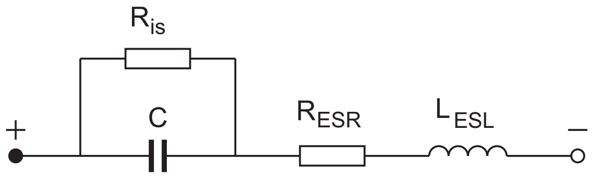
Aluminum Capacitors

SYMBOLS AND TECHNICAL TERMS	
SYMBOLS	DESCRIPTION
C	Capacitance
C_R	Rated capacitance
U	Voltage
U_R	Rated voltage
U_S	Surge voltage
U_B	Working voltage, operating voltage
U_{rev}	Reverse voltage
I, I~, I_{AC}	Alternating current
I_R	Rated alternating current, Ripple current
I_L	Leakage current
I_{Lt}	Leakage current for acceptance test
I_{LB}, I_{OP}	Operational leakage current
R	Resistance
R_{ESR}; ESR	Equivalent series resistance
R_{is}	Insulation resistance
L	Inductance
L_{ESL}, ESL	Equivalent series inductance
$\tan \delta$	Dissipation factor (tangent of loss angle)
Z	Impedance
X	Reactance
X_C, Z_C	Capacitive reactance
X_L, Z_L	Inductive reactance
T	Temperature
T_a	Ambient temperature
T_s	Surface temperature
ΔT	Difference of temperature, temperature rise
T_{UC}	Upper category temperature
T_{LC}	Lower category temperature
f	Frequency
f_r	Resonance frequency
$\omega = 2 \pi f$	Angular frequency
F_s	Case surface area
λ	failure rate
L	Lifetime multiplier

DESIGN AND POLARITY

The dielectric of an electrolytic capacitor with aluminum electrodes is made of aluminum oxide. One end of the dielectric sits firmly on an aluminum foil - the anode - while the other end sits on a liquid or solid electrolyte - the cathode. Power to the cathode is supplied via a second aluminum foil having a natural oxide layer as a dielectric with a blocking effect of just 1 - 2 V. (Many years of use have resulted in wrongly describing this power supply foil as 'cathode'). In its basic design the electrolytic capacitor is thus a direct current polarity-dependent capacitor (polarized style) with the positive pole being applied to the anode.

Apart from these so-called polarized electrolytic capacitors there are non-polarized capacitors available where the power supply foil is replaced by a second anode foil of the same type (non-polarized, bipolar style). This specific design allows operation with direct current of any polarity, as well as with pure alternating current.



C = capacitance of the oxide layer
R_{is} = oxide layer insulation resistance
R_{ESR} = equivalent series resistance
L_{ESL} = equivalent series inductance

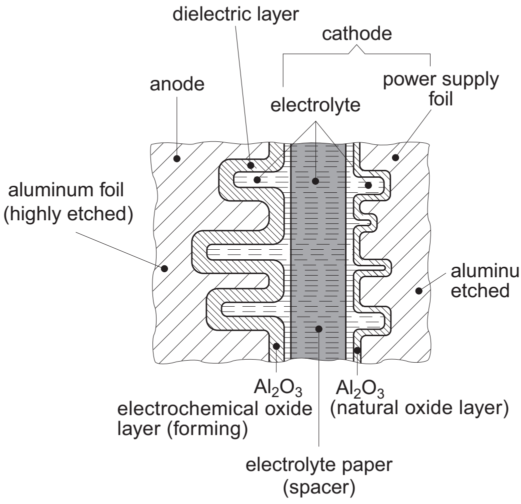


Fig. 1: Basic design of an electrolytic capacitor and equivalent circuit diagram

CLASSIFICATION

Depending on applications and requirements, electrolytic capacitors are classified as:

a) Long-life grade (LL)
Electrolytic capacitors designed for increased requirements.

b) General-purpose grade (GP)
Electrolytic capacitors designed for general requirements.

Furthermore, all capacitor types have been subdivided by their application classes according to DIN 40040.

STORAGE LIFE

During transport or storage, the temperature of electrolytic capacitors is allowed to fall below their lower category temperature and reach a minimum of - 65 °C, while their upper category temperature may not be exceeded.

Depending on the design and the purity of the materials used, electrolytic capacitors offer very good storage properties. They can be stored in dry rooms at temperature ranging from - 40 °C to + 40 °C (preferably between 0 °C and + 25 °C) for up to three years without any restriction. Within that period it is possible to apply the fully-rated voltage to the capacitors without any further preparation. This procedure neither impairs the capacitor's operational reliability nor its life expectancy.

All electrolytic capacitors have a leakage current when a direct current is applied. This leakage current depends on time, voltage, and temperature. After long dead storage this leakage current will increase and, for a short time, can be 10 times greater at the time of reuse. The capacitor will not be damaged and its life expectancy will not be impaired if the rated voltage is applied directly after long storage. In general, the expected continuous operating leakage current will be re-attained or fall below its value after about 30 minutes. Any operation below the rated voltage will result in a significantly lower leakage current.

ELECTRICAL PARAMETERS

Rated Voltage U_R and Operating Voltage U_B

The rated voltage is defined as the voltage for which the capacitor has been designed and after which it is designated. The operating voltage may be smaller, but may never exceed the rated voltage value. A reduction in the operating voltage will not significantly increase the capacitor's lifetime. The capacitors may be charged with the specified rated direct voltage in the specified operating temperature range. In case of ripple alternating voltage, the peak voltage value must not exceed the rated value.

ELECTRICAL PARAMETERS (Continued)

Surge Voltage U_S

The surge voltage is defined as the maximum voltage which may be applied to the capacitor for a short time only (in one hour a maximum of five times with a duration of one minute each.) The surge voltage may not be used for periodic charge and discharge.

$U_S = 1.15 \cdot U_R$ for $U_R \leq 250$ V

$U_S = 1.10 \cdot U_R$ for $U_R > 250$ V

Ripple Alternating Voltage

The ripple voltage is defined as the effective value alternating voltage with which the capacitor may be charged in addition to direct voltage. The peak value of resulting ripple DC voltage must not exceed the rated voltage value. A reverse polarity voltage with a peak value of > 1.5 V must not occur.

