Film Capacitors

Quality

Date: June 2018

Corporate goals
Our aim is to play a leading role among the world's most competitive companies in the sector of electronic components. This aim is shared by the EPCOS quality and environment management system.

1 EPCOS quality system

1.1 Our commitment to quality

The quality of our products and services is an essential part of our corporate strategy with the main objective of customer satisfaction. For us, quality means providing products and services that offer maximum benefit to our customers worldwide as well as to understand the needs and expectations of all our interested parties. Quality also means ensuring competitiveness and thus securing our future, by continuous maintenance of our growing organizational knowledge.

Consistent application of a quality management system results in flawless products and a high level of user benefit from our components. It creates excellent quality of logistics and services and guarantees attractive price/ performance ratios.

Our quality management system is always in line with the most stringent international standards.

1.2 Quality management system

The quality management system to ISO/TS 16949:2009 is applied throughout the company and is used to implement the EPCOS quality policy. The implications include:

- as a rule, product and process developments follow the rules of APQP[1)],
- quality tools such as FMEA[2)], DoE[3)] and SPC[4)] to minimize risks and ensure continuous improvements in conjunction with regular internal audits and QM reviews.

1.3 Certification

The EPCOS quality management system forms the basis for the certification to ISO 9001:2008 and ISO/TS 16949:2009 that comprises the EPCOS plants and sales organizations.
The company certificates are posted on the EPCOS Internet (www.epcos.com/quality).

1.4 Production sequence and quality assurance

The business groups implement the corporate specifications for quality management in procedural and work instructions referred to products and processes.

The following example shows quality assurance applied to the production sequence of film capacitors.

1) APQP= Advanced Product Quality Planning
2) FMEA= Failure Modes and Effects Analysis
3) DoE= Design of Experiments
4) SPC= Statistical Process Control

Production sequence and quality assurance during film capacitors manufacture (Stacked-film)

