise on the internal temperature increase of the component. Some thermal simulations have shown that the third of this value is a good compromise.

$(t_{ae})_i$: for French climate, we have to take 11°C for "Ground; stationary; non weather protected" ("ground ; fixed" of MIL-HDBK-217F) environment, and 14°C for the world-wide climate.
$(t_{ac})_i$: is obtained, taking the mean value of the temperature increase observed on the PCB near the components as compared to the external temperature of the equipment, and adding the value of $(t_{ae})_i$ for the considered phase.

$$t_{ac} = \text{Average temperature increase of the PCB near components} + t_{ae}$$

For a storage or permanent working phase we have: ΔT_i = average of the difference between maximal and minimal temperatures per cycle seen by the equipment on the considered phase. If this value is below 3°C, we have to put ΔT_i =0, taking into account the fact that for these conditions, thermomechanical stresses are thermally independent in the COFFIN-MANSON equation.

For majority of the applications, a day is corresponding to one cycle, and ΔT_i is corresponding to the annual daily mean of the daylight / night temperature difference seen by the equipment park in the considered climate. For the French climate, ΔT_i =8°C. For the word wide climate, ΔT_i =10°C.

A daily temperature variation is always superimposed to a permanent working phase according to the climatical environment of the equipment. For an on/off working this daily variation is also applied on the equipment, however, only the greater temperature variation has to be taken into account, because the highest one has the main effect on the reliability of the device packages and on the mounting process.

Table of climates

Climate type	t_{ae} night	t_{ae} day-light	t_{ae} mean day-light/night	ΔT_i day-light/night
World wide	5°C	15°C	14°C	10°C
France	6°C	14°C	11°C	8°C

8 – MISSION PROFILES EXAMPLES

Mission profiles described here after are given for examples.

<u>Telecoms :</u>

There is only one annual working phase to consider for a permanent working.
Table 4 is given for a permanent working. Values for "ground; stationary; non weather protected"(Ground; Fixed for Mil-HDBK-217F) are given for French climate, but other climates can be calculated.

Environment types	Equipment types	$(t_{ae})_i$ °C	$(t_{ac})_i$ °C	τ_1	τ_{on}	τ_{off}	n_1 cycles/year	ΔT_1 °C/cycle
Ground; Benign : (G_B)	switching	20	30	1	1	0	365	0
Ground; Benign : (G_B)	Transmitting	20	40	1	1	0	365	0
Ground; Fixed : (G_F)	Transmitting and access	11	31	1	1	0	365	8

Table 4

<u>Military and civilian avionics</u>:

Described mission profiles here after are corresponding to the MIL-HDBK-217F "Airborne; Inhabited; Cargo" environment.

Several working phases are considered:

- The working rate considers only one internal working temperature for the equipment, and takes into account the total hours of annual working.

- Three phases of thermal cycling are taken in account:
. Phase 1: 1^{rst} daily switch on.
. Phase 2: switch off between two flights, while air conditioning of the plane is working.
. Phase 3: plane on the ground, not working

For more complex mission profiles, all the temperatures gradient seen by components during the various different workings and storage cycles have to be taken into account.

Mission profile phases		Annual working rate for the equipment			1rst daily switching on		Switch off Between two fights		Ground non working	
Plane types	$(t_{ac})_1$ °C	τ_1	τ_{on}	τ_{off}	n_1 cycles/year	ΔT_1 °C/cycle	n_2 cycles/year	ΔT_2 °C/cycle	n_3 cycles/year	ΔT_3 °C/cycle
A340	40	0.61	0.61	0.39	330	$\frac{\Delta Tj}{3}$ +30	330	$\frac{\Delta Tj}{3}$ +15	35	10
A330	40	0.54	0.54	0.46	330	$\frac{\Delta Tj}{3}$ +30	660	$\frac{\Delta Tj}{3}$ +15	35	10
A320	40	0.58	0.58	0.42	330	$\frac{\Delta Tj}{3}$ +30	1155	$\frac{\Delta Tj}{3}$ +15	35	10
Regional plane	40	0.61	0.61	0.39	330	$\frac{\Delta Tj}{3}$ +30	2970	$\frac{\Delta Tj}{3}$ +15	35	10
Business plane	40	0.22	0.22	0.78	300	$\frac{\Delta Tj}{3}$ +30	300	$\frac{\Delta Tj}{3}$ +30	65	10
Weapons plane	60	0.05	0.05	0.95	200	$\frac{\Delta Tj}{3}$ +50	0	0	165	10
Military cargo	50	0.05	0.05	0.95	250	$\frac{\Delta Tj}{3}$ +40	0	0	115	10
Patroller	50	0.09	0.09	0.91	300	$\frac{\Delta Tj}{3}$ +40	0	0	65	10
Helicopter	50	0.06	0.06	0.94	300	$\frac{\Delta Tj}{3}$ +40	0	0	65	10

Table 5

Automotive:

Described mission profiles here after are corresponding to the MIL-HDBK-217F "Ground; mobile" environment.

Several working phases are considered:

- The working rates considers three different internal working temperatures for the equipment, and takes into account the annual working hours for each of these temperatures. The overall working time is estimated to 500 hours.

- Two Thermal cycling are considered:
    Phase 1: 2 night starts.
    Phase 2: 4 day light starts.

Phase 3: non-used vehicle, dormant mode 30 days per year.

Mission profile phases	Temp. 1		Temp. 2		Temp. 3		Ratios on/off		2 night starts		4 day light starts		Non used vehicle	
Application types	$(t_{ac})_1$ °C	τ_1	$(t_{ac})_2$ °C	τ_2	$(t_{ac})_3$ °C	τ_3	τ_{on}	τ_{off}	n_1 cycles/year	ΔT_1 °C/cycle	n_2 cycles/year	ΔT_2 °C/cycle	n_3 cycles/year	ΔT_3 °C/cycle
Motor control	32	0.020	60	0.015	85	0.023	0.058	0.942	670	$\frac{\Delta Tj}{3}$ +55	1340	$\frac{\Delta Tj}{3}$ +45	30	10
Passenger compartment	27	0.006	30	0.046	85	0.006	0.058	0.942	670	$\frac{\Delta Tj}{3}$ +30	1340	$\frac{\Delta Tj}{3}$ +20	30	10

Table 6

Spatial:

Described mission profiles here after are corresponding to the MIL-HDBK-217F "Space; flight" environment.

Only one working phase is taken into account during each orbital revolution (LEO), or earth revolution (GEO).

Application types	$(t_{ac})_1$ °C	τ_1	τ_{on}	τ_{off}	n_1 cycles/year	ΔT_1 °C/orbit
Low earth orbit (LEO) with On/Off cycling	40	0,15	0,15	0,85	5256	$\frac{\Delta Tjc}{3}+7$
Low earth orbit (LEO) permanent working	40	1	1	0	5256	3
Geostationary earth orbit (GEO) permanent working	40	1	1	0	365	8

Table 7

Military:

Described mission profiles here after are corresponding to the MIL-HDBK-217F "Ground; mobile" environment.

Two working phases are taken into account:

Phase 1: 36 annual switch on

Phase 2: 365 days of dormant mode

Working ratio: 1%. Mean temperature of components during the working phase: 26°C.

Application type	$(t_{ac})_1$ °C	τ_1	τ_{on}	τ_{off}	n_1 cycles/year	ΔT_1 °C/cycle	n_2 cycles/year	ΔT_2 °C/cycle
Portable Radio	26	0,01	0,01	0,99	36	$\frac{\Delta Tj}{3}+15$	365	8

Table 8

EQUIPPED PRINTED CIRCUIT BOARD
HYBRID CIRCUITS

FAILURE RATE CALCULATION OF AN EQUIPPED PRINTED CIRCUIT BOARD

Equipped board failure rate: $\boxed{(A+B) \times 10^{-9} \text{ /hour}}$, with: A = connections and components ; B = board

$$\mathbf{A} = \sum \lambda_s + \sum \lambda_f + \left(1+3.10^{-3}\times\left[\sum_{i=1}^{j}(\pi_n)_i \times (\Delta T_i)^{0.68}\right]\right)\times \sum \lambda_d$$

Surface mounted components + Trough hole components + Miscellaneous connections

λ_S : Failure rate of each particular surface mounted component (with its influence factors) expressed in 10^{-9}/hour*.

λ_f : Failure rate of each trough hole component (with its influence factors) expressed in 10^{-9}/hour *.

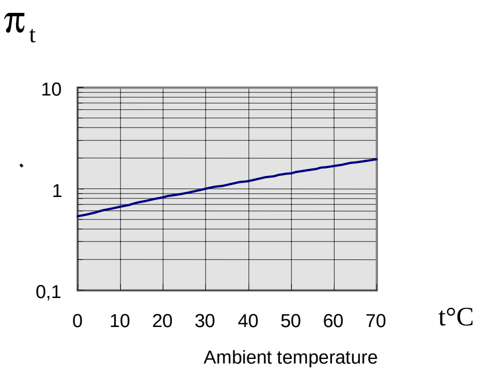
* If the failure rate is 3.10^{-9} / h, take λ_S (or λ_f) =3

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the ith phase of the mission profile.	

Miscellaneous connections	λ_d FIT
Manual soldering	0.5
Connecting with insulating transfer	0.5
Crimp…	0.3
Wrapped connection	0.01
Pressfit connection	0.006

$(t_{ae})_i$: average external ambient temperature of the equipment, during the i^{th} phase of the mission profile.
$(t_{ac})_i$: average internal ambient temperature, near the components, where the temperature gradient is cancelled.
$(\pi_n)_i$: i^{th} influence factor related to the annual cycle number of thermal variation, seen by the board, with an amplitude of ΔT_i .
ΔT_i : i^{th} thermal variation amplitude of the mission profile.

$$\mathbf{B} = 5.10^{-3}\pi_t.\pi_c\left[N_t\sqrt{1+\frac{N_t}{S}} + N_p.\frac{1+0.1\sqrt{S}}{3}.\pi_L\right]\times\left(1+3.10^{-3}\times\left[\sum_{i=1}^{j}(\pi_n)_i\times(\Delta T_i)^{0.68}\right]\right)$$



N_t = **Total number of holes** (for through holes components and vias)

S = **Board surface** (cm²)

N_p = **number of tracks**

Default value:

$$N_p = \frac{(\text{total number of connections})}{2} = \frac{\sum N_s + \sum N_f}{2}$$

N_S : number of connections for each particular surface mounted component.

N_f : number of connections for each particular trough hole component.

Mathematical expression for π_t
$\pi_t = e^{1740\left(\frac{1}{303}-\frac{1}{273+t_A}\right)}$ with t_A : ambient temperature

Number of layers influence	
Number of layers	π_C
≤ 2	1
> 2	$0.7\sqrt{(\text{number of layers})}$

Influence of the track width						
Predominant track width (mm)	0.56	0.35	0.23	0.15	0.10	0.08
π_L	1	2	3	4	5	6

HYBRID CIRCUITS

Hybrid circuit failure rate: $(A+B)\ x\ 10^{-9} / \ hour$ A = Add on components and packages; B = substrate and deposited components

$$\mathbf{A} = \sum \lambda_S + \left(0.023\times\left(|\alpha_S - \alpha_C|\right)^{1.68}\right)\times\left(2.7\times10^{-3}\times\left[\sum_{i=1}^{j}(\pi_n)_i\times(\Delta T_i)^{0.68}\right]\right)\times 0.2\times\pi_p\times D^{1.57}$$

Add on components + package

λ_S : **Failure rate** of each add on component expressed in 10^{-9} /hour, (with its influence factors)*

* *If the failure rate is* $3.10^{-9}/h$, *take* $\lambda_S = 3$

D: hybrid circuit diagonal, or distance between farest pins, in millimeters.

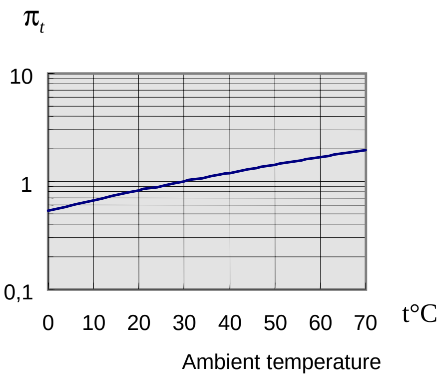
Connecting type	π_p
Single in line	1
Double in line	2
Peripheral	4

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7\times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

α_S	Linear thermal expansion coefficient of the mounting substrate of the hybrid in ppm/°C
α_C	Linear thermal expansion coefficient of the hybrid substrate in ppm/°C

$$\mathbf{B} = \left\{5\times10^{-3}\pi_c\left[N_t\sqrt{1+\frac{N_t}{S}} + N_p\frac{1+0.1\sqrt{S}}{3}\pi_L + 0.8N_x\right] + \pi_t\left[\sum(0.01R_e + 0.04R_m)\pi_i + 0.1C\right]\right\}\times\left(1+2.7\times10^{-3}\times\left[\sum_{i=1}^{j}(\pi_n)_i\times(\Delta T_i)^{0.68}\right]\right)$$

interconnections, crossovers deposited components



Mathematical expression for π_t
$\pi_t = e^{1740\left(\frac{1}{303}-\frac{1}{273+t_A}\right)}$ with t_A : ambient temperature

C : Number of deposited capacitors
R_e : Number of thick film resistors having a same factor π_i *
R_m : Number of thin film resistors having a same factor π_i *

Precision factor *	π_i
Tolerance > 5%	1
Tolerance from 1 to 5%	1.5
Tolerance < 1%	2

* *: Count apart resistors according to* π_i

N_p = number of tracks
Default value: $= \frac{(\text{number of components connections})}{2}$

Number of layers influence	
Number of layers	π_C
≤ 2	1
> 2	$0.7\sqrt{(\text{number of layers})}$

N_X : **number of crossover**

S = Substrate surface (cm²)
N_t = number of holes for interconnections

Tracks width influence						
Predominant width (mm)	0,56	0,35	0,23	0,15	0,10	0,08
π_L	1	2	3	4	5	6

INTEGRATED CIRCUITS

INTEGRATED CIRCUITS

VALIDITY DOMAIN

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

The main failure mechanisms to assess are following:

- For Silicon technologies:
    - Electromigration
    - oxides ageing
    - hot electrons
    - charge gain and charge (for the write – erase cycles of the various programmable memories).

- For GaAs technologies:
    - Gate sink
    - Ohmic contact degradation
    - Gate and drain lagging.
    - Electromigration.

- Packages:
    - thermal fatigue
    - Purple plague.

Estimated failure rates are valid, only if the coldest part temperature of the considered card is over the dew point temperature.
The model does not include the failure rate due to soft errors* provoked by the creation of electron - hole pair, on the passage of alpha particle emitted by the package materials. This failure rate due to soft errors may be of the same order of magnitude as the intrinsic failure rate, especially for dynamic memories.

* When the function is fully retrievable without outside intervention.

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

ÉVALUATION DE LA TEMPÉRATURE DE JONCTION D'UN CIRCUIT INTEGRÉ

1.PREFERRED METHOD

- To evaluate the junction temperature of an integrated circuit, the preferred method is to calculate on the basis of thermal resistive network models, for instance as defined in UTE C 96024.

2.DEFAULT METHOD

- By default, the following simplified method will be used:

2.1 The junction temperature is given according to the average power dissipated in the integrated circuit by one of the following equations:

$$\boxed{\begin{aligned} t_j &= t_a + P \times R_{ja} \\ t_j &= t_c + P \times R_{jc} \end{aligned}}$$

in which:

t_a	= ambient temperature around the integrated circuit (°C)
t_c	= case temperature of the integrated circuit (°C)
t_j	= junction temperature of the integrated circuit (°C)
R_{ja}	= junction-ambient thermal resistance of the integrated circuit (°C/W)
R_{jc}	= junction-case thermal resistance of the integrated circuit (°C/W)
P	= average power dissipated by the integrated circuit (Watt)

note: the following equation applies:

junction-ambient thermal resistance = junction-case thermal resistance + case-ambient thermal resistance

2.2. Evaluating thermal resistance

2.2.1. Preferred method

The preferred method is to take the thermal resistance value specified or published by the manufacturers.

2.2.2. Default method

By default, the values given in table 9 will be taken according to S and K, where:

S: is the number of pins of the package.
K: is the cooling factor given, according to the velocity of air V in m/s, by the following equation:

$$\boxed{K = \frac{0.59V + 1.11}{V + 0.7}}$$

Practical values of K are given in table 10.

Table 9: Thermal resistance as a function of package type, the pin number and airflow factor

	Package thermal resistance of integrated circuits as a function of: **S**: number of pins, **K**: airflow factor (*see table 10*)	
	Junction-case thermal resistance R_{jc} (°C/W)	Junction-ambient thermal resistance R_{ja} (°C/W)
DIL ceramic package	$0.23\left(10 + \frac{1520}{S+3}\right)$	$(0.23 + 0.66K)\left(10 + \frac{1520}{S+3}\right)$
DIL plastic package	$0.33\left(10 + \frac{1520}{S+3}\right)$	$(0.23 + 0.66K)\left(10 + \frac{1520}{S+3}\right)$
PLCC plastic package	$0.28\left(15 + \frac{1600}{S+3}\right)$	$(0.28 + 0.72K)\left(10 + \frac{1600}{S+3}\right)$
SOJ and SOL plastic package	$0.28\left(15 + \frac{1760}{S+3}\right)$	$(0.28 + 0.72K)\left(10 + \frac{1760}{S+3}\right)$
TSOP plastic package	$0.4\left(20 + \frac{2500}{S+3}\right)$	$(0.4 + 0.6K)\left(20 + \frac{2500}{S+3}\right)$
PGA ceramic package	$0.33\left(10 + \frac{1440}{S+3}\right)$	$(0.33 + 0.66K)\left(10 + \frac{1440}{S+3}\right)$
QFP plastic package	$0.4\left(27 + \frac{2260}{S+3}\right)$	$(0.4 + 0.6K)\left(27 + \frac{2260}{S+3}\right)$
BGA plastic package	$0.4\left(6.6 + \frac{1.1\times10^6}{S^2}\right)$	$(0.4 + 0.6\mathrm{K})\left(6.6 + \frac{1.1\times10^6}{\mathrm{S}^2}\right)$

Table 10: Typical values of the air flow speed V, and the air flow factor K
.

	V (m/s)	K
Natural convection	0.15	1.4
Slightly assisted cooling	0.5	1.2
Fan assisted cooling	1	1
Forced cooling	4	0.7

2.3.Evaluating the average power dissipated by an integrated circuit P (Watt)

2.3.1. Preferably use the real average power dissipated by the integrated circuit.

2.3.2 By default, use the following method:

2.3.2.1 CMOS family

2.3.2.1.1 CMOS digital circuit, other than memory and 74 ACT family circuits

Calculate:

$$\boxed{P = \frac{P_1(P_1 + 3.5)}{3P_1 + 5}}$$

The value of P_1 *is calculated from one or the other following formulas:*

a) If an equivalent capacitance C_{pd} is specified :

$$\boxed{P_1 = \left(V_{cc}{}^2 \times f\right) \times \left[C_{pd}\left(\text{number of individual functions}\,*\right) + C_L\left(\text{number of output pin}\right)\right] \times 10^{-6}}$$

b) If a current consumption I_S is specified at a specified frequency f_S (Mhz):

$$\boxed{P_1 = V_{cc}.I_s.\,{}^{f}\!/\!_{f_s} + V^2{}_{cc}.f.C_{L}.\left(\text{number of outputs}\right) \times 10^{-6}}$$

where

P_1 = Maximum power (Watts)
V_{cc} = Supply voltage (Volts)
f = working frequency (Mhz)
C_{pd} = Equivalent capacitance for calculating dissipated power for each individual function, in pF
C_L = Load capacitance on outputs, for each output, in pF
I_S = specified value of the consumption current at a specified frequency f_S, and when outputs are not charged.
f_S = value of the specified frequency for the consumption (Mhz)

notes: 1) *in b case , the number of individual function has disappeared ,because the consumption current is only specified for circuits with one complex elementary function.*

2) Sometimes the working frequency f *is assimilated to* f_S

** This number is equal to 1, except in case of integrated circuits fitted with a package including several functions, the drawn current of which is defined individually*

The default values for V_{cc}, C_L, C_{pd} , f, are as follows:

V_{cc} = 5 volts or 3 volts
C_L = 50 pF
f = 30 Mhz for HC family; 50 Mhz for AC family.
C_{pd} : according to specification or catalogue.

.

