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TECHNICAL REPORT

colour inside

Application of fixed capacitors in electronic equipment – Part 1: Aluminium electrolytic capacitors

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FOREWORD

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IEC TR 63362-1 has been prepared by IEC technical committee 40: Capacitors and resistors for electronic equipment. It is a Technical Report.

This first edition cancels and replaces CLC/TR 50454 published in 2008. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Complete technical revision, details of cleaning processes and failure modes added.

b) Inclusion of parts of JEITA RCR 2367D.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
40/2881/DTR	40/2908/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

A list of all parts in the IEC 63362 series, published under the general title *Application of fixed capacitors in electronic equipment*, can be found on the IEC website.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

APPLICATION OF FIXED CAPACITORS IN ELECTRONIC EQUIPMENT –

Part 1: Aluminium electrolytic capacitors

1 Scope

This document establishes guidelines for the application and use of aluminium electrolytic capacitors in electronic equipment.

The information given in this document applies to capacitors with non-solid electrolyte but can, in its appropriate clauses, apply to capacitors with solid electrolyte as well.

Electrolytic capacitors in general – and aluminium electrolytic capacitors in particular – are an exception in the capacitor field because of the components' close interaction of physics and chemistry. Therefore, aluminium electrolytic capacitors show, in various aspects, a technical behaviour unaccustomed to the user. That could easily lead to misapplications and even to endangering of persons and goods. The aim of this document is to minimize these risks by providing detailed information on the specific peculiarities of the component.

2 Normative references

There are no normative references in this document.

NOTE Further information about related standards can be found in Bibliography at the end of this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
anode
positive electrode
aluminium (preferably aluminium foil) of extreme purity that is etched in most cases in order to increase the electrode's surface and, consequently, the capacitor's capacitance yield

3.2
cathode
negative electrode
working electrolyte that is a conductive material

Note 1 to entry: Working electrolyte in the case of capacitors with solid electrolyte is a layer of manganese dioxide MnO_2, conductive organic salt (e.g. TCNQ) or conductive polymer (e.g. polypyrrole, PEDOT).

Note 2 to entry: PEDOT is a thiophene-based doped polymer, which is used as a solid cathode in aluminium electrolytic capacitors, often combined with an additional liquid electrolyte.

3.3
dielectric
aluminium oxide (Al_2O_3) which is formed on the anode's surface by an anodizing process

3.4
contact element for the negative electrode
high-purity aluminium foil ("cathode foil") in the case of capacitors with non-solid electrolyte or silver paste on graphite or other conductive connections in the case of capacitors with solid electrolyte

3.5
separator
layers (preferably of special paper) that separate the anode foil from the "cathode foil" in the case of capacitors with non-solid electrolyte

Note 1 to entry: The other purpose of the separators is to retain the working electrolyte.

3.6
polarity
polarized electrolytic capacitor

Note 1 to entry: For special purposes, so-called non-polar (bipolar) capacitors can be provided. Such special types consist in principle of an internal back-to-back connection of two basically polarized elements.

3.7
sealing
polymer-based material to close the aluminium case

Note 1 to entry: The internal element of a non-solid electrolytic capacitor is normally encapsulated in an aluminium case closed with a sealing material which is never perfectly gas-tight. Because of using a non-solid electrolyte, of which, some constituents are slowly diffusing through the sealing, the electrical characteristics of the capacitor are changing gradually over its entire life.

4 Protection measures – insulation

Capacitors can be either completely or partially covered with sleeving or coating, or not covered at all. It should be noted that, in particular for capacitors with liquid electrolyte, the capacitor case is not insulated from the cathode terminal. The case can be connected to the electrolyte through the contact element for the negative electrode.

Axial leaded capacitors have a direct contact between the case and the cathode terminal. Radial leaded capacitors have an undefined electrical contact through electrolyte or other parts inside the case. Dummy pins are left potential-free or can be connected to the potential of the negative terminal. Metal parts other than terminals should never make contact to conducting tracks or metal parts of other components.

The standard sleeving must be considered as protection against contact only, and does not offer any functional insulation. If electrical insulation is required, an additional insulation is necessary.

Special care needs to be taken if the mounting requires electrical insulation, such as:

- other components are in touch with capacitors;
- unprotected live wires or PCB tracks are underneath the capacitors;
- capacitors are in contact with the enclosure;
- capacitors are mounted by metal clamps.

For such cases, the sleeving material needs to be agreed on case by case between the manufacturer and the customer.

The sleeving can deteriorate depending on the environmental conditions, e.g.:

- upon exposure to high temperature, polyvinyl chloride (PVC) sleeving can become brittle which could potentially lead to cracks;
- for polyethylene terephthalate (PET) based sleeving, exposure to high temperature and high humidity can lead to hydrolysis.