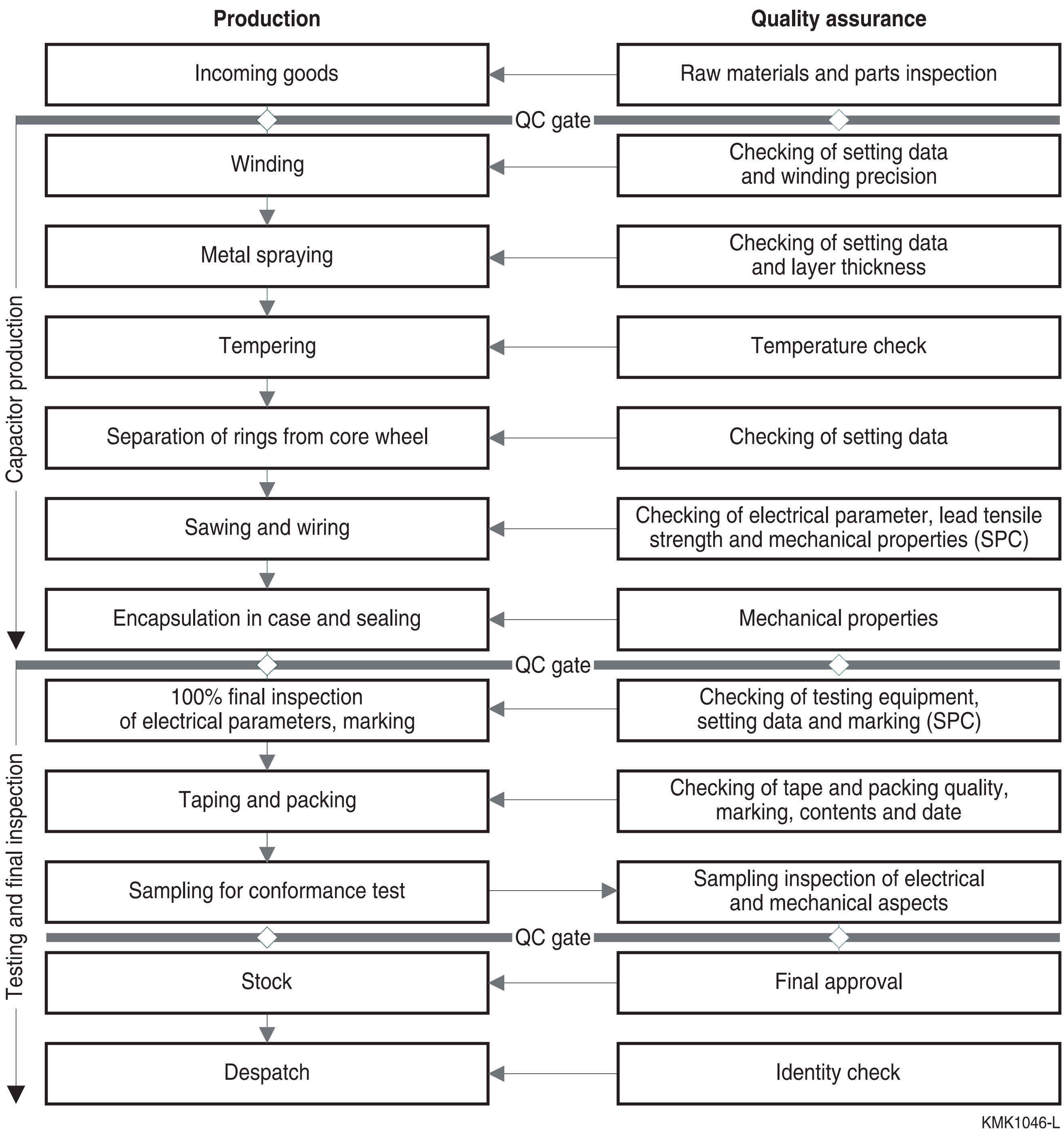

Figure 1
Quality assurance in the production process (Stacked-film capacitors)

Production sequence and quality assurance during film capacitors manufacture (Wound-film)