Reverse Voltage U_{rev}

A reverse polarity of up to 1.5 V is permissible.

CAPACITANCE

Rated Capacitance C_R

The rated capacitance is defined as the capacitance value, after which the capacitor has been designated. The capacitance value may vary within the permissible tolerance limits.

Alternating Voltage Capacitance C_W

The AC capacitance normally corresponds to the rated capacitance value. It is determined by measuring the AC resistance at an AC voltage of ≤ 0.5 V. Since AC capacitance depends on frequency and temperature, a specific measuring frequency and temperature have to be agreed upon. IEC 60384-4 stipulates a frequency of 100 Hz and a temperature of 20 °C.

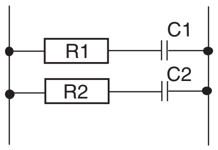
Direct Voltage Capacitance C_{DC}

The DC capacitance is determined from the quantity of charge which is stored after a DC voltage charging of the capacitor. The measurement is effected during a single discharge under specified conditions. The measuring procedures are described in DIN 41 328. If both values, C and C_{DC}, are measured at an electrolytic capacitor, the result will always be: $C < C_{DC}$.

Depending on the design $C_{DC} \approx (1.05...1.30) \times C$.

Temperature Dependence of AC Capacitance

The measured AC capacitance decreases with falling temperatures. Falling temperatures result in an increased viscosity of electrolyte and thus in an increasing ohmic resistance. In fact, a model calculation shows that the total capacitance of capacitive surface elements which are parallel connected via different series resistors R_1, R_2, etc. will decrease, if the series resistors increase. Usually this behavior is described as follows: “High-resistive coupled surface elements have a lower capacitive effect.”



$$R1 \neq R2$$
$$C1 = C2$$
$$Z1 \neq Z2$$
$$Z_i = \sqrt{R_i^2 + Z_{Ci}^2}, \quad Z_{Ci} = \frac{1}{\omega C_i}, \quad \omega = 2\pi f$$
$$\frac{1}{Z} = \sum_{i=1}^{n} \frac{1}{Z_i}$$

Fig. 2: Detail from an equivalent circuit diagram for two surface elements

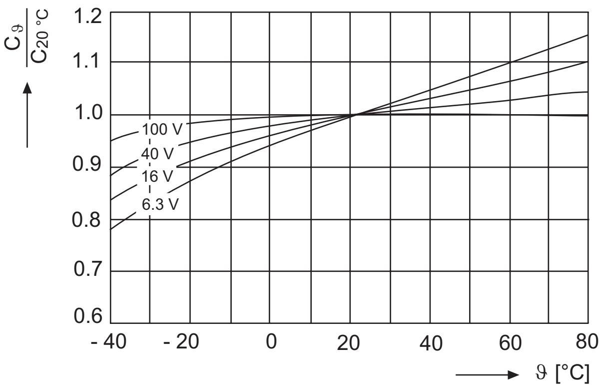


Fig. 3: Typical temperature dependent behavior of AC capacitance

Frequency Dependence of AC Capacitance

The frequency dependence of AC capacitance is similar to its temperature dependence. The capacitive partial resistance Z_{Ci} decreases with increasing frequency f. At the same time the influence of the ohmic partial resistance R_i of the AC resistance Z_i is increasing. In this case, too, “high-resistive coupled surface elements have a lower capacitive effect”.

EQUIVALENT SERIES RESISTANCE R_{ESR}

The equivalent series resistance is defined as the ohmic part of the AC resistance describing the losses occurring in an electrolytic capacitor. It consists of three partial resistance values: the lead and the foil resistance, the electrolyte paper resistance, and the oxide layer resistance. Just as any other ohmic resistance, R_{ESR} is temperature-dependent, too. Moreover, it contains a frequency-dependent part - the oxide layer resistance. R_{ESR} is usually calculated from the dissipation factor tan δ as follows:

EQUIVALENT SERIES RESISTANCE R_{ESR} (Continued)

$$R_{ESR} = \frac{\tan\delta}{\omega C} = \frac{\tan\delta}{2 \cdot \pi \cdot f \cdot C}$$

R_{ESR} [Ω]
C [F]
f [Hz]

In practical operation the lower limit of the R_{ESR} is given by the ohmic part of the contact points and the foil resistance values. Thus it will not always be possible to achieve calculated values below 0.03 Ω.

The foil resistance and R_{ESR} can further be reduced by using the multiple tab technique. This technique consists of creating multiple contact points with the outer contact elements distributed uniformly across the anode and cathode foils. At the same time, the R_{ESR}-dependent capacitor values such as the dissipation factor, the impedance, and the maximum AC rating are clearly improved.

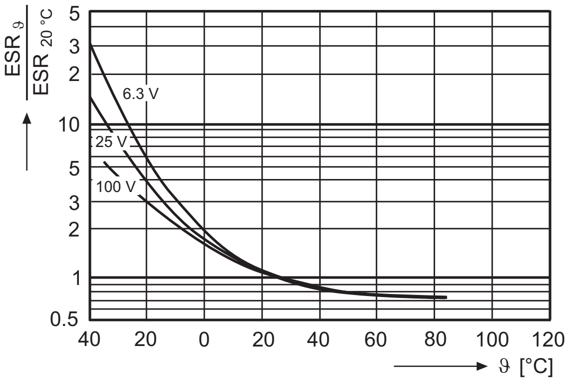


Fig. 4: Temperature dependence of R_{ESR} (approx. values)

DISSIPATION FACTOR TAN δ

The dissipation factor tan δ is defined as the ratio between the equivalent series resistance R_{ESR} reactance $Z_{L,\,C} = \omega L - 1 / \omega C$ (see Fig. 5). It is frequency-dependent via the reactance $Z_{L,C}$ and temperature dependent via the equivalent series resistance R_{ESR}.

