TRANSLATION OF TECHNICAL TERMS

SOME IMPORTANT TERMS	DES TERMES IMPORTANTES	EINIGE WICHTIGE BEGRIFFE
Ambient temperature (T_{amb})	température ambiante	Umgebungstemperatur
Assessment level	niveau d'assurance	Gütebestätigungsstufe
Axial terminations	sorties axiales	axiale Anschlußdrähte
Capacitance	capacité	Kapazität
Charge	charge	laden
Climatic category	catégorie climatique	Klimakategorie
Dimensions	dimensions	Maße
Discharge	décharge	entladen
Dissipation factor (tan δ)	tangente de l`angle de pertes	Verlustfaktor
Endurance	endurance	Dauerspannungsprüfung
Equivalent series resistance (ESR)	résistance série équivalente	äquivalenter Serienwiderstand
Equivalent series inductance (ESL)	inductance série équivalente	äquivalente Serieninduktivität
Failure rate	taux de fiabilité	Ausfallrate
Frequency (f)	fréquence	Frequenz
General purpose grade	usage général	allgemeine Anforderungen
Impedance (Z)	impédance	Scheinwiderstand, Impedanz
Leadless	sans fils	unbedrahtet
Leakage current (I_l)	courant de fuite	Reststrom
Long life grade	longue durée de vie	erhöhte Anforderungen
Method	méthode	Verfahren
Mounting	montage	Montage
No visible damage	aucun dommage	keine sichtbaren Schäden
Open circuit	circuit ouvert	Unterbrechung
Mounting hole diagram	dessin de montage	Bohrungsraster
Rated capacitance (C_R)	capacité nominale	Nennkapazitat
Rated voltage (U_R)	tension nominale	Nennspannung
Recovery	reprise	Nachbehandlung
Forming voltage (U_F)	tension de formation	Formierspannung
Requirements	exigences	Anforderungen
Reverse voltage (U_{rev})	tension inverse	Umpolspannung
Ripple current (I_R)	courant ondulé	überlagerter Wechselstrom
Short circuit	court-circuit	Kurzschluß
Surface mounting device (SMD)	composant pour montage en surface	oberflächenmontierbares Bauelement
Surge voltage (U_S)	surtension	Spitzenspannung
Terminal pitch	distance entre les connections	Rastermaß
Terminations	sorties	Anschlüsse
Useful life	durée de vie	Brauchbarkeitsdauer
Visual examination	examen visuel	Sichtkontrolle

CAPACITOR PRINCIPLES

The essential property of a capacitor is to store electrical charge. The amount of electrical charge (Q) in the capacitor (C) is proportional to the applied voltage (U). The relationship of these parameters is:

$$Q = C \times U$$

where:

Q = charge in coulombs (C)

C = capacitance in farads (F)

U = voltage in volts (V).

The value of capacitance is directly proportional to the (anode) surface area and inversely proportional to the thickness of the dieletric layer, thus:

$$C = \varepsilon_O \times \varepsilon_r \times \frac{A}{d}$$

where:

ε_O = absolute permittivity (8.85×10^{-12} F/m)

ε_r = relative dielectric constant (dimensionless)

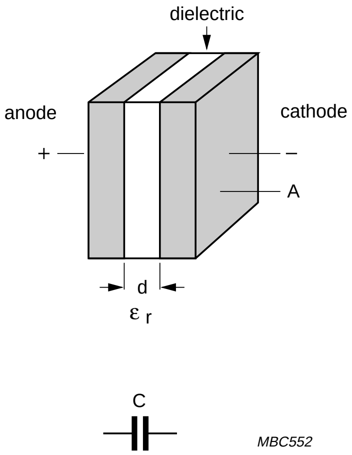
A = surface area (m^2)

d = thickness of the dielectric (oxide layer in electrolytic capacitors) (m).

Energy content of a capacitor

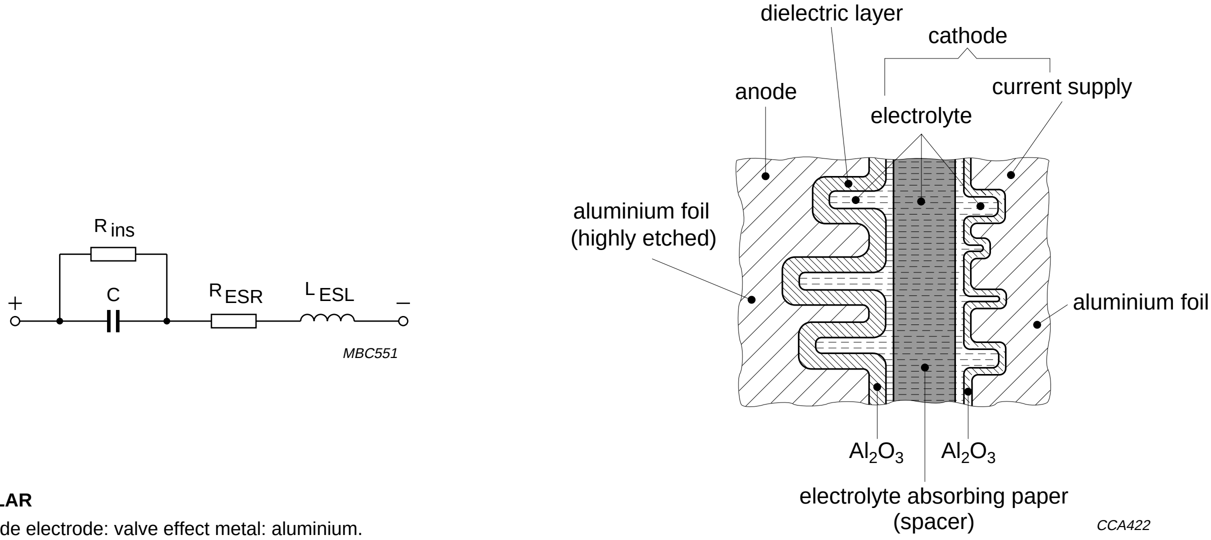
The energy content of a capacitor is given by:

$$W_E = \frac{1}{2} \times C \times U^2$$



NON-POLAR

Fig.1 Equivalent circuit of an ideal capacitor.



POLAR

Anode electrode: valve effect metal: aluminium.

Dielectric: Al_2O_3

Cathode electrode, solid or non-solid electrolyte depending on technology:

non-solid: wet electrolyte, spacer and aluminium foil

solid: solid electrolyte (e.g. manganese dioxide), graphite and silver epoxy.

Fig.2 Equivalent circuit of an electrolytic capacitor.

ELECTRICAL BEHAVIOUR

CHARACTERISTICS OF ELECTROLYTIC CAPACITORS VARY WITH TEMPERATURE, TIME AND APPLIED VOLTAGE.