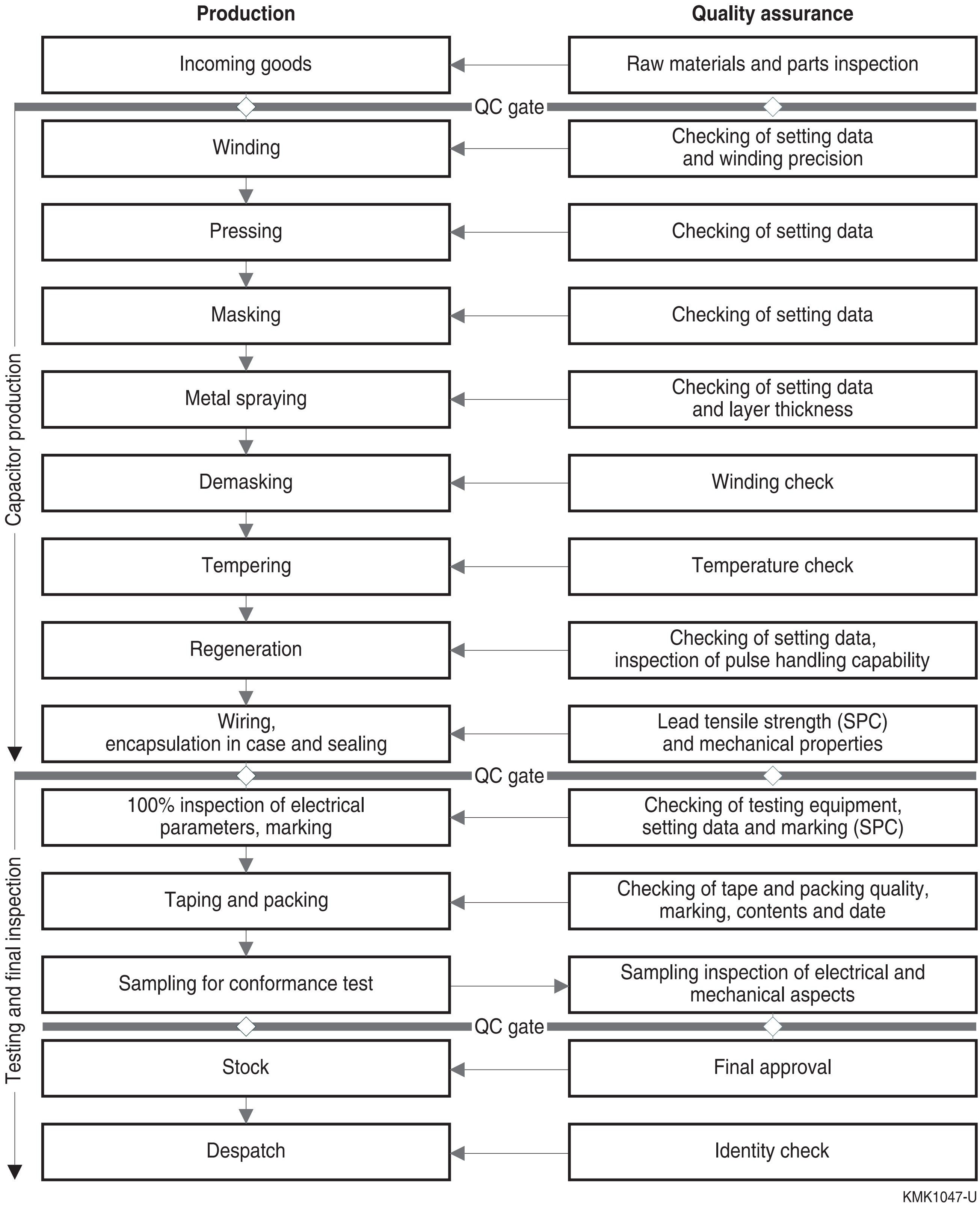

Figure 2
Quality assurance in the production process (Wound-film capacitors)

1.5 Delivery quality

"Delivery quality" means compliance with the agreed data at the time of delivery.

1.6 Failure criteria

A component is defective if one of its features does not correspond to the specification of the data sheet or an agreed delivery specification.

1.7 Incoming goods inspection at the customer

For the incoming inspection, we recommend the use of a random sampling plan according to ISO 2859-1:1999 (contents compliant with MIL STD 105 D:1964 or IEC 60410:1973).

The test methods used and the AQL must be coordinated between the customer and suppliers.

1.8 Final inspection/approval for shipment

Final inspection verifies the major properties of the end products batch by batch, usually by means of fully automated electrical selection tests.

Approval for shipment helps certify that the shipped products comply with the specifications. It includes:

- testing of principal parameters,
- identification check and visual assessment,
- examination of papers accompanying the batch.

1.9 Duration of use

The duration of use in terms of reliability is the time period during which random failures occur, i.e. the range in the product operating life in which the failure rate remains largely constant (early failures and end of operating life excepted). The value depends strongly on conditions of use.

1.10 Reliability

A variety of endurance tests and environmental tests are conducted to assure the product reliability. These tests are derived from the extremes of expected application conditions, with test conditions intensified to obtain authoritative results within a reasonable period.

The reliability testing programs of EPCOS are based on the test plans of international standards and customer requirements.

EPCOS performs reliability tests to qualify new component families and for periodic requalification.

1.11 Traceability

At all stages of production, components are identified by papers accompanying each batch. The completion of manufacturing and testing steps is confirmed and documented. This enables the batch to be traced back through the production process.

After delivery, traceability to the internal release inspections ("quality control gates") is ensured by the batch number which is printed on the label.

1.12 Bar code label

The packing of all EPCOS components bears a bar code label stating the type, ordering code, quantity, date of manufacture and batch number. This enables a component to be traced back through the production process, together with its batch and test report.