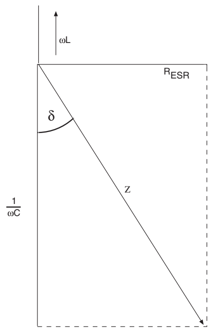


Fig. 5: Vector diagram of the AC values of an electrolytic capacitor

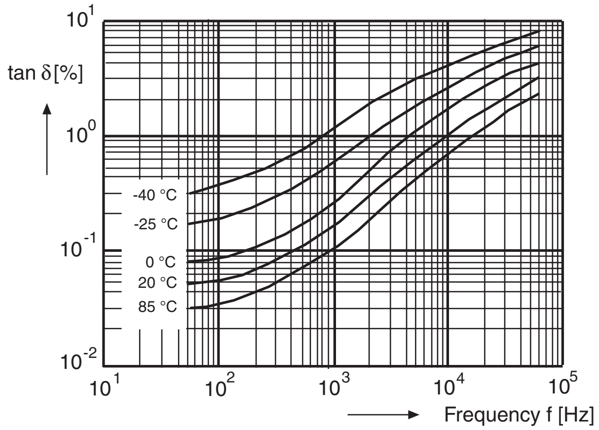


Fig. 6: Typical frequency dependence of tan δ at various temperatures

IMPEDANCE Z

The amount of impedance Z of an electrolytic capacitor is calculated from the geometrical sum of the capacitive reactance $Z_C = 1 / \omega C$ of the inductive reactance $Z_L = \omega L$ and of the equivalent series resistance R_{ESR}.

$$Z = \sqrt{R^2_{ESR} + (\omega L - 1/\omega C)^2}$$

Figure 7 shows the ideal frequency curve of the impedance indicated on a double-logarithmic scale. The strong temperature dependence of the R_{ESR} value can also be seen.

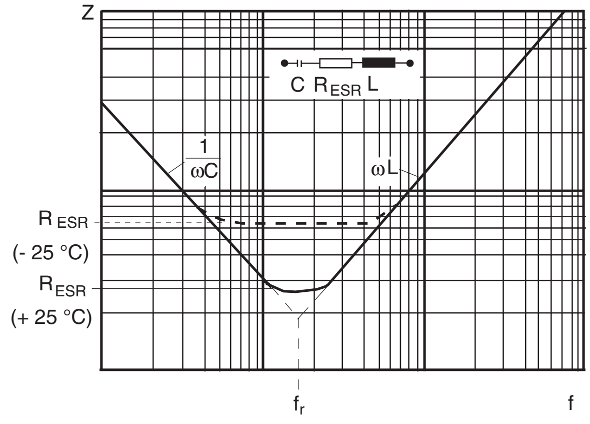


Fig. 7: Idealized frequency dependent impedance curve at + 25 °C and - 25 °C

LEAKAGE CURRENT I_L

The leakage current is defined as the current flowing through the capacitor when a direct voltage is applied subsequent to the charging of the capacitor. Generally speaking, this

LEAKAGE CURRENT I_L (Continued)

leakage current is caused by ’defects’ in the oxide dielectric. These defects range from crystal defects, stress,cracks, and installation-related damage, to a partial solution caused by the operating electrolyte. The leakage current is a measure of the ‘forming state’, i.e. of the regeneration to be effected on the oxide dielectric. This current depends on a multitude of factors, such as time, voltage, temperature, type of electrolyte, and ‘history’ of the capacitor.

Time Dependence of the Leakage Current

At the moment the measuring voltage is applied, a peak current occurs which depends on the capacitor’s forming state as well as on the internal resistance of the voltage source. When the measuring voltage (charging of the capacitor) is reached, the current first drops with time until it takes on a small, nearly constant final value which ideally is only determined by the dynamic balance (temperature and voltage dependent) between the build-up and reduction of the oxide layer. This value is the operational leakage current I_{LB}. As can be expected, the operational leakage current level depends on the (measuring) voltage applied and on the temperature. Furthermore, the value of the operational leakage current is determined by the effective surface of the etched aluminum foil (capacitance of the capacitor), the type of electrolyte, and the level of the anode’s (pre)forming voltage. Since the measurement of the operational leakage current, due to the long measurement period ($10 < t_M$ 60 min), will be feasible only in specific cases, shorter measurement periods of preferably one minute or five minutes have been accepted for general measurement regulations. The values measured in this way are described as leakage current for acceptance tests. In this case, the measuring voltage corresponds to the rated voltage of the capacitor.

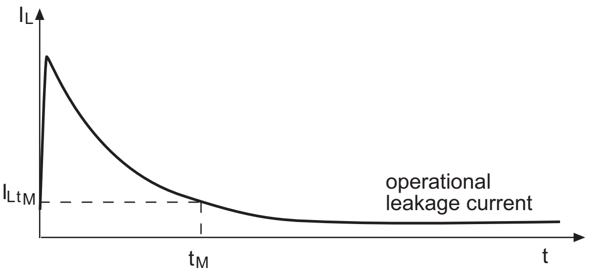


Fig. 8: Typical variation with time of the leakage current

Voltage Dependence of the Leakage Current

Figure 9 shows the qualitative leakage current behavior. The leakage current I_L increases with the operating voltage U_B. The more the operating voltage approaches the (pre)forming voltage U_F of the anode, the steeper the slope (exponential rise), especially after exceeding the rated voltage U_R. The leakage current, however, loses more and more of its original meaning. Specifically in the U_S...U_F range the current can no longer be described as the measure of the regeneration work to be effected on the oxide layer. Above the surge voltage U_S there is an increasing tendency towards secondary reactions such as temperature rise, heavy formation of gas, electrolyte degradation, and inappropriate formation of oxide. For this reason any continuous operation above the rated voltage U_R is not tolerable. The conditions for exceeding the rated voltage on a short-time basis are stipulated under the heading ‘surge voltage’ (see surge voltage U_S).