Operating conditions for which sleeving deterioration is expected need to be agreed on case by case between the manufacturer and the customer.

5 General application limits

5.1 Polarity – Reverse voltage

Electrolytic capacitors for DC applications require polarization.

The polarity of each capacitor is checked both in circuit design and in mounting. Polarity is clearly indicated on the capacitor. For short periods, a limited reverse voltage can be allowed as specified in the relevant specification by the manufacturer. Exceeding the specified reverse voltage can induce damage by causing overheating, over-pressure and dielectric breakdown and can be associated with open circuit or short-circuit conditions – it is the most severe failure mechanism with aluminium electrolytic capacitors. There could even be a destruction of the capacitor. Protections need to be used if there are reverse voltage risks (see Clause 10).

5.2 Voltage

5.2.1 General

Exceeding the capacitors' specified voltage limits can cause premature damage (e.g. by breakdown with open or short circuit) affecting the useful life. Even destruction of the capacitor can be the consequence.

5.2.2 Rated voltage

The rated voltage U_R given in the relevant specification or by the manufacturer is the value permitted for continuous operation in the rated temperature range.

5.2.3 Surge voltage

For short periods, the voltage can be increased up to the surge voltage value in accordance with IEC 60384-4, IEC 60384-18, IEC 60384-25, IEC 60384-26 and to the manufacturer's specification.

5.2.4 Transient voltages

The surge voltage value can be exceeded for very short periods or short pulses if allowed by the manufacturer and when in accordance with the relevant specification or detailed specification by the manufacturer. A test method is given in IEC 60384-4, IEC 60384-18, IEC 60384-25, IEC 60384-26.

Such special operating conditions need to be agreed on case by case between the customer and the manufacturer.

5.3 Temperature range

The capacitors are to be used within the specified temperature range (category temperature range).

Applicable temperature ranges are given in the relevant specifications and/or in manufacturer's data. A general principle is that lower ambient temperature means longer life. Therefore, electrolytic capacitors should be placed at the coolest positions wherever possible.

Exceeding the permitted temperature causes overheating and over-pressure, which can affect the useful life and induce damage. Even destruction of the capacitor can be the consequence.

5.4 Ripple current

The sum of DC voltage and superimposed ripple voltage is specified to be within rated voltage and 0 V at any time.

Electrolytic capacitors are not normally designed for AC application (see Clauses 1 and 17).

No excessive ripple current is allowed to pass. Exceeding the ripple current specification reduces life and can induce overheating and over-pressure. Even destruction of the capacitor can be the consequence.

The useful life of the capacitor is a function of the r.m.s. ripple current. Temperature, frequency and cooling conditions as well as applied DC voltage are other factors influencing the useful life.

5.5 Charge – Discharge

Under the conditions defined in IEC 60384-4, IEC 60384-18, IEC 60384-25, IEC 60384-26, or in the manufacturer's specifications, frequent charge/discharge operation is allowed.

Exceeding charge/discharge frequency leads to a high ripple current and induces damage by overheating and overpressure or breakdown with open circuit or short circuit, leading to a reverse voltage risk (see 5.1). Even destruction of the capacitor can be the consequence.

Rapid charge/discharge operating conditions in applications such as robotics or servo drives need to be agreed on case by case between customer and manufacturer.

6 Storage, transportation, and operation

It is recommended to store the capacitors at temperatures between 5 °C to 35 °C and a relative humidity of less than 75 %, and in original packaging.

Storage of the capacitors above recommended temperatures (5 °C to 35 °C) in off-duty condition can cause an increase of the leakage current to more than 10 times the maximum limit (see IEC 60384-4, IEC 60384-18, IEC 60384-25, IEC 60384-26). This is caused by the special characteristics of the dielectric material (e.g. aluminium oxide in case of aluminium electrolytic capacitors). This leakage current is not only dependent on the capacitor's design, but is also a function of time, the applied voltage, temperature, and the capacitor's history, such as storage conditions and duration. Although the initial leakage current can be significantly increased after storage, it will decrease to a stable value upon application of voltage.

Manufacturers' recommendations (reforming procedures, etc.) need to be considered after extended storage (for more details see IEC 60384-4, IEC 60384-18, IEC 60384-25, IEC 60384-26). High humidity and/or high temperature can impair solderability and taping.

Storage at conditions defined above has a negligible effect on capacitance, tangent of loss angle or equivalent series resistance, and impedance.