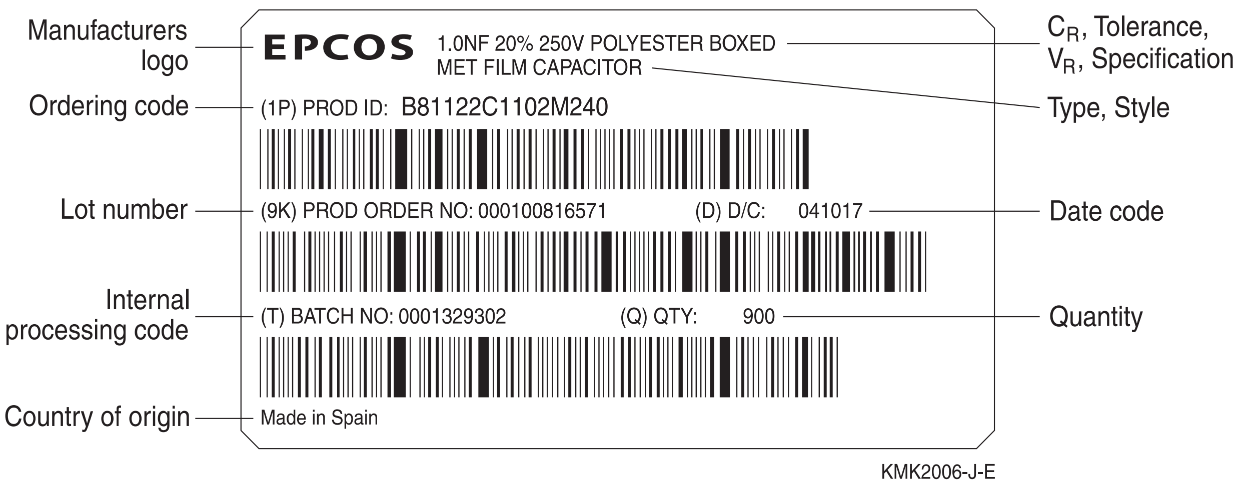

Figure 3
Label example

1.13 Electrical and mechanical properties

The measuring conditions can be found in the chapter "General technical information". The product data and relevant tolerance limits are defined in the respective data sheets.

1.14 Dimensions

The dimensional drawings in the individual data sheets are definitive for the dimensions.

1.15 Finish

The finish of film capacitors is assessed in compliance with EPCOS finish specifications. For more detailed specification, refer to the "General technical information" chapter. When applicable, the individual data sheets are definitive for finishing.

1.16 Failure rate (long-term failure rate)

The failure rate is defined as the failure percentage divided by a specified operating period. The failure rate is expressed in fit (failures in 10^9 component hours) or as percentage of failures in 1000 hours.
1 fit = $1 \cdot 10^{-9}$/h (fit = failure in time)

Example of a failure rate λ_{test} determined by a useful life test:

1. Number of components tested $N = 8000$
2. Operating hours $t_b = 25000$ h
3. Number of failures $N = 2$

$$\lambda_{test} = \frac{n}{N} \cdot \frac{1}{t_b} = \frac{2}{8000} \cdot \frac{1}{25000h} = 10\,\text{fit} = 0.001\% / 1000\,\text{h}$$

Failure rate specifications must include failure criteria, operating conditions and ambient conditions.

When plotted against time, the failure rate of components usually shows a characteristic bathtub curve with the following three periods:

I early failure period
II useful period
III wear-out failure period

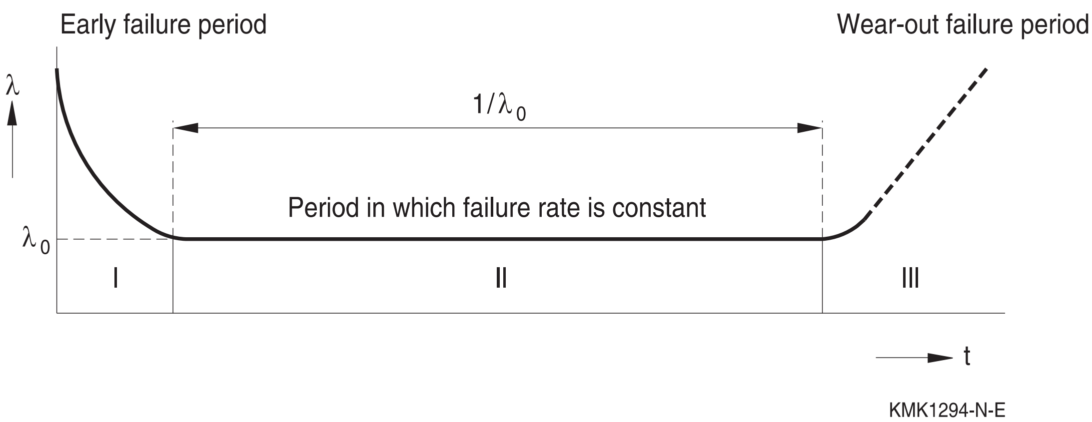

Figure 4
Typical failure rate curve of a product

Unless otherwise specified, the failure rate refers to the useful period (II). During this period, an approximately constant failure rate λ_0 can be assumed.

1.17 Conversion factors for failure rates

The conversion factors for different load conditions can be derived from IEC 61709:2011.

1.18 Failure rate and mean operating time to failure (MTTF)

Several conclusions can be extracted from the assumption that during the service period, the failure rate, $\lambda(t)$, is actually constant:

$$\lambda(t) \approx \lambda_0 = \text{const.}$$

In particular, it can be demonstrated that the distribution of failures is exactly exponential in this approximation, being the cumulative distribution function:

$$F(t) = 1 - e^{-\lambda_0 t}$$

This function gives the probability that a product fails by a specified time *t*. It is often interpreted as the population fraction failing by time *t*.