The hatched area in Figure 9a illustrates an empirical evaluation of practical leakage current measurements. It shows the recommended approximate values for the relative leakage current dependence of U_B for $U_B \leq U_R$.

Curve A describes a small capacitor with a low rated voltage (e.g. 6 V) and a one minute leakage current value in the order of 1 µA. Curve B is typical of a middle sized high-voltage capacitor (e.g. UR = 350 V) with a 1-minute leakage current value of approximatly 100 µA (at room temperature).

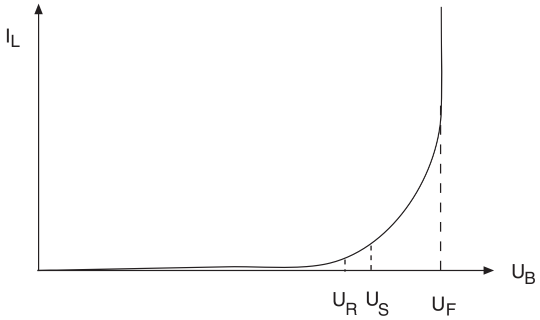


Fig. 9: Typical variation of leakage current with applied voltage

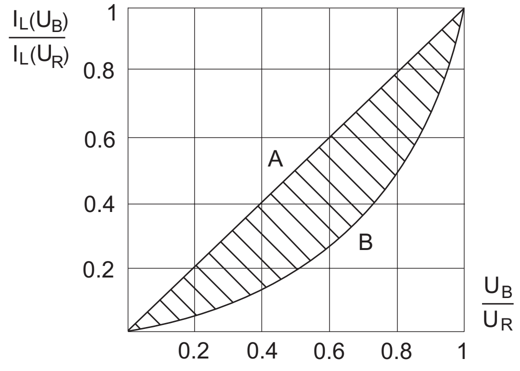


Fig. 9a: Typical size dependant relation (see text)

Temperature Dependence of the Leakage Current

Although there are numerous causes for leakage current, only one can be described as having a more clearly defined temperature dependence - i.e. the dynamic balance between partial solution and build-up of the oxide layer. As a

LEAKAGE CURRENT I_L (Continued)

measure of this parameter the operating leakage current I_{LB} has been introduced under section ‘Time dependence of the leakage current’. The model of the rate of (electro) chemical reactions increasing with temperature can be qualitatively applied here. Hence it follows that I_{LB} increases with temperature. Figure 10 shows some empirical values.

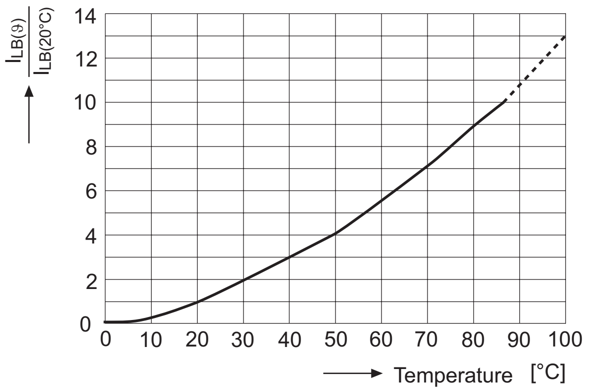


Fig. 10: typical variation of leakage current with temperature

Leakage Current for Acceptance Test I_{Lt}

IEC 60384-4 and EN 130300 stipulate the measurement procedures for determining the leakage current for acceptance tests I_{Lt}. Based on these standards and due to different measuring periods (30 s, $I_{Lo.5;}$ 2 min, I_{L2}; 5 min, I_{L5}) the threshold values for the Vishay Roederstein electrolytic capacitors are those that are calculated from the leakage current equations of the respective type specifications.

ALTERNATING CURRENT

The alternating current is defined as the effective value of the alternating current with which the capacitor is charged.

Rated Alternating Current I_R

The permissible rated alternating current is defined in such a way that at an upper category temperature T_{UC} and at a frequency of 100 Hz (measuring frequency of capacitance and dissipation factor), the temperature of the case surface area rises by 3 K. The resulting AC values I_R are indicated in the data sheets for each capacitor.

Maximum Permissible Alternating Current I, AC Rating

The maximum permissible alternating current rating depends on ambient temperature $T_{a'}$ case surface area $F_{s'}$ equivalent series resistance R_{ESR} (or the dissipation factor tan δ), as well as on excess surface temperature ΔT (temperature rise, difference between surface temperature T_s and ambient temperature T_a). The permissible temperature rise ΔT is specified by the respective manufacturer. For Vishay Roederstein electrolytic capacitors this value is based on IEC 60384-4 and is 3 K in relation to the upper category temperature T_{uc}. Due to the temperature and frequency dependence of the equivalent series resistance R_{ESR} (or the dissipation factor tan δ) the maximum permissible alternating current is also dependent on the alternating current frequency f. Since the life expectancy of an electrolytic capacitor is considerably determined by its thermal load (permutation model, see section Lifetime), the temperature rise caused by an AC load presents a significant factor of the capacitor's lifetime. The individual lifetime tables show the interrelation between the maximum permissible alternating current I, the ambient temperature $T_{a'}$ the surface temperature $T_{s'}$ the alternating current frequency f, as well as the lifetime. (Sections Standard Lifetime Conversion Table and Type Specific Lifetime Conversion Table explain the use of these tables.)

ELECTRICAL STRENGTH OF THE INSULATION

The insulating sleeve can withstand a voltage of at least 1000 V.

INSULATION RESISTANCE OF THE INSULATION

The insulation resistance of the sleeve material is a minimum of 100 MΩ.

CLIMATIC CONDITIONS

For reasons of reliability and due to the temperature dependence of electrical parameters certain limits have to be observed for the climatic conditions. The upper and lower category temperature are considered important climatic conditions for electrolytic capacitors. Furthermore the degree of humidity has to be taken into account. These three values are indicated in coded form in the applicability class and IEG climatic category (see section Climatic and Applicability Categories).