2.3.2.1.2 CMOS digital circuits of the 74 ACT family

Calculate:

$$\boxed{P = \frac{P_I(P_I + 3.5)}{3P_I + 5}}$$

with

$$\boxed{P_I = 1{,}6.10^{-3} \times V_{cc} \times (\text{number of input pins}) + V_{cc}{}^2 \times f \times 10^{-6}\left[C_{pd} \times (\text{number of individual functions *}) + C_L \times (\text{number of output pins})\right]}$$

The default values for V_{cc}, C_L, C_{pd}, f, are as follows:

V_{cc} = 5 volts
C_L = 50 pF
C_{pd} = according to specification or catalogue
f = 50 Mhz

2.3.2.2. Bipolar, gallium arsenide, NMOS digital circuits

Calculate:

$$\boxed{P = \frac{P_M(P_M + 3.5)}{3P_M + 5} \text{ (in Watts)}}$$

where $P_M = \text{maximum continuous power} = V_{cc}\ \text{typical} \times I_{cc}\ \text{maximum}$

2.3.2.3. Circuits with a standby mode (for example: MOS memories)

Calculate:

$$\boxed{P = P_p \frac{d}{100} + P_r \times \left(1 - \frac{d}{100}\right)}$$

in which

d	= activation ratio as a percentage.
P_p	= worst case power consumption (specified or published)
P_r	= Power consumed in standby mode: $P_r = (V_{cc}\text{typical}) \times (I_{cc}\text{stand by})$

THE RELIABILITY MODEL

1. GENERAL FORM OF THE MODEL AND DEFINITIONS

- For an active device, the failure rate is noted λ and breaks down as :

$$\boxed{\lambda = \lambda_{die} + \lambda_{package}}$$

in which

$$\boxed{\lambda_{die} = \lambda_{thermal\ effects} + \lambda_{EOS\ effects}}$$

and

$$\boxed{\lambda_{package} = \lambda_{ethermomechanical\ effects}}$$

INTEGRATED CIRCUITS

Specification : CEI 60748

MATHEMATICAL MODEL :

$$\lambda = \left(\underbrace{\left\{ \lambda_1 \times N \times e^{-0.35 \times a} + \lambda_2 \right\} \times \left\{ \frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right\}}_{\lambda_{die}} + \underbrace{\left\{ 2.75 \times 10^{-3} \times \pi_\alpha \times \left(\sum_{i=1}^{z} (\pi_n)_i \times (\Delta T_i)^{0.68} \right) \times \lambda_3 \right\}}_{\lambda_{package}} + \underbrace{\left\{ \pi_I \times \lambda_{EOS} \right\}}_{\lambda_{overstress}} \right) \times 10^{-9} / h$$

NECESSARY INFORMATIONS:

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i[th] phase of the mission profile.
$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.
λ_1 : per transistor base failure rate of the integrated circuit family. See table13.
λ_2 : failure rate related to the technology mastering of the integrated circuit. See table 13.
N : number of transistors of the integrated circuit.
a : [(year of manufacturing) – 1998].
$(\pi_t)_i$: i[th] temperature factor related to the i[th] junction temperature of the integrated circuit mission profile.
τ_i : i[th] working time ratio of the integrated circuit for the i[th] junction temperature of the mission profile.
τ_{on} : total working time ratio of the integrated circuit. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$
τ_{off} : time ratio for the integrated circuit being in storage (or dormant). With $\tau_{on} + \tau_{off} = 1$
π_α : influence factor related to the thermal expansion coefficients difference, between the mounting substrate and the package material.
$(\pi_n)_i$: i[th] influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .
ΔT_i : i[th] thermal amplitude variation of the mission profile.
λ_3 : base failure rate of the integrated circuit package. See table 14.
π_I : influence factor related to the use of the integrated circuit (interface or not).
λ_{EOS} : failure rate related to the electrical overstress in the considered application..

Technological structure	Temperature factor π_t
MOS **BiCMOS** (low voltage)	$e^{\left[A\left(\frac{1}{328}-\frac{1}{273+t_j}\right)\right]}$ A=3480 ; (Ea=0.3 eV)
Bipolar **BiCMOS** (high voltage)	$e^{\left[A\left(\frac{1}{328}-\frac{1}{273+t_j}\right)\right]}$ A=4640 ; (Ea=0.4 eV)
AsGa Numerical	$e^{\left[A\left(\frac{1}{373}-\frac{1}{273+t_j}\right)\right]}$ A=3480 ; (Ea=0.3 eV)
AsGa MMIC	$e^{\left[A\left(\frac{1}{373}-\frac{1}{273+t_j}\right)\right]}$ A=4640 ; (Ea=0.4 eV)
t_j = Junction temperature in °C .	

Interface Circuits Typical calculated values			λ_{EOS} FIT	π_I
Function	**Electrical environment**			
Interfaces	Computer		10	1
	Telecoms	switching	15	1
		transmitting, access, subscriber cards	40	1
		subscriber equipment	70	1
	Railways, payphone		100	1
	Civilian avionics (on board calculators)		20	1
	Voltage supply, Converters		40	1
Non Interfaces	All electrical environment		-	0

Mathematical expression of the influence factor Π_α	$\pi_\alpha = 0.06 \times (\lvert\alpha_S - \alpha_C\rvert)^{1.68}$
Mismatch between substrate and package for the thermal expansion coefficient	$\lvert\alpha_S - \alpha_C\rvert$
α_S	See table 11
α_C	See table 11

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = \left[\frac{\Delta T_j}{3} + (t_{ac})_i\right] - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

INTEGRATED CIRCUITS

THERMAL EXPANSION COEFFICIENTS α_S AND α_C.

Linear thermal expansion coefficients	**Material type**	**Values in ppm/°C**
α_S (Substrate)	Epoxy Glass (FR4, G-10)	16
	PTFE Glass (polytetrafluoroethylene)	20
	Flexible substrate (Polyimide Aramid)	6.5
	Cu/Invar/Cu (20/60/20)	5.4
α_C (Component)	Epoxy (Plastic package)	21.5
	Alumina (ceramic package)	6.5
	Kovar (Metallic package)	5

Table 11

FAILURE DISTRIBUTION

- For non interfaces integrated circuits

Environment type	Stuck at Valim in %	Stuck at ground %	Open circuit %
Ground; Benign	50	50	0
Ground; Fixed Ground; mobile	5	5	90

Table 12

- For interfaces circuits, quasi totality of defects are open circuits.

CALCULATION EXAMPLE :

A microprocessor failure rate has to be calculated for an "automotive passenger compartment" mission profile.
This microprocessor has the following characteristics :
Manufacturing year : 1999 a=1999-1998=1 (See necessary information section)
Technology : numerical CMOS λ_1=3.4x10^{-6} and λ_2=1.7 (See table 13)
Transistor number : 1.5x10^6
Dissipated power by the component : 0.5 W
PQFP 80 pins package α_C=21.5 (See table 11)
Mounting substrate FR4 α_S=16 (See table 11) Then π_α=1
This circuit is not an interface. Then π_I =0.
Temperature increase related to fact that the circuit works, is given with natural convection (then K=1.4) by the following formulas. Junction – ambient thermal resistance for the PQFP package is given in table 9 :

$$RTH_{ja} = (0.4 + 0.6 \times 1.4) \times \left(27 + \frac{2260}{80+3}\right) = 67°C/W$$

Then ΔT_j= 67x0.5= 34°C

Mission profile from table 6 is following :

$(t_j)_1$= 27+34 = 61°C then $(\pi_t)_1 = e^{\left[3480\left(\frac{1}{328} - \frac{1}{273+61}\right)\right]} = 1.21$

$(t_j)_2$= 30+34 = 64°C then $(\pi_t)_2 = e^{\left[3480\left(\frac{1}{328} - \frac{1}{273+64}\right)\right]} = 1.33$

$(t_j)_3$= 85+34 = 118°C then $(\pi_t)_3 = e^{\left[3480\left(\frac{1}{328} - \frac{1}{273+118}\right)\right]} = 5.5$

$(t_{ae})_1$ is 14°C for world wide climate

$(t_{ac})_1$ average temperature during the working phases is : $\frac{0.006 \times 27 + 0.046 \times 30 + 0.006 \times 85}{0.058} = 35°C$

For the night starts phase, t_{ae} is 5°C ; for the day light starts phase t_{ae} is 15°C, then :

$\Delta T_1 = \left(\frac{34}{3} + 35\right) - 5 = 41$ $\Delta T_2 = \left(\frac{34}{3} + 35\right) - 15 = 31$ $\Delta T_3 = 10$

$$\lambda = \left(\underbrace{\left\{3.4\times10^{-6}\times1.5\times10^{6}\times e^{-0.35\times1} + 3.4\right\}\times\left\{\frac{1.21\times0.006+1.33\times0.046+5.5\times0.006}{0.058+0.942}\right\}}_{\lambda_{die}} + \left\{\underbrace{2.75\times10^{-3}\times1\times\left((670)^{0.76}\times(41)^{0.68}+(1340)^{0.76}\times(31)^{0.68}+(30)^{0.76}\times(10)^{0.68}\right)\times11.5}_{\lambda_{package}}\right\} + \left\{\underbrace{0\times\lambda_{EOS}}_{\lambda_{overstress}}\right\} \right)\times10^{-9}/h$$

The failure rate for this component will be 136 FIT for this mission profile.

INTEGRATED CIRCUITS

VALUES OF λ_1 AND λ_2 FOR INTEGRATED CIRCUITS FAMILIES

ABBREVIATIONS	TYPES	N Is the representative number of transistors	λ_1 in FIT	λ_2 in FIT
SILICON	**MOS : STANDARD CIRCUITS (3)**			
	Digital circuits, Micros, DSP	4 per gate	$3.4\ 10^{-6}$	1.7
	Linear circuits	Actual number	$1.0\ 10^{-2}$	4.2
	Digital / linear circuits (Telecom, CAN, CNA, RAMDAC, …)	Actual number	$2.7\ 10^{-4}$	20
	MEMORIES:			
ROM	Read only memory	1 per bit	$1.7\ 10^{-7}$	8.8
DRAM/VideoRAM/AudioRAM	Dynamic, Read Access Memory	1 per bit	$1.0\ 10^{-7}$	5.6
High speed SRAM, FIFO	Static Read Access Memory - First in First out register;(“ mixed MOS ”)	4 per bit	$1.7\ 10^{-7}$	8.8
Low consumption SRAM	Static Read Access Memory - Low consumption; (CMOS)	6 per bit	$1.7\ 10^{-7}$	8.8
Double access SRAM	Double Access Static RAM	8 per bit	$1.7\ 10^{-7}$	8.8
EPROM,UVPROM,REPROM	Electrically programmable, UV erasable - Read only memory			
OTP	One time programmable EPROM	1 / programmable point	$2.6\ 10^{-7}$	34
FLASH	Electrically programmable and erasable (block) (1)			
EEPROM, flash EEPROM	Electrically programmable and erasable (word) (2)	2 / programmable point	$6.5\ 10^{-7}$	16
(1) Whole memory array or blocks of words erasable (2) Blocks of words or word erasable (3) MOS include CMOS, HCMOS, NMOS, … technologies				
SILICON	**MOS : ASIC CIRCUITS**			
	Standard Cell, Full Custom	4 per gate	$1.2\ 10^{-5}$	10
	Gate Arrays	4 per gate	$2.0\ 10^{-5}$	10
	USER PROGRAMMABLE LOGIC DEVICE:			
LCA (RAM based)	Logic Cell Array electrically configured by external memory	40 per gate (1)	$4.0\ 10^{-5}$	8.8
PLD (GAL, PAL) (2)	Electrically Programmable and erasable (AND/OR array)	3 par grid point	$1.2\ 10^{-3}$	16
CPLD (EPLD,MAX,FLEX, FPGA, etc)	Electrically Programmable (interconnected macrocells array) (2)	100 per macrocell	$2.0\ 10^{-5}$	34
(1) or 4000 per macrocell ; (2) EEPROM, EPROM, or Antifuse technologies.				
SILICON	**BIPOLAR CIRCUITS (1)**			
	Digital circuits	3 per gate	$6.0\ 10^{-4}$	1.7
	Linear circuits (FET, others)	Actual number	$2.2\ 10^{-2}$	3.3
	MMIC	Actual number	1.0	3.3
	Linear / Digital circuits, low voltage (<30V)	Actual number	$2.7\ 10^{-3}$	20
	Linear / Digital circuits, high voltage(>=30V)	Actual number	$2.7\ 10^{-2}$	20
	MEMORIES – PROGRAMMABLE ARRAYS- GATE ARRAYS:			
SRAM	Static read access memories	2.5 per bit	$3.0\ 10^{-4}$	1.7
PROM,	Programmable read only memory	1.2 /, programmable point	$1.5\ 10^{-4}$	32
PLD (PAL)	One time electrically programmable logic array (AND / OR arrays)	1.6 per grid point	$1.5\ 10^{-4}$	32
	Gate arrays	3 per gate	$1.0\ 10^{-3}$	10
Bipolar include : TTL, MTTL, LSTTL, FET, JFET, ECL, etc… technologies.				
SILICON	**BIPOLAR AND MOS CIRCUITS (BICMOS)**			
	Digital circuits	4 per gate	$1.0\ 10^{-6}$	1.7
	Linear / digital circuits low voltage (< 6V)	Actual number	$2.7\ 10^{-4}$	20
	Linear / digital circuits, high voltage (>= 6V) and Smart Power	Actual number	$2.7\ 10^{-3}$	20
SRAM	Static Read Access Memory	4 per bit	$6.8\ 10^{-7}$	8.8
	Gate arrays	4 per gate	$6.4\ 10^{-5}$	10
ARSÉNIURE DE GALLIUM				
Digital	with only normally on transistors.	5 per gate	2.5	25
Digital	with normally off and normally on transistors.	3 per gate	$4.5\ 10^{-4}$	16
MMIC	Low noise or low power (< 100mW) microwave circuits.	Actual number	2.0	20
MMIC	Power (> 100mW) microwave circuits.	Actual number	4.0	40

table 13

INTEGRATED CIRCUITS

VALUES OF λ_3 INTEGRATED CIRCUITS PACKAGES

Abbreviation	**Material type**	**Description**	**Pin number :** S	λ_3 in FIT
SO ,SOP	Epoxy	Plastic Small Outline, L lead	4 à 32	$= 0.042 \times S^{1.5}$
Power SO	Epoxy	idem SO with heat sink		idem SO
SOJ	Epoxy	Plastic Small Outline, J Lead	16 à 24	$= 0.023 \times S^{1.57}$
VSOP	Epoxy	Very Small Outline, L Lead	40 à 56	$= 0.012 \times S^{1.65}$
SSOP	Epoxy	Shrink Small Outline, L Lead	4 à 56	$= 0.011 \times S^{1.6}$
TSSOP	Epoxy	Thin Shrink Small Outline, L Lead	4 à 56	$= 0.011 \times S^{1.6}$
TSOP I ; 0.65 mm pitch	Epoxy	Thin Small Outline, L Lead on small edge	18 à 24	$= 0.011 \times S^{3.2}$
TSOP I ; 0.5 mm pitch	Epoxy	Thin Small Outline, L Lead on small edge	18 à 32	$= 0.023 \times S^{3.1}$
TSOP II ; 0.8 mm pitch	Epoxy	Thin Small Outline, L Lead on long edge.	28 à 54	$= 0.043 \times S^{1.7}$
TSOP II ; 0.65 mm pitch	Epoxy	Thin Small Outline, L Lead on long edge.	14 à 32	$= 0.011 \times S^{1.6}$
TSOP II ; 0.5 mm pitch	Epoxy	Thin Small Outline, L Lead on long edge.	34 à 60	$= 0.023 \times S^{1.57}$
TSOP II ; 0.4 mm pitch	Epoxy	Thin Small Outline, L Lead on long edge.	34 à 60	$= 0.043 \times S^{1.64}$
PLCC	Epoxy	Plastic Leaded Chip Carrier, J Lead	20 à 84	$= 0.023 \times S^{1.57}$
CLCC	Alumina	Ceramic Leadless (and Leaded) Chip Carrier		idem PLCC
MQUAD	Kovar	Metallic Quad Flat Package (PLCC footprint)		idem PLCC
PQFP, TQFP	Epoxy	Plastic (Thin) Quad Flat pack, L Lead	32 à 40	1.4
			40 à 60	2.6
			60 à 68	4.5
			68 à 110	11.5
			110 à 225	26
			225 à 280	32.5
			280 à 304	47.3
ED QUAD, Power QUAD	Epoxy	idem PQFP with heat sink (exposed slug)		idem PQFP
CQFP, CERQUAD	Alumina	Ceramic Quad Flat pack		idem PQFP
MQFP, MQUAD	Kovar	Metallic Quad Flat pack		idem PQFP
PBGA	Epoxy	Plastic Ball Grid Array- pitch >1mm	64 à 80	12
			80 à 160	17.3
			160 à 280	27.7
			280 à 400	53.3
SBGA	Epoxy	Shrink BGA-pitch=1mm-Body=42.5x42.5 mm^2	580	74
SBGA	Epoxy	Shrink BGA-pitch=1mm-Body=27x27 mm^2	672	34.5
CBGA	Alumina	Ceramic		idem PBGA
PDIL	Epoxy	Plastic Dual In Line	8 à 64	$= 9 + 0.09 \times S$
CDIL, CERDIP	Alumina	Ceramic Dual In Line	8 à 64	$= 9 + 0.09 \times S$
PPGA	Epoxy	Plastic Pin Grid Array	40 à 160	$= 9 + 0.09 \times S$
CPGA	Alumina	Ceramic Pin Grid Array	40 à 160	$= 9 + 0.09 \times S$

Table 14

DIODES AND THYRISTORS, TRANSISTORS, OPTOCOUPLERS

ACTIVE DISCRETE

EVALUATING THE JUNCTION TEMPERATURE OF DIODES AND TRANSISTORS

To evaluate the junction temperature of a transistor or diode, the preferred method for critical cases is to measure or calculate on the basis of thermal resistive network models (for instance, as defined in UTE C96024).

By default, the following simplified method will be used :

The junction temperature is given according to the average dissipated power, by one of the following equations :

$$\boxed{\begin{array}{c} t_j = t_a + P \times R_{ja} \\ t_j = t_c + P \times R_{jc} \end{array}}$$

Where :

t_a = ambient temperature around the case (°C)

t_c = case temperature (or socket temperature) (°C)

t_j = junction temperature (°C)

R_{ja} = Thermal resistance (junction-ambient) of the component. (°C/W)

R_{jc} = Thermal resistance junction-case or mounting base). (°C/W)

P = average power dissipated. (in watt)

Tableau 15 gives various thermal resistance values.

The first column gives the junction-case thermal resistance R_{jc} for power components or certain applications (such as use of a heat sink or insertion in a socket)

The second column gives the junction-ambient thermal resistance R_{ja} for components used in conditions of natural cooling, without additional heat sink.

The third column gives the junction-ambient thermal resistance for components soldered in a “surface mount” production line.

Thermal resistance depends largely on the type of case, but also on the size of the die and the internal fixing mode (bonding, hard solder, soft solder): the values given represent realistic examples.

Note the following equation :

(junction - ambient) thermal resistance = (junction - case) thermal resistance + (case - ambient) thermal resistance

ACTIVE DISCRETE

VALUES OF λ_B AND JUNCTION RESISTANCES FOR ACTIVE DISCRETE COMPONENTS

Package abbreviations	**Rjc** **°C/W**	**Rja** **°C/W**	**Rja mounted component °C/W**	λ_B **FIT**
TO-18	130	450		1
TO-39	35	200		2.0
TO-92	100	300		1
SOT-23			400	1.0
SOT-143			400	1.0
SOT-223			85	3.4
SOT-323			600	0.8
SOT-343			600	0.8
SOT-346			500	1
SOT-363			600	0.8
SOT-457			350	1.1
SOT-89			125	2.0
SOT-32 (TO-126)	10	100		5.3
SOT-82	10	100		5.3
DPACK (SOT428)			30	5.1
D2PACK			15	5.7
TO-220	3			5.7
TO-218 (SOT-93)	1.5			6.9
TO-247	1			6.9
ISOTOP	0.25			20.0
SOT-90B (optocoupler)		250		4.1
SO-8 (optocoupler)			300	4.5
DO-34 (DO-204AG)		500		2.5
DO-35 (DO-204AH)		400		2.5
DO-41 (DO-204AL) (glass)		150		2.5
DO-41 (DO-204AL) (plastic)		100		1
F 126		70		1
micromelf			600	2.5
SOD-80 (minimelf)			600	2.5
melf			450	5.0
SOD-110			350	0.8
SOD-123			600	1.0
SOD-323			600	0.7
SOD-523			100	0.5
SMA			600	1.8
SMB (DO-214)			75	2.4
SMC (DO-215)			25	5.1
DO-220	3			5.7
SOD-15			20	5.1

Table 15

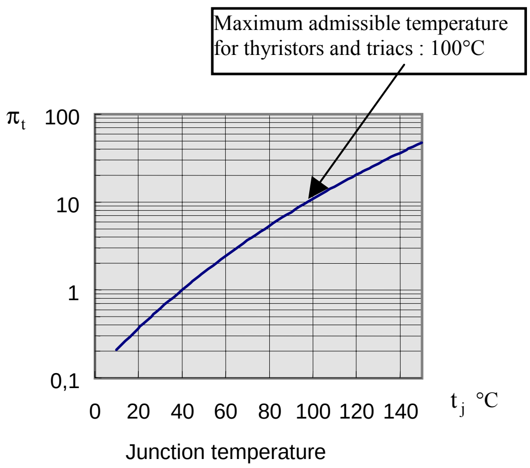
Silicon : signal diodes; PIN; fast and slow recovery rectifier diodes; SCHOTTKY; up to 3A
Thyristors, triacs up to 3A
Zener diodes up to 1.5W
Transient voltage suppressors, up to 5 kW (peak, 10µs/1000µs)
Gallium arsenide diodes, up to 0.1W

MATHEMATICAL MODEL

$$\lambda = \left[\underbrace{\{\pi_U \times \lambda_0\} \times \left\{ \frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right\}}_{\lambda_{die}} + \left\{ \underbrace{\left(2.75 \times 10^{-3} \times \sum_{i=1}^{z} (\pi_n)_i \times (\Delta T_i)^{0.68} \right) \times \lambda_B}_{\lambda_{package}} \right\} + \left\{ \underbrace{\pi_I \times \lambda_{EOS}}_{\lambda_{ooverstress}} \right\} \right] \times 10^{-9} / h$$

NECESSARY INFORMATION:

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i[th] phase of the mission profile.
$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.
π_U : use factor (permanent or not)
λ_0 : base failure rate of the die. See table on this page
$(\pi_t)_i$: i[th] temperature factor related to the i[th] junction temperature of the diode mission profile.
τ_i : i[th] working time ratio of the diode for the i[th] junction temperature of the mission profile.
τ_{on} : total working time ratio of the diode. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$
τ_{off} : time ratio for the diode being in storage (or dormant) mode.
$(\pi_n)_i$: i[th] influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .
ΔT_i : i[th] thermal amplitude variation of the mission profile.
λ_B : base failure rate of the diode package. See table 15.
π_I : influence factor related to the use of the diode (protection interface or not).
λ_{EOS} : failure rate related to the electrical overstress in the considered application..