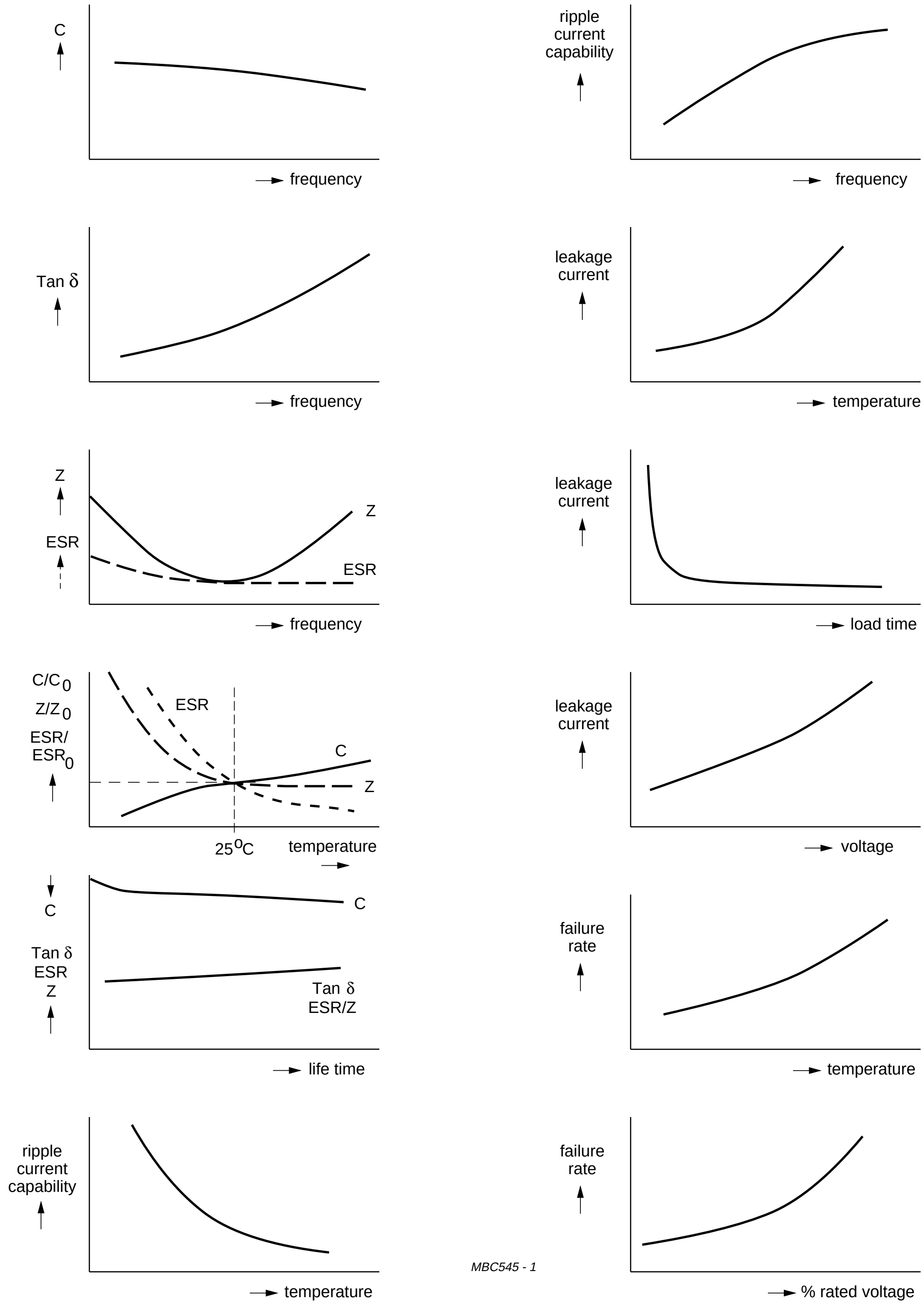


Fig.3 Typical variation of electrical parameters as a function of frequency, ambient temperature, voltage and time.

CONSTRUCTION

Examples

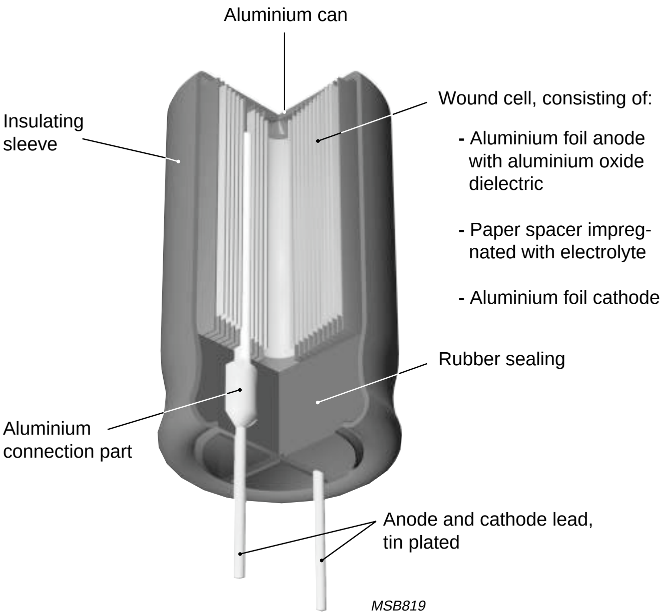


Fig.4 Radial Aluminium.

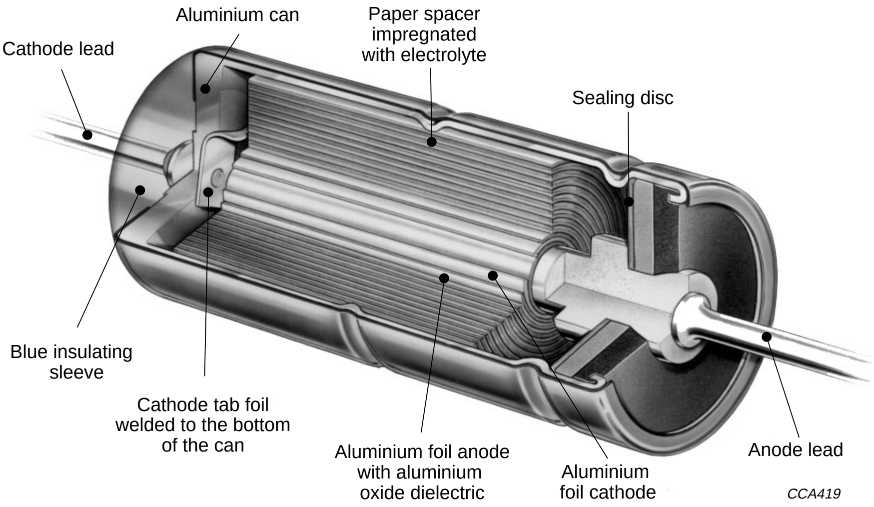


Fig.5 Axial Aluminium.

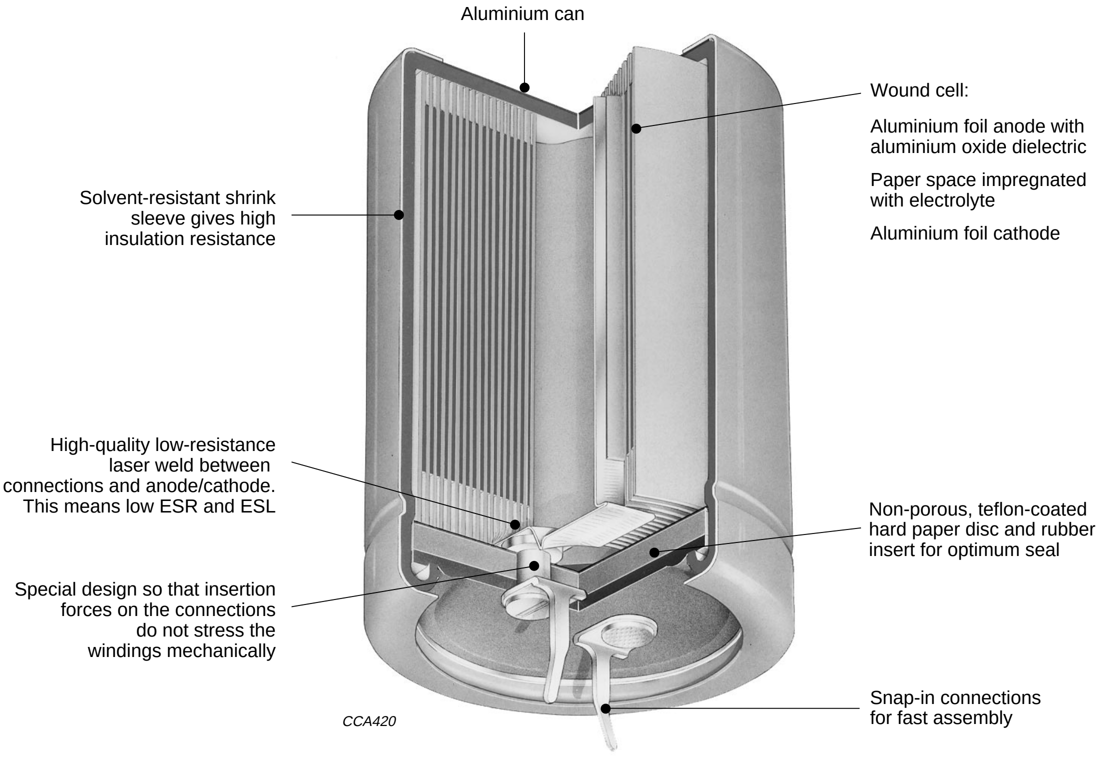


Fig.6 Large Aluminium, snap-in.