Upper Category Temperature T_{UC}

The use of electrolytic capacitors is subject to specific upper temperature limits. Exceeding these limits may result in early failure of the capacitor. To avoid this, upper category temperatures are fixed which indicate the maximum permissible ambient temperature of the capacitor for continuous operation. The upper category temperature is given with the temperature range value in the data sheets. Sections Maximum Permissible Alternating Current I, AC Rating and Lifetime have shown that the electrolytic capacitor's lifetime and reliability depend considerably on the capacitor's temperature. This is why Vishay recommend using the capacitor at the lowest temperature possible to increase lifetime and reliability. Furthermore, Vishay recommend mounting the electrolytic capacitors inside the units at positions having a low ambient temperature.

CLIMATIC CONDITIONS (Continued)

Lower Category Temperature T_{LC}

Due to an impaired electrolytic conductivity, a decreasing temperature results in higher values for impedance and dissipation factor (or R_{ESR} values). Most capacitor applications limit such an increase to specific threshold values. For this reason it is practical to stipulate a lower category temperature which is also indicated in the temperature range value given in the data sheet. It should be emphasized, however, that an operation below the specified lower category temperature is possible without damaging the capacitor. This is particularly true if the capacitor is exposed to an alternating-current load. Compared to the lower ambient temperature, the alternating current flowing through the increased equivalent series resistance can heat the electrolytic capacitor to such an extent, that its properties still ensure proper functioning of the unit.

Climatic and Applicability Categories

According to DIN 40040 the applicability class is given in form of a three-letter code. The IEC publication indicates a so-called Category (IEC Climatic Category). The data sheets list both specifications. The first letter in the DIN 40040 formula stands for the lower category temperature, the second for the upper category temperature, and the third for the permissible humidity.

40 / 085 / 56
56 days damp heat (tested according to IEC 60068-1)
upper category temperature 85 °C
lower category temperature - 40 °C

DIN CLIMATIC CATEGORY

1st letter lower category temperature	F - 55 °C	G - 40 °C	H -25 °C	
2nd letter upper category temperature	K 125 °C	M 100 °C (105 °C)	P 85 °C	S 70 °C
3rd letter	C	D	E	F
relative humidity/ annual average 30	≤ 95 %	≤ 80 %	≤ 75 %	≤ 75 %
days/year max.	100 %	100 %	95 %	95 %
occasional formation	100 %	90 %	85 %	85 %
of dew permissible	yes	yes	yes*	yes

* rare and mild formation of dew permissible

HOW TO USE ELECTROLYTIC CAPACITORS

Date of Manufacture (Code) IEC 60062

The month and the year of manufacture are indicated. The year is given first, followed by the month.

Code (year)		Code (month)	
1995	F	January	1
1996	H	February	2
1997	J	March	3
1998	K	April	4
1999	L	May	5
2000	M	June	6
2001	N	July	7
2002	P	August	8
2003	R	September	9
2004	S	October	0
2005	T	November	N
2006	U	December	D
2007	V		
2008	W		

Example: 2000 May: M5

Alternatively it is possible to indicate the year and the week. In this case the first two figures indicate the year and the last two the week.

Example: 2003, 20th week: 0320

Pulse Handling

Vishay Roederstein electrolytic capacitors exhibit good pulse handling characteristics. However, due to continuously increased surface gain of anode foils, absolute compliance with the IEC requirement

$$\frac{\Delta C}{C} \le \pm 10\ \% \text{ after } 10^6 \text{ switching cycles}$$

cannot be guaranteed without taking specific measures, which need prior agreement.

Vibration Resistance

If not otherwise indicated in the data sheets, the IEC Publication 60068-2 is applicable: test F_C at 5 g; stress period: 1.5 hours; frequency 10 to 55 Hz, maximum displacement 0.35 mm.

Mounting Position

Care should be taken when mounting capacitors which have a pressure release valve. In vertical mounting the valve should always be at the top to avoid electrolytic leakage if the pressure valve is triggered. Similarly, when mounting the capacitor in a horizontal position the pressure valve should be in the "12-O'clock position".

HOW TO USE ELECTROLYTIC CAPACITORS
(Continued)

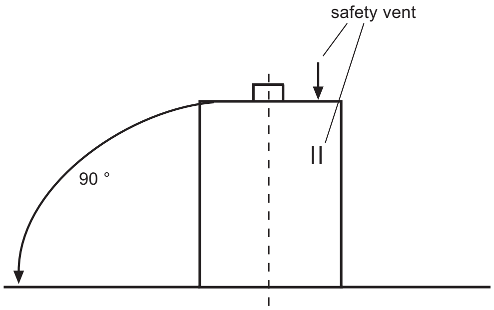


Fig. 11: Recommended mounting position

We recommend not to have PC-board traces below radial aluminum electrolytic capacitors.

Low and High Pressure

Vishay Roederstein electrolytic capacitors may be used at any low pressure and at any altitude. The operating temperature should not fall below the lower category temperature. The capacitors may not be used at pressures exceeding 120 kPa.

Cleaning, Moulding

Halogenated hydrocarbons, particularly CFCs (chlorofluorocarbons), are frequently used for the cleaning of boards. There are for instance several FREON types (registered trademark of Du Pont) based on 1,1,1-Trichlorotrifluoroethane.

The manufacturers of aluminum electrolytic capacitors warn against the use of these solvents since a corrosive effect on aluminium is definitely possible. This corrosive mechanism, which may be triggered by the external influence of compounds containing CFCs, is very complex and can lead to consequential changes. Only the strict compliance with a number of clearly defined conditions can provide any protection against the penetration of solvents. We do not consider it necessary to list the conditions here but would advise you against using halogenated compounds for cleaning. Moreover, you should check whether the plastic insulation is resistant to the detergent you want to use. Ketone type solvents (e.g. acetone, methyl ethyl ketone) and ester type solvents (e.g. ethyl acetate, butyl acetate) should preferably not be used or only after checking their effect in the cleaning process. The same applies to aromatic hydrocarbons (e.g. xylenes) and aliphatic hydrocarbons (e.g. petroleum ether).

