PRECAUTIONS AND GUIDELINES

For conductive polymer aluminum electrolytic solid capacitors, please refer to PRECAUTIONS AND GUIDELINES (Conductive Polymer)

Designing Device Circuits

1 Select the capacitors to suit installation and operating conditions, and use the capacitors to meet the performance limits prescribed in this catalog or the product specifications.

2 Polarity

Aluminum Electrolytic Capacitors are polarized.
Apply neither reverse voltage nor AC voltage to polarized capacitors. Using reversed polarity causes a short circuit or venting. Before use, refer to the catalog, product specifications or capacitor body to identify the polarity marking. (The shape of rubber seal does not represent the directional rule for polarity.)
Use a bi-polar type of non-solid aluminum electrolytic capacitor for a circuit where the polarity is occasionally reversed.
However, note that even a bi-polar aluminum electrolytic capacitor must not be used for AC voltage applications.

3 Operating voltage

Do not apply a DC voltage which exceeds the full rated voltage.
The peak voltage of a superimposed AC voltage (ripple voltage) on the DC voltage must not exceed the full rated voltage.
A surge voltage value, which exceeds the full rated voltage, is prescribed in the catalogs, but it is a restricted condition, for especially short periods of time.

4 Ripple current

Do not apply overcurrent which exceeds the full rated ripple current. The superimposition of a large ripple current increases the rate of heating within the capacitor. When excessive ripple current is imposed the internal temperature increases which may occur failure mode as follows.
・Shorten lifetime
・Open vent
・Short circuit
The rated ripple current has been specified at a certain ripple frequency. The rated ripple current at several frequencies must be calculated by multiplying the rated ripple current at the original frequency using the frequency multipliers for each product series. For more details, refer to the paragraph on Aluminum Electrolytic Capacitor Life.

5 Category temperature

Do not apply over temperature which exceeds the maximum category temperature.
The use of a capacitor outside the maximum rated category temperature will considerably shorten the life or cause the capacitor to vent.
The relation between the lifetime of aluminum electrolytic capacitors and ambient temperature follows Arrhenius' rule that the lifetime is approximately halved with each 10℃ rise in ambient temperature.

6 Life expectancy

Select the capacitors to meet the service life of a device.

7 Charge and discharge

Do not use capacitors in circuits where heavy charge and discharge cycles are frequently repeated. Frequent and sharp heavy discharging cycles will result in decreasing capacitance and damage to the capacitors due to generated heat. Specified capacitors can be designed to meet the requirements of charging-discharging cycles, frequency, operating temperature, etc.

8 Failure mode of capacitors

Non-solid aluminum electrolytic capacitors, in general, have a lifetime which ends in an open circuit, but depending on conditions of usage or products type, failure mode of capacitors will be venting.
Please contact a representative of Nippon Chemi-Con.

9 Insulating

Electrically isolate the following parts of a capacitor from the negative terminal, the positive terminal and the circuit traces.
・The outer can case of a non-solid aluminum capacitor.
・The dummy terminal of a non-solid aluminum capacitor, which is designed for mounting stability.

10 The outer sleeve

The outer sleeve of a capacitor is not assured as an insulator (Except for screw type).

11 Condition

Do not use/expose capacitors to the following conditions.
a) Oil, water, salty water storage in damp locations.
b) Direct sunlight
c) Toxic gases such as hydrogen sulfide, sulfurous acid, nitrous acid, chlorine or its compounds, and ammonium
d) Ozone, ultraviolet rays or radiation
e) Severe vibration or mechanical shock conditions beyond the limits prescribed in the catalogs or the product specification.

12 Mounting

a) The paper separators and the electrolytic-conductive electrolytes in a non-solid aluminum electrolytic capacitor are flammable.
Leaking electrolyte on a printed circuit board can gradually erode the copper traces, possibly causing smoke or burning by short-circuiting the copper traces.
Verify the following points when designing a PC board.
・Provide the appropriate hole spacing on the PC board to match the terminal spacing of the capacitor.
・Make the following open space over the vent so that the vent can operate correctly.

Case diameter	Clearance
ϕ6.3 to ϕ16mm	2mm minimum
ϕ18 to ϕ35mm	3mm minimum
ϕ40mm and up	5mm minimum

・Do not place any wires or copper traces over the vent of the capacitor.
・Installing a capacitor with the vent facing the PC board needs an appropriate ventilation hole in PC board.
・Do not pass any copper traces beneath the seal side of a capacitor. The trace must pass 1 or 2mm to the side of the capacitor.
・Avoid placing any heat-generating objects adjacent to a capacitor or even on the reverse side of the PC board.
・Do not pass any via holes underneath a capacitor on double sided PC board.
・In designing double-sided PC boards, do not locate any copper trace under the seal side of a capacitor.

b) Do not mount the terminal side of a screw mount capacitor downwards. If a screw terminal capacitor is mounted on its side, make sure the positive terminal and vent are higher than the negative terminal.
Do not tighten the screws of the terminals and the mounting clamps over the specified torque prescribed in the catalog or the production specification.

c) For a surface mount capacitor, design the copper pads of the PC board in accordance with the catalog or the product specifications.

13 Others

a) Using capacitor for applications which always consider safety. Consult with our factory before use in applications which can affect human life.(space equipment, aerial equipment, nuclear equipment, medical equipment, vehicle control equipment, etc) Please note that the product, which is designed only for specific usage cannot be used in other usages.(ex. Photo flash type, etc.)
b) The electrical characteristics of capacitors vary in respect to temperature, frequency and service life. Design the device circuits by taking these changes into account.
c) Capacitors mounted in parallel need the current to flow equally through the individual capacitors.
d) Capacitors mounted in series require resistors in parallel with the individual capacitors to balance the voltage.