Special care needs to be taken with respect to exposure to halogenated chemicals (see also Clause 15). International shipments might be subjected to fumigation treatment with halogenated gases (e.g. methyl bromide). These gases could penetrate the sealing and potentially lead to internal corrosion.

Capacitors are generally housed in high purity aluminium with typically low mechanical strength. Shocks must be avoided and the manufacturer's packaging must always be used to transport capacitors.

7 External pressure (not relevant for capacitors with solid electrolyte)

7.1 Low air pressure

Minimum air pressure is 8 kPa for short periods, for example 5 min accordance with IEC 60384-4.

7.2 High air pressure

If the capacitor is operated under conditions higher than natural ambient air pressure, the manufacturer needs to be consulted. The maximum operating pressure depends upon size and style of the capacitor. It should be specified by the manufacturer on request. Exceeding the specified value can damage the capacitor (e.g. destroyed cases, open pressure relief device, short circuit, etc.).

8 Self-recharge phenomenon (dielectric absorption)

Even if aluminium electrolytic capacitors are totally discharged, these components can afterwards develop some voltage without external influence. This self-recharge phenomenon is known as "dielectric absorption" or as "dielectric relaxation" (can exceed 15 % of the capacitor's rated voltage).

The capacitor is a non-ohmic conductor and has, therefore, a non-uniform distribution of the electric field. This is correlated with electric space charges within the dielectric layer. In the case of open terminals, an increasing voltage is built up during the electric charges' relaxation.

Depending on the capacitor type and its designed voltage, such self-recharge can result in values (even several tens of volts) which could represent some risk: damage of semiconductor devices, solder bath sparking during soldering, sparking when by-passing the terminals, and so on.

Therefore, appropriate measures are advisable if such risks are to be avoided. In particular, for capacitors of high capacitance and high electric charge, it is recommended, for instance, to keep the terminals shorted or to repeat the discharge before mounting or soldering them.

9 Flammability (passive and active)

9.1 General

Aluminium electrolytic capacitors contain materials that can ignite under the influence of external fire (passive flammability) or in the case of a defect of the component (active flammability). Such flammable parts of the capacitor are for instance: plastic parts, sleeves, moulding compounds, separator of the capacitors' winding element, in some cases working electrolytes.

9.2 Passive flammability

Under the influence of high external energy, such as fire or electricity, the flammable parts can ignite. If, for equipment safety approvals, information about passive flammability is required, the manufacturers need to be consulted. Related information can be obtained for example from

IEC 60384-1, which refers to the needle flame test (IEC 60695-11-5) for testing the passive flammability of capacitors. The severities and requirements for different categories of flammability are listed in IEC 60384-1.

9.3 Active flammability

In rare cases, the component can ignite caused by heavy overload or some capacitor defect. One reason could be that during the operation of an aluminium electrolytic capacitor with non-solid electrolyte, there is a small quantity of hydrogen developed in the component. Under normal conditions, this gas permeates easily out of the capacitor. But under exceptional circumstances, higher gas amounts can develop and can catch fire if sparking occurs at the same time.

As explained above, a fire occurrence cannot be totally excluded. Therefore, it is recommended to use special measures in critical applications (e.g. additional encapsulation of the equipment for mining applications).

10 Internal pressure and pressure relief device

(Not relevant for capacitors with solid electrolyte).

During the operation of the aluminium electrolytic capacitor with non-solid electrolyte, some gas develops in the component. Under normal conditions, this small amount permeates without any problems slowly out of the capacitor. But in cases like an overload, application of reverse voltage, or a malfunction of the capacitor can cause a higher gas production that cannot be covered by the normal permeation and leads to a considerable overpressure in the component.

This high internal pressure can lead to the rupture of capacitor sealing/body/casing. The relevant detail specifications will indicate whether the capacitor is equipped with a specific pressure relief device ("safety vent") which opens at a relatively low pressure and, therefore, limits the abovementioned risk of rupture.

The test of the proper function of this pressure relief device is specified in IEC 60384-1. The test methods described therein prove whether the pressure relief device covers the majority of the fault events.

In rare cases, such as extreme overload or ignition of gas inside the capacitor (through sparking caused by breakdown), a fully functioning pressure relief device does not react in time. Therefore, capacitors exposed to such limit conditions need to be shielded. The same applies in the case of testing the pressure relief device.

When using the capacitors, care needs to be taken to ensure that the proper function of the pressure relief device is not impaired, for instance by mounting measures such as clamps or glue and potting compounds (see also 14.1.4, Position of the pressure relief device).

11 Working electrolytes and contact with an electrolyte

(Not relevant for capacitors with solid electrolyte).