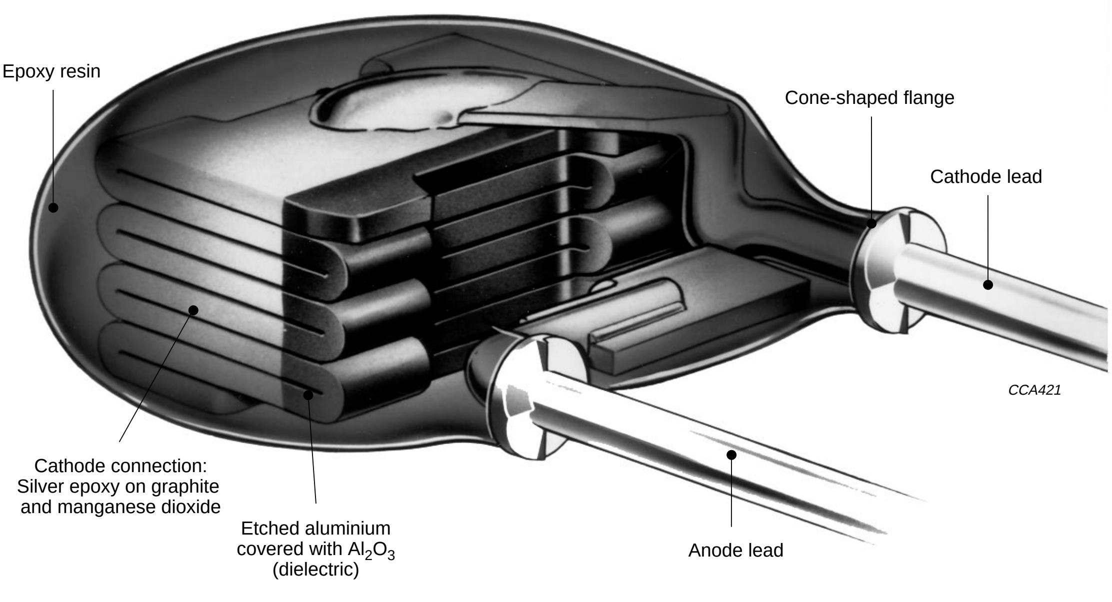


Fig.7 Solid Aluminium (SAL), radial.

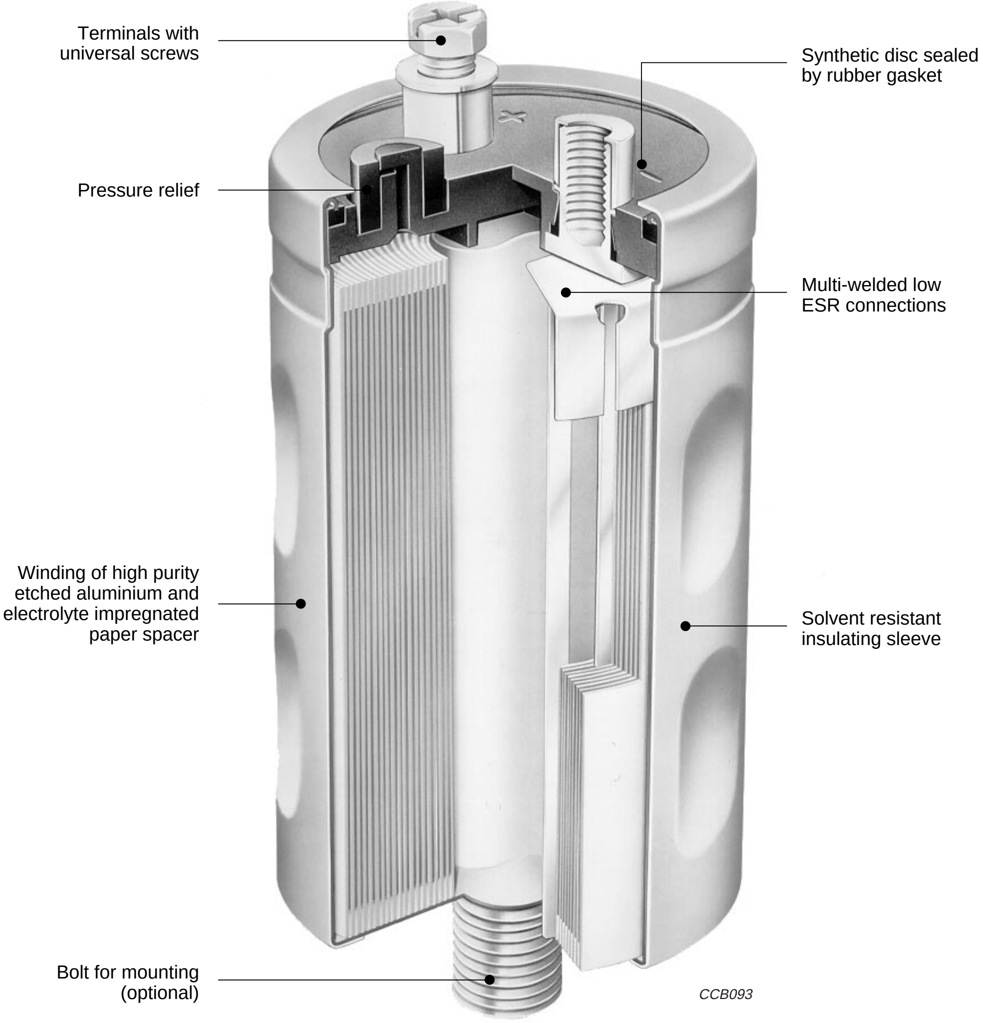


Fig.8 Large Aluminium, screw terminal.

DEFINITIONS OF ELECTRICAL PARAMETERS

Sequence of measurement for tests are in accordance with *"IEC 384-4"*:

1. Leakage current (I_L)
2. Capacitance (C_R)
3. Dissipation factor (tan δ or ESR)
4. Impedance (Z).

Capacitance

AC CAPACITANCE OF AN ELECTROLYTIC CAPACITOR

The capacitance of an equivalent circuit, having capacitance, resistance and inductance in series, measured with alternating current of approximately sinusoidal waveform at a specified frequency; refer to Fig.9.

Standard measuring frequencies for electrolytic capacitors are 100 or 120 Hz.

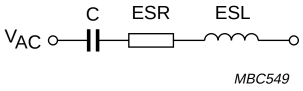


Fig.9 AC equivalent circuit of an electrolytic capacitor.