We recommend using water-based or alcohol-based detergents (e.g. ethanol, isopropanol, isobutyl alcohol, various ethylene glycols, etc.). We also recommend continuous monitoring of the cleaning bath in order to avoid the accumulation of corrosive agents (e.g. chlorides from solder residues, possibly sulphonates from surface active agents). Careful drying should immediately follow cleaning.

Similar procedures should be observed when electrolytic capacitors are varnished or moulded. Care must be taken that any varnish or moulding components such as resin, hardener, accelerator, thinner, filler, coloring matter, etc. do not contain any halogen.

ELECTROLYTE

The operating electrolyte is an electrically conductive liquid. Its composition differs according to type and voltage range. A polar organic liquid of a high boiling point with a certain amount of salt provides its ionic conductivity. Halogenated hydrocarbons are not used. Water may occur as a constituent of the electrolyte. The salts used can be organic or inorganic.

The electrolytes can be mixed with water. Since they have an almost neutral pH value, there will be no acidic or caustic reaction. Its flash point is always above 80 °C. They do not contain any easily or highly ignitable agents and no explosive substances.

Great attention is given to selecting only those electrolytic constituents that combine the least possible toxicity with the utmost environmental compatibility. Unfortunately the present state of technological development does not always enable us to fully avoid the use of substances which are considered harmful. However, we do not use highly toxic, carcinogenic, or questionable compounds. Extreme care should be taken when handling electrolytic liquid that has leaked out.

- Avoid skin contact.
- Do not inhale vapors.
- Provide sufficient ventilation.

If the electrolyte has come into contact with your skin, mucous membrane, or eyes, immediately rinse carefully for several minutes under running water. Remove affected clothing. Seek medical attention if you have swallowed any liquid.

We would like to remind you that the following errors will trigger the safety mechanism and may result in a discharge of electrolytic fluid:

- reverse polarity
- excessive voltage
- excessive current load
- overheating

DISPOSAL OF USED ALUMINUM ELECTROLYTIC CAPACITORS

Due to potential harmful effects to the environment, special regulations have to be observed which dictate the disposal of capacitors as toxic waste.

Important remarks:

The aluminum electrolytic capacitors do not contain any polychlorinated biphenyls (PCB) or similar substances that may produce dioxins when burning. Moreover, during manufacture we do not use any substances that may harm the ozone layer.

OPERATIONAL RELIABILITY

The specifications regarding the reliability of electrolytic capacitors refer to:

1) the failure rate during operation

2) the beginning of wear-out failures (end of lifetime)

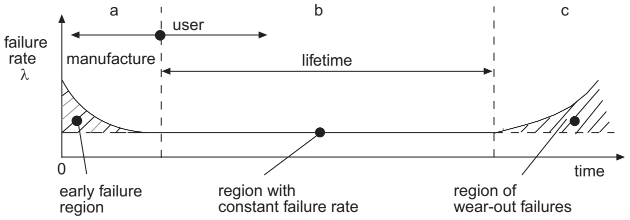


Fig. 12: Failure rate (λ) as a function of time (‘bath-tub life curve’)

Early failures (region a) of electrolytic capacitors occur during the manufacturing process and are eliminated. We normally expect a constant low failure rate (λ) during the stated lifetime of capacitors (region b). Subsequently the electrolytic capacitors will tend to suffer failures due to drying out (region c).

Endurance Test

IEC 60384-4 and EN 130300 define the criteria for permissible changes in the values of electrical parameters following endurance tests at rated voltage and upper category temperature. The duration and the conditions for the specific capacitor types are given in the respective separate specifications. The endurance test does not allow any direct assessment of the lifetime of an electrolytic capacitor. Therefore the duration of the test must not be confused with the indicated lifetime of the respective capacitor type.

If one of the following conditions is not met, the capacitor has failed the test.

FAILURE CRITERIA FOR ENDURANCE TEST

CRITERIA	VOLTAGE RANGE	CHANGE IN CAPACITANCE	RATIO OF FINAL VALUE TO SPECIFIED THRESHOLD VALUE		
	V	(%)	TAN Δ	Z	I_L
A	$6.3 \le U_R$ $6.3 < U_R \le 160$ $160 < U_R$	$-40 \le \Delta C/C \le +25$ $-30 \le \Delta C/C \le +30$ $-15 \le \Delta C/C \le +15$	≤ 1.5	≤ 3	≤ 1
B	$6.3 \le U_R$ $6.3 < U_R \le 160$ $160 < U_R$	$-30 \le \Delta C/C \le +15$ $-15 \le \Delta C/C \le +15$ $-10 \le \Delta C/C \le +10$	≤ 1.3	≤ 2	≤ 1
C	$16 \le U_R$ $16 > U_R$	$-25 \le \Delta C/C \le +25$ $-20 \le \Delta C/C \le +20$	≤ 1.5 ≤ 1.5	- -	 ≤ 1
D		$-20 \le \Delta C/C \le +20$	≤ 2	≤ 2	≤ 1
E		$-15 \le \Delta C/C \le +15$	≤ 1.5	≤ 2	≤ 1
F		$-20 \le \Delta C/C \le +20$	≤ 2	-	≤ 1
G		$-20 \le \Delta C/C \le +20$	≤ 1.5	-	≤ 1

OPERATIONAL RELIABILITY (Continued)

Lifetime

The lifetime is defined as the period during which a specified failure rate is not exceeded under given operating conditions and under specified failure criteria. The indicated lifetime usually is based on a 60 % upper confidence level.

The lifetime is continuously confirmed by accelerated sample tests at the upper category temperature. At temperatures > 40 °C for every temperature rise of 10 K the acceleration factor for electrolytic capacitors is assumed to halve the lifetime at the same failure rate (10 K rule).

In principle, the lifetime is determined by the loss of electrolyte. The degree of electrolyte loss (diffusion through the sealing elements) depends on the time, the electrolytic vapor pressure, the individual interaction of electrolytic solvent with the sealing materials and geometric factors.