Capacitors with non-solid electrolyte contain high purity aluminium foils and separators that are impregnated with a suitable electrolyte. To give the electrolytic capacitor a long and stable life, the ingredients must be very pure. Impurities such as halogens (e.g. chloride) or foreign metals must be kept as low as possible.

The electrolyte is a biodegradable liquid based on a stable solvent with a high boiling point as the main ingredient (common solvents are γ-butyrolactone or ethylene glycol). Furthermore, the electrolyte consists of an acid base system and other added chemicals that are dissolved in it. It has a low toxicity, but prolonged inhalation of vapours or ingestion should be avoided.

However, it is advisable to avoid contact with the skin or the eyes. Exposure of electrolyte on the skin must immediately be treated by rinsing with water. Exposure to the eyes must be treated by flushing for 10 min by rinsing with water. Medical attention should be sought if problems persist. Inhalation of electrolyte vapours or aerosols from electrolyte must be avoided. If vapour of electrolyte is present, the air in the room must be ventilated. Smoke from burning electrolyte is irritating but does not contain dioxins or similar highly toxic substances. If electrolyte gets on cloth, it can be washed with water.

12 Parallel and series connection of capacitors

12.1 General

Connection of aluminium electrolytic capacitors in series/parallel banks gives rise to the following considerations. Subclauses 12.2 to 12.5 provide guidelines for parallel and series connection of capacitors. Individual differences in component characteristics for different manufacturers need to be considered. Detailed information for balancing resistors can be obtained from manufacturers.

12.2 Voltage sharing between devices

This factor is influenced by the leakage current difference between the individual capacitors in the chain. It is very important that the leakage current differences are compensated for at the design stage as fairly small differences can cause problems.

This is normally evidenced at turn on as an overvoltage condition on the components with the lowest leakage currents and can lead to premature failure.

Depending on the circuit configuration of the bank and failure mode, other components which were initially unaffected could at this stage be subjected to voltages considerably in excess of the ratings and will also fail.

This leakage current difference is normally controlled by the use of resistors across each of the individual components, or in the case of a common centre connection, by only two resistors.

12.3 Circuit configuration

There are two major configurations to consider when constructing a series/parallel bank of capacitors. The advantages and disadvantages of each are outlined below but the final choice needs to be made by the equipment designer:

a) **Option 1: Individual balancing resistors (see Figure 1)**

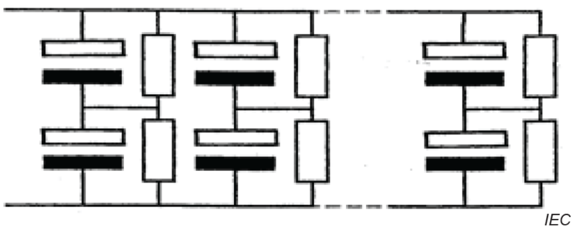

Figure 1 – Individual balancing resistors

Advantages

If one capacitor fails and becomes short circuit, then the capacitor in series with it will almost certainly fail but the other capacitors in the bank should be unaffected.

Disadvantages

More complex construction, many resistors to be fitted. Additional cost of resistors.

b) **Option 2: Common centre connection (see Figure 2)**

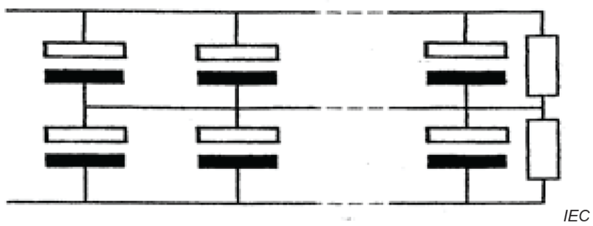

Figure 2 – Common centre connection

Advantages

As the number of capacitors in parallel increases, so the effective capacitance at the top and bottom of the bank will tend to equalise; this will give better balancing during transient conditions.

Also, the average total leakage current at the top and bottom of the bank will become closer giving improved balancing under steady-state conditions.

Only two resistors required. In some cases, the difference between the leakage currents at the top and bottom of the bank can be so small as to render the use of resistors unnecessary.

Disadvantages

If one capacitor goes short circuit, the other half of the bank will be exposed to the full voltage and can cause several further failures.

Of course, combinations of the above basic configurations are in use too, as shown in Figure 3. Capacitor banks can be subdivided into groups of option 2 (common centre connection).