DC CAPACITANCE OF AN ELECTROLYTIC CAPACITOR (FOR TIMING CIRCUITS)

DC capacitance is given by the amount of charge which is stored in the capacitor at the rated voltage (U_R).
DC capacitance is measured by a single discharge of the capacitor under defined conditions. Measuring procedures are described in *"DIN 41328, sheet 4"* (withdrawn).

At any given time, the DC capacitance is higher than the AC capacitance.

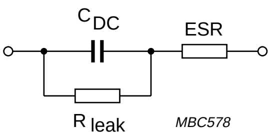


Fig.10 DC equivalent circuit of an electrolytic capacitor.

RATED CAPACITANCE (C_R)

The capacitance value for which the capacitor has been designed and which is usually indicated upon it.

Preferred values of rated capacitance and their decimal multiples are preferably chosen from the E3 series of *"IEC Publication 63"*.

TOLERANCE ON RATED CAPACITANCE
Preferred values of tolerances on rated capacitance

−20/+20%	**−10/+50%**	**−10/+30%**	**−10/+10%**
M	**T**	**Q**	**K**

These values depend on the relevant series.

Voltage

RATED VOLTAGE (U_R)

The maximum direct voltage, or peak value of pulse voltage which may be applied continuously to a capacitor at any temperature between the lower category temperature and the rated temperature.

CATEGORY VOLTAGE (U_C)

The maximum voltage which may be applied continuously to a capacitor at its upper category temperature.

TEMPERATURE DERATED VOLTAGE

The temperature derated voltage is the maximum voltage that may be applied continuously to a capacitor, for any temperature between the rated temperature and the upper category temperature.

RIPPLE VOLTAGE (U_{RPL})

An alternating voltage may be applied, provided that the peak voltage resulting from the alternating voltage, when superimposed on the direct voltage, does not exceed the value of rated direct voltage or fall under 0 V and that the ripple current is not exceeded.

REVERSE VOLTAGE (U_{REV})

The maximum voltage applied in the reverse polarity direction to the capacitor terminations.

SURGE VOLTAGE (U_S)

The maximum instantaneous voltage which may be applied to the terminations of the capacitor for a specified time at any temperature within the category temperature range.

Temperature

CATEGORY TEMPERATURE RANGE

The range of ambient temperatures for which the capacitor has been designed to operate continuously: this is defined by the temperature limits of the appropriate category.

RATED TEMPERATURE

The maximum ambient temperature at which the rated voltage may be continuously applied.

MINIMUM STORAGE TEMPERATURE

The minimum permissible ambient temperature which the capacitor shall withstand in the non-operating condition, without damage.

Resistance/Reactance

EQUIVALENT SERIES RESISTANCE (ESR)

The ESR of an equivalent circuit having capacitance, inductance and resistance in series measured with alternating current of approximately sinusoidal waveform at a specified frequency; refer to Fig.9.

EQUIVALENT SERIES INDUCTANCE (ESL)

The ESL of an equivalent circuit having capacitance, resistance and inductance in series measured with alternating current of approximately sinusoidal waveform at a specified frequency; refer to Fig.9.

DISSIPATION FACTOR (TANGENT OF LOSS ANGLE; tan δ)

The power loss of the capacitor divided by the reactive power of the capacitor at a sinusoidal voltage of specified frequency:

$\tan\delta = ESR \times 2\pi fC$ (approximation formula)

IMPEDANCE (Z)

The impedance (Z) of an electrolytic capacitor is given by capacitance, ESR and ESL in accordance with the following equation (see Fig.11):

$$Z = \sqrt{ESR^2 + \left(2\pi f ESL - \frac{1}{2\pi f C}\right)^2}$$

Current

LEAKAGE CURRENT (I_L)

Leakage current flows through a capacitor when a DC voltage is applied in correct polarity. It is dependent on voltage, temperature and time.

Leakage current for acceptance test (I_{L5})

In accordance with international standards *("IEC 384-4"* and *"CECC 30300")* the leakage current (I_{L5}) **after 5 minutes** application of rated voltage at 20 °C, is considered as an acceptance requirement.

The leakage current requirements for the majority of Philips electrolytic capacitors, are lower than specified in *"IEC 384-4"* or *"CECC 30300"*.

If, for example, after prolonged storage and/or storage at excessive temperature (>40 °C), the leakage current at the first measurement does not meet the requirements, pre-conditioning shall be carried out in accordance with *"CECC 30300 subclause 4.1"*.

Leakage current at delivery (I_{L1} or I_{L2})

In addition to I_{L5}, the leakage current **after 1 minute** application of rated voltage (I_{L1}) is specified in most of the detail specifications.

For some series this value is specified **after 2 minutes** (I_{L2}).

Operational leakage current (I_{OP})

After continuous operation (1 hour or longer) the leakage current will normally decrease to less than 20% of the 5 minute value (I_{L5}).

The operational leakage current depends on applied voltage and ambient temperature; see Tables 1 and 2.

Leakage current after storage with no voltage applied (shelf life)

If non-solid electrolytic capacitors are stored above room temperature for long periods of time, the oxide layer may react with the electrolyte, causing increased leakage current when switched on for the first time after storage.

Table 1 Typical multiplier of operational leakage current as a function of ambient temperature (as far as allowed for the corresponding series)

SYMBOL	MULTIPLIER									
T_{amb} (°C)	–55	–40	–25	0	20	45	65	85	105	125
I_{OP}/I_L	<0.5	0.5	0.6	0.8	1	1.5	2.5	4	7	10

Table 2 Typical multiplier of operational leakage current as a function of applied voltage

SYMBOL	MULTIPLIER								
U/U_R	<0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
I_{OP}/I_L	0.1	0.15	0.2	0.3	0.4	0.5	0.65	0.8	1

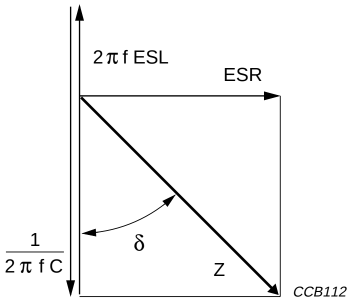


Fig.11 Vector diagram showing the AC parameters of a capacitor.

Ripple current (I_R)

Any pulsating voltage (or ripple voltage superimposed on DC bias) across a capacitor results in an alternating current through the capacitor.

Because of ohmic and dielectric losses in the capacitor, this alternating current produces an increase of temperature in the capacitor cell.

The heat generation depends on frequency and waveform of the alternating current.

The maximum RMS value of this alternating current, which is permitted to pass through the capacitor during its entire specified useful life (at defined frequency and defined ambient temperature), is called **rated ripple current** (I_R).

The rated ripple current is specified in the relevant detail specifications at 100 or 120 Hz (in special cases at 100 kHz) and at upper category temperature.

Usually the rated ripple current will cause a temperature increase of the capacitor's surface of approximately 3 or 5 K (dependent on series) compared with ambient temperature. A further temperature increase of 3 or 5 K will be found in the core of the capacitor.

This temperature rise is the result of the balance between heat generated by electric losses:

$$P = I_R^2\ ESR$$

and the heat carried off by radiation, convection and conduction:

$$P = \Delta T \times A \times \beta;\ I_R = \sqrt{\frac{\Delta T \times A \times \beta}{ESR}}$$

I_R can be determined by the equation:

$$I_R = \sqrt{\frac{\Delta T \times A \times \beta}{ESR}}$$

where:

ΔT = difference of temperature between ambient and case surface

A = geometric surface area of the capacitor

β = specific heat conductivity, dependent on the size of the capacitor.

The heat, generated by ripple current, is an important factor of influence for non-solid electrolytic capacitors for calculating the useful life under certain circumstances.

In the detail specifications this factor is considered in the so-called ‘life-time nomograms’ (‘Multiplier of useful life’ graph) as a ratio between actual ripple current (I_A) and rated ripple current (I_R), drawn on the vertical axis.