For practical purposes, the temperature dependence is described by way of an equation which was used by Arrhenius to describe the effect of temperature on the rate of chemical reactions. The frequently used 10 K-rule only provides a practical approximation formula for usual temperature range.

Failure Criteria for Lifetime Indication

Based on IEC 60384-4 or EN1300300, the indicated lifetime values are defined as follows:

a) load factors
  - rated voltage U_R
  - rated alternating current I_R
  - upper category temperature T_{UC}

b) failure criteria

FAILURE	PARAMETER	LL GRADE (LONG)	GP GRADE
complete	all	short circuit or break	
change failure	tan δ or R_{ESR} I_L Z	> 3 x initial threshold value > initial threshold value > 3 x initial threshold value	
	$\Delta C / C$	> ± 30 %	> ± 40 %

The ratio between complete failure and change failure should be 1:9

Failure Rate

The failure rate λ (fit = failure time) is defined as the quotient of the number of failures, and the product of the number of test components and the test period (component operating time).

$$\lambda = \frac{\text{number of failures}}{\text{number of test components x test period}}$$

The failure rate provides the basis for reliability forecasts. Usually the failure rate is given with the unit 10^{-9}/h = 1 fit (failure in time) at an UCL (Upper Confidence Level) of 60%. The failure rates indicated apply to T_a = 40 °C and U_B = 0.5 x U_R. The failure rate is temperature and voltage dependent. The conversion table given below shall be used in the case of other conditions.

Load Voltage

RATED VOLTAGE LOAD	CONVERSION FACTOR
100 %	2.0
75 %	1.4
50 %	1.0
25 %	0.8
10 %	0.6

TEMPERATURE	CONVERSION FACTOR
≤ 40 °C	1
55 °C	3
70 °C	8
85 °C	20
105 °C	90
125 °C	360

Cumulative Failure Frequency

The share of failed components during a stress period (to be specified).

STANDARD LIFETIME CONVERSION TABLE

The lifetime conversion table is used to describe the relation between user current, ambient temperature and lifetime at various frequencies. It should be used to determine lifetime under the conditions in the application. The following standard table applies to all types where no specific conversion table has been integrated in the data sheet. The table indicates minimum values.

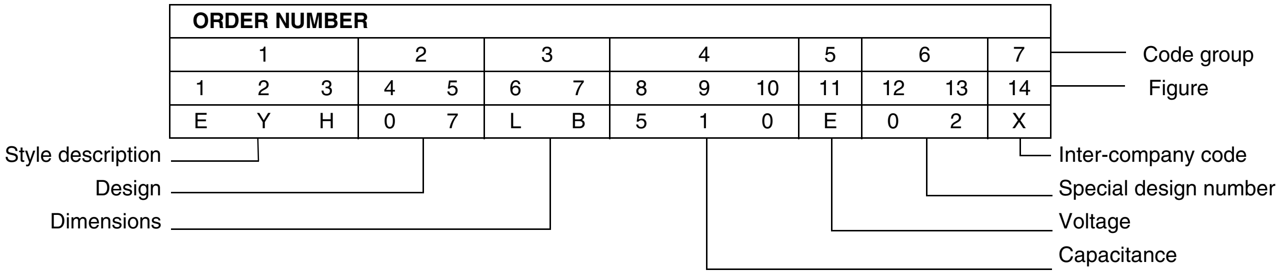
STANDARD LIFETIME CONVERSION TABLE

For all surface mount and radial series

I/I_R (FREQUENCY DEPENDENT)						**Surface temperature rise ΔT_s (°C)**	**LIFETIME MULTIPLIER L (depending on I/I_R and T_a)**													
FREQUENCY [Hz]							**AMBIENT TEMPERATURE T_a [°C]**													
50	**100**	**250**	**500**	**1000**	**> 2500**		**T_{UC} - 85**	**T_{UC} - 75**	**T_{UC} - 65**	**T_{UC} - 55**	**T_{UC} - 45**	**T_{UC} - 40**	**T_{UC} - 35**	**T_{UC} - 30**	**T_{UC} - 25**	**T_{UC} - 20**	**T_{UC} - 15**	**T_{UC} - 10**	**T_{UC} - 5**	**T_{UC}**
0.2	0.2	0.2	0.2	0.2	0.2	0.1	596	298	149	75	37	26	19	13	9.3	6.6	4.7	3.3	2.33	1.65
0.4	0.4	0.4	0.4	0.4	0.5	0.5	560	280	140	70	35	25	18	12	8.8	6.2	4.4	3.1	2.19	1.55
0.6	0.6	0.6	0.6	0.7	0.7	1.2	505	252	126	63	32	22	16	11	7.9	5.6	3.9	2.8	1.97	1.39
0.7	0.8	0.8	0.9	0.9	0.9	2.1	437	218	109	55	27	19	14	9.6	6.8	4.8	3.4	2.4	1.71	1.21
0.9	1.0	1.1	1.1	1.1	1.2	3.3	362	181	91	45	23	16	11	8.0	5.7	4.0	2.8	2.0	1.41	1.00
1.1	1.2	1.3	1.3	1.3	1.4	4.8	288	144	72	36	18	13	9.0	6.4	4.5	3.2	2.3	1.6	1.13	
1.3	1.4	1.5	1.5	1.6	1.6	6.5	220	110	55	27	14	9.7	6.9	4.9	3.4	2.4	1.7	1.2		
1.5	1.6	1.7	1.7	1.8	1.9	8.4	161	80	40	20	10	7.1	5.0	3.6	2.5	1.8	1.3			
1.7	1.8	1.9	1.9	2.0	2.1	11	113	56	28	14	7.1	5.0	3.5	2.5	1.8	1.2				
1.9	2.0	2.1	2.2	2.2	2.3	13	76	38	19	9.5	4.8	3.4	2.4	1.7	1.2					
2.1	2.2	2.3	2.4	2.5	2.6	16	49	25	12	6.1	3.1	2.2	1.5	1.1						
2.2	2.4	2.5	2.6	2.7	2.8	19	30	15	7.6	3.8	1.9	1.3								
2.4	2.6	2.7	2.8	2.9	3.0	22	18	9.1	4.5	2.3	1.1					**combination**				
2.6	2.8	2.9	3.0	3.1	3.3	26	10	5.2	2.6	1.3					**not**					
2.8	3.0	3.2	3.2	3.3	3.5	30	5.7	2.8	1.4					**permitted**						
3.0	3.2	3.4	3.5	3.6	3.7	34	3.0	1.5												
3.2	3.4	3.6	3.7	3.8	4.0	38	1.5													