For protection diodes	tj = ambient temperature
other diodes	tj = ambient temp. +($R_{th} \times P$)

Mathematical formula for π_t

$$\pi_t = e^{4640\left(\frac{1}{313} - \frac{1}{t_j + 273}\right)} \quad \textit{(0.4 electron-volt)}$$

Protection diodes as interface; typical calculated values			λ_{EOS} FIT	π_I
Function	**Electrical environment**			
Protection Interface	Computer		10	1
	Telecoms	switching	15	1
		transmitting access, subscriber cards	40	1
		Subscriber equipment	70	1
	Railways, payphone		100	1
	Civilian avionics (on board calculators)		20	1
	Voltage supply, Converters		40	1
Non Interfaces	All electrical environment			0

Failure rate for tj=40°C (expressed in FIT)			λ_0
Silicon diodes	signal (<1A)		0.07
	Recovery , rectifier 1A à 3A		0.1
	Zener (regulator) ≤ 1.5 watt		0.4
	suppressor	Transient voltage	2.3
		Trigger transient voltage	2
Gallium arsenide diodes (≤ 0.1 W)			0.3
Thyristors, triacs (≤ 3A)			1

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \leq 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = \left[\frac{\Delta T_j}{3} + (t_{ac})_i \right] - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th phase of the mission profile.	

Type of use		π_U
Thyristors and triacs	Permanent use*	10
	Occasional use* (ratio off/on>1)	1
Other diodes		1

* : *Expression " use " is corresponding to a switching conditions the, component is reverse biased part of the time . When the component is forward biased permanently, take* Π_U *=1*

Failure distribution			
	Zener diodes	Thyristors	Others
Short circuits	70%	20%	80%
Open circuits	20%	20%	20%
Zener voltage drift	10%		
Forward leakage current drift		60%	

Notet 1 ***: Predicted values can be reached by Schottky diodes only if it is a Platinum-Nickel structure***

Note 2 : ***Diodes used as a protection function must be specified for this function (voltage suppressor). In the contrary case, the given failure rate*** λ_{EOS} ***for the electrical environment might be higher.***

Silicon : Rectifier diodes; fast recovery rectifier diodes; SCHOTTKY; above 3A
Thyristors, triacs; above 3A
Zener diodes above 1.5W
Transient voltage suppressors 5 kW (en crête, 10µs/1000µs)
Gallium arsenide diodes, above 0.1W

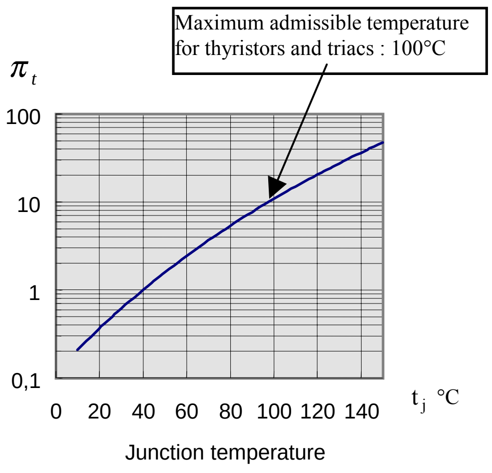
} excepted modules

MATHEMATICAL MODEL

$$\lambda = \left\{ \underbrace{\{\pi_U \times \lambda_0\} \times \left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on}+\tau_{off}}\right]}_{\lambda_{die}} + \left\{\underbrace{\left(2.75\times10^{-3}\times\sum_{i=1}^{z}(\pi_n)_i\times(\Delta T_i)^{0.68}\right)\times\lambda_B}_{\lambda_{package}}\right\} + \left\{\underbrace{\pi_I\times\lambda_{EOS}}_{\lambda_{overstress}}\right\} \right\}\times 10^{-9}/h$$

NECESSARY INFORMATION:*

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i[th] phase of the mission profile.
$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.
π_U : use factor (permanent or not)
λ_0 : base failure rate of the die. See table on this page
$(\pi_t)_i$: i[th] temperature factor related to the i[th] junction temperature of the diode mission profile.
τ_i : i[th] working time ratio of the diode for the i[th] junction temperature of the mission profile.
τ_{on} : total working time ratio of the diode. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$
τ_{off} : time ratio for the diode being in storage (or dormant) mode.
$(\pi_n)_i$: i[th] influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .
ΔT_i : i[th] thermal amplitude variation of the mission profile.
λ_B : base failure rate of the diode package. See table 15.
π_I : influence factor related to the use of the diode (protection interface or not).
λ_{EOS} : failure rate related to the electrical overstress in the considered application..



For protection diodes	tj = ambient temperature
other diodes	tj = ambient temp. +($R_{th} \times P$)

Protection diodes as interface; typical calculated values			λ_{EOS} FIT	π_I
Function	**Electrical environment**			
Protection Interface	Computer		10	1
	Telecoms	switching	15	1
		transmitting access, subscriber cards	40	1
		Subscriber equipment	70	1
	Railways, payphone		100	1
	Civilian avionics (on board calculators)		20	1
	Voltage supply, Converters		40	1
Non Interfaces	All electrical environment			0

Mathematical formula for π_t

$$\pi_t = e^{4640\left(\frac{1}{313}-\frac{1}{t_j+273}\right)} \quad (0.4 \text{ electron-volt})$$

Failure rate for tj=40°C (expressed in FIT)			λ_0
Silicon Diodes	Recovery , rectifier (>3A)		0.7
	Zener (regulator) >1,5 watt		0.7
	suppressor	Transient voltage	0.7
		Trigger transient voltage	3
Gallium arsenide diodes (>0,1 w)			1
Thyristors, triacs (>3A)			3

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = \left[\frac{\Delta T_j}{3} + (t_{ac})_i\right] - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

Type of use		π_U
Thyristors and triacs	Permanent use*	10
	Occasional use* (ratio off/on>1)	1
Other diodes		1

* : *Expression " use " is corresponding to a switching conditions the, component is reverse biased part of the time . When the component is forward biased permanently, take* Π_U *=1*

Failure distribution			
	Zener diodes	Thyristors	Others
Short circuits	70%	20%	80%
Open circuits	20%	20%	20%
Zener voltage drift	10%		
Forward leakage current drift		60%	

Notet 1 ***: Predicted values can be reached by Schottky diodes only if it is a Platinum-Nickel structure***

Note 2 : ***Diodes used as a protection function must be specified for this function (voltage suppressor). In the contrary case, the given failure rate*** λ_{EOS} ***for the electrical environment might be higher.***

Silicon, junction, FET, MOS; up to 5 watts
Gallium Arsenide ; up to 1 watt.

MATHEMATICAL MODEL

$$\lambda = \left(\underbrace{\{\pi_S \times \lambda_0\} \times \left\{ \frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right\}}_{\lambda_{die}} + \left\{ \underbrace{2.75\times10^{-3} \times \left(\sum_{i=1}^{z} (\pi_n)_i \times (\Delta T_i)^{0.68} \right) \times \lambda_B}_{\lambda_{package}} \right\} + \left\{ \underbrace{\pi_I \times \lambda_{EOS}}_{\lambda_{overstress}} \right\} \right) \times 10^{-9}/h$$

NECESSARY INFORMATIONS :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

π_S : charge factor.

λ_0 : base failure rate of the die. See table on this page

$(\pi_t)_i$: i^th temperature factor related to the i^th junction temperature of the transistor mission profile.

τ_i : i^eme working time ratio of the transistor for the i^th junction temperature of the mission profile.

τ_{on} : total working time ratio of the transistor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the transistor being in storage (or dormant) mode.

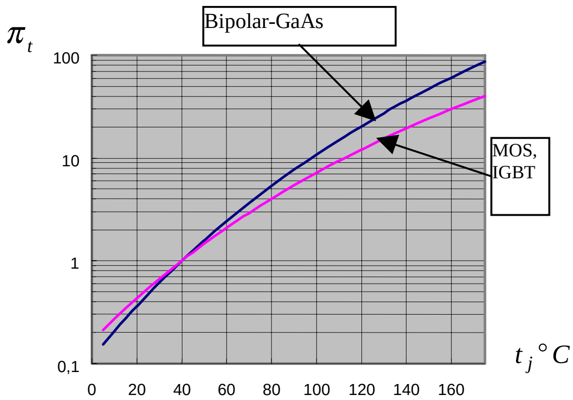
$(\pi_n)_i$: i^th influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .

ΔT_i : i^th thermal amplitude variation of the mission profile.

λ_B : base failure rate of the transistor package. See table 15.

π_I : influence factor related to the use of the transistor (protection interface or not).

λ_{EOS} : failure rate related to the electrical overstress in the considered application..



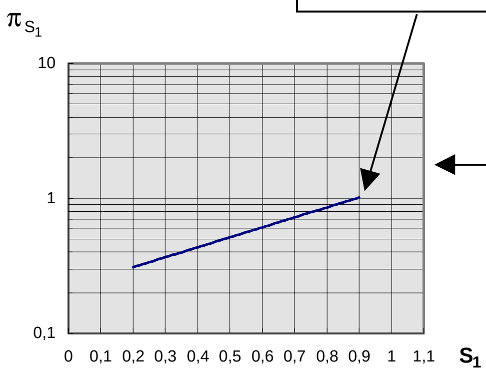
Protection transistor as interface; typical calculated values			λ_{EOS} FIT	π_I
Function	**Electrical environment**			
Protection Interface	Computer		10	1
	Telecoms	switching	15	1
		transmitting access, subscriber cards	40	1
		Subscriber equipment	70	1
	Railways, payphone		100	1
	Civilian avionics (on board calculators)		20	1
	Voltage supply, Converters		40	1
Non Interfaces	All electrical environment			0

Failure rate for tj=40°C (expressed in FIT)	λ_0
Silicon transistors • Bipolar; npn; pnp • MOS p, n ; FET	0.75
Gallium Arsenide transistors	0.3

Mathematical formulas for π_t and π_S		
π_t	Bipolar GaAs	$\pi_t = e^{4640(\frac{1}{373} - \frac{1}{t_j + 273})}$ (activation energy: 0.4 ev)
	MOS IGBT	$\pi_t = e^{3480(\frac{1}{373} - \frac{1}{t_j + 273})}$ (activation energy: 0.3 ev)
π_S	FET,MOS IGBT	$\pi_{S1} = 0.22e^{1.7S_1}$ $\Pi_{S2} = 0.22e^{3S_2}$
	Bipolar	$\Pi_S = 0.22e^{1.7S}$

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase		$\Delta T_i = \left[\frac{\Delta T_j}{3} + (t_{ac})_i\right] - (t_{ae})_i$
For a permanent working phase, storage or dormant		ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th phase of the mission profile.

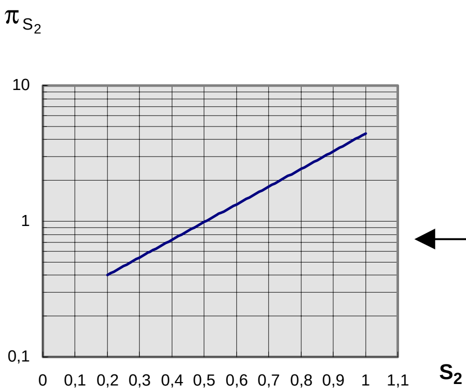
Maximum admissible value



FET, MOS :

$$\pi_S = \pi_{S_1} \times \pi_{S_2}$$

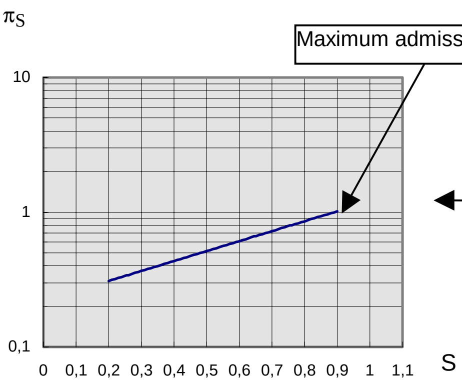
$$S_1 = \frac{\text{Maximum repetitive applied} V_{DS} \text{ voltage}}{\text{Minimum specified } V_{DS} \text{ voltage}}$$



- **S_2** is accepted up to 1 since the destructive gate oxide voltage value is normally three times greater than the maximum rated V_{gs} voltage (for MOS transistors).
- These values (maximum and destructive V_{gs} values) shall be checked during the qualification process.
  For instance, if the maximum rated V_{gs} voltage is 20 volts, the destructive V_{gs} voltage value must be greater than 60 volts (practically between 60 and 80 volts).

$$S_2 = \frac{\text{Maximum repetitive applied } V_{GS} \text{ voltage}}{\text{Minimum specified } V_{GS} \text{ voltage}}$$

Maximum admissible value



BIPOLAR

$$S = \frac{\text{Maximum repetitive applied } V_{CE} \text{ voltage}}{\text{Minimum specified } V_{CE} \text{ breakdown voltage}}$$

Fragile assembly :
1 – Cavity package weighting more than 0.1g
2 – Package weighting more than 0.1g and fixed by leads (more than 2 mm)

Strong assembly :
1 – Molded plastic components (lead less than 2 mm) or DIL, or surface mounted component (SMT)
2 – Firmly fixed packages (screw, clips, glue)
3 – Components weighting more than 0.1g

Failure distribution		%
Silicon	Short-circuits	85
	Open-circuits	15
Gallium - arsenide	Short-circuits	95
	Open-circuits	5

Silicon : 5 watts or more
Gallium arsenide : 1 watt. Or more

Excepted modules

CAUTION !
Under cyclic operation, the life time is limited !

MATHEMATICAL MODEL

$$\lambda = \left(\underbrace{\{\pi_S \times \lambda_0\} \times \left\{ \frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right\}}_{\lambda_{die}} + \left\{ \underbrace{\left(2.75\times10^{-3} \times \sum_{i=1}^{z} (\pi_n)_i \times (\Delta T_i)^{0.68} \right)}_{\lambda_{package}} \times \lambda_B \right\} + \left\{ \underbrace{\pi_I \times \lambda_{EOS}}_{\lambda_{overstress}} \right\} \right) \times 10^{-9} / h$$

NECESSARY INFORMATIONS :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i[th] phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

π_S : charge factor.

λ_0 : base failure rate of the die. See table on this page

$(\pi_t)_i$: i[th] temperature factor related to the i[th] junction temperature of the transistor mission profile.

τ_i : i[th] working time ratio of the transistor for the i[th] junction temperature of the mission profile.

τ_{on} : total working time ratio of the transistor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the transistor being in storage (or dormant) mode.

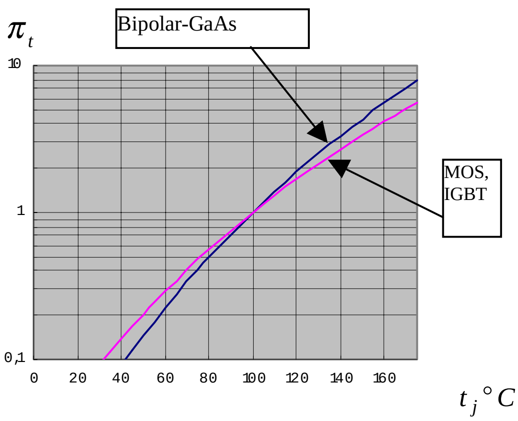
$(\pi_n)_i$: i[th] influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .

ΔT_i : i[th] thermal amplitude variation of the mission profile.

λ_B : base failure rate of the transistor package. See table 15.

π_I : influence factor related to the use of the transistor (protection interface or not).

λ_{EOS} : failure rate related to the electrical overstress in the considered application..



Protection transistor as interface; typical calculated values			λ_{EOS} FIT	π_I
Function	**Electrical environment**			
Protection Interface	Computer		10	1
	Telecoms	switching	15	1
		transmitting access, subscriber cards	40	1
		Subscriber equipment	70	1
	Railways, payphone		100	1
	Civilian avionics (on board calculators)		20	1
	Voltage supply, Converters		40	1
Non Interfaces	All electrical environment			0

Failure rate for tj=100°C (expressed in FIT)	λ_0
Silicon transistors • Bipolar; npn; pnp • MOS p, n ; FET	2
Gallium Arsenide transistors	1

Mathematical formulas for π_t and π_S		
π_t	Bipolar GaAs	$\pi_t = e^{4640\left(\frac{1}{373} - \frac{1}{t_j+273}\right)}$ (activation energy : 0.4 ev)
	MOS IGBT	$\pi_t = e^{3480\left(\frac{1}{373} - \frac{1}{t_j+273}\right)}$ (activation energy : 0.3 ev)
π_S	FET,MOS IGBT	$\pi_{S_1} = 0.22e^{1.7S_1}$ $\pi_{S_2} = 0.22e^{3S_2}$
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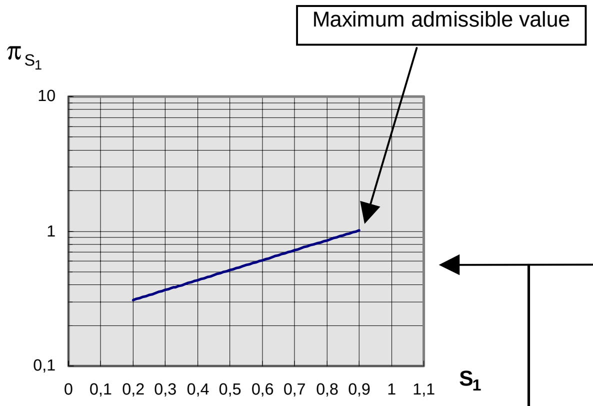
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = \left[\frac{\Delta T_j}{3} + (t_{ac})_i\right] - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

POWER TRANSISTORS



Life expectancy

Under cyclic operation, the number of cycles is limited to:

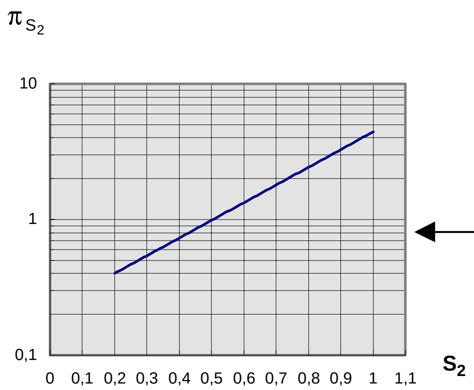
$$N = 10^7 e^{-0.05 \Delta t_j}$$

Δt_j : junction temperature range

FET, MOS :

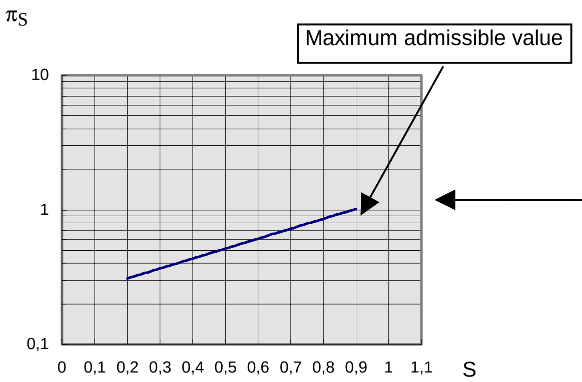
$$\pi_S = \pi_{S_1} \times \pi_{S_2}$$

$$S_1 = \frac{\text{Maximum repetitive applied} V_{DS} \text{ voltage}}{\text{Minimum specified } V_{DS} \text{ voltage}}$$



- **S_2** is accepted up to 1 since the destructive gate oxide voltage value is normally three times greater than the maximum rated V_{gs} voltage (for MOS transistors).
- These values (maximum and destructive V_{gs} values) shall be checked during the qualification process.
  For instance, if the maximum rated V_{gs} voltage is 20 volts, the destructive V_{gs} voltage value must be greater than 60 volts (practically between 60 and 80 volts).

$$S_2 = \frac{\text{Maximum repetitive applied } V_{GS} \text{ voltage}}{\text{Minimum specified } V_{GS} \text{ voltage}}$$



BIPOLAR

$$S = \frac{\text{Maximum repetitive applied } V_{CE} \text{ voltage}}{\text{Minimum specified } V_{CE} \text{ breakdown voltage}}$$

Fragile assembly :
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Strong assembly :
1 – Molded plastic components (lead less than 2 mm) or DIL, or surface mounted component (SMT)
2 – Firmly fixed packages (screw, clips, glue)
3 – Components weighting more than 0.1g

Failure distribution		%
Silicon	Short-circuits	85
	Open-circuits	15
Gallium - arsenide	Short-circuits	95
	Open-circuits	5

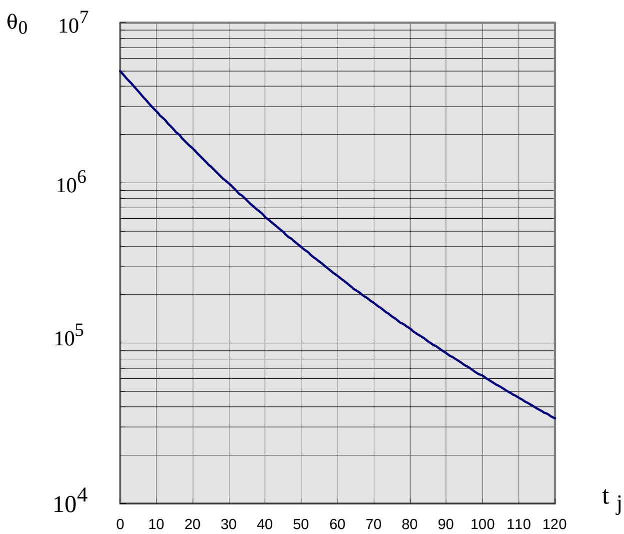
OPTOCOUPLERS
Life expectancy

The operating time must not exceed the life expectancy value θ. Beyond this time, the failure rate λ could not be assumed to be constant.