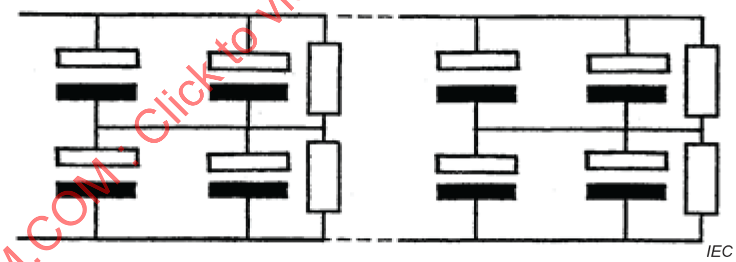

Figure 3 – Group-balancing resistors

The consequent advantages and disadvantages of both options apply when using the circuit diagram as shown in Figure 3.

12.4 Balancing resistors for voltage sharing

12.4.1 General

When aluminium electrolytic capacitors are connected in series, the voltage ratio across the series capacitors will be equal to the ratio of their insulation resistances (or to the reciprocal ratio of their leakage currents, respectively), see 12.1. As there are remarkable spreads of leakage currents to be taken into consideration, it is advisable to use balancing resistors to control the voltage sharing across each device.

12.4.2 Voltage sharing analysis

Consider the circuit consisting of two capacitors in series (C_1 and C_2) with balancing resistors (R_1 and R_2) shown in Figure 4.

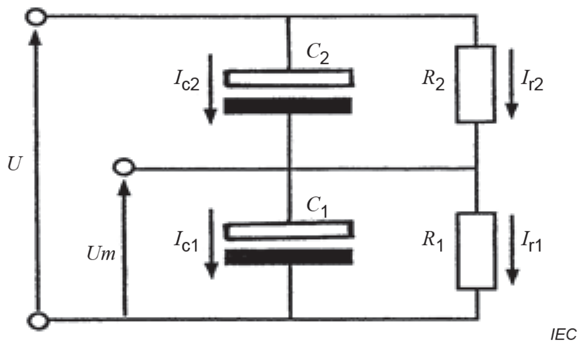

Figure 4 – Voltage sharing analysis

If a voltage U is applied across this capacitor and resistor network then, when equilibrium is reached, the currents I_{c1}, I_{c2}, I_{r1} and I_{r2} will flow as shown.

The sum of the currents through the top half of the network will equal the sum of the currents through the bottom half of the network, thus:

$$I_{c1} + I_{r1} = I_{c2} + I_{r2} \tag{1}$$

The voltage at the mid-point, denoted by U_m, will be given by:

$$U_m = I_{r1} \times R_1 \tag{2}$$

Combining equations (1) and (2) gives:

$$U_m = (I_{c2} - I_{c1} + I_{r2}) \times R_1 \tag{3}$$

Furthermore, since I_{r2} can be defined as:

$$I_{r2} = \frac{(U - U_m)}{R_2} \tag{4}$$

It can be shown that:

$$U_m = \frac{(I_{c2} - I_{c1}) \times R_1 \times R_2}{(R_1 + R_2)} + \frac{U \times R_1}{(R_1 + R_2)} \tag{5}$$

This shows that the mid-point voltage U_m is dependent on the difference in capacitor leakage current ($I_{c2} - I_{c1}$), the applied voltage U and the values of the resistors used.

Since the values of the balancing resistors will normally be equal, we can set both R_1 and R_2 equal to R and simplify the equation to give:

$$U_m = \frac{(I_{c2} - I_{c1}) \times R}{2} + \frac{U}{2} \quad (6)$$

This clearly demonstrates that the mid-point voltage U_m deviates from the ideal value of $U/2$ by an offset voltage $(I_{c2} - I_{c1}) \times R/2$, which is determined by the resistor value and the difference in leakage currents between the two capacitors.

12.4.3 Resistor tolerance

The effect of different resistor values (varying within normal tolerance) can be shown by examining equation (5).

For example, suppose the resistors have a ± 5 % tolerance and one resistor is on bottom limit and the other on top limit. We can set R_1 = 0,95 × R and R_2 = 1,05 × R, which gives:

$$U_m = \frac{(I_{c2} - I_{c1}) \times R \times 0{,}9975}{2} + \frac{U \times 0{,}95}{2} \quad (7)$$

In this case, the ideal mid-point voltage of $U/2$ is reduced by 5 % and the offset voltage due to leakage current difference is slightly reduced by a factor of 0,997 5.

12.4.4 Choice of resistor value

Equation (6) can also be rearranged to determine the value of balancing resistor necessary for a given set of conditions, thus:

$$R = \frac{(2 \times U_m - U)}{(I_{c2} - I_{c1})} \quad (8)$$

To calculate the maximum resistor value required, set U to the value of applied voltage and set U_m to the maximum acceptable mid-point voltage, usually the rated voltage of the capacitor.

The difference in leakage current $(I_{c2} - I_{c1})$ will depend on the capacitor in use, the temperature of operation and the eventual voltage that each capacitor settles to.