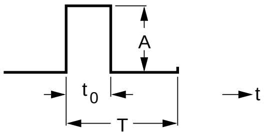
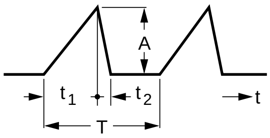
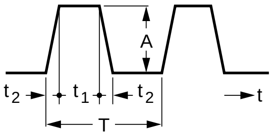
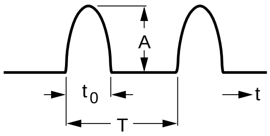
Care should be taken to ensure that the actual ripple current remains inside the graph at any time of the entire useful life. If this cannot be realized, it is more appropriate to choose a capacitor with a higher rated voltage or higher capacitance, than originally required by the application.

The internal losses and the resultant ripple current capability of electrolytic capacitors are frequency dependent. Therefore, a relevant frequency conversion table (‘Multiplier of ripple current as a function of frequency’) is stated in the detail specifications.

CALCULATION OF THE APPLICABLE RMS RIPPLE CURRENT

Non-sinusoidal ripple currents (if not accessible by direct measurement) have to be analyzed into a number of sinusoidal ripple currents by means of Fourier-analysis; the vectorial sum of the currents thus found may not exceed the applicable ripple current.

For some frequently occurring waveforms, approximation formulae are stated in Fig.12 for calculating the corresponding RMS value.

WAVE FORM	RMS VALUE
	$A\sqrt{\frac{t_0}{T}}$
	$A\sqrt{\frac{t_1+t_2}{3T}}$
	$A\sqrt{\frac{3t_1+2t_2}{3T}}$
	$A\sqrt{\frac{t_0}{2T}}$

CCA416

Fig.12 Approximation formulae for RMS values of non-sinusoidal ripple currents.

STORAGE

No pre-condition will be necessary for Philips electrolytic capacitors, when stored under standard atmospheric conditions *("IEC 68-1, clause 5.3.1")* for the following periods of time:

3 years for non-solid 85 °C types

4 years for non-solid 105 °C types

10 years for non-solid 125 °C types

20 years for solid types.

After these periods, the leakage current for acceptance test shall not exceed twice the specified I_{L5} requirement.

To ensure good solderability and quality of taping, for all types and prior to mounting, the storage time shall not exceed 3 years. This means for example: 2 years storage time between manufacture and arrival at the customer, plus 1 year in customer storage.

OPERATIONAL CONDITIONS

Charge-discharge proof

This term means the capability of capacitors to withstand frequent switching operations without significant change of capacitance.

Philips Al-electrolytic capacitors are charge-discharge proof in accordance with *"IEC 384-4"* and *"CECC 30300 subclause 4.20":* unless otherwise specified, 10^6 switching operations (RC = 0.1 s) shall not cause a capacitance change of more than 10%.

Non-frequent charging and discharging, without a series resistor, will not damage the capacitor.

If a capacitor is charged and discharged continuously several times per minute, the charge and discharge currents have to be considered as ripple currents flowing through the capacitor. The RMS value of these currents should be determined and the resultant value must not exceed the applicable limit.

Endurance test

In *"IEC 384-4"* or *"CECC 30300"* the criteria for the acceptable drift of electrical parameters after the endurance test at U_R and upper category temperature are defined.

Test duration and conditions per series are stated in the relevant detail specification.

The endurance test does not provide information about the useful life of a capacitor, as no failure percentage is defined for this investigation.

Useful life

Useful life (other names: load life, life time or typical life time) is that period of time, during which a given failure percentage may occur, under well defined conditions and requirements. Useful life data are usually calculated with a confidence level of 60%.

High quality of materials and controlled manufacturing processes provided, the useful life of non-solid electrolytic capacitors is solely determined by evaporation of electrolyte through the sealing.

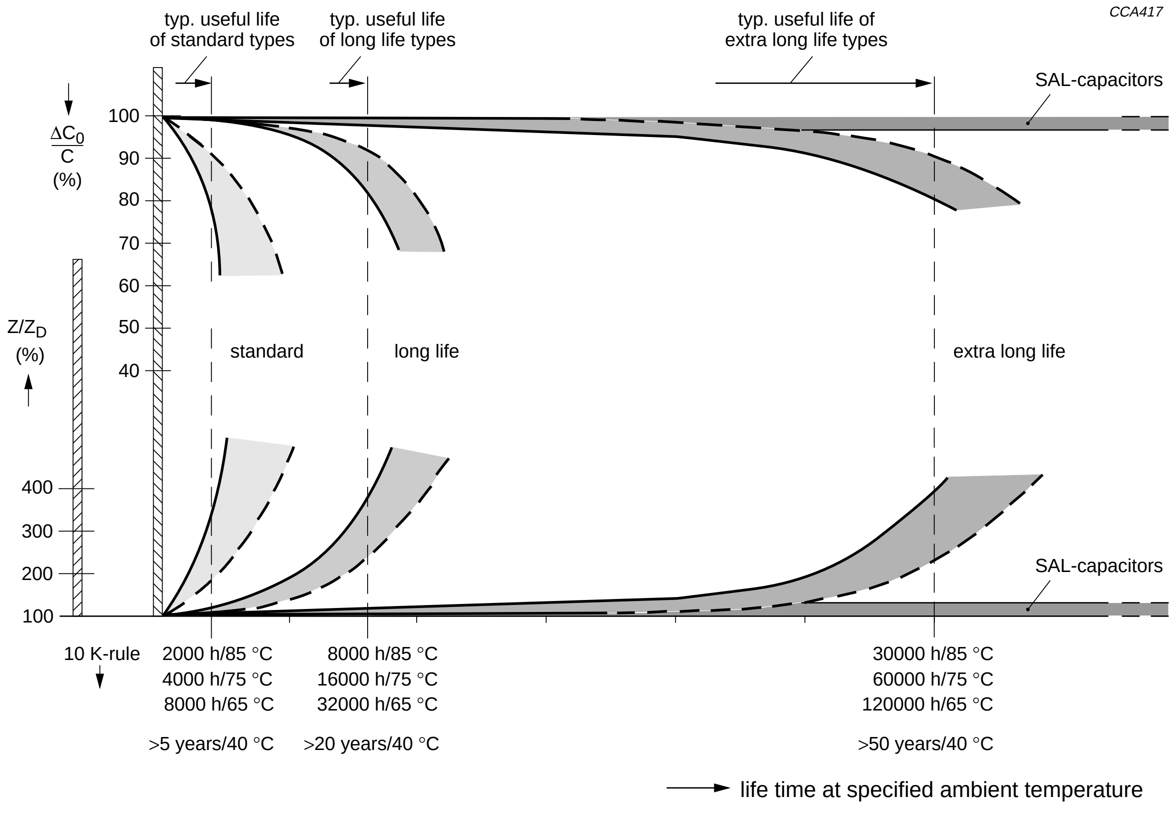
Figure 13 shows the principal electrical consequences of this electrolyte loss: increasing impedance and decreasing capacitance at the end of useful life, for different non-solid types.

Due to the fact that no liquid electrolyte is used in solid aluminium electrolytic capacitors, the associated failure mechanism does not occur.

The influence of temperature on useful life is indicated by the so-called ‘10 K-rule’ under the horizontal axis of the graph. The ‘10 K-rule’ means approximately, that double the life time can be expected per 10 K temperature decrease; this principle is derived from the well known law of Arrhenius about acceleration of reaction processes.

The exact temperature dependence of useful life for a particular range is given in the corresponding detail specification in the ‘life-time nomogram’ (‘Multiplier of useful life’ graph in the detail specifications). Detailed performance requirements, on which the definition ‘useful life’ is based, are also stated in the relevant detail specifications.