Necessary information	for
Junction temperature t_j	θ_0
Input current (operating and test condition)	κ_0, κ_2
Initial, final transfer ratio	κ_1

$\theta = \theta_0 \times \kappa_0 \times \kappa_1 \times \kappa_2 \times \kappa_3$ hours

For molded plastic optocouplers, the temperature junction must not exceed 90°C



Life expectancy in hours= f(junction temperature t_j)

Optocoupler life expectancy θ_0 according to the junction temperature and the following failure criterion:

- Transfer ratio measurement conditions

  $V_{CE} = 5$ volts $I_F = 2$mA

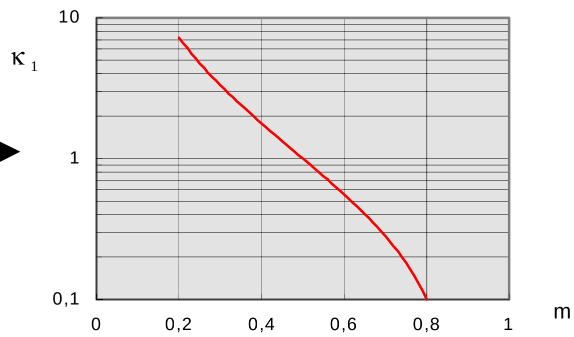
  $$\frac{\text{Final transfert ratio}}{\text{Initial transfert ratio}} = m = 0.5$$

- For an operating current of 50 mA

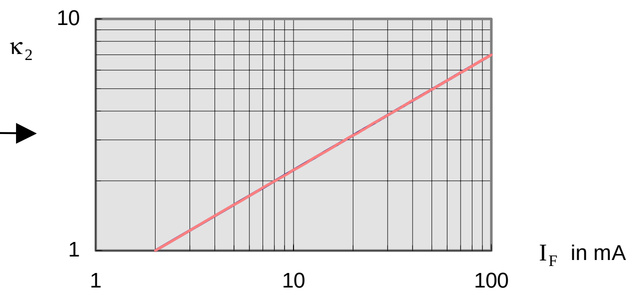
Note : The life expectancy is estimated for a cumulative failure ratio of 10%

Life expectancy θ_0
$0.4e^{\frac{4640}{t_j+273}}$

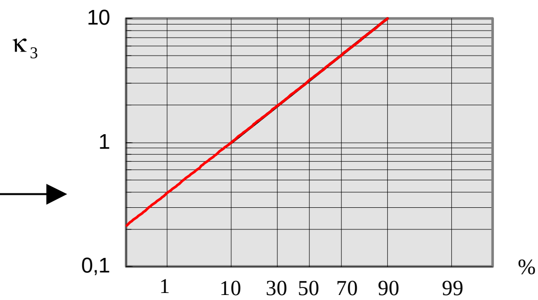
$$\kappa_0 = \frac{50}{\text{input current (operating, mA)}}$$



κ_1 according to the selected ratio $m = \frac{\text{Final transfert ratio}}{\text{Initial trans fer ratio}}$



κ_2 according to the measured current I_F of the transfer ratio (testing conditions).



κ_3 for a cumulative failure ratio different from10%

OPTOCOUPLERS
Failure rate

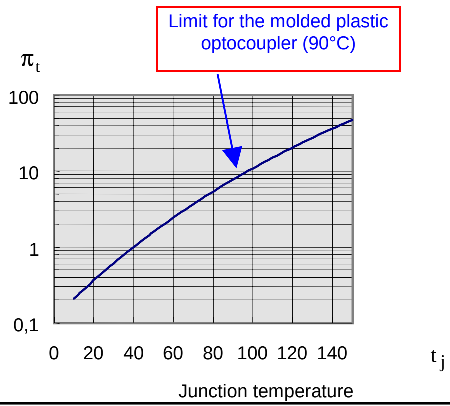
MATHEMATICAL MODEL

$$\lambda = \left(\underbrace{\{2.2\times\pi_S\}\times\left\{\frac{\sum_{i=1}^{y}(\pi_t)_i\times\tau_i}{\tau_{on}+\tau_{off}}\right\}}_{\lambda_{die}} + \left\{\underbrace{\left(2.75\times10^{-3}\times\sum_{i=1}^{z}(\pi_n)_i\times(\Delta T_i)^{0.68}\right)}_{\lambda_{package}}\times\lambda_B\right\} + \left\{\underbrace{\pi_I\times\lambda_{EOS}}_{\lambda_{overstress}}\right\} \right)\times10^{-9}\ /\ h$$

✐CAUTION !
Life expectancy is limited !

NECESSARY INFORMATIONS :

- $(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the ith phase of the mission profile.
- $(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.
- π_S : charge factor.
- $(\pi_t)_i$: ith temperature factor related to the ith junction temperature of the optocoupler mission profile.
- τ_i : ith working time ratio of the optocoupler for the ith junction temperature of the mission profile.
- τ_{on} : total working time ratio of the optocoupler. With: $\tau_{on} = \sum_{i=1}^{y}\tau_i$
- τ_{off} : time ratio for the optocoupler being in storage (or dormant) mode.
- $(\pi_n)_i$: ith influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .
- ΔT_i : ith thermal amplitude variation of the mission profile.
- λ_B : base failure rate of the optocoupler package. See table 15.
- π_I : influence factor related to the use of the optocoupler (interface or not).
- λ_{EOS} : failure rate related to the electrical overstress in the considered application..



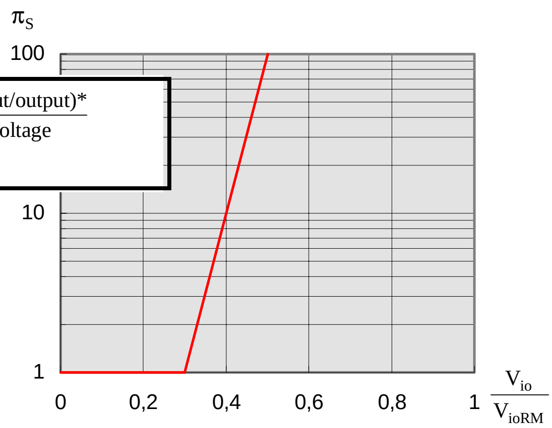
t_j = ambient temperature + (power dissipation*) x R_{ja}

* emitter + receiver

Optocoupler as interface; typical calculated values			λ_{EOS}	π_I
Function	**Electrical environment**		FIT	
Protection Interface	Computer		10	1
	Telecoms	switching	15	1
		transmitting access, subscriber cards	40	1
		Subscriber equipment	70	1
	Railways, payphone		100	1
	Civilian avionics (on board calculators)		20	1
	Voltage supply, Converters		40	1
Non Interfaces	All electrical environment			0

$\frac{V_{io}}{V_{ioRM}}$ $\frac{\text{permanent applied voltage (input/output)*}}{\text{peak, repetitive insulation voltage}}$

* without considering partial discharges.



Influence of the applied voltage between input-output

Failure distribution	
Open circuits	50%
Short circuits	10%
Drift	40%

Mathematical formula π_t

$$\pi_t = e^{4640\left(\frac{1}{313}-\frac{1}{t_j+273}\right)}$$ (activation energy : 0.4 ev)

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = \left[\frac{\Delta T_j}{3} + (t_{ac})_i\right] - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^{th} phase of the mission profile.	

OPTOELECTRONICS

NOTE:

Optical components failure rates in this section are only given for the ground fixed environment, with a permanent working mission profile, and a daylight-night thermal cycling lesser than 3°C.

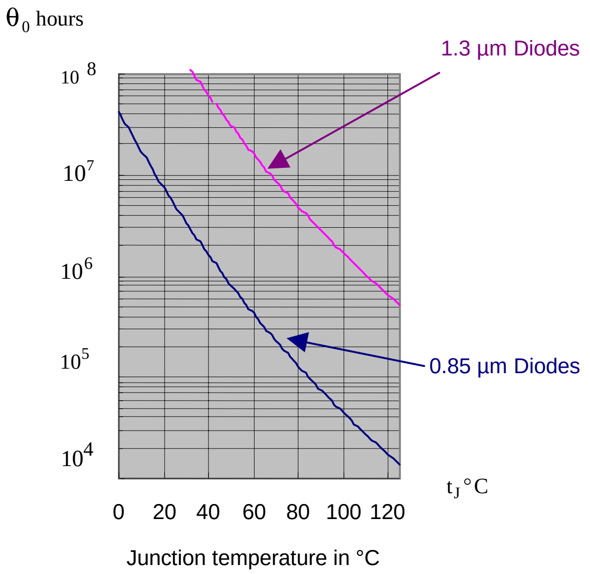
LIGHT EMITTING DIODES
Life expectancy

$$\theta = \theta_0 \times \kappa_0 \times \kappa_1 \times \kappa_2 \times \kappa_3 \quad \text{hours}$$

The operating time must not exceed the life expectancy value θ .
Beyond this time the failure rate λ could not be assumed to be constant.

Necessary information	for
Junction temperature t_j	θ_0
Operating current	κ_0
Measurement current (for optical power)	κ_2

$$\kappa_0 = \frac{100}{\text{operating input current(mA)}}$$



Life expectancy θ_0 of a LED according to the junction temperature t_j

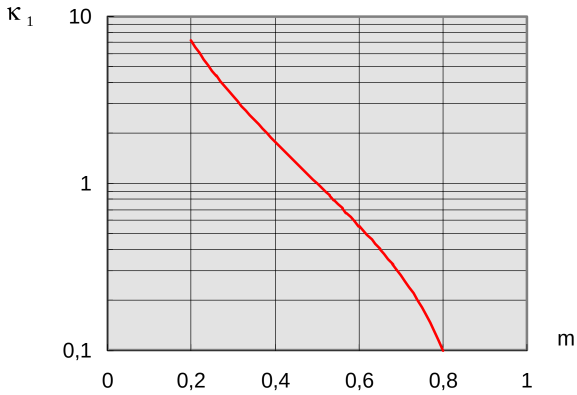
- For an operating current of 100mA
- For the failure criterion :

$$m = \frac{\text{Final optical power}}{\text{Initial optical power}} = 0.5$$

(with an optical power measuring current equal to 100 mA)

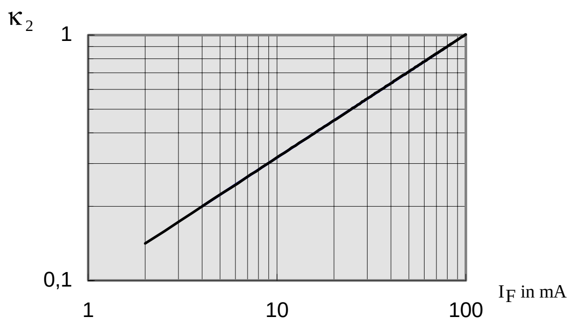
Note : The life expectancy θ_0 is evaluated for a cumulative failure ratio of 10%

Diode Types	Life expectancy θ_0 expressed in hours
0,85 µm Diodes	$2.3\times10^5 e^{7000\left(\frac{1}{t_j+273}-\frac{1}{343}\right)}$ (0.6 electron-volt)
1,3 µm Diodes	$8.7\times10^6 e^{7000\left(\frac{1}{t_j+273}-\frac{1}{343}\right)}$ (0.6 electron-volt)

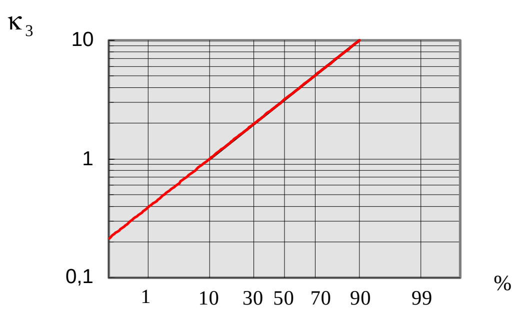


κ_1 according to the selected ratio m:

with $m = \frac{\text{Final optcal power}}{\text{Initial optical power}}$



κ_2 according to the optical power measuring current



κ_3 for a cumulative failures different from 10%

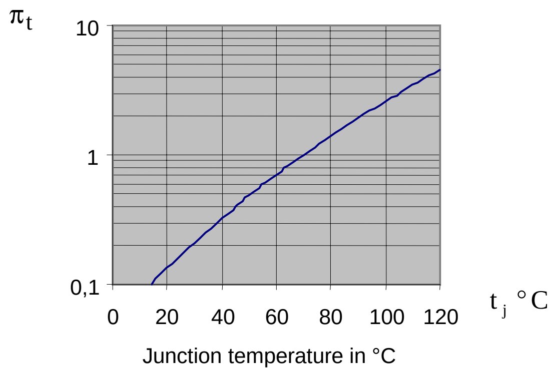
LIGHT EMITTING DIODES MODULES (datacom.) Failure rate

Specifications :
CEI 60747
CEI 62007

MATHEMATICAL MODEL

$$\lambda = \lambda_0 \times \pi_t \times 10^{-9} \quad /h$$

✐CAUTION !
The life expectancy is limited !



Necessary information	**for**
Junction temperature tj	π_t
Module type	λ_0

Temperature influence

$$t_j = t_c + R_{th} \times P$$

P = applied power

t_c = case temperature

R_{th} = thermal resistance (junction/case)

- measured
- or rated
- by default, 150°C/W

Module type	λ_0 FIT
Elementary emitter module with fibered DEL without electronic	100
Emitter module with fibered DEL and DEL driver	130
Emitter / receiver module with fibered DEL + PIN + electronics with or without clock recovery.	180
Emitter / receiver module with fibered DEL +APD + electronics with or without clock recovery	200

Mathematical formula for π_t

$$\pi_t = e^{4060\left(\frac{1}{343} - \frac{1}{t_j + 273}\right)} \quad \text{(activation energy : 0.35eV)}$$

Failure distribution according to package type	**With window**	**With fibre**
Short circuit (forward degradation)	70%	40%
Open	10%	10%
Optical coupling, or fiber	20%	50%

LASER DIODES
Life expectancy

$\theta = \theta_0 . \kappa_1 . \kappa_2$ in hours

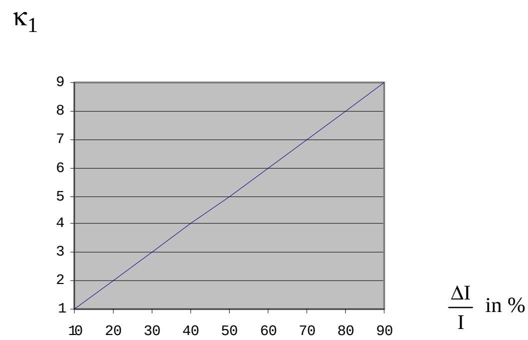
κ_1 is function of the failure criterion, which is the shift of the operating current at constant optical power, $\frac{\Delta I}{I}$ in %

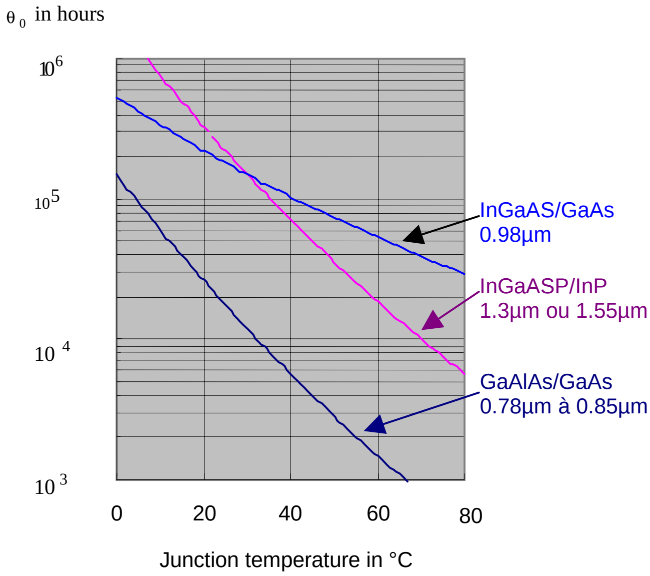
- For emitter laser of numerical systems and pump lasers, take a criterion of 50%
- For emitter laser of analog systems and WDM, take 10%

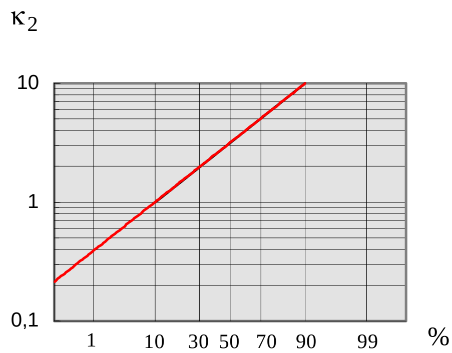
κ_2 is function of the cumulative failures at the life expectancy value.

- Take generally 10%

The failure rate λ is assumed to be constant (after the infant mortality time), but only within the life expectancy limit θ .







Diode Types	Life expectancy θ_0
GaAlAs/GaAs diode (0.78m ; 0.85µm)	$4\times10^{3}e^{7000\left(\frac{1}{t_j+273}-\frac{1}{318}\right)}$ (0.6 electron-volt)
InGaAsP/InP diodes (1.2µm ; 1.6µm)	$1.5\times10^{5}e^{7000\left(\frac{1}{t_j+273}-\frac{1}{303}\right)}$ (0.6 electron-volt)
InGaAs/GaAs diodes (0.98µm)	$1.5\times10^{5}e^{3500\left(\frac{1}{t_j+273}-\frac{1}{303}\right)}$ (0.3 electron-volt)

Note: LASER diodes are sensitive to electrostatic discharges (ESD), consequently their reliability is reduced, even with a low discharge.

LASER DIODES MODULES
Failure rate

MATHEMATICAL MODEL

$$\lambda = \lambda_0 \times \pi_t \times 10^{-9} \quad /h$$

✐CAUTION !
The life expectancy is limited !

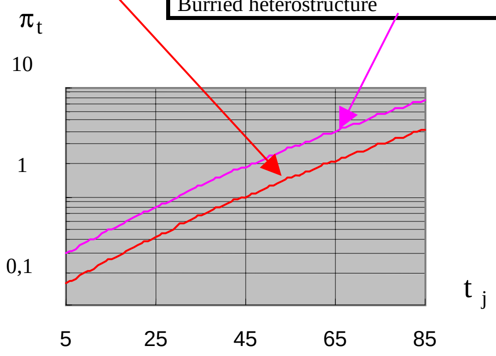
Necessary information		for
Junction temperature	tj	π_t
Type of material, internal structure.		π_t ; λ_0
Type of module		λ_0

GaAlAs/ GaAs

- gain guiding (transmitting ; 0.84µm)
- index guiding (compact disks ; 0.8µm ; with window)

InGaAs/InP
Burried heterostructure ; Pérot-Fabry or distributed feedback (DFB) 1.3µm or 1.55µm

InGaAs/GaAs
Burried heterostructure



Junction temperature °C

Temperature influence

t_j = (submount or case temperature) + $R_{th} \times (P_e - P_0)$

R_{th} = thermal resistance (junction/case or junction/submount)

P_e = applied electrical power (W)

P_e = optical power (W) (two facets)

Mathematical formulas for π_t	
GaAlAs/GaAs	$\pi_t = e^{4060\left(\frac{1}{318} - \frac{1}{t_j + 273}\right)}$
InGaAsP/InP	$\pi_t = e^{4060\left(\frac{1}{303} - \frac{1}{t_j + 273}\right)}$
InGaAs/GaAs	$\pi_t = e^{4060\left(\frac{1}{303} - \frac{1}{t_j + 273}\right)}$

Material	Window	Module type	λ_0 FIT
GaAlAs/GaAs	0.8µm	Elementary emitter modules *	3000
InGaAs/InP	1.2 to 1.6µm	Elementary emitter modules * without electronics	40
InGaAs/InP	1.2 to 1.6µm	Emitter module with electronics.	60
InGaAs/InP	1.2 to 1.6µm	Emitter/receiver module, with Laser PIN and electronics, with or without clock recovery (without crystal)	80
InGaAs/InP	1.2 to 1.6µm	Integrated modulator laser module	100
InGaAs/InP	1.48 µm	Pump laser module Power <= 100mW	200
InGaAs/InP	1.48 µm	Pump laser module Power >100mW.	850**
InGaAs/GaAs	0.98µm	Pump laser module	1000

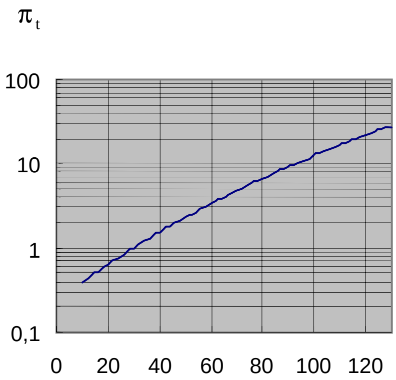
- ** Generally an elementary laser module is made of a control photodiode, a laser diode and a coupling element. For other more complex structures, the failure rates mentioned in this table, include all the other elements excepted the thermoelectric cooler and the thermistor.*
- *** Start of production.*

Failure modes according to the module type.				
1.3µm/1.55µm modules (monomode fiber 9/125)	diodes failure	• Degradation of the spectrum • Current increase	10%	
	Coupling failure	• High drop in output power	90%	
Pump laser Modules (0.98 1.48µm)	diodes failure	• High current increase	90%	
	Coupling failure	• High drop in output power	10%	
0.85µm modules (monomode fiber 9/125)			**modules** transmission)	**compact disks**
	diodes failure	• No laser effect • Degradation of the spectrum • Current increase	80%	100%
	Coupling failure	• High drop in output power	10%	0%
	Broken fiber	• No output power	10%	0%

MATHEMATICAL MODEL

$\lambda = \lambda_0 \times \pi_t \times 10^{-9}$ /h

Necessary information	for
Junction temperature tj	π_t
Type (silicon, GaAlAs, PIN , APD, module)	λ_0



Junction temperature tj is admitted to be equal to the ambient temperature

Temperature influence

Type		λ_0 FIT
PIN diodes	Silicon (0.7-1.1µm window)	5
	InGaAs (1.2-1.6µm window)	10
APD diodes (avalanche)	Silicon	20
	Germanium	40
	InGaAs	80
PIN module + electronics with or without clock recovery		30
APD module + electronics with or without clock recovery		100

Mathematical formula for π_t

$$\pi_t = e^{4060\left(\frac{1}{303} - \frac{1}{t_j + 273}\right)}$$

0.35 electron – volt

Failure modes according to package types	With window	With fibre
Short circuit (reverse degradation)	80%	40%
Open circuit	20%	10%
Coupling	0%	50%

PASSIVE OPTIC COMPONENTS

MATHEMATICAL MODEL

$$\lambda = \lambda_0 \times 10^{-9} \quad /h$$

Specification : CEI 61300

Note:
Cycling temperature effects on theses components is not really known. λ_0 values are given for a ground fixed environment and a constant temperature comprised between 20°C and 40°C.