The *reliability function*, R(t), also called the survival function, is often interpreted as the population fraction surviving time *t*. R(t), being the probability of success, is therefore the complement of F(t):

$$R(t) = 1 - F(t)$$

Finally, another extremely significant definition is the mean time to failure (MTTF), which in general is the expected life of a non-repairable product. It can be defined in terms of the reliability function:

$$\text{MTTF} = \int_0^\infty R(t)dt = \int_0^\infty e^{-\lambda_0 t}dt = \frac{1}{\lambda_0}$$

In any case, the MTTF is a measure of the centre of a life distribution. In the exponential approximation, the MTTF is the same as the median of the distribution (most probable case).

At this point, it is essential to understand any figure of MTTF or λ (and any other magnitude derived from them) as statistical averages. A **constant failure rate** actually means that failure occurs **randomly** with a mean frequency given by the inverse of λ. It is also very common (but completely erroneous) to assume that the MTTF indicates a minimum time between failures, which is absolutely not the case. On the contrary, failures will occur randomly, the distribution being:

$$F(t) = 1 - e^{-\lambda_0 t} = 1 - e^{-\frac{1}{\text{MTTF}}}$$

It is however true that, for a given period of time [0,t] the bigger the MTTF, the smaller the probability of finding a failure. Suppose we are testing, in the proper climatic and electrical conditions (given by IEC 1709), a high enough number of units of our product (whose λ_0 = 2 fit, i.e. MTTF = $5 \cdot 10^8$ hours). The previous equation is then telling us that after $5 \cdot 10^8$ hours, 63% (~$1 - 1/e$) of the pieces will have failed. Please observe that even in the ideal case (a very big sample) some of the pieces will have failed before this time ($5 \cdot 10^8$ hours). Attending to the exponential distribution, for example, 1% of the pieces will have failed after ~$5 \cdot 10^6$ hours, i.e. 100 times earlier than the MTTF. We stress, once again, that this is a statistical value that may present some deviations in different realizations.

1.19 Reference conditions and failure rate calculation

As already said, standard failure rate figures are always calculated referred to certain climatic, mechanical and electrical reference conditions. The exact conditions are indicated in the IEC 1709 norm for the different passive components. In case of film capacitors:

- Among others, the relevant **climatic conditions** (as per IEC 721-3-3:2002, class 3k3), read:

Temperature limits	Rate of change of temperature	Condensation
+5 to +40 °C	0.5 °C/min	No

  Attention is driven in the mentioned standard to the fact **that combinations of the environmental parameters given may increase the effect on a particular component**. As we will be discussing later on this document, this especially applies to the presence of high relative humidity in addition to biological conditions or to conditions of chemically active substances.

- The **electrical stress** should be 50% of the rated voltage at 40 °C ($V/V_R = 0.5$).
- The **mechanical stress** is also specified in IEC 721-3-3:2002 with class 3M3.

For a correct understanding of failure rate figures, it is essential to take into account that any failure rate estimation is related to these general conditions and applies to the constant failure rate period (as explicitly mentioned in the IEC61709:2011 standard). Components may however not always operate under these standard conditions. In which case, failure rates different to those given for the reference will be expected.

In the case of film capacitors, the two most relevant parameters affecting the failure rate are temperature and voltage. In the IEC61709:2011 standard, models for stress factors are consequently applied in order to convert the failure rates under reference conditions to values applying for operating conditions. The conversion should be carried out according to:

$$\lambda = \lambda_{ref} \cdot \pi_V \cdot \pi_T$$

where the correction factors are those indicated in following tables:

T (°C)	π_T
≤40	1.0
50	1.8
55	2.3
60	3.1
70	5.2
80	9.0
85	12
90	16
100	33
105	50
110	77
120	206
125	346

V/V_R	π_V
10%	0.26
25%	0.42
50%	1.00
60%	1.42
70%	2.04
80%	2.93
90%	4.22
100%	6.09
110%	9.00
120%	13.00

1.20 Service life t_{SL}

In the context of the exponential approximation and, following our earlier reasoning, the service life of our product is directly related to the duration of the intrinsic failure period (II, of the bathtub curve, page 7), which is also proportional to the inverse of the constant failure rate λ_0. Given the statistical nature of this figure, any estimation for a certain product will be inherently linked to a certain confidence level. We therefore calculate the service life after:

$$t_{SL} = \frac{p}{\lambda_0}$$

where p is a factor related to the confidence level of the estimation:

confidence level (%)	p
37	0.716
63	0.333
75	0.207
90	0.076
95	0.037
98	0.015

It is important to remark that using the proposed formula, the environmental and operating conditions for which t_{SL} applies are exactly those of λ_0. For a detailed example of good use of the formula and the correction factors, see next section.