Installing Capacitors

1 Installing

a) Used capacitors are not reusable, except in the case that the capacitors are detached from a device for periodic inspection to measure their electrical characteristics.
b) If the capacitors have self charged, discharge in the capacitors through a resistor of approximately 1kΩ before use.
c) If capacitors are stored at a temperature of 35℃ or more and more than 75%RH, the leakage current may increase. In this case, they can be reformed by applying the rated voltage through a resistor of approximately 1kΩ.
d) Verify the rated capacitance and voltages of the capacitors when installing.
e) Verify the polarity of the capacitors.
f) Do not use the capacitors if they have been dropped on the floor.
g) Do not deform the cases of capacitors.
h) Verify that the lead spacing of the capacitor fits the hole spacing in the PC board before installing the capacitors. Some standard pre-formed leads are available.
i) For radial or snap-in terminals, insert the terminals into PC board and press the capacitor downward until the bottom of the capacitor body reaches PC board surface.
j) Do not apply any mechanical force in excess of the limits prescribed in the catalogs or the product specifications of the capacitors.
Also, note the capacitors may be damaged by mechanical shocks caused by the vacuum/insertion head, component checker or centering operation of an automatic mounting or insertion machine.

2 Soldering and Solderability

a) When soldering with a soldering iron
- Soldering conditions (temperature and time) should be within the limits prescribed in the catalogs or the product specifications.
- If the terminal spacing of a capacitor does not fit the terminal hole spacing of the PC board, reform the terminals in a manner to minimize a mechanical stress into the body of the capacitor.
- Remove the capacitors from the PC board, after the solder is completely melted, reworking by using a soldering iron minimizes the mechanical stress to the capacitors.
- Do not touch the capacitor body with the hot tip of the soldering iron.

b) Flow soldering
- Do not dip the body of a capacitor into the solder bath only dip the terminals in. The soldering must be done on the reverse side of PC board.
- Soldering conditions (preheat, solder temperature and dipping time) should be within the limits prescribed in the catalogs or the product specifications.
- Do not apply flux to any part of capacitors other than their terminals.
- Make sure the capacitors do not come into contact with any other components while soldering.

c) Reflow soldering
- Soldering conditions (preheat, solder temperature and soldering time) should be within the limits prescribed in the catalogs or the product specifications.
- When setting the temperature infrared heaters, consider that the infrared absorption causes material to be discolored and change in appearance.
- Do not solder capacitors more than two times using reflow. If you need to do three times, be sure to consult with us.
- Make sure capacitors do not come into contact with copper traces.
- Vapor phase soldering (VPS) is not used.

d) Do not re-use surface mount capacitors which have already been soldered.
In addition, when installing a new capacitor onto the assembly board to rework, remove old residual flux from the surface of the PC board, and then use a soldering iron within the prescribed conditions.
e) Confirm before running into soldering that the capacitors are SMD for reflow soldering.

3 Handling after soldering

Do not apply any mechanical stress to the capacitor after soldering onto the PC board.
a) Do not lean or twist the body of the capacitor after soldering the capacitors onto the PC board.
b) Do not use the capacitors for lifting or carrying the assembly board.
c) Do not hit or poke the capacitor after soldering to PC board. When stacking the assembly board, be careful that other components do not touch the aluminum electrolytic capacitors.
d) Do not drop the assembly board.

4 Cleaning PC boards

a) Do not wash capacitors by using the following cleaning agents.
- Halogenated solvents; cause capacitors to fail due to corrosion.
- Alkali system solvents; corrode (dissolve) an aluminum case.
- Petroleum and terpene system solvents; cause the rubber seal material to deteriorate.
- Xylene; causes the rubber seal material to deteriorate.
- Acetone; erases the marking.

Solvent resistant capacitors are only suitable for washing using the cleaning conditions prescribed in the catalogs or the product specifications. In particular, ultrasonic cleaning will accelerate damaging capacitors.

b) Verify the following points when washing capacitors.
- Monitor conductivity, pH, specific gravity, and the water content of cleaning agents. Contamination adversely affects these characteristics.
- Be sure not to expose the capacitors under solvent rich conditions or keep capacitors inside a closed container. In addition, please dry the solvent sufficiently on the PC board and the capacitor with an air knife (temperature should be less than the maximum rated category temperature of the capacitor) over 10 minutes.
Aluminum electrolytic capacitors can be characteristically and catastrophically damaged by halogen ions, particularly by chlorine ions, though the degree of the damage mainly depends upon the characteristics of the electrolyte and rubber seal material. When halogen ions come into contact with the capacitors, the foil corrodes when voltages applied. This corrosion causes ; extremely high leakage current, which causes in line with, venting, and an open circuit.

Global environmental warnings (Greenhouse effects and other environmental destruction by depletion of the ozone layer), new types of cleaning agents have been developed and commercialized as substitutes for CFC-113,1,1,2-trichloroethlene and 1,1,1-trichloroethylene. The following are recommended as cleaning conditions for some of new cleaning agents.

–Higher alcohol system cleaning agents
Recommended cleaning agents:
Pine Alpha ST-100S (Arakawa Chemical)
Clean Through 750H, 750K, 750L, and 710M (Kao)
Technocare FRW-14,15,16,17 (Momentive performance materials)
Cleaning conditions:
Using these cleaning agents capacitors are capable of withstanding immersion or ultrasonic cleaning for 