Component types		λ_0 in FIT
Attenuators	Bulk	2
	Fusion splice (attenuation <= 10db)	2
	Fusion splice (attenuation > 10db)	10
	Pasted splice	10
Fusing - stretching couplers	1 to 2	25
	1 to n, with n <= 5	50
Integrated optical couplers	1 to n	60
Multiplexer / Demultiplexer	Fusing - stretching 1 to 2	25
	Fusing - stretching 1 to n	50
	Micro-optic	60
Connectors	1 optical contact	5
Jumper or optical cord	2 optical contacts and fibre	10
Optical fibre (cable)	For 100 km or per section (any length)	500
Doped optical fibre, Si matrix. (5à30m)	Per section, any length	1

MISCELLANEOUS OPTIC COMPONENTS

MATHEMATICAL MODEL

$$\lambda = \lambda_0 \times 10^{-9} \quad /h$$

Note:
Cycling temperature effects on theses components is not really known. λ_0 values are given for a ground fixed environment and a constant temperature comprised between 20°C and 40°C.

Components types		λ_0 in FIT
LiNbO3 modulator		1000
Isolator		10
Accordable filter		330*
Bragg array filter		15
Optical commutator	Electromechanical with mirror	200
	Integrated with prism	200
VCSEL 840 nm		300*
Trench reception photodiode		tbd
Phasor		tbd
Monolithic Duplexor		tbd
Thermoelectric cooler		20
Thermistor		0.34

**Values are given for a starting production*

CAPACITORS AND THERMISTORS (NTC)

FIXED PLASTIC,PAPER, DIELECTRIC CAPACITORS

Radio interference suppression capacitors (plastic, paper)

MATHEMATICAL MODEL

$$\lambda = 0.1 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 1.4 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i[th] phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i[th] temperature factor related to the i[th] junction temperature of the capacitor mission profile.

τ_i : i[th] working time ratio of the capacitor for the i[th] junction temperature of the mission profile.

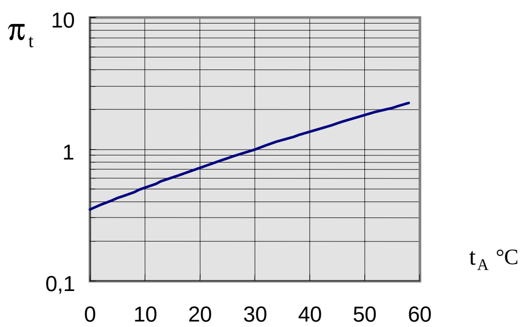
τ_{on} : total working time ratio of the capacitor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the capacitor being in storage (or dormant) mode.

$(\pi_n)_i$: i[th] influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .

ΔT_i : i[th] thermal amplitude variation of the mission profile.

Continuous voltage applied to the capacitor	See note*
Peak value of the alternative voltage applied to the capacitor	See note*
Rated voltage of the capacitor.	See note*



Ambient temperature in °C

Temperature factor π_t

Failure modes	
Short circuits	10%
Open circuits	90%

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

Mathematical formula for π_t
$\pi_t = e^{2900\left(\frac{1}{303} - \frac{1}{273 + t_A}\right)}$ with t_A : ambient temperature

***NOTE** : *The following conditions must be respected, to obtain field values in conformance with those calculated with the above formulas::*

- For **radio interference suppression** capacitors the ratio $\frac{\text{peak voltage}}{\text{rated voltage}}$ must be less or equal to **0.8**
- For other **non radio interference suppression** specified capacitors, this same ratio must be less or equal to **0.2**

with : peak voltage = continuous voltage + peak value of the alternative voltage

CERAMIC CAPACITORS
Difined temerature coefficient - Class I

MATHEMATICAL MODEL

$$\lambda = 0.05 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 3.3 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i^th temperature factor related to the i^th junction temperature of the capacitor mission profile.

τ_i : i^th working time ratio of the capacitor for the i^th junction temperature of the mission profile.

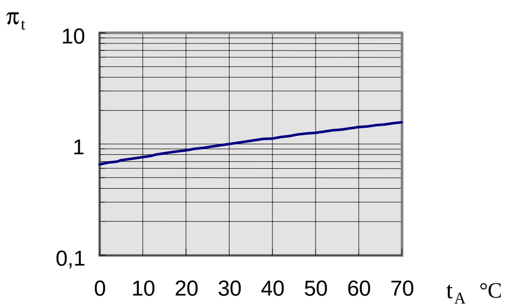
τ_{on} : total working time ratio of the capacitor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the capacitor being in storage (or dormant) mode.

$(\pi_n)_i$: i^th influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .

ΔT_i : i^th thermal amplitude variation of the mission profile.

Continuous voltage applied to the capacitor	See note*
Peak value of the alternative voltage applied to the capacitor	See note*
Rated voltage of the capacitor.	See note*



Ambient temperature in °C

Temperature factor π_t

Mathematical formula for π_t
$\pi_t = e^{1160\left(\frac{1}{303} - \frac{1}{273+t_A}\right)}$ with t_A : ambient temperature

Failure modes	
Short circuits	70%
Open circuits	10%
Drifts	20%

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th phase of the mission profile.	

*** <u>NOTE</u>** : *The following condition must be respected, to obtain field values in conformance with those calculated with the above formulas:*

the ratio $\frac{\text{peak voltage}}{\text{rated voltage}}$ must be less or equal to **0.5**

with : peak voltage = continuous voltage + peak value of the alternative voltage

CERAMIC CAPACITORS

Non defined temperature coefficient - Class II

RADIO INTERFERENCE SUPPRESSION CAPACITORS (Ceramic, class II)

MATHEMATICAL MODEL

$$\lambda = 0.15 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 3.3 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} \,/\, h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^{th} phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i^{th} temperature factor related to the i^{th} junction temperature of the capacitor mission profile.

τ_i : i^{th} working time ratio of the capacitor for the i^{th} junction temperature of the mission profile.

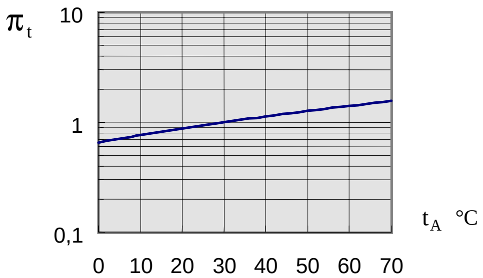
τ_{on} : total working time ratio of the capacitor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the capacitor being in storage (or dormant) mode.

$(\pi_n)_i$: i^{th} influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .

ΔT_i : i^{th} thermal amplitude variation of the mission profile.

Continuous voltage applied to the capacitor	See note*
Peak value of the alternative voltage applied to the capacitor	See note*
Rated voltage of the capacitor.	See note*



Ambient temperature in °C

Temperature factor π_t

Mathematical formula for π_t
$\pi_t = e^{1160\left(\frac{1}{303} - \frac{1}{273 + t_A}\right)}$ with t_A : ambient temperature

Failure modes	Other ceramic, class II capacitors	Radio interference suppression capacitors
Short circuits	90%	70%
Open circuits	10%	30%

Mathematical expression of the Influence factor $(\pi_n)_i$		
	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^{th} phase of the mission profile.	

***NOTE** : *The following conditions must be respected, to obtain field values in conformance with those calculated with the above formulas::*

- For **radio interference suppression** capacitors the ratio $\frac{\text{peak voltage}}{\text{rated voltage}}$ must be less or equal to **0.8**
- For other **non radio interference suppression** specified capacitors, this same ratio must be less or equal to **0.5**

with : peak voltage = continuous voltage + peak value of the alternative voltage

TANTALUM CAPACITORS
SOLID ELECTROLYTE

MATHEMATICAL MODEL

$$\lambda = 0.4 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 3.8 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i^th temperature factor related to the i^th junction temperature of the capacitor mission profile.

τ_i : i^th working time ratio of the capacitor for the i^th junction temperature of the mission profile.

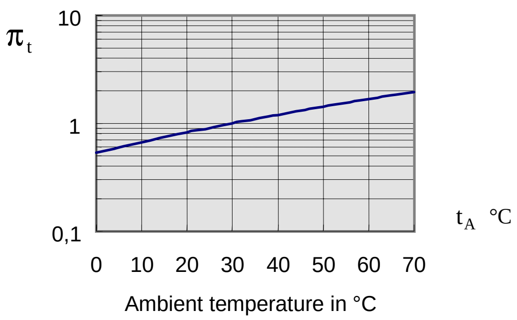
τ_{on} : total working time ratio of the capacitor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the capacitor being in storage (or dormant) mode.

$(\pi_n)_i$: i^th influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .

ΔT_i : i^th thermal amplitude variation of the mission profile.

Continuous voltage applied to the capacitor	See note 1
Peak value of the alternative voltage applied to the capacitor	See note 1
Rated voltage of the capacitor.	See note 1
Situation of the capacitor	See note 2



Temperature factor π_t

Mathematical formula for π_t
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273+t_A}\right)}$ with t_A : ambient temperature

Failure modes	
Short circuits	80%
Open circuits	20%

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \leq 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase		$\Delta T_i = (t_{ac})_i - (t_{ae})_i$
For a permanent working phase, storage or dormant		ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th phase of the mission profile.

NOTE 1: *The following condition must be respected, to obtain field values in conformance with those calculated with the above formulas:*

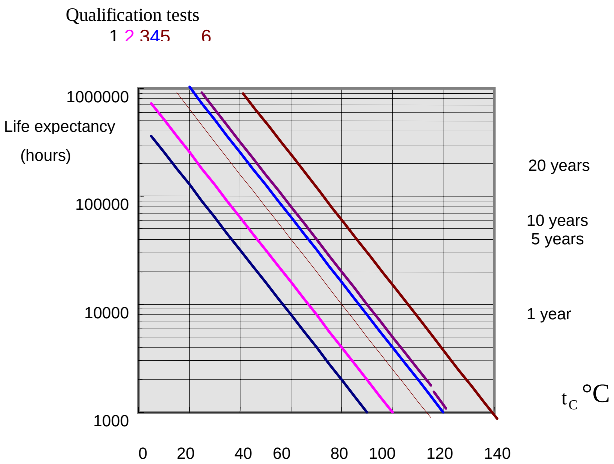
the ratio $\frac{\text{peak voltage}}{\text{rated voltage}}$ must be less or equal to **0.5**

with : peak voltage = continuous voltage + peak value of the alternative voltage

***NOTE 2** : Caution must be taken to the fire risk if the current is not limited (a fuse might be placed serially in one of the branches, between which the tantalum capacitor is positioned) .*

ALUMINUM ELECTROLITIC CAPACITORS
(NON SOLID ELECTROLYTE)
Life expectancy

Failure rate of non solid electolyte aluminum capacitors is assumed to be constant but only within the life expectancy limits.



Life expectancy according to qualifications
Test conditions of the capacitor

Qualification test conditions (duration , temperature) According to capacitor types		
Qualification tests	**Duration (hours)**	**temperature (°C)**
1	1000	85
2	2000	85
3	5000	85
4	2000	105
5	10 000	85
6	2000	125

With : t_C : **temperature of the capacitor**, default value

$$t_C = t_{ambient} + 5°C$$

<u>*NOTE 1</u> : *Life expectancy depends on the operating temperature and on the qualification test conditions (i.e on the technology type)*

<u>*NOTE 2</u> : *Ambient temperature for non solid electrolyte aluminum capacitor is taken at its immediate vicinity.(overheating of the other components has to be taken into account).*

Mathematical formula for the life expectancy

$$\textbf{Life expectancy (hours)} = \text{qualification test duration} \times 2^{\left(\frac{(T_M+5)-T_C}{10}\right)}$$

with T_M : maximum temperature of the climatic category

ALUMINUM ELECTROLYTIC CAPACITORS

NON SOLID ELECTROLYTE **Specification : CEI 60384**

MATHEMATICAL MODEL

$$\lambda = 1.3 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] \times \pi_A + 1.4 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i[th] phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i[th] temperature factor related to the i[th] junction temperature of the capacitor mission profile.

τ_i : i[th] working time ratio of the capacitor for the i[th] junction temperature of the mission profile.

τ_{on} : total working time ratio of the capacitor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the capacitor being in storage (or dormant) mode.

π_A :factor related to the self heating

$(\pi_n)_i$: i[th] influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .

ΔT_i : i[th] thermal amplitude variation of the mission profile.

Continuous voltage applied to the capacitor — See note 1

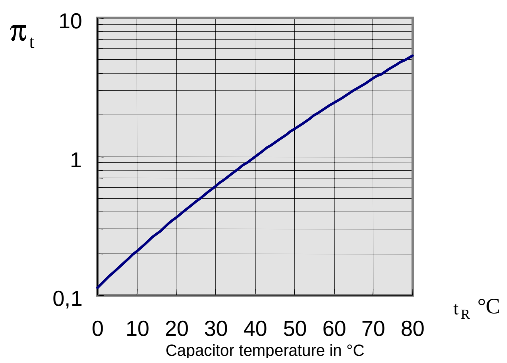
Rated voltage of the capacitor. — See note 1

Applied ripple current

Maximum admissible ripple current.

CAUTION !

Life expectancy of non solid electrolyte, aluminum capacitors is limited and very sensible to ambient temperature



Temperature factor π_t

Failure modes		
Rated voltage	**< 350 V**	**≥350 V**
Short circuits	30%	50%
Open circuits	30%	0%
Drifts	40%	50%

Mathematical expression of the Influence factor $(\pi_n)_i$		
	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase		$\Delta T_i = \left[\frac{T_R}{3} + (t_{ac})_i \right] - (t_{ae})_i$
For a permanent working phase, storage or dormant		ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.

Mathematical formula for π_t
$\pi_t = e^{4640\left(\frac{1}{313} - \frac{1}{273 + t_R}\right)}$ with t_R : capacitor temperature

Peak value of the pulsed current		**π_A**
Ratio	≤ 1.5	1
$\frac{\text{Peak value of pulse current}}{\text{Maximum admissible ripple current}}$	1.5 à 2	3
	2 à 3	10

Capacitor temperature t_R °C:

CAUTION !

The capacitor temperature is different of the ambient temperature if a current flows through the capacitor (particularly pulses for example) or if it is heated by a radiative environment (a dissipating component), it is necessary to :

- Measure the case temperature
- Or, by default

⇒ Take into account the heat dissipated by the radiative environment.

⇒ Take into account the temperature rise Δt due to the current through the capacitor (self heating) by:

$$\Delta t = 20 \left(\frac{\text{Applied ripple current}}{\text{Maximum admissible current}} \right)^2$$

<u>* NOTE 1</u> : *The following condition must be respected, to obtain field values in conformance with those calculated with the above formulas:*

the ratio $\frac{\text{peak voltage}}{\text{rated voltage}}$ must be less or equal to **0.5**

with : peak voltage = continuous voltage + peak value of the alternative voltage

ALUMINUM ELECTROLYTIC CAPACITOR
(SOLID ELECTROLYTE)

MATHEMATICAL MODEL

$$\lambda = 2.4 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 1.4 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i[th] phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i[th] temperature factor related to the i[th] junction temperature of the capacitor mission profile.

τ_i : i[th] working time ratio of the capacitor for the i[th] junction temperature of the mission profile.

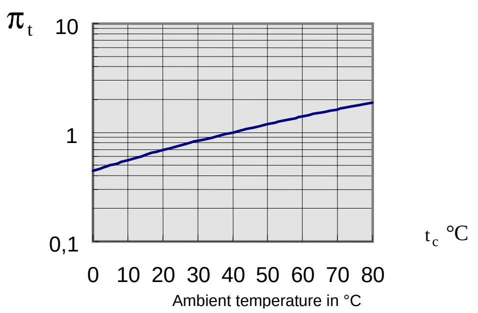
τ_{on} : total working time ratio of the capacitor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the capacitor being in storage (or dormant) mode.

$(\pi_n)_i$: i[th] influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i.

ΔT_i : i[th] thermal amplitude variation of the mission profile.

Continuous voltage applied to the capacitor	See note*
Peak value of the alternative voltage applied to the capacitor	See note*
Rated voltage of the capacitor.	See note*



Temperature factor π_t

Failure modes	
Short circuits	10%
Open circuits	90%

Mathematical formula for π_t
$\pi_t = e^{1740\left(\frac{1}{313} - \frac{1}{273+t_A}\right)}$ with t_A : ambient temperature

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

*** NOTE** : *The following condition must be respected, to obtain field values in conformance with those calculated with the above formulas:*

the ratio $\frac{\text{peak voltage}}{\text{rated voltage}}$ must be less or equal to **0.8**

ALUMINUM ELECTOLYTIC CAPACITORS
(POLYMER ELECTROLYTE)

MATHEMATICAL MODEL

$$\lambda = 0.6 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 1.4 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i^th temperature factor related to the i^th junction temperature of the capacitor mission profile.

τ_i : i^th working time ratio of the capacitor for the i^th junction temperature of the mission profile.

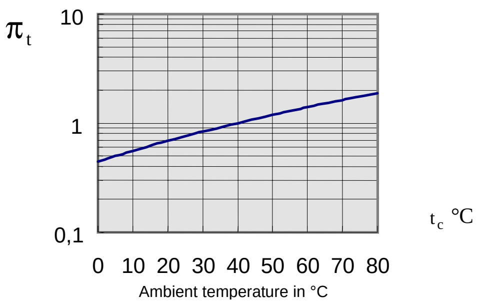
τ_{on} : total working time ratio of the capacitor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the capacitor being in storage (or dormant) mode.

$(\pi_n)_i$: i^th influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .

ΔT_i : i^th thermal amplitude variation of the mission profile.

Continuous voltage applied to the capacitor	See note*
Peak value of the alternative voltage applied to the capacitor	See note*
Rated voltage of the capacitor.	See note*



Temperature factor π_t

Mathematical formula for π_t
$\pi_t = e^{1740\left(\frac{1}{313} - \frac{1}{273+t_A}\right)}$ with t_A : ambient temperature

Failure modes	
Short circuits	10%
Open circuits	90%

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \leq 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th phase of the mission profile.	

***NOTE** : *The following condition must be respected, to obtain field values in conformance with those calculated with the above formulas:*

the ratio $\frac{\text{peak voltage}}{\text{rated voltage}}$ must be less or equal to **0.8**

with : peak voltage = continuous voltage + peak value of the alternative voltage

VARIABLES CERAMIC CAPACITORS
DISKS (DIÉLECTRIC :CERAMIC)

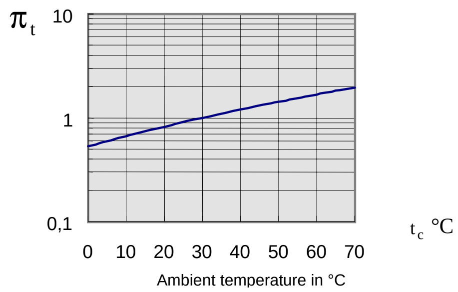
MATHEMATICAL MODEL

$$\lambda = 0.16 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 3.3 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the ith phase of the mission profile.
$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.
$(\pi_t)_i$: ith temperature factor related to the ith junction temperature of the capacitor mission profile.
τ_i : i^{eme} working time ratio of the capacitor for the ith junction temperature of the mission profile.
τ_{on} : total working time ratio of the capacitor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$
τ_{off} : time ratio for the capacitor being in storage (or dormant) mode.
$(\pi_n)_i$: ith influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .
ΔT_i : ith thermal amplitude variation of the mission profile.

Continuous voltage applied to the capacitor	See note*
Peak value of the alternative voltage applied to the capacitor	See note*
Rated voltage of the capacitor.	See note*



Temperature model π_t

Mathematical formula for π_t
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273 + t_A}\right)}$ with t_A : ambient temperature

Failure modes	
Short circuits	40%
Open circuits	10%
Drifts	50%

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase		$\Delta T_i = (t_{ac})_i - (t_{ae})_i$
For a permanent working phase, storage or dormant		ΔT_i =average per cycle of the (t_{ae}) variation, during the ith phase of the mission profile.

*** NOTE** : *The following condition must be respected, to obtain field values in conformance with those calculated with the above formulas:*

the ratio $\frac{\text{peak voltage}}{\text{rated voltage}}$ must be less or equal to **0.5**

with : peak voltage = continuous voltage + peak value of the alternative voltage

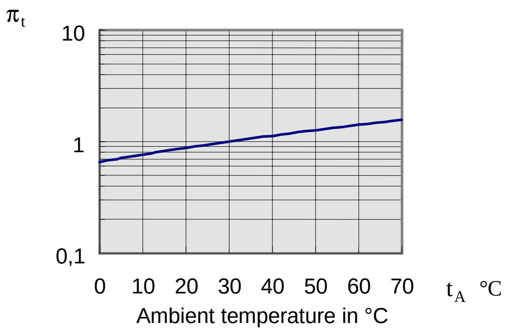
THERMISTORS
With negative temperature coefficient (NTC)

MATHEMATCAL MODEL

$$\lambda = 3\times\left(\left[\frac{\sum_{i=1}^{y}(\pi_t)_i\times\tau_i}{\tau_{on}+\tau_{off}}\right]+2.7\times10^{-3}\times\left[\sum_{i=1}^{j}(\pi_n)_i\times(\Delta T_i)^{0.68}\right]\right)\times10^{-9}/h$$

NECESSARY INFORMATION :

$t_{ae})_i$	: average outside ambient temperature surrounding the equipment, during the i^{th} phase of the mission profile.
$(t_{ac})_i$	: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.
$(\pi_t)_i$	: i^{th} temperature factor related to the i^{th} junction temperature of the thermistor mission profile.
τ_i	: i^{th} working time ratio of the thermistor for the $i^{ème}$ junction temperature of the mission profile.
τ_{on}	: total working time ratio of the thermistor. With: $\tau_{on} = \sum_{i=1}^{y}\tau_i$
τ_{off}	: time ratio for the thermistor being in storage (or dormant) mode.
$(\pi_n)_i$	: i^{th} influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i .
ΔT_i	: i^{th} thermal amplitude variation of the mission profile.