1.21 Practical example

Suppose we have a product that will be used at the rated voltage and a stable temperature of 85 °C. For estimating the failure rate of this product, an accelerated endurance test has been performed at the reference conditions (40 °C & V = 0.5 V_R). Further details of the test are:

- Number of components tested (N): 20000
- Duration of the test (T): 50000 hours
- Number of failures at the end of the test (n): 1

A good estimator for the failure rate can then be calculated in terms of the total testing time, which results of multiplying the duration of the test by the number of samples tested (TTT = N · T),

$$\hat{\lambda}_{ref} = \frac{n}{TTT} = \frac{n}{N \cdot T} = \frac{1}{20000 \cdot 50000\ h} = 1 \cdot 10^{-9}\ h^{-1}$$

Accordingly, we conclude that the failure rate of this product operating at reference conditions is $\lambda_0 = 1$ fit:

$$\lambda_{ref} = 1 \cdot 10^{-9}\ h^{-1},\ \text{at}\ \left(40\ ^\circ C\ \&\ V = 0.5\ V_R\right)$$

The standard factors shown in previous section can be used for calculating the failure rate at the operating conditions:

$$\lambda_0^{op} = \lambda_{ref} \cdot \pi_T^{85\ ^\circ C} \cdot \pi_V^{V_R} = 1 \cdot 10^{-9} \cdot 12 \cdot 6.09\ h^{-1} = 73.10 \cdot 10^{-9}\ h^{-1} \approx 73\ \text{fit}$$

And the corresponding service life under the same operating conditions can be then calculated with a *98% confidence level* after:

$$t^{op}_{SL,98\%} = \frac{p^{98\%}}{\lambda^{op}_0} = \frac{0.015}{73.1 \cdot 10^{-9}}\ h \approx 200000$$

Now, note that if we wanted to restrict our estimation to a lower confidence level, i.e. 90%, the result would then have been:

$$t^{op}_{SL,90\%} = \frac{p^{90\%}}{\lambda^{op}_0} = \frac{0.076}{73.1 \cdot 10^{-9}}\ h \approx 1000000$$

Both figures are compatible, and should be interpreted as follows. For a big enough sample of products that are being tested under the given operating conditions, 98% of the pieces will be fully operative after 200000 working hours, but after 1000000 working hours, only 90% of them will remain.

1.22 Conditions of use

EPCOS products may only be used in line with the technical specifications and installation instructions and must comply with the state of the art. Non-observance of limits, operating conditions or handling guidelines can lead to disturbances in the circuit and other undesirable consequences such as a higher failure rate.

In this connection, please note the "Important notes".

Should you have any application-referred questions, please contact our experts, who will be pleased to advise you.

1.23 Customer complaints

If a fault occurs in a product despite careful manufacture and testing, please contact your local sales organization. They will register your complaint and forward it to the relevant technical departments for rapid handling.

EPCOS treats technical complaints according to the 8D[5)] methodology; i.e. with the use of interdisciplinary teams who aim to implement rapid countermeasures and sustained corrections and answer all complaints with an 8D report.

In order to be able to deal quickly and smoothly with complaints, the following data are helpful:

- Number of components subject to complaint or returned
- Fault description (with photos if applicable)
- How and when was the fault detected?
- Logistics data (delivery note no., batch no., date code)
- Operating conditions
- Operating duration up to occurrence of the fault
- Measurement parameters in the case of divergent technical data

5) 8D = 8 disciplines

In the event of transport damage, we would ask you to describe this in more detail and if required to mark it so that it can be distinguished from any further damage sustained during the return shipment. The original package should also be checked and any damage to be described.

In order to avoid further damage, the original packaging should also be used for the return shipment.

In case of receiving a damaged delivery, please document this damage with a signature of the forwarding company on the delivery papers.