If the capacitor leakage currents are measured at an identical voltage, then there will usually be some difference between the values: one will be higher than the other.

When placed in the circuit, it is important to note that initially the capacitor with the higher leakage current will have a lower voltage across it. Since the leakage current depends on the applied voltage (the lower the voltage the lower the leakage current), this capacitor will tend to settle to a lower leakage current.

The opposite will be true for the capacitor with the higher voltage across it. Since this will reduce the difference between the leakage currents, the mid-point voltage U_m will move closer to $U/2$.

For practical purposes the difference in leakage currents at rated temperature can be estimated as:

$$I_{c2} - I_{c1} = \frac{0{,}0015 \times C_R \times U}{2000} \left[\frac{\text{mA}}{\mu\text{F} \times \text{V}}\right] \quad (9)$$

where C_R is the rated capacitance, and U is the applied voltage across the pair of capacitors.

Table 1 gives examples using this approach.

Table 1 – Balancing examples

Capacitance µF	**Rated voltage** V	$I_{c2} - I_{c1}$ mA	U V	U_m V	**Balancing resistor** R kΩ
3 300	450	1,11	800	450	90
2 200	400	0,66	700	400	152
470	400	0,14	750	400	355
470	400	0,14	700	400	709
1 000	200	0,15	385	200	100
3 300	350	0,87	600	350	115

Appropriate considerations apply if more than 2 capacitors are to be connected in series.

12.5 Component failure

The mode of failure will be the same as for normally connected capacitors. However, the energy available in bank connected configurations is much greater, which can lead to melted busbars, shattered capacitor decks, and the possibility of explosion.

In addition, during failure, it is likely that the failing component will be in a short-circuit condition. It is recommended that if failure has occurred, then all components which probably have been subjected to excess voltages are replaced. This step will maintain the overall reliability of the equipment.

13 Clearance and creepage distances

13.1 Distances inside the capacitor

Because of the particularities of the component, there is no need to specify distances inside the capacitor. The technical requirements are proven by the test sequence of the relevant sectional and detail specifications. In particular, the requirements of the test's endurance, surge voltage, vibration, and shock or bump are to be met.

13.2 Distances outside the capacitor

According to the relevant specifications for aluminium electrolytic capacitors, the components are to be designed for use in electronic equipment. Therefore, the capacitors need to meet the technical requirements as specified for these applications. For instance, such specifications are given in IEC 62368-1, *Audio/video, information and communication technology equipment – Part 1: Safety requirements* and IEC 60664-1, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*.

If aluminium electrolytic capacitors are intended to be used in applications different from electronic equipment, other requirements can be agreed upon between the customer and the manufacturer.

14 Capacitor mounting

14.1 General conditions for mounting

14.1.1 Mounting position

A general principle is that lower ambient temperatures result in a longer useful life of the capacitor. Therefore, electrolytic capacitors should be positioned at the coolest place on the board. It should be ensured that electrolytic capacitors are placed away from heat emitting components such as power resistors, switching diodes/transistors, transformers or heat sinks. Adequate space should be allowed between components for cooling air to circulate, particularly when high ripple current or charge/discharge loads are applied. Alternatively, capacitors can be cooled using a heat sink with adequate mounting to increase the ripple current or charge/discharge capability of the component if in accordance with the manufacturer's specifications.

Screw terminal capacitors must not be mounted with terminals facing down unless otherwise specified. For more details about mounting of screw terminal capacitors, the components supplier needs to be asked for guidance.

14.1.2 Polarity indication

DC electrolytic capacitors are normally polarized components and require correct polarization in the circuitry. Application of wrong polarity can destroy the component (refer to Clause 10). In order to ensure the correct mounting position and identification of the polarity, a clear + and/or – should be given on the board lay-out printing.

14.1.3 Hole/pad distance

The component manufacturer specification contains recommendations for the design of circuit board holes, matching the terminal pitch and tolerances. The same applies to the landing pads of SMD capacitors.

14.1.4 Position of the pressure relief device

Proper functioning of the pressure relief device (vent) is only secured if there is adequate space between vent and adjacent parts. The space required above the pressure relief device can differ for each capacitor, type, size or by manufacturer. Check catalogues or consult the manufacturers. The following distances are recommended as a guideline:

Capacitors nominal case diameter	Space around pressure relief device
<16 mm	> 2 mm
> 16 mm to < 40 mm	> 3 mm
40 mm	> 5 mm

The mounting position of the capacitor needs to be determined under consideration of the location of the vent. For example, mounting of screw-terminal capacitors with the vent facing upwards is recommended, and in case of horizontal mounting, with the vent at the 12 o'clock position.