T_{UC}	upper category temperature (°C)
I	user current (A)
I_R	100 Hz alternating current (A) at upper category temperature T_{UC} taken from respective data sheet.
T_a	ambient temperature of electrolytic capacitor (°C)
ΔT_s	surface temperature rise of electrolytic capacitor due to user current (°C)
L	lifetime multiplier

PRODUCT CODE



ORDER NUMBER														
Code group	1			2		3		4			5	6		7
Figure	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	E	Y	H	0	7	L	B	5	1	0	E	0	2	X

Code Group 1

Code group 1 consists of three characters (1st, 2nd, 3rd *place) which provide the code indicating the respective series.

Examples of series codes:

EKF, EKA, EKB, EKE, ELM, EBM, EGM, EYH, EYN

* For two-letter type-codes the third place is a blank.

Code Group 2

Code group 2 consists of two digits (4th and 5th place) which provide the numerical code for specifying a particular design.

Description:

4th place:

0 = standard design, polarized

2 = bipolar / non-polarized

5th place:
0 = standard design
1 = smooth case bottom, clamp (Design A)

2 = threaded mounting stem (Design B)
3 = mounting ring
5 = radial types with standard lead spacing, wires cut to
4, 5 mm length (3 mm and 4 mm on request) lead spacing: 2, 2.5, 3.5, 5, 7.5 mm
6 = radial types with snap-in leads (lead spacing: 5, 7.5 mm)
7 = radial types with snap-in pins (spacing: 10 mm)
8 = radial types with snap-in pins (spacing: 10 mm)
9 = radial types, short leads, standard lead spacing bent open to 5 mm

PRODUCT CODE (continued)

Code Group 3

Code group 3 consists of two letters (6th and 7th place) indicating the capacitor's (nominal) dimensions. The 6th place stands for the diameter D and the 7th for the length L.

RADIAL TYPES (WIRE LEADS)	
6th place	7th place
D (mm)	L (mm)
3 = N	5 = P
4 = M	7 = M
5 = A	9 = Z
6.3 = B	10 = V
8 = P	11 = A
8.5 = C	11.5 = B
10 = D	12 = T
12.5 = F	12.5 = C
12.5/13 = G	16 = D
14 = H	20 = E
16 = J	22 = F
18 = K	25 = G
22 = L	27 = N
25 = P	30 = J
	31.5 = S
	35 = U
	35.5 = L
	36.5 = R
	40 = K

AXIAL TYPES	
6th place	7th place
D (mm)	L (mm)
3.3 = A	7 = M
4.5 = B	8 = N
6 = C	10 = K
6.5 = D	11 = A
8 = F	17 = B
10 = G	18 = L
12 = H	20 = C
14 = J	25 = D
16 = K	30 = E
18 = L	35 = F
21 = M	40 = G
25 = N	45 = H
30 = P	50 = J

CAN TYPES	
6th place	7th place
D (mm)	L (mm)
20 = S	20 = W
22 = L	25 = U
25 = A	30 = V
30 = B	35 = A
35 = C	40 = B
40 = D	45 = C
45 = M	50 = D
50 = E	55 = E
55 = F	60 = F
60 = G	65 = H
65 = H	70 = G
76 = K	80 = J
	90 = K
	105 = M
	114 = O
	120 = P
	125 = R
	135 = S
	144 = T
	166 = X

Code Group 4

Code group 4 consists of three figures (8th, 9th, and 10th place) which indicate the capacitance values.

8th place: number of place before the decimal point
9th and 10th place: capacitance value

Example:

047 = 0.47 µF
110 = 1.0 µF
210 = 10.0 µF
310 = 100 µF
447 = 4700 µF
522 = 22000 µF

Code Group 5

Code group 5 consists of one place (11th place) and provides the letter code indicating the capacitor's rated DC voltage [V].

A	B	C	D	Z	E	F	G	H	U	J	W	L	M	S	N	V	O	K	R	X	P	Y
4	6.3	10	16	33	25	35	40	50	60	63	80	100	160	200	250	300	350	360	385	400	450	500

PRODUCT CODE (continued)

Code Group 6

Code group 6 consists of two figures (12th and 13th place) which indicate the capacitance tolerances and special designs. The 12th place can also be taken by a letter which in this case indicates the type of packaging.

12th and 13th place	DIN IEC 62 Coding
00 = standard design	
01 = case insulation	
02 = full insulation	
03 = lead length 3 mm	
04 = lead length 4 mm	
05 = capacitance tolerance -10 + 50 %	T
06 = capacitance tolerance -10 + 30 %	Q
07 = capacitance tolerance ± 10 %	K
08 = capacitance tolerance ± 15 %	
09 = capacitance tolerance ± 20 %	M
10 - 99 = other special designs	

Note

(05 to 09 is only mentioned if there is a deviation of the standard tolerance)

12th place

LETTER CODE	DESIGN	CASE DIAMETER (mm)	TYPE OF PACKAGING	LEAD SPACING (mm)
A	Axial	3.3........16	Reel	-
B	Axial	3.3........16	Ammo	-
L	Radial	4........8	Ammo	5
M	Radial	4........8	Ammo	2.5
N	Radial	8	Ammo	3.5
G	Radial	10 and 12.5	Ammo	5
G	Radial	16 and 18	Ammo	7.5

Code Group 7

Code group 7 consists of 1 place (14th place) and is reserved for inter-company coding.
(ex. production line, production place)