Exceeding those requirements shall not necessarily induce a malfunction of the equipment involved. The performance requirements offer advice on the choice of components and design of the circuitry.



C_0 = initial value of capacitance.
Z_D = specified limit of impedance.

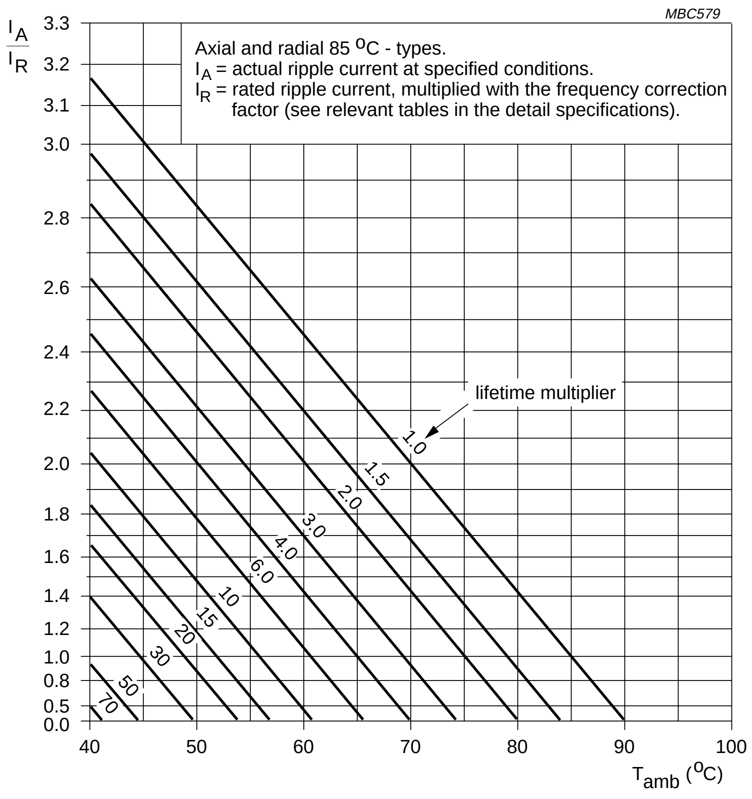
Fig.13 Principal trend of electrical parameters during useful life of different electrolytic capacitors.

CALCULATION OF USEFUL LIFE BY MEANS OF ‘LIFE-TIME NOMOGRAMS’

Based on the Arrhenius law and on experience for some decades, a nomogram is specified in the detail specification for each range, where the influence of ambient temperature and ripple current on the expected useful life is shown. Ripple currents at other frequencies than specified must be corrected using the frequency conversion tables in the relevant detail specification.

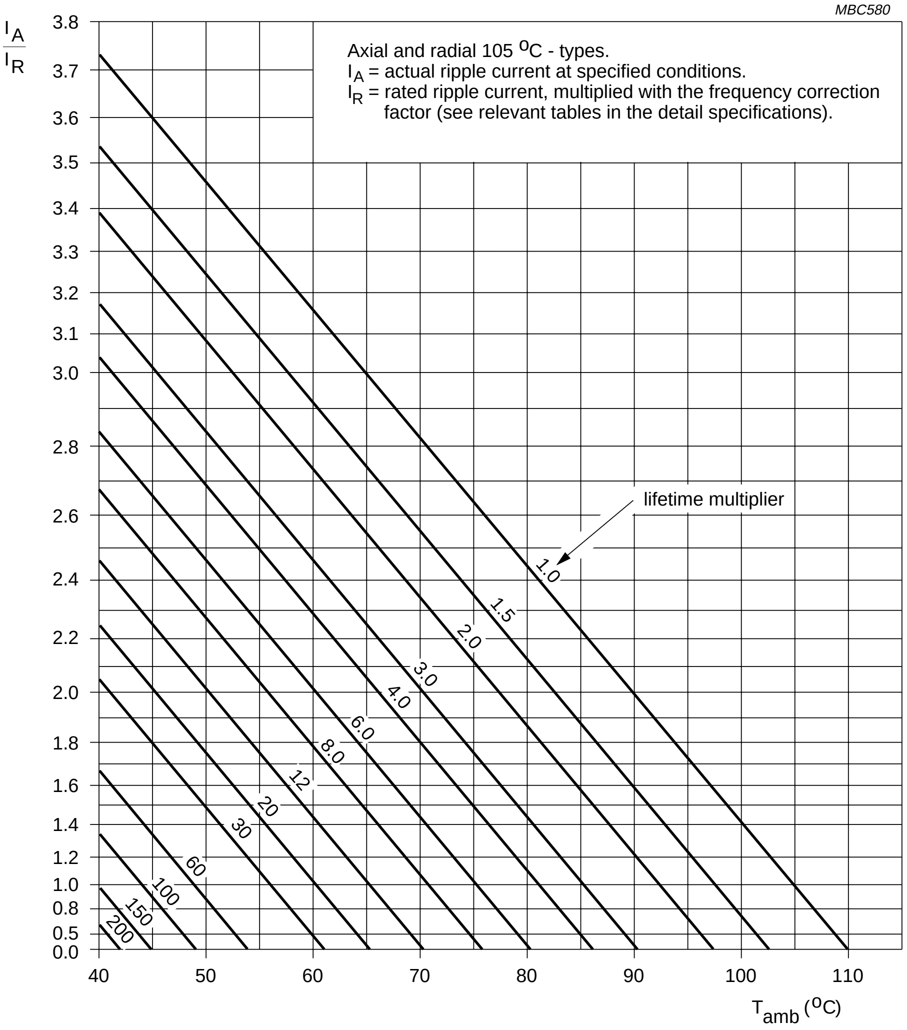
The ratio of ripple current (I_A/I_R) is plotted on the vertical axis and the ambient temperature (T_{amb}) on the horizontal. At the intersection of these two operational conditions the appropriate multiplier (correction factor) for useful life can be read. The useful life under certain conditions shall be calculated by multiplying (or dividing respectively) the specified useful life, with the resultant correction factor.

The useful life determined by this procedure is normally valid for applications without forced cooling. Under certain conditions and with additional cooling, the useful life may be considerably extended.



Axial and radial 85 °C types.

Fig.14 Typical example of a life-time nomogram: useful life as a function of ambient temperature and ripple current load.



Axial and radial 105 °C types.

Fig.15 Typical example of a life-time nomogram: useful life as a function of ambient temperature and ripple current load.

EXAMPLES FOR THE USE OF ‘LIFE-TIME NOMOGRAMS’

Example 1

Temperature in (operating) equipment is 45 °C.

Ripple current load is exactly the rated value (thus: $I_A/I_R = 1$).

Which useful life can be expected (without pause and storage times):

1. for a capacitor with a specified useful life of 2000 hours at 85 °C?
2. for a capacitor with a specified useful life of 2000 hours at 105 °C?

Solution:

The corresponding life-time multiplier may be found at the intersection between the vertical ‘45 °C’-line and the horizontal ‘1’-line. For the 85 °C type this is ‘30’ (see Fig.14) and for the 105 °C type it is ‘90’ (see Fig.15).

Resulting useful life is thus:

1. for 85 °C type: 30 × 2000 hours = 60000 hours or about 7 years
2. for 105 °C type: 90 × 2000 hours = 180000 hours or about 20 years.

Example 2

Which life time requirement has to be fulfilled by the capacitors, if the equipment life shall be 10 years (approx. 100000 hours), consisting of 1000 hours at 75 °C + 9000 hours at 65 °C + 90000 hours at 40 °C? No ripple current applied (thus: $I_A/I_R = 0$).