14.1.5 Board holes under the insulation

Since a capacitor’s insulation sleeve must not make contact with molten solder, openings in the printed circuit board must not be positioned in places where parts of a capacitor could be located on the other side of the board.

14.1.6 Double-sided printed circuit boards

Conductors or lands underneath upright mounted electrolytic capacitors are not allowed. Metal parts other than terminals must not make contact with conductors or metal parts of other components.

14.1.7 Case polarity

Axial leaded capacitors have a direct contact between case and cathode terminal. However, radial leaded capacitors have an undefined case-to-cathode contact through the electrolyte or other parts inside the case. Dummy pins can be left potential-free or be connected to the potential of the negative terminal. Metal parts other than terminals should never make contact with conductors or metal parts of other components.

14.2 Component preparation

The limits of the terminals' mechanical strength are given in the relevant specifications and/or in the instructions of the component’s manufacturer. In particular, terminals specified to be rigid ones must not be bent. During cutting, bending or cropping operations, lead wires need to be fixed sufficiently close to the capacitors body in order to avoid excessive stress to the terminations (and welding spots, sealing, etc.). Special care should be taken when manual bending of terminations is required.

14.3 Mounting

14.3.1 Discharging

Before handling the capacitor, it must be ensured that the electrolytic capacitor is sufficiently discharged (refer to Clause 8).

14.3.2 Ratings and polarity

Prior to mounting the capacitor, the correct rated values as well as correct polarity must be checked.

14.3.3 Lead stress

There must be no excessive mechanical stress to the terminals of electrolytic capacitors. If a capacitor cannot be inserted easily, excessive force should not then be applied.

Capacitors showing signs of mechanical damage should not be used.

14.3.4 Fixing torque

Excessive torque during tightening the screw terminals can affect the performance of the capacitor or damage the sealing. Maximum permissible torques are given in the relevant specifications and/or are specified by the component’s manufacturer.

Too low a fixing torque can cause high contact resistance issues and must be avoided.

14.3.5 Capacitor fixing

If capacitors have to be mounted by additional means, the mounting accessories recommended by the supplier should be used. In the case of fixation by resin, it is important to consider fixation versus vibration load, making sure the fixed components are vibrating in phase.

When fixing to a heatsink the thermal resistance of the resin needs to be considered, as this can impair the load capability of the component.

14.4 Soldering

14.4.1 Preheat temperature

Preheating of the capacitor must not exceed its upper category temperature. If this cannot be avoided due to process requirements, it is advisable to consult the component's supplier prior to doing so.

14.4.2 Soldering temperature and duration

Soldering conditions (e.g. soldering temperature vs. duration, minimum distance of soldering from the body) are given in the relevant specifications and/or the data sheets of the component’s supplier. The insulation sleeve or other plastic parts must never be touched by a soldering iron or molten solder, or by other hot parts. Reflow soldering is only suitable for surface mount capacitors or pin-in-paste enabled designs, and only one reflow cycle is permitted. Should more reflow cycles be necessary, the component's manufacturer needs to be asked for guidance.

14.4.3 Care after soldering

After an electrolytic capacitor has been soldered onto the circuit board, no mechanical force (like straightening, bending, twisting and/or tilting) is to be applied.

14.5 Transport and handling of assembled devices

During transport and handling of assembled devices (e.g. printed circuit boards), do not misuse electrolytic capacitors as a "handle". It should be ensured that during transportation, the capacitors are protected in such a manner as to prevent physical damage from occurring (e.g. during mounting of the printed circuit board into an assembly, or stacking printed circuit boards).

15 Cleaning solvents and processes

15.1 General

In principle, aluminium electrolytic capacitors are not designed to withstand cleaning solvents. If cleaning of a board is necessary, select capacitors designed to withstand the cleaning process, and observe the cleaning conditions specified in the catalogue or in the manufacturer's specification.

15.2 Cleaning solvents

15.2.1 Halogenated solvents (e.g. CFC)

Aluminium electrolytic capacitors are susceptible to damage by contact with halogen ions. These very small ions can penetrate through the sealing and cause internal corrosion, leading to premature failure of the component.

Cleaning solvents (both CFC and non-CFC) can swell the sleeve and could affect the legibility of the marking if applied for excessive duration and/or applied with excessive mechanical forces (pressures) and/or high temperatures.

15.2.2 Halogenated hydrocarbons

Apart from the fact that these solvent kinds are ozone depleting chemicals, and as such hazardous to the environment, they can weaken the sealing elements of the capacitors. For this reason, halogenated hydrocarbons are not recommended for board cleaning purposes. The limiting conditions given by the component supplier need to be adhered to, if the use of such chemicals is unavoidable.