Temperature factor π_t

Mathematical formula for π_t
$\pi_t = e^{1160\left(\frac{1}{303}-\frac{1}{273+t_A}\right)}$ with t_A : ambient temperature

Répartition des défauts	
Courts circuits	70%
Circuits ouverts	10%
Dérives	20%

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7\times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^{th} phase of the mission profile.	

RESISTORS AND POTENTIOMETERS

FIXED, LOW DISSIPATION FILM RESISTORS
HIGH STABILITY (RS), GENERAL PURPOSE (RC), " MINIMELF "

MATHEMATICAL MODEL

$$\lambda = 0.1 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 1.4 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i^th temperature factor related to the i^th junction temperature of the resistor mission profile.

τ_i : i^th working time ratio of the resistor for the i^th junction temperature of the mission profile.

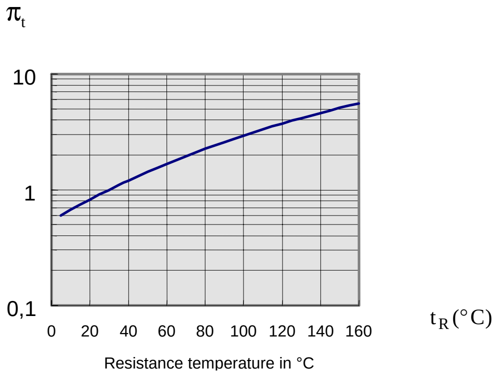
τ_{on} : total working time ratio of the resistor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the resistor being in storage (or dormant) mode.

$(\pi_n)_i$: i^th influence factor related to the annual cycles number of thermal variations seen by the resistor, with the amplitude ΔT_i .

ΔT_i : i^th thermal amplitude variation of the mission profile.

Power applied to the resistor.
Rated power of the resistor.



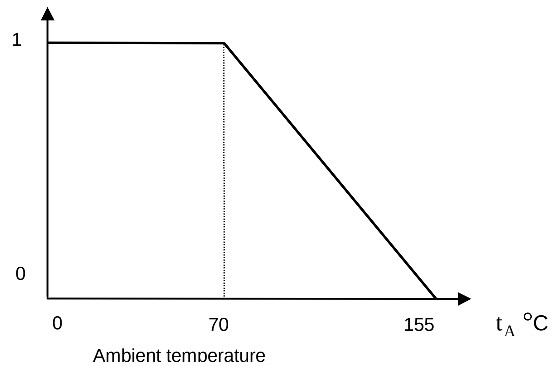
Failure modes	
Open circuits	40%
Drifts	60%

Mathematical formula for π_t	
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273 + t_R}\right)}$	with t_R =Resitor temperature t_A = Ambient temperature $t_R = t_A + 85 \times \frac{\text{Operating power}}{\text{Rated power}}$

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th phase of the mission profile.	

For information :
Maximum operating power *(derating curve)*

Ratio : $\frac{\text{Maximum operating power}}{\text{Rated power}}$



HOT MOLDED CARBON COMPOSITION, FIXED RESISTORS

MATHEMATICAL MODEL

$$\lambda = 0.5 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 1.4 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i^th temperature factor related to the i^th junction temperature of the resistor mission profile.

τ_i : i^th working time ratio of the resistor for the i^th junction temperature of the mission profile.

τ_{on} : total working time ratio of the resistor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

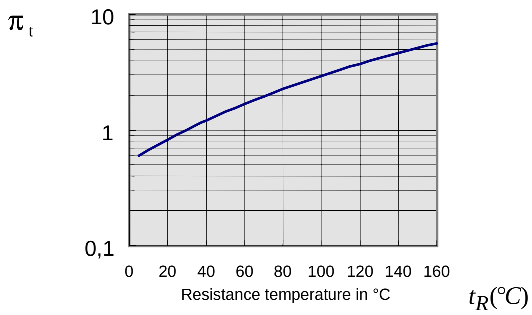
τ_{off} : time ratio for the resistor being in storage (or dormant) mode.

$(\pi_n)_i$: i^th influence factor related to the annual cycles number of thermal variations seen by the resistor, with the amplitude ΔT_i .

ΔT_i : i^th thermal amplitude variation of the mission profile.

Power applied to the resistor.

Rated power of the resistor.



Failure modes	
Short circuits	0%
Open circuits	100%

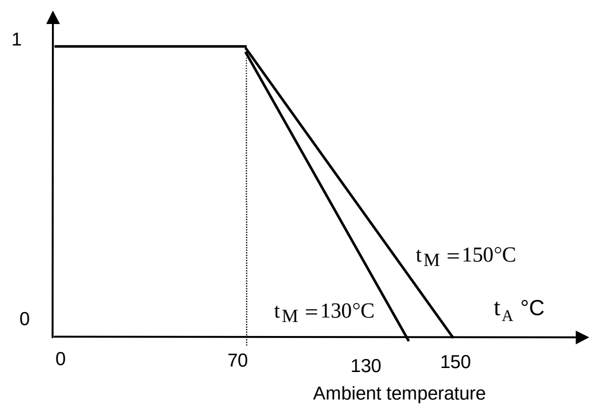
Mathematical formula for π_t	
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273 + t_R}\right)}$	with t_R = Resistance temperature t_A = Ambient temperature t_M = maximum rated temperature **For** t_M=130°C $t_R = t_A + 60 \times \frac{\text{Operating power}}{\text{Rated power}}$ **For** t_M = 150°C $t_R = t_A + 80 \times \frac{\text{Operating power}}{\text{Rated power}}$

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th phase of the mission profile.	

For information :

Maximum operating power *(derating curve)*

Ratio : $\frac{\text{Maximum operating power}}{\text{Rated power}}$



FIXED, HIGH DISSIPATION FILM RESISTORS

MATHEMATICAL MODEL

$$\lambda = 0.4 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 1.4 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i^th temperature factor related to the i^th junction temperature of the resistor mission profile.

τ_i : i^th working time ratio of the resistor for the i^th junction temperature of the mission profile.

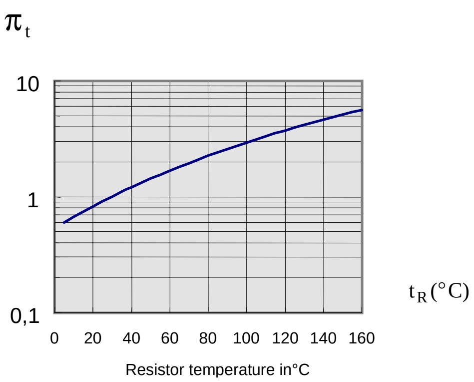
τ_{on} : total working time ratio of the resistor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the resistor being in storage (or dormant) mode.

$(\pi_n)_i$: i^th influence factor related to the annual cycles number of thermal variations seen by the resistor, with the amplitude ΔT_i .

ΔT_i : i^th thermal amplitude variation of the mission profile.

Power applied to the resistor.
Rated power of the resistor.



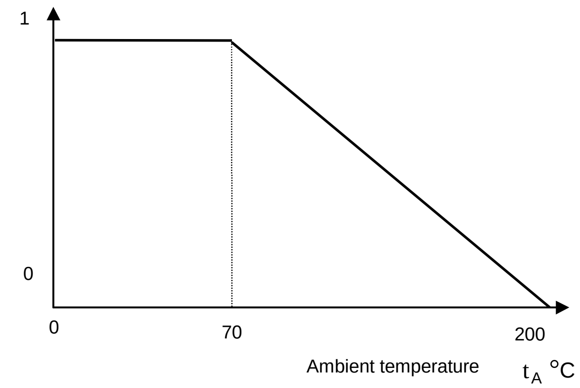
Failure modes	
Short circuits	0%
Open circuits	100%

Mathematical formula for π_t	
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273+t_R}\right)}$	with t_R = Resistor temperature t_A = Ambient temperature $t_R = t_A + 130 \times \frac{\text{Operating power}}{\text{Rated power}}$

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = \left[(t_{ac})_i + \frac{t_R}{3} \right] - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th phase of the mission profile.	

For information :
Maximum operating power *(derating curve)*

Ratio : $\frac{\text{Maximum operating power}}{\text{Rated power}}$



LOW DISSIPATION WIREWOUND RESISTORS

MATHEMATICAL MODEL

$$\lambda = 0.3 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 1.4 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i^th temperature factor related to the i^th junction temperature of the resistor mission profile.

τ_i : i^th working time ratio of the resistor for the i^th junction temperature of the mission profile.

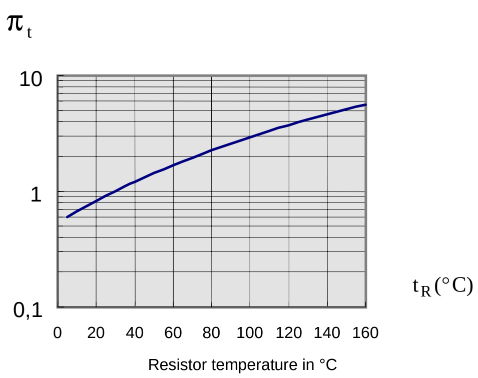
τ_{on} : total working time ratio of the resistor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the resistor being in storage (or dormant) mode.

$(\pi_n)_i$: i^th influence factor related to the annual cycles number of thermal variations seen by the resistor, with the amplitude ΔT_i .

ΔT_i : i^th thermal amplitude variation of the mission profile.

Power applied to the resistor.
Rated power of the resistor.



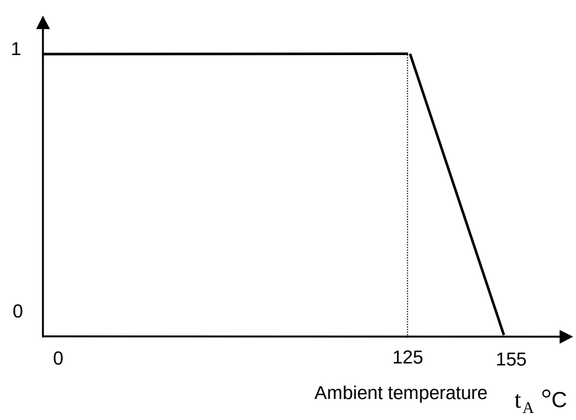
Failure modes	
Short circuits	0%
Open circuits	100%

Mathematical formula for π_t	
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273 + t_R}\right)}$	with t_R = Resistor temperature t_A = Ambient temperature $t_R = t_A + 30 \times \frac{\text{Operating power}}{\text{Rated power}}$

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th phase of the mission profile.	

For information :
Maximum operating power *(derating curve)*

Ratio : $\frac{\text{Maximum operating power}}{\text{Rated power}}$



HIGH DISSIPATION WIREWOUND RESISTORS

MATHEMATICAL MODEL

$$\lambda = 0.4\times\left(\left[\frac{\sum_{i=1}^{y}(\pi_t)_i\times\tau_i}{\tau_{on}+\tau_{off}}\right]+1.4\times10^{-3}\times\left[\sum_{i=1}^{j}(\pi_n)_i\times(\Delta T_i)^{0.68}\right]\right)\times10^{-9}/h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th^ phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i^{th} temperature factor related to the i^{th} junction temperature of the resistor mission profile.

τ_i : i^{th} working time ratio of the resistor for the i^{th} junction temperature of the mission profile.

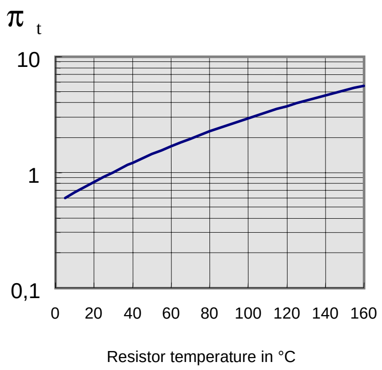
τ_{on} : total working time ratio of the resistor. With: $\tau_{on} = \sum_{i=1}^{y}\tau_i$

τ_{off} : time ratio for the resistor being in storage (or dormant) mode.

$(\pi_n)_i$: i^{th} influence factor related to the annual cycles number of thermal variations seen by the resistor, with the amplitude ΔT_i .

ΔT_i : i^{th} thermal amplitude variation of the mission profile.

Power applied to the resistor.
Rated power of the resistor.



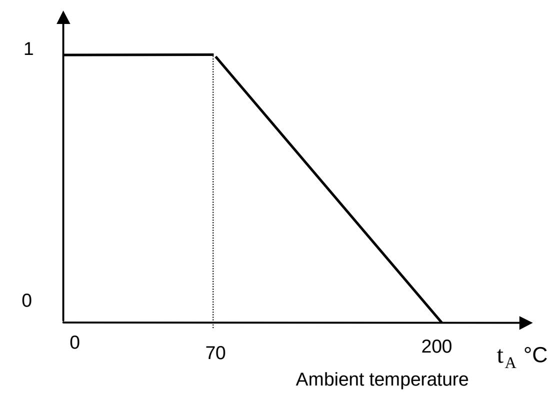
Failure modes	
Short circuits	0%
Open circuits	100%

Mathematical formula for π_t	
$\pi_t = e^{1740\left(\frac{1}{303}-\frac{1}{273+t_R}\right)}$	with t_R = Resistor temperature t_A = Ambient temperature $t_R = t_A + 130\times\frac{\text{Operating power}}{\text{Rated power}}$

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7\times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = \left[(t_{ac})_i + \frac{t_R}{3}\right] - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^{th} phase of the mission profile.	

For information :
Maximum operating power *(derating curve)*

Ratio : $\frac{\text{Maximum operating power}}{\text{Rated power}}$



FIXED, LOW DISSIPATION SURFACE MOUNTING RESISTORS AND RESISTIVE ARRAY

MATHEMATICAL MODEL

$$\lambda = 0.01 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] \times \sqrt{N} + 3.3 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i^th temperature factor related to the i^th junction temperature of the resistor mission profile.

τ_i : i^th working time ratio of the resistor for the i^th junction temperature of the mission profile.

τ_{on} : total working time ratio of the resistor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the resistor being in storage (or dormant) mode.

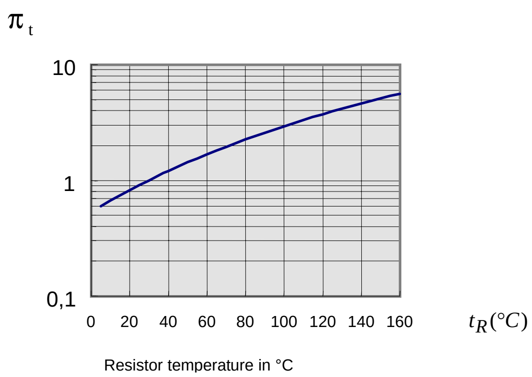
N : resistors number of the resistive array.

$(\pi_n)_i$: i^th influence factor related to the annual cycles number of thermal variations seen by the resistor, with the amplitude ΔT_i .

ΔT_i : i^th thermal amplitude variation of the mission profile.

Power applied to the resistor.

Rated power of the resistor..



Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \leq 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th phase of the mission profile.	

Mathematical formula for π_t

$$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273 + t_R}\right)}$$

with

t_R = resistor temperature

t_A = Ambient temperature

t_M = Maximum rated category ,

pour t_M = 125° C

$$t_R = t_A + 55 \times \frac{\text{Operating power}}{\text{Rated power}}$$

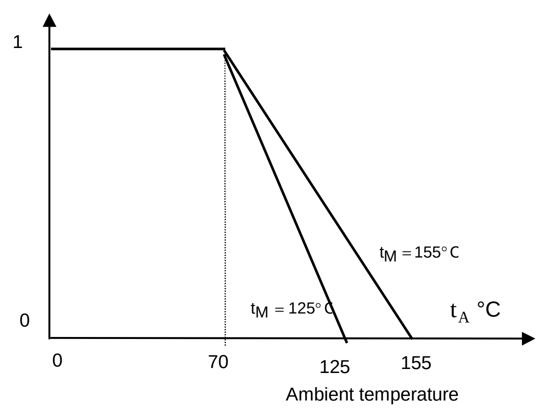
pour t_M = 155° C

$$t_R = t_A + 85 \times \frac{\text{Operating power}}{\text{Rated power}}$$

For information :

Maximum operating power *(derating curve)*

Ratio : $\frac{\text{Maximum operating power}}{\text{Rated power}}$



Failure modes	
Drifts	60%
Open circuits	40%

NON WIREWOUND CERMET POTENTIOMETER
(one or several turn)

MATHEMATICAL MODEL

$$\lambda = 0.3 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] \times \pi_Y + 1.2 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

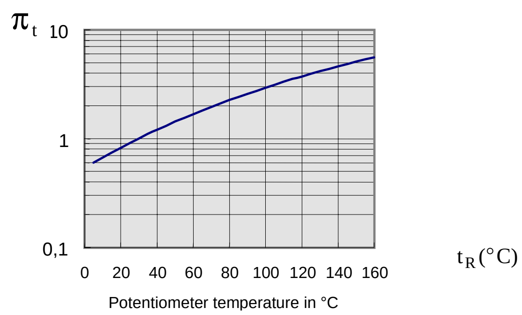
NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^{th} phase of the mission profile.
$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.
$(\pi_t)_i$: i^{th} temperature factor related to the i^{th} junction temperature of the resistor mission profile.
τ_i : i^{th} working time ratio of the resistor for the i^{th} junction temperature of the mission profile.
τ_{on} : total working time ratio of the resistor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$
τ_{off} : time ratio for the resistor being in storage (or dormant) mode.
π_Y : factor related to the annual number of shaft rotation.
$(\pi_n)_i$: i^{th} influence factor related to the annual cycles number of thermal variations seen by the resistor, with the amplitude ΔT_i .
ΔT_i : i^{th} thermal amplitude variation of the mission profile.

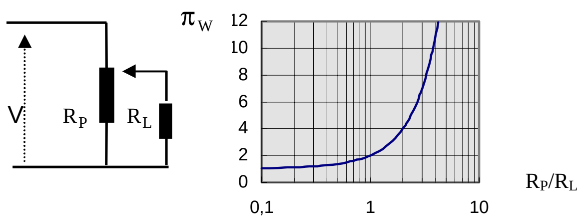
R_L and R_P for π_W calculation.

Power applied to the resistor.
Rated power of the resistor..

Failure modes	
Open circuits	80%
Drifts	20%



Number of annual shaft rotations	π_Y
$\leq$ 10	0.2
$>$ 10	1



Mathematical formulas for π_t , and π_W

$$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273 + t_R}\right)}$$

and

$$\pi_W = 1 + \frac{1}{2}\left[\frac{R_P{}^2}{4R_L{}^2} + \frac{R_P}{R_L}\right]$$

with

t_R = potentiometer temperature
t_A = ambient temperature
t_M = maximum rated temperature ,

for **t_M = 125° C**

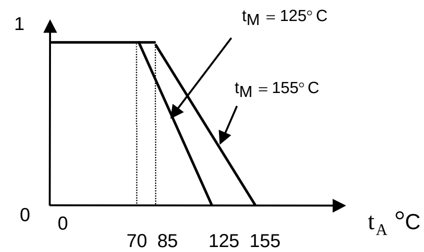
$$t_R = t_A + 55 \times \frac{\frac{V^2}{R_p} \times \pi_W}{\text{Rated power}}$$

for **t_M = 155° C**

$$t_R = t_A + 70 \times \frac{\frac{V^2}{R_p} \times \pi_W}{\text{Rated power}}$$

For information :
Maximum operating power *(derating curve)*

Ratio : $\frac{\text{Maximum operating power}}{\text{Rated power}}$



NON WIREWOUND CERMET POTENTIOMETER
(one or several turn)

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \leq 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^{th} phase of the mission profile.	

INDUCTORS AND TRANSFORMERS

INDUCTORS AND TRANSFORMERS

MATHEMATICAL MODEL

$$\lambda = \lambda_0 \times \left(\left[\frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right] + 7\times10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th^ phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

$(\pi_t)_i$: i^th^ temperature factor related to the i^th^ junction temperature of the component mission profile.

τ_i : i^th^ working time ratio of the component for the i^th^ junction temperature of the mission profile.

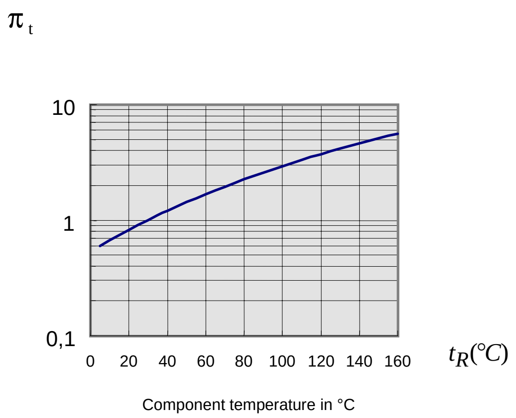
τ_{on} : total working time ratio of the component. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the component being in storage (or dormant) mode.

$(\pi_n)_i$: i^th^ influence factor related to the annual cycles number of thermal variations seen by the component, with the amplitude ΔT_i .

ΔT_i : i^th^ thermal amplitude variation of the mission profile.

Power lossed by the component.
Radiating surface of the component.



Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase of a power inductor		$\Delta T_i = \left[(t_{ac})_i + \frac{t_R}{3} \right] - (t_{ae})_i$
For an on/off phase of a low current inductor		$\Delta T_i = (t_{ac})_i - (t_{ae})_i$
For a permanent working phase, storage or dormant		ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th^ phase of the mission profile.

Mathematical formula for π_t	
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273+t_R}\right)}$	with : t_R = component temperature t_A = ambient temperature around component $t_R = t_A + 8.2 \times \frac{\text{Power loss (watt)}}{\text{Radiating surface (dm}^2)}$

Failure rates according to the component type (FIT)			**λ_0**
Inductors	Low current inductors	fixed	0.2
		variable	0.4
	Power inductors (50 Hz, chopping, filtering)		0.6
Transformers	Signal transformers		1.5
	Power transformers		3

Failure modes	
Short circuits	20%
Open circuits	80%

MICROWAVE PASSIVE COMPONENTS, PIEZOELECTRIC COMPONENTS AND SURFACE ACOUSTIC WAVE FILTERS

MICROWAVE PASSIVE COMPONENTS, PIEZOELECTRIC COMPONENTS AND SURFACE ACOUSTIC WAVE FILTERS

MATHEMATICAL MODEL

$$\lambda = \lambda_0 \times \left(\left[\frac{\tau_{on}}{\tau_{on} + \tau_{off}} \right] + 3 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :

$t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^th phase of the mission profile.

$(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.

τ_i : i^th working time ratio of the resistor for the i^th junction temperature of the mission profile.

τ_{on} : total working time ratio of the resistor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$

τ_{off} : time ratio for the resistor being in storage (or dormant) mode.

$(\pi_n)_i$: i^th influence factor related to the annual cycles number of thermal variations seen by the resistor, with the amplitude ΔT_i .

ΔT_i : i^th thermal amplitude variation of the mission profile.

Component types		λ_0 FIT
Wicrowave passive components	fixed	2
	variables	4
	with ferrite	4
Piezoelectric components	Resonators quartz or ceramic filters	5
	Oscillators : XO, PXO	10
	Oscillators : VCXO, TCXO	15
	Oscillators : OCXO	30
Acoustic wave filters		15

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \leq 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase of a passive, piezoelectric or acoustic microwave component	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^th phase of the mission profile.	

-

RELAYS

-

RELAYS

EVALUATING VOLTAGE AND CURRENT (Vt, It) IN TRANSIENT CONDITIONS
(VOLTAGE AT THE TERMINALS OF A CONTACT AND CURRENT THROUGH THE CONTACT)

1. PREFERRED METHOD

The preferred method is to measure Vt, It in transient conditions, or evaluate them by analysing the actual circuit diagram.

2. DEFAULT METHOD

By default, the following methods will be used (depending on how much is known about the circuit).

2.1. **Calculate** or measure the voltage and current V, I in steady state conditions (Voltage at the terminals, current through the contact).

2.2. **Determine** the *figure 1* equivalent circuit diagram from the actual circuit diagram.

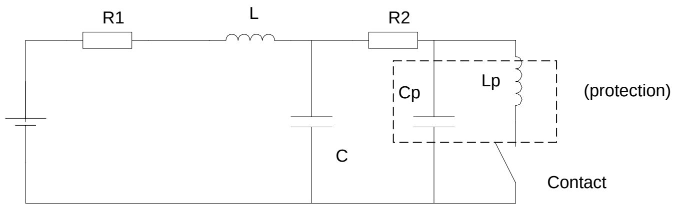


Figure 1 • *Equivalent diagram representing the circuit of a relay contact*

2.2.1. **The inductance L** is given by the sum of all series inductance values in the real contact circuit (only inductances of greater than 100 µH are included, and protection inductance Lp is not included)

2.2.2. The value of **capacitor C** is the sum of the capacitance values of the capacitors across the terminals of the contact in the real circuit: only capacitors with a value of greater than 100 pF and located within the area bounded by the contact and the first inductance of more than 100 µH in the real circuit are counted (see figure 2). The line capacitance is included (100 pF per metre). The value of the protection capacitor Cp is not included.

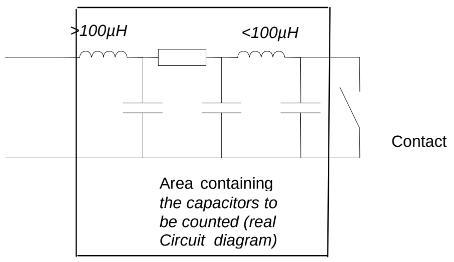


Figure 2 • *Positions of capacitors in the real circuit diagram for which the values must be counted in C*

2.2.3. The respective values of resistors R1 and R2 are the sum of the resistors found in the real circuit diagram, on the one hand in the area marked in figure 2, and on the other hand outside the area (the resistance of the protection circuit is not included).

2.2.4. Inductor Lp and capacitor Cp are respectively the protection inductor and protection capacitor (not included when calculating L or C).
Note - Protection diodes, if any are also not included (nor is the associated protection resistor, as stated in section 2-2-3).

2.3. **Calculate** the voltage Vt and current It in transient conditions

2.3.1. The tables in figures 4, 5 and 6 give ratios Vt/V and It/I (V, I in steady state conditions; Vt, It in transient condition) according to how much is known about the contact circuit. For greater clarity, the tables are given, according to circuit type (resistive, capacitive, inductive, inductive and capacitive), summarised as shown in figure 3, in other words in the four regions defined by the values of inductors L and capacitors C. The four regions are bounded by the characteristic values of L (100 µH) and C (1 nF).

-

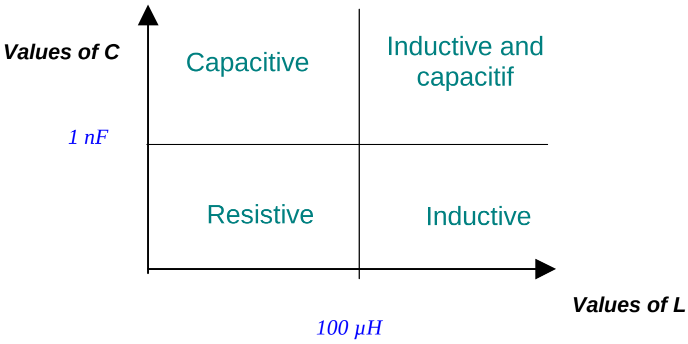
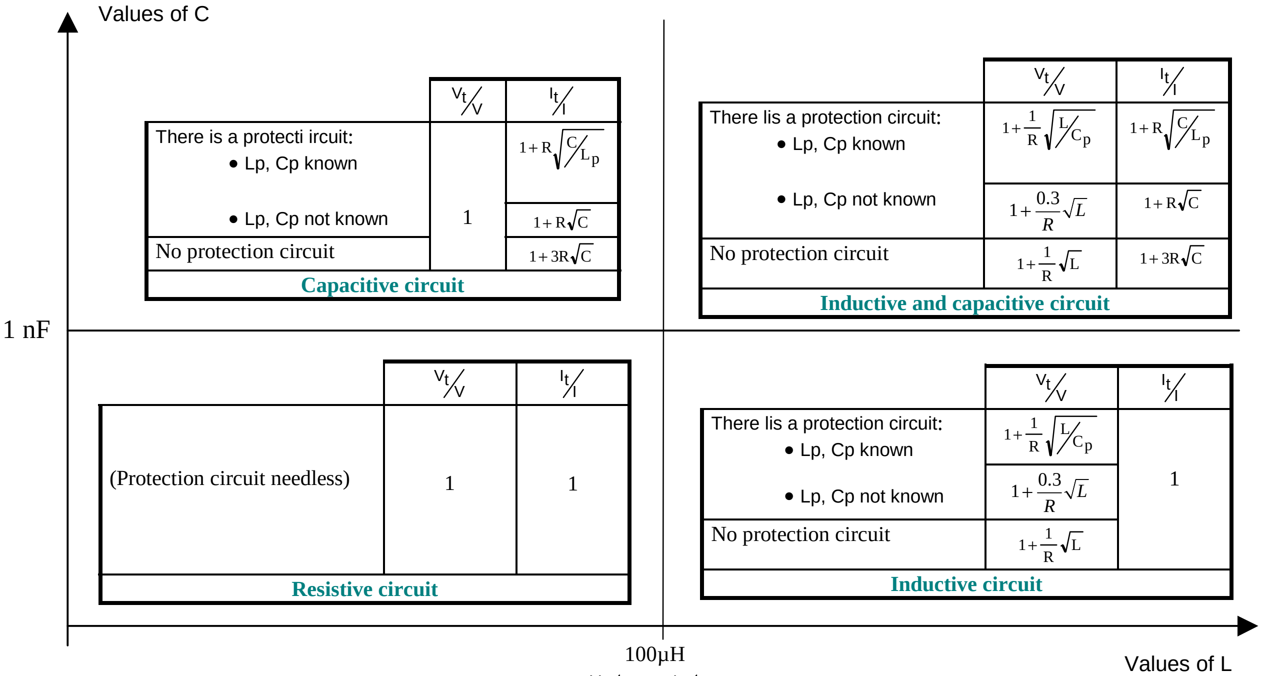


Figure 3 - *Regions adopted for the purposes of figures 4, 5 and 6*

2.3.2. Results

A. <u>Case 1: values of L, C and R are known</u> (respectively in mH, nF and kΩ), with R = Rl + R2.
The equations which give the transient values Vt, It for voltage and current, which are needed to calculate lifetime θ and pollution factor π_p , are given in the tables in figure 4 according to values of L, C, R (R = R1 + R2), Cp and Lp, which are assumed known. What is in fact given are the ratios Vt/V and It/I, with V and I being values in steady state conditions for voltage at the terminals with the contact open and current through the contact).



	V_t/V	I_t/I
There is a protecti ircuit: • Lp, Cp known	1	$1+R\sqrt{C/L_p}$
• Lp, Cp not known		$1+R\sqrt{C}$
No protection circuit		$1+3R\sqrt{C}$
Capacitive circuit		

	V_t/V	I_t/I
There lis a protection circuit: • Lp, Cp known	$1+\frac{1}{R}\sqrt{L/C_p}$	$1+R\sqrt{C/L_p}$
• Lp, Cp not known	$1+\frac{0.3}{R}\sqrt{L}$	$1+R\sqrt{C}$
No protection circuit	$1+\frac{1}{R}\sqrt{L}$	$1+3R\sqrt{C}$
Inductive and capacitive circuit		

	V_t/V	I_t/I
(Protection circuit needless)	1	1
Resistive circuit		

	V_t/V	I_t/I
There lis a protection circuit: • Lp, Cp known	$1+\frac{1}{R}\sqrt{L/C_p}$	1
• Lp, Cp not known	$1+\frac{0.3}{R}\sqrt{L}$	
No protection circuit	$1+\frac{1}{R}\sqrt{L}$	
Inductive circuit		

Figure 4 : *Evaluating the ratios* V_t/V *and* I_t/I *according to* $R = R_1 + R_2$, C, L, *and* C_p, L_p

(R in kΩ, C, C_p in nF ; L , L_p in mH)

-

B. Case 2: values of L. C and R are not known, but the equivalent diagram has been constructed and the nature of the circuit - capacitive or inductive and capacitive - is known.

The tables in figure 5 give ratios Vt/V and It/I according to how much is known about Lp, Cp and depending on whether the life expectancy or failure rate is being calculated.

Values of C

Capacitive circuit

	V_t/V	I_t/I	
There is a protection circuit		pour le calcul de θ_b	π_b
• C_p, L_p known	1	5	2
• C_p, L_p not known	1	20	2
No protection circuit	1	20	3

Inductive and capacitive circuit

	V_t/V		I_t/I	
There is a protection circuit	To calculate θ_b	π_b	To calculate θ_b	π_b
• C_p, L_p known	3	2	5	2
• C_p, L_p not known	10	2	20	2
No protection circuit	10	3	20	3

1 nF

Resistive circuit

	V_t/V	I_t/I
(protection circuit needless)	1	1

Inductive circuit

	V_t/V		I_t/I
There is a protection circuit	To calculate θ_b	π_b	
• C_p, L_p known	3	2	1
• C_p, L_p not known	10	2	1
No protection circuit	10	3	1

100µH

Values of L

Figure 5 : *Evaluating ratios* V_t/V *and* I_t/I *when L and C are not known.*

C. Case 3: Nothing is known about the electrical circuit of the contact, the table in figure 6 gives default values for the ratios V_t/V and I_t/I (depending whether life expectancy θ_b or failure rate (π_p factor) is being calculated).

Valeurs de C

	V_t/V		I_t/I	
Protection unknown	To calculate θ_b	π_b	To calculate θ_b	π_b
	10	2	20	2

Valeurs de L

Figure 6 : *Default values of* V_t/V *and* I_t/I *when nothing is known about the electrical circuit of the contact*

MERCURY WETTED REED RELAYS
LOW POWER
BALANCED – LATCHING BALANCED
(power up to 250 W)

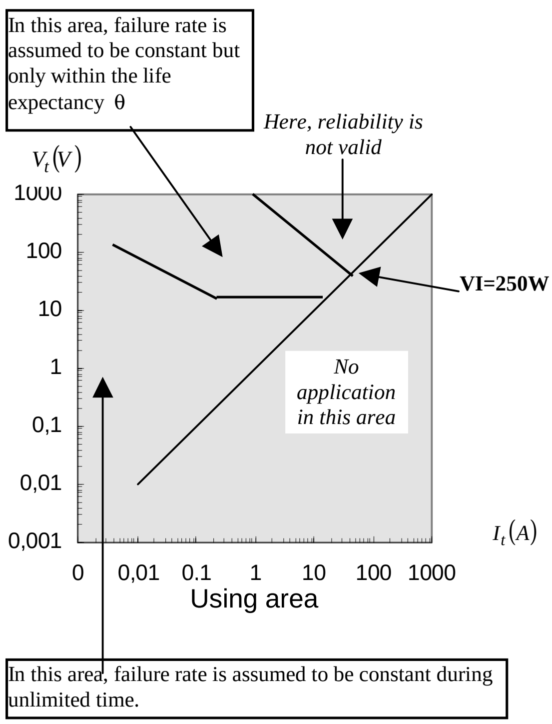
LIFE EXPECTANCY :θ

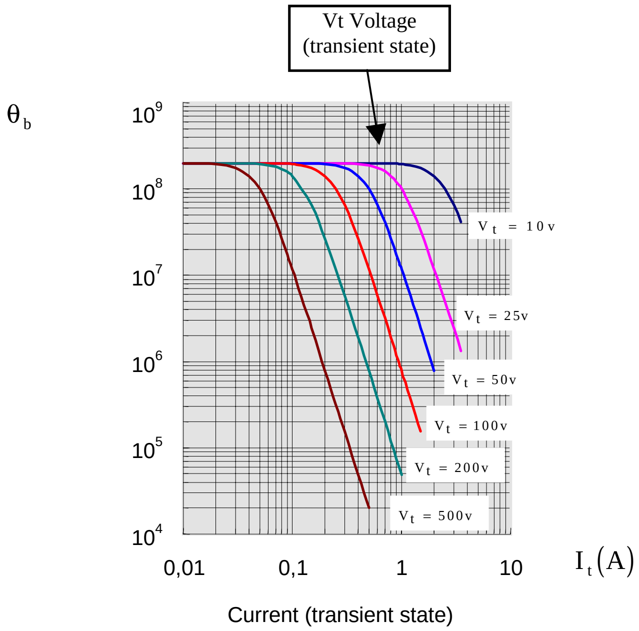
$$\theta = \theta_b \frac{1}{\pi_t \times N} \text{ in h}$$

- π_t is given in next page (same factor as λ for the failure rate).
- N : Number of cycles per hour

Mathematical formula for θ_b

$$\theta_b = \frac{2\times10^8}{1+\left(\frac{V_t \times I_t}{25}\right)^4}$$





The voltage V_t and the current I_t values (transient state) are given in pages 79 to 81. (Select the appropriate column "θ_b calculation").

θ_b depending on the voltage V_t and the current I_t in transient state (see pages 79 à 81)

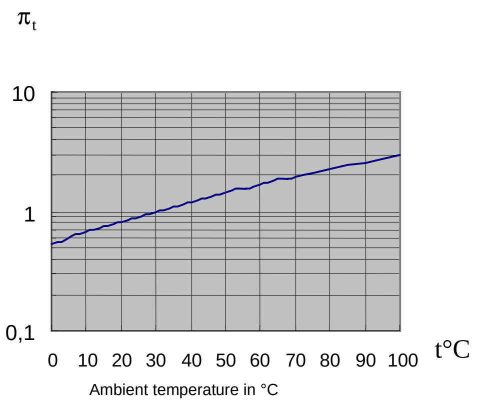
MERCURY WETTED REED RELAYS
LOW POWER
BALANCED – LATCHING BALANCED
(power up to 250 W)

MATHEMATICAL MODEL

$$\lambda = 03 \times \pi_t \times \pi_T \times \pi_Y \times \pi_C \times \left(1 + 2.7 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68}\right]\right) \times 10^{-9} / h$$

with $\pi_C = \pi_{C1}$ or π_{C2}

CAUTION !
Life expectancy is limited !



Necessary information	for
Current, voltage	θ
Load circuit	θ
Number of active contacts	π_C
Operating cycles per hours: mean number N	π_y
Ambient temperature t_A	π_t
Relay type	π_T

Relay type	π_T
Monostable	1
Bistable latching	5

Mathematical expression of the Influence factor $(\pi_n)_i$		
	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

Operating cycles per hours: mean number N	π_y
N≤10	1
N>10	$\sqrt{\frac{N}{10}}$

Number of breaker active contacts "break contact" or "make contact"	π_{C1}
No contact of this type	0
1	1
2	1.5
3	2
4	2.5

Mathematical formula for π_t
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273 + t_A}\right)}$ with t_A : ambient temperature

Number of inverter active contact "break contact" or "make contact"	π_{C2}
No contact of this type	0
1	1.8
2	3
3	4.3
4	5.5
6	8

Failure modes	
Short circuits	50%
Open circuits	50%

DRY REED RELAY
BALANCED – LATCHING BALANCED
(power up to 150 W)

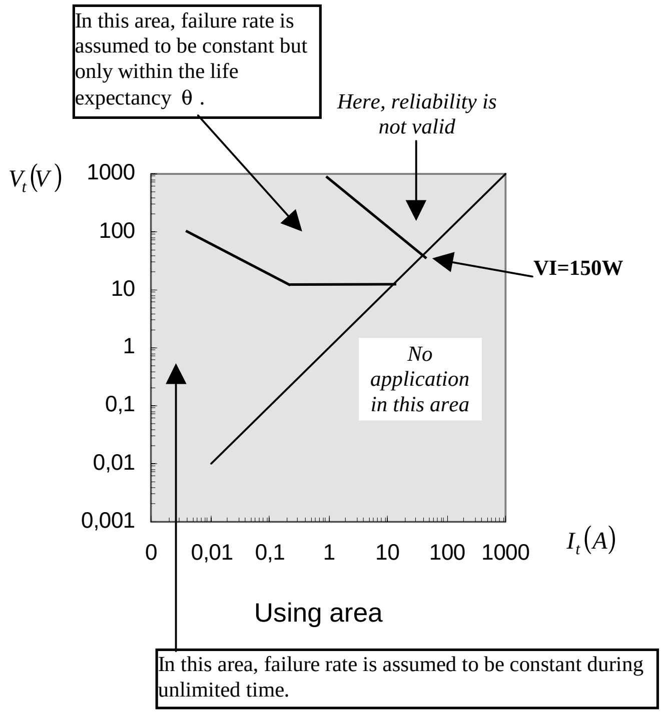
LIFE EXPECTANCY: θ

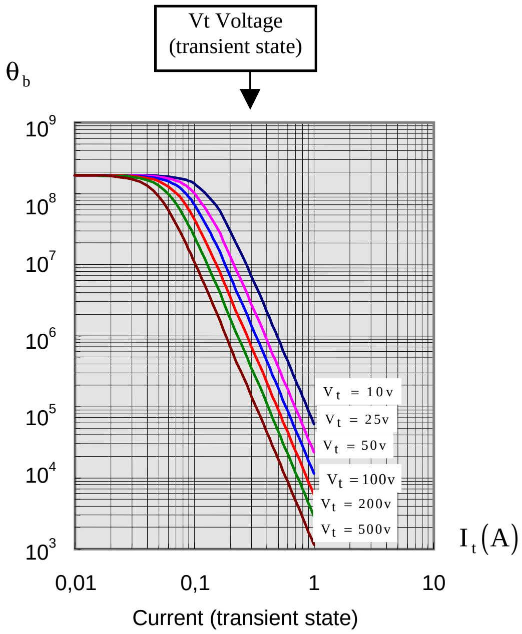
$$\theta = \theta_b \frac{1}{\pi_t \times N} \text{ in h}$$

- π_t is given in next page (same factor as λ for the failure rate).
- N : Number of cycles per hour

Mathematical formula for θ_b

$$\theta_b = \frac{1.8 \times 10^8}{1 + \left(\frac{V_t}{2}\right) \times \left(\frac{I_t}{0,2}\right)^4}$$





The voltage V_t and the current I_t values (transient state) are given in pages 79 to 81. (Select the appropriate column "θ_b calculation").

θ_b depending on the voltage V_t and the current I_t in transient state (see pages 79 à 81)

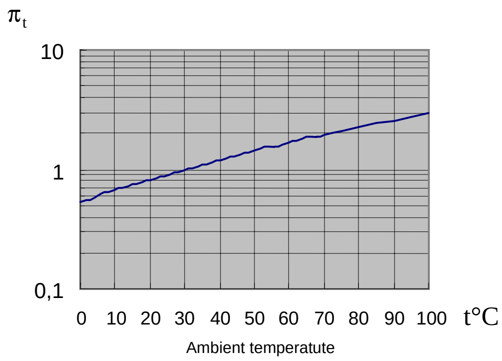
DRY REED RELAY
BALANCED – LATCHING BALANCED
(power up to 150 W)

MATHEMATICAL MODEL

$$\lambda = 0.75 \times \pi_t \times \pi_T \times \pi_p \times \pi_Y \times \pi_C \times \left(1 + 2.7\times10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68}\right]\right) \times 10^{-9} / h$$

with $\pi_C = \pi_{C1}$ or π_{C2}

✎**CAUTION !**
Life expectancy is limited!



Necessary information	for
Current, voltage	θ
Load circuit	θ
Number of active contacts	π_C
Operating cycles per hours: mean number N	π_y , F_y
Ambient temperature t_A	π_t
Relay type	π_T
Environment	π_p

Relay type	π_T
Monostable	1
Bistable latching	5

Number of breaker active contacts "break contact" or "make contact"	π_{C1}
No contact of this type	0
1	1
2	1.5
3	2
4	2.5

Operating cycles per hours: mean number N	π_y
N≤10	1
N>10	$\sqrt{\frac{N}{10}}$

Number of inverter active contact "break contact" or "make contact"	π_{C2}
No contact of this type	0
1	1.8
2	3
3	4.3
4	5.5
6	8

Mathematical formula for π_t
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273+t_A}\right)}$ with t_A : ambient temperature

Pollution factor π_p depending on the operating cycle rate ,

Voltage Vt and current It (transient state).

Failure modes	
Short circuits	50%
Open circuits	50%

Cycle rate : N operating cycles per hour	F_y
N<0.1	0.1
0.1≤N<1	N
N>1	1

F_y

Influence factor product $V_t \times I_t \times F_y$	π_p
$V_t \times I_t \times F_y \le 1$	2
$V_t \times I_t \times F_y \ge 1$	1

The voltage V_t and the current I_t values (transient state) are given in pages 79 to 81. (Select the appropriate column " π_p calculation").

V_t , I_t

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

ELECTROMECHANICAL RELAYS
Miniature or card – European type
THERMAL RELAYS
(power up to 500 W)

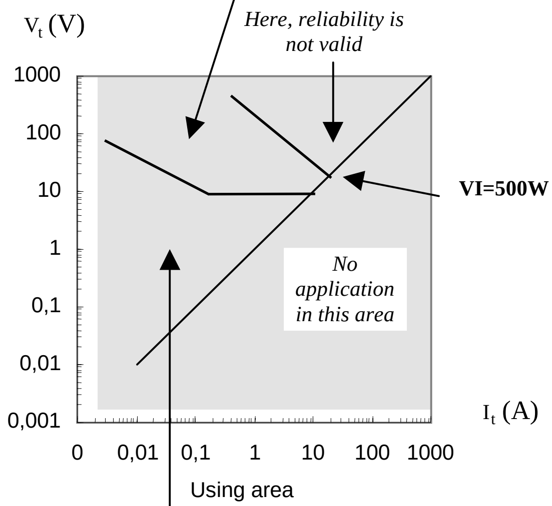
Specification : CEI 60255

LIFE EXPECTANCY θ

$$\theta = \theta_b \frac{1}{\pi_t \times N} \quad \text{in h}$$

In this area, failure rate is assumed to be constant but only within the life expectancy θ .

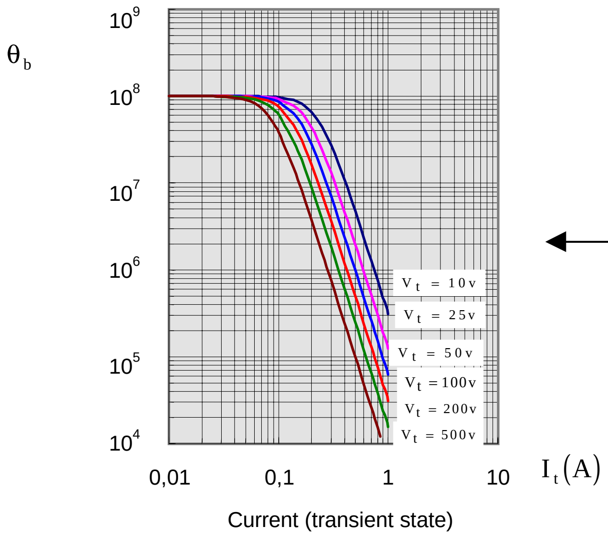
- π_t is given in next page (same factor as λ for the failure rate).
- N : Number of cycles per hour



In this area, failure rate is assumed to be constant during unlimited time.

Mathematical formula for θ_b
$\theta_b = \dfrac{10^8}{1 + 2V_t \times \left(\dfrac{I_t}{0.5}\right)^4}$

Vt Voltage (transient state)



The voltage V_t and the current I_t values (transient state) are given in pages 79 to 81. (Select the appropriate column " θ_b calculation").

θ_b depending on the voltage V_t and the current I_t in transient state (see pages 79 à 81)

Pollution factor π_p depending on the operating cycle rate , voltage Vt and current It (transient state).

Cycle rate : N operating cycles per hour	F_y
N<0.1	0.1
0.1≤N<1	N
N≥1	1

F_y

The voltage V_t and the current I_t values (transient state) are given in pages 79 to 81. (Select the appropriate column " π_p calculation").

V_t, I_t

Influence factors:	π_p			
• $V_t.I_t.F_y$ (product) • gaseous environment • Relay type	$V_t.I_t.F_y \leq 10$ pollution level			$V_t.I_t.F_y \geq 10$ Any
	low*	moderate*	high*	environment
Hermetically sealed	2	2	2	1
Sealed	2.5	3	10	1
Dust protected	3	5	20	1
Exposed contact relay	5	10	40	1
see table 3-b, *page* 14				

ELECTROMECHANICAL RELAYS
Miniature or card – European type
THERMAL RELAYS
(power up to 500 W)

Specification : CEI 60255

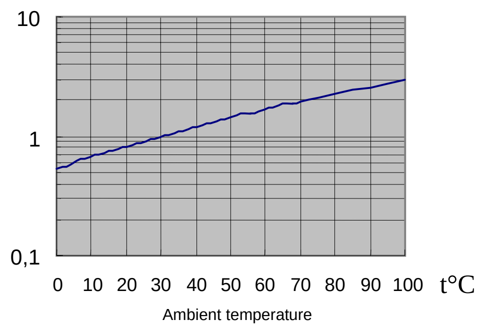
MATHEMATICAL MODEL

$$\lambda = 1.5 \times \pi_t \times \pi_T \times \pi_p \times \pi_Y \times \pi_C \cdot \left(1 + 2.7 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68}\right]\right) \times 10^{-9} / h$$

with $\pi_C = \pi_{C1}$ or π_{C2}

✎CAUTION !
Life expectancy is limited !

π_t



Necessary information	for
Current, voltage	θ
Load circuit	θ
Number of active contacts	π_C
Operating cycles per hours: mean number N	π_y, F_y
Ambient temperature t_A	π_t
Relay type	π_T
Environment	π_p

Mathematical formula for π_t
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273 + t_A}\right)}$ with t_A : ambient temperature

Number of breaker active contacts "break contact" or "make contact"	π_{C1}
No contact of this type	0
1	1
2	1.5
3	2
4	2.5

Relay type	π_T
Electromechanical (miniature and European)	1
Thermal relay	10

Number of inverter active contact "break contact" or "make contact"	π_{C2}
No contact of this type	0
1	1.8
2	3
3	4.3
4	5.5
6	8

Operating cycles per hours: mean number N	π_y
N≤10	1
N>10	$\sqrt{\frac{N}{10}}$

Mathematical expression of the Influence factor $(\pi_n)_i$		
	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

Failure modes	
Short circuits	20%
Open circuits	80%

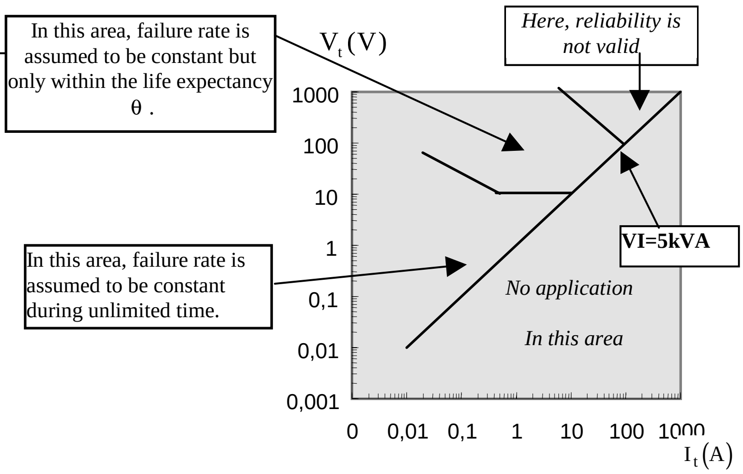
INDUSTRIAL RELAYS
(electromechanical)
HIGH VOLTAGE VACUUM RELAYS
POWER MERCURY WETTED RELAYS
D.C. current (< 5 kW) and A.C. current (< 5 kVA)

Specification : CEI 60255

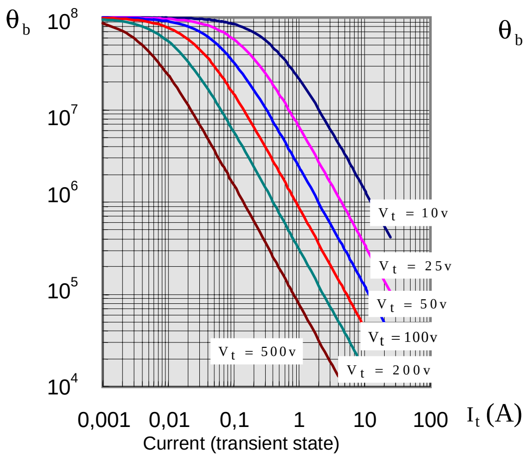
LIFE EXPECTANCY θ :

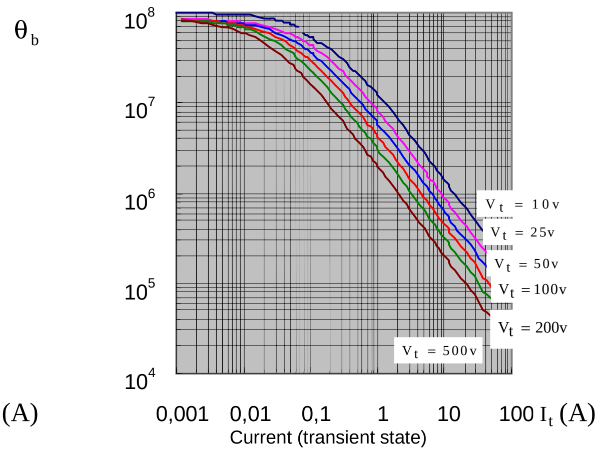
$$\theta = \theta_b \frac{1}{\pi_t \times N} \text{ in h}$$

- π_t is given in next page (same factor as λ for the failure rate).
- N : Number of cycles per hour



Mathematical formulas for θ_b	
D.C. relays	A.C. relays
$\theta_b = \dfrac{10^8}{1+100\left(\dfrac{V_t}{50}\right)^{1.5} \times \left(\dfrac{I_t}{2}\right)^{1.3}}$	$\theta_b = \dfrac{10^8}{1+100\left(\dfrac{V_t}{220}\right)^{0.5} \times \dfrac{I_t}{3}}$





θ_b depending on the voltage V_t and the current I_t in transient state (see page 79 to 81), for D.C. current relays (on the left) and A.C. current relays (on the right).

The voltage V_t and the current I_t values (transient state) are given in pages 79 to 81 (select the appropriate column "θ_b calculation")

Pollution factor π_p depending on operating cycle rate, gaseous environment and voltage Vt, current It (transient state).

Influence factors:	**π_p for D.C. relays**			
• product $V_t.I_t.F_y$ • gaseous environment • relay type	$V_t.I_t.F_y \le 50$ Pollution level low*	 moderate*	 high*	$V_t.I_t.F_y > 50$ Any environment
Mercury wetted relays	1	1	1	1
Hermetically sealed	2	2	2	1
Sealed	2.5	3	10	1
Dust protected	3	5	20	1
Exposed contact relay	5	10	40	1
** See table* 3-b, *page* 14				

Influence factors:	**π_p for A.C. relays**			
• product $V_t.I_t.F_y$ • gaseous environment • relay type	$V_t.I_t.F_y \le 300$ Pollution level low*	 moderate*	 high*	$V_t.I_t.F_y > 300$ Any environment
Mercury wetted relays	1	1	1	1
Hermetically sealed	2	2	2	1
Sealed	2.5	3	10	1
Dust protected	3	5	20	1
Exposed contact relay	5	10	40	1
** See table* 3-b, *page* 14				

V_t, I_t

V_t, I_t

F_y

The voltage V_t and the current I_t values (transient state) are given on pages 79 to 81. (Select the appropriate column " π_p calculation").

F_y

Cycle rate : N operating cycles per hour	F_y
N<0.1	0,1
0.1≤N<1	N
N>1	1

INDUSTRIAL RELAYS
(electromechanical)
HIGH VOLTAGE VACUUM RELAYS
POWER MERCURY WETTED RELAYS
D.C. current (< 5 kW) and A.C. current (< 5 kVA)

Specification : CEI 60255

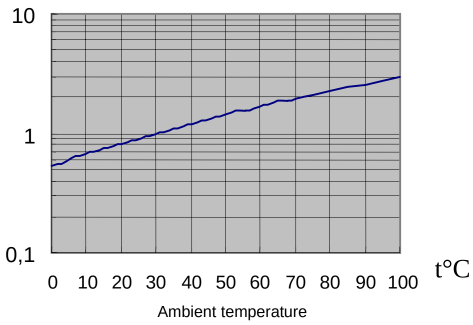
MATHEMATICAL MODEL

$$\lambda = 0.5 \times \pi_t \times \pi_T \times \pi_p \times \pi_Y \times \pi_C \times \left(1 + 2.7 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68}\right]\right) \times 10^{-9} / h$$

with $\pi_C = \pi_{C1}$ or π_{C2}

CAUTION ! Life expectancy is limited !

π_t



Necessary information	for
Current, voltage	θ
Load circuit	θ
Number of active contacts	π_C
Operating cycles per hours: mean number N	π_y, F_y
Ambient temperature t_A	π_t
Relay type	π_T
Environment	π_p

Mathematical formula for π_t
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273+t_A}\right)}$ with t_A : ambient temperature

Number of breaker active contacts "break contact" or "make contact"	π_{C1}
No contact of this type	0
1	1
2	1.5
3	2
4	2.5

Relay types	π_T
Industrial relay	2.5
High voltage vacuum relays	2.5
Power mercury wetted relays	1

Number of inverter active contact "break contact" or "make contact"	π_{C2}
No contact of this type	0
1	1.8
2	3
3	4.3
4	5.5
6	8

Operating cycles per hours: mean number N	π_y
N≤10	1
N>10	$\sqrt{\frac{N}{10}}$

Mathematical expression of the Influence factor $(\pi_n)_i$		
	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

Failure modes	
Short circuits	20%
Open circuits	80%

SWITCHES AND KEYBOARDS

Specifications : CEI 60132
CEI 60948

SWITCHES AND KEYBOARDS

MATHEMATICAL MODEL

$$\lambda = \lambda_0 \times N \times \left(1 + 2.7\times10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68}\right]\right) \times 10^{-9} / h$$

CAUTION!
Life expectancy is limited !

Base failure rate in FIT	λ_0
Toggle switches Push button switches Keyboards	1.5
Rotary switches	2.5

Necessary information	for
Switch type	λ_0, N
Number of contacts	N
Environment	π_E

Type	N
Reversible (toggle or push button)	N = 2x (number of "break-make" contacts)
Others commutators	N = number of contacts
Keyboards	N = number of keys

Life expectancy limitation
Failure rate is assumed to be constant but only within the specified number of switching cycles. *For example* : • Toggle and push button switches : between 20 000 and 100 000 (sensitive switches) • Rotary switches : 20 000 • Keyboards : between 500 000 and 1 000 000

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

CONNECTORS

CONNECTORS
CIRCULAR,RECTANGULAR, COAXIAL, FOR PRINTED CIRCUIT BOARD AND SOCKETS

The failure rate is given for a mated pair of connerctors

MATHEMATICAL MODEL

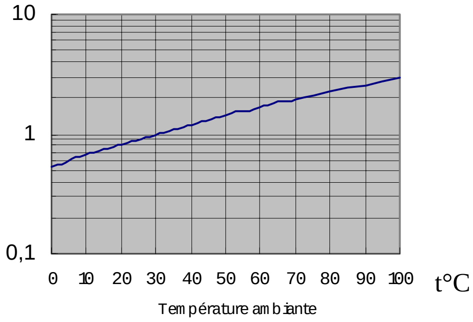
$$\lambda = \lambda_0 \times \pi_t \times \pi_C \times \pi_M \times \pi_i \times \left(1 + 2.7\times10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68}\right]\right) \times 10^{-9} / h$$

CAUTION !
The life expectancy is limited: The number of mating / unmating cycles must not exceed the specified value (or the value given by the manufacturer).

Base failure rate FIT (these values are given for a contact pair)	λ_0
Circular and rectangular connectors	0.5
Coaxial connectors	0.7
Printed circuit board connectors (and comparable)	1
Sockets	1

Necessary information	**for**
Connector type	λ_0
Contact area material	π_M
Number of active contacts	π_C
Contact current intensity	π_i
Nominal current	π_i
Ambient temperature	π_t

π_t



Contact surface coating (for a mating pair of connectors)	π_M
Gold/Gold	1
Silver/Silver	2
Tin/Tin	3
Others (edge card connector)	8

Contact current intensity		π_i
Ratio: $\dfrac{\text{Current}}{\text{Nominal current}}$	≤ 0.5	1
	> 0.5	2

Mathematical formula for π_t
$\pi_t = e^{1740\left(\frac{1}{303} - \frac{1}{273+t_A}\right)}$ with t_A : ambient temperature

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \leq 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	

Number of active contacts: N	π_C
Coaxial connectors	1
Others	$\sqrt{N}$

DISPLAYS, SOLID STATE LAMPS

DISPLAYS

Specification : CEI61747

MATHEMATICAL MODEL

$$\lambda = \lambda_0 \times \left(1 + 2.5\times10^{-2} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68}\right]\right) \times 10^{-9} / h$$

NECESSARY INFORMATION :
Display type

Display types : values in FIT	λ_0
LCD ≤ 10 characters	50
CRT display (10 inches with control electronic)	2500
LCD display (10 inches with control electronic)	1900

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^{th} phase of the mission profile.	

SOLID STATE LAMPS

Specification : CEI60747

MATHEMATICAL MODEL

$$\lambda = 2 \times \left(1 + 2.7\times10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68}\right]\right) \times 10^{-9} / h$$

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \le 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i^{th} phase of the mission profile.	

PROTECTION DEVICES

PROTECTION DEVICES and THERMISTORS (PTC)

Specifications : CEI 60099
CEI 60269
CEI 60738
CEI 61051

MATHEMATICAL MODEL

$$\lambda = (\lambda_0 + \pi_I \times \lambda_{EOS}) \times 10^{-9} / h$$

NECESSARY INFORMATION :
Device type
Electrical environment

Device type		λ_0 in FIT	π_I
Diodes	Transient voltage suppressor	See pages 36 to 39	1
	Trigger transient voltage suppressor	See pages 36 to 39	1
Thermistors (PTC)		5	1
Varistors		1	1
Fuses		10	0
Arrestors	Solid state (100A - 10/1000µs wave)	100	0
	Gas tube (≥5KA - 8/20µs wave)	6000	0

Electrical environment		λ_{EOS} FIT
Computer		10
Telecoms.	switching	15
	transmitting access, subscriber card	40
	Subscriber equipment	70
Railways, payphone		100
Civilian avionics (on board calculators)		20
Voltage supply, Converters		40

ENERGY DEVICES
THERMAL MANAGEMENT DEVICES
DISK DRIVE

BATTERIES – FANS – THERMOELECTRIC COOLERS DISK DRIVE

Specifications : CEI 60086 – CEI 60285 – CEI 60535 – CEI 60879 – CEI 61436 – CEI 61440.

MATHEMATICAL MODEL

$$\lambda = \lambda_0 \times 10^{-9} / h$$

NECESSARY INFORMATION :
Device type

Device type		λ_0 in FIT
Batteries: primary cells*		20
Batteries: secondary cells	Ni-Cd	100
	Li-Ion	150
Fans for integrated circuits (CPU)*		500
Ball bearing fans*		1500
Bearing fans*		2500
Thermo-electric cooler		20
Long duration disk drive		2800

* Caution: life expectancy of these devices is limited.

CONVERTERS

Specification : CEI 60146

MATHEMATICAL MODEL

$$\lambda = \lambda_0 \times \left(1 + 3 \times 10^{-3} \times \left[\sum_{i=1}^{j} (\pi_n)_i \times (\Delta T_i)^{0.68} \right] \right) \times 10^{-9} / h$$

NECESSARY INFORMATION :
Converter type

Converter type	λ_0 in FIT
Converters < 10W	100
Converters between 10 and 30W	130

Mathematical expression of the Influence factor $(\pi_n)_i$	$n_i \leq 8760$ Cycles/year	$(\pi_n)_i = n_i^{0.76}$
	$n_i > 8760$ Cycles/year	$(\pi_n)_i = 1.7 \times n_i^{0.60}$
n_i : Annual number of cycles with the amplitude ΔT_i		
For an on/off phase	$\Delta T_i = (t_{ac})_i - (t_{ae})_i$	
For a permanent working phase, storage or dormant	ΔT_i =average per cycle of the (t_{ae}) variation, during the i[th] phase of the mission profile.	