Solution:

The mentioned life-times shall be converted to specified 85 °C or 105 °C life-times, i.e. they have to be divided through the correction factors found at the intersection of the respective operational conditions (see Table 4).

The required life-time can be fulfilled by types with a specified useful life of:

1. >2970 hours at 85 °C i.e. a 3000 hours/85 °C type, or
2. >935 hours at 105 °C i.e. a 1000 hours/105 °C type.

Example 3

Which internal temperature may occur in the equipment, if the actual ripple current at 10 kHz is 3 times higher than specified for a 16 V-type and the load limit may not be exceeded?

Solution:

The ripple current must first be converted from 10 kHz to 100 Hz by using the conversion table (see typical example, Table 3). This shows that the conversion factor for a 16 V-type is 1.2.

$I_A/I_R = 3$ at 10 kHz and must be divided by 1.2, resulting in $I_A/I_R = 2.5$ at 100 Hz.

The load limit is defined by the diagonal line ‘multiplier 1’ in the relevant nomogram.

This means here: the vertical line on the intersection of $I_A/I_R = 2.5$ and the multiplier 1-line shows the maximum permitted internal temperature:

1. for 85 °C types this is max. 59 °C
2. for 105 °C types this is max. 79 °C.

The corresponding life-time in this case is equal to the specified useful life.

Table 3 Typical example of a frequency conversion table (I_R/I_{RO}) as a function of frequency; I_{RO} = ripple current at 100 Hz

FREQUENCY (Hz)	**I_R MULTIPLIER**		
	U_R = 6.3 to 25 V	**U_R = 35 and 40 V**	**U_R = 50 and 63 V**
50	0.95	0.85	0.80
100	1.00	1.00	1.00
300	1.07	1.20	1.25
1000	1.12	1.30	1.40
3000	1.15	1.35	1.50
≥10000	1.20	1.40	1.60

Table 4 Life-time calculation in "Example 2"

LIFE CONDITIONS	**85 °C TYPES** (see Fig.14)	**105 °C TYPES** (see Fig.15)
1000 hours at 75 °C	1000/2.9 = 345 hours	1000/8 = 125 hours
9000 hours at 65 °C	9000/6 = 1500 hours	9000/20 = 450 hours
90000 hours at 40 °C	90000/80 = 1125 hours	90000/250 = 360 hours
	sum for 85 °C = **2970** hours	sum for 105 °C = **935** hours

FAILURE RATE (λ)

The failure rate is defined by the number of components failing within a unit of time, related to the total quantity of components observed:

$$\lambda = \frac{\text{number of failures (statistical upper limit 60\%)}}{\text{total number of components} \times \text{duration}}$$

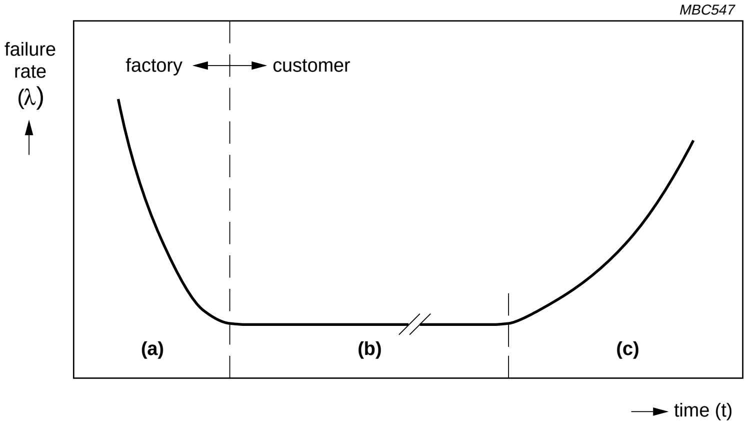
or

$$\lambda = \frac{\text{failure percentage (\%)}}{100 \times \text{duration}}$$

$\mathrm{MTBF} = \frac{1}{\lambda}$ however, for an individual component it is not longer than the specified useful life.

The failure rate (λ) is generally expressed in so-called 'fit' (**f**ailure **i**n **t**ime) = 10^{-9}/hours with an upper confidence level (UCL) of 60%. It is calculated from results of periodical tests in the quality laboratories or derived from field observations respectively.

Usually the failure rate during time shows the well known 'bathtub' curve (see Fig.16).



a) Initial failure period ('infant mortality').
b) Random failure period (= useful life period).
c) Wear-out failure period.

Fig.16 Failure rate (λ) as a function of time ('bathtub' curve).

There are 3 periods in a typical capacitor life cycle:

1. Initial failure period, showing a rapidly decreasing failure rate. During production of Philips electrolytic capacitors, initial failures are removed after re-forming (which is a short burn-in); all capacitors shipped, have passed burn-in.
2. Random failure period, showing a low and constant failure rate. This period is identical with ‘useful life’. The sum total of all (drift and accident) failures during this period, related to the total number of observed capacitors, is called ‘failure percentage’. Both are specified in the detail specification of the relevant series.
3. Wear-out failure period, showing an increasing failure rate due to gradual deterioration.

Since the failure rate mainly depends on two stress factors (temperature and applied voltage), it is usually specified under reference conditions, which are: T_{amb} = 40 °C and U = 0.5 U_R.

For other operational conditions, λ has to be converted correspondingly with the aid of Figs 17 and 18, failure rates as a function of stress factors (T and U/U_R) for non-solid and SAL electrolytic capacitors.

CLIMATIC CATEGORY

For each capacitor range the climatic category in accordance with *“IEC 68-1”* is stated in the relevant detail specification. The climatic category consists of three digit groups; example given in Table 5.

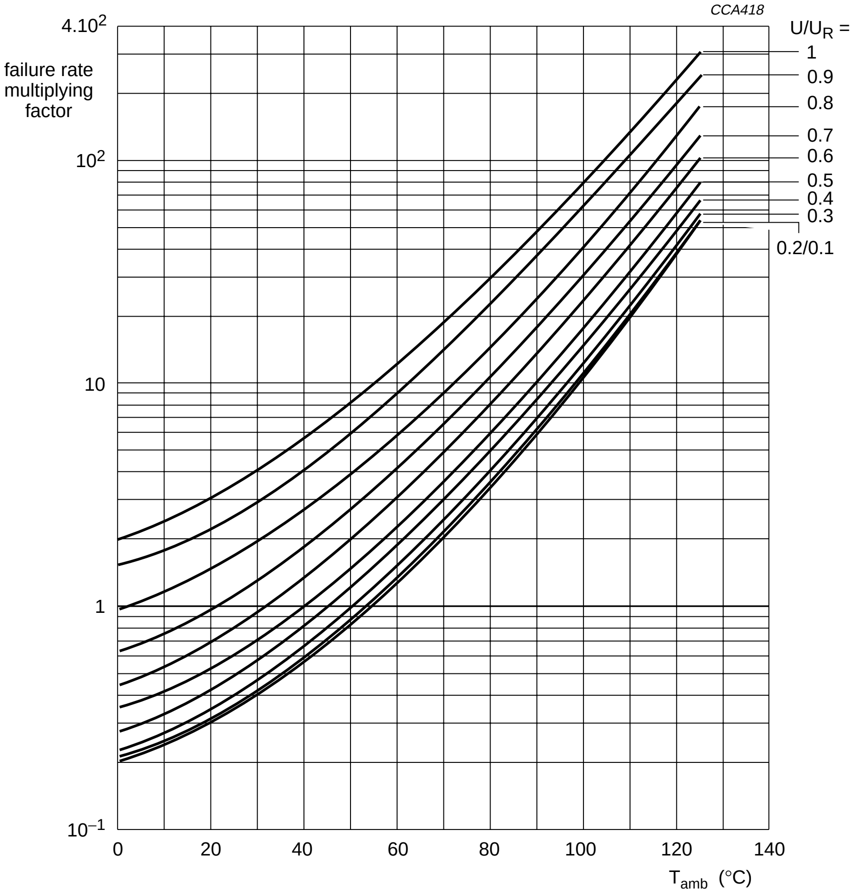


Fig.17 Conversion factors for failure rate (λ) as a function of ambient temperature (T_{amb}) and voltage ratio (U/U_R) for non-solid electrolytic capacitors.

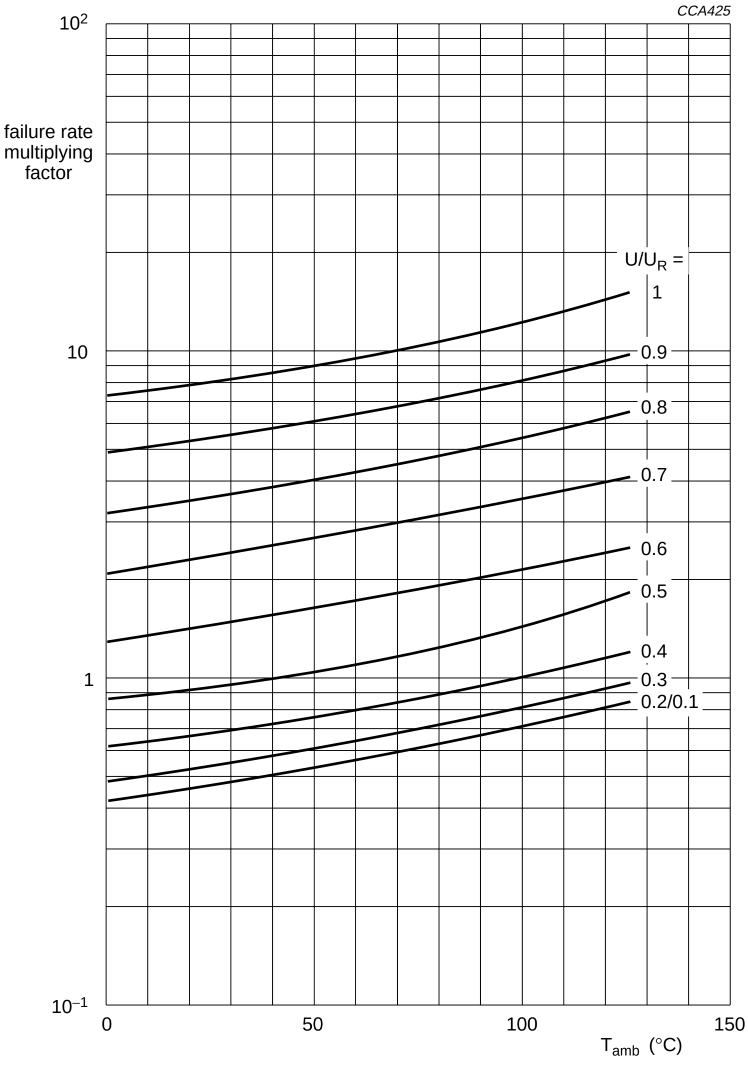


Fig.18 Conversion factors for failure rate (λ) as a function of ambient temperature (T_{amb}) and voltage ratio (U/U_R) for SAL electrolytic capacitors.

Table 5 Example of climatic categories

Example:	40 /	085 /	56	
	40			lower category temperature (here: –40 °C)
		085		upper category temperature (here: +85 °C)
			56	duration of test ‘damp heat, steady state’ (here: 56 days)

Table 6 Maximum humidity condition indication for the application class

CODE LETTER	RELATIVE AIR HUMIDITY			
	YEARLY AVERAGE	30 DAYS PER YEAR	OCCASIONALLY	DEWING
C	≤95%	100%	100%	permitted
D	≤80%	100%	90%	permitted
E	≤75%	95%	85%	slightly/rarely
F	≤75%	95%	85%	not permitted

APPLICATION CLASS

Although the German standard *“DIN 40040”* has been withdrawn, it is still widely used in industrial specifications for the definition of climatic working conditions. The application class consists of 3 code letters which have the following meanings.

Code letter meanings

1st letter:	lower category temperature F: –55 °C; G: –40 °C; H: –25 °C
2nd letter:	upper category temperature P: +85 °C; M: +100 (+105) °C; K: +125 °C
3rd letter:	maximum humidity conditions (see Table 6)

MOUNTING

Mounting position of non-solid Al-electrolytic capacitors

Snap-in and printed wiring (PW) as well as solder lug (SL) power electrolytic capacitors, in addition to the larger case sizes of axial and radial types, are normally equipped with pressure relief in the aluminium case. These and all smaller case size types, may be mounted in any position.

Screw-terminal power electrolytic capacitors have a pressure relief in the sealing disc. These types shall be mounted so that no emissions of electrolyte or vapour may reach either the conductors under voltage, or other parts of the printed circuit board. Vertical (pressure relief up) or horizontal (pressure relief on the upper side) mounting position is recommended.

Design rules for ‘capacitor batteries’

MECHANICAL

Philips power electrolytic capacitors are mainly used in power supply applications under high ripple current load. In these circumstances, the capacitors must be mounted with a distance of ≥15 mm from each other, in order to allow sufficient air circulation and to prevent mutual radiation.

Likewise, if axial or radial types are subject to high ripple load, they shall be mounted with sufficient distance (e.g. ≥10 mm) from each other for good convection.

ELECTRICAL

Parallel connection

Al-electrolytic capacitors may be connected in parallel, but for safety reasons, large sizes should be individually guarded against sudden energy discharge of the whole battery due to a defective specimen.

With smaller batteries, this safeguarding is sufficiently ensured by current limiting resistors.

Series connection

Al-electrolytic capacitors may be connected in series, but when doing so it should be noted that the voltage distribution will be according to their leakage currents. This phenomenon may induce irregularities in voltage load and cause maximum ratings to be exceeded; this could have drastic consequences, especially with high voltage capacitors.

Series-connected electrolytic capacitors should therefore be, either supplied by galvanically separated voltage sources or the voltages shall be proportionally distributed by balancing resistors.

The balancing resistors can be dimensioned in accordance with the following approximation formula:

$$R_{sym} \text{ (in k}\Omega) = 10000/C_R \text{ (in }\mu\text{F)}$$

Combined series/parallel connection

The above mentioned rules for both series and parallel connection are accordingly valid for any combination of these two cases.

MARKING

Philips electrolytic capacitors are identified in accordance with *“IEC”* rules. When sufficient space is available, capacitors are marked with the following details:

Rated capacitance	in µF (the ‘µ’ sign represents the position of the decimal point)
Rated voltage	in V
Tolerance on rated capacitance	if necessary, as a letter code in accordance with *“IEC 62”*, e.g. T for –10/+50% M for ±20% K for ±10% Q for –10/+30% A for tolerance according to detail specification
Group number	3-digit part of the catalogue number, e.g. 036 for RSP series
Name of manufacturer	PHILIPS or PH or P
Date code	abbreviation in 2 digits *(“IEC 62”)*, e.g. 1st digit D = 1993 E = 1994 F = 1995 H = 1996 J = 1997 K = 1998 L = 1999 2nd digit 1 = January 2 = February ... 9 = September O = October N = November D = December example: F5 = produced in 1995, May production date may also be stated as year/week code example: 9525 = produced in 1995, 25th week Date code may also be stamped in the case.
Factory code	indicating the factory of origin
Polarity identification	strip, band or negative symbol (‘–’ sign) to indicate the negative terminal and/or a ‘+’ sign to identify the positive terminal.