15.2.3 Aqueous solutions

Aqueous solutions with a mild detergent can be used for cleaning of electrolytic capacitors. However, it is recommended that immediate drying of the component in hot air is carried out at approximately 85 °C (but not higher than the capacitor's upper category temperature) for at least 5 min. Water can become entrapped beneath the sleeve which will not be adequately dispelled by evaporation at room temperature. Water can become trapped underneath the sleeve and can cause hydration and discolouration of the aluminium case's surface, and the insulation performance can be reduced. After aqueous cleaning, the sleeve can swell when exposed to high temperatures. Detailed information can be obtained from manufacturers.

15.2.4 Alcohols

The following alcohols are good for cleaning, but still there are issues to be checked.

- Cleaner based with higher alcohol: marking on the sleeve can disappear.
- Isopropyl alcohol: marking on the sleeve can disappear. If xylene is added to improve performance, the solvent can swell the sealing rubber.

15.2.5 Alkaline solvents

After cleaning with alkaline solvents, the capacitor is to be thoroughly rinsed with water in order to remove alkali residue completely. Such residues could cause corrosion of the aluminium case.

15.2.6 Other cleaning solvents

Do not clean the capacitors using solvents, unless so specified in the catalogue or the manufacturer's specification.

Use of one of the following chemicals, among others, for cleaning can damage the capacitor:

- xylene, toluene: degradation of sealing rubber;
- acetone: disappearance of markings;
- terpene, petro-based solvents: degradation of sealing rubber.

15.3 Cleaning of circuit board

15.3.1 Cleaning processes

Cleaning of a board should follow an appropriate method described in the catalogue or in the manufacturer's specification. Excessive cleaning can induce invasion of cleaning agent into a capacitor through the sealing and followed repeated electrolysis by the solvent, electrolyte and aluminium foils in a capacitor. The insulation of the oxide film is deteriorated the leakage current can increase. The inner pressure will rise, followed by activation of the pressure valve. Deterioration of electrical characteristics or open circuit can arise.

Cleaning can be made by static immersion of a board in a cleaning solvent, ultrasonic agitation in the solvent, steam cleaning, flow of a cleaning solvent, or spray of the solvent. Combinations of these methods are generally used for cleaning. The total time spent for cleaning should not exceed the time specified in the catalogue or the manufactures specification. The temperature of solvent in the immersion should be less than 60 °C and below the boiling point of the solvent being used.

Insufficient cleaning also causes some problems. If some flux with strong activator is left between a capacitor and a board, the flux can erode electrodes, and even can cause tracking of conductor pattern. If such flux remains for a long time at the sealing of a capacitor, halogen ions can invade into a capacitor and electrolysis can occur, as in a case of improper cleaning.

15.3.2 Process control during cleaning

15.3.2.1 Mixing of flux in cleaning solvent:

Perform control of cleaning agents (conductivity, pH, specific weight, and water content).

The cleaning agent used in cleaning can be contaminated by foreign materials such as flux. Halogen compounds added to solvent as activators are concentrating in these materials and the cleaning process becomes equivalent to that made in a halogen containing cleaning agent.

15.3.2.2 Cleaning equipment and handling of work in cleaning process:

It is important that the output ultrasonic power in the equipment is not too large. Too large an output can result in resonance of the board on which capacitors are mounted and the breaking of solder joints, or even the breaking of internal connections of a capacitor. If the power is not specified in the catalogue or the manufacturer's specification, the following is a common condition:

- output power of ultrasonic bath: less than 20 W/L;
- frequency: below 40 kHz;
- cleaning time: less than 5 min.

Take care that the surfaces of capacitors don't rub each other while in ultrasonic cleaning. The marking of sleeve can be erased.

15.3.3 Process control after cleaning

Do not leave a board in a closed container or similar environment. Capacitors are exposed to a similar environment as during vapour cleaning, and solvent can enter into a capacitor through the sealing.

Be sure to check the work is well dried after cleaning. If not dried enough, the status of a capacitor is similar to being under cleaning and the solvent can enter into the capacitor. If a capacitor is mounted to a board in close contact, complete drying is rather difficult. If not specified, the following condition is used for drying: hot air blow of temperature less than rated temperature for more than 10 min.

15.3.4 Other precautions

The components sleeve can re-shrink or crack if rapid heating above 100 °C is applied just after cleaning.

Special care is recommended when inflammable solvents are used.

16 Potting and gluing

16.1 General

For details about potting and gluing of capacitors, the component manufacturer needs to be asked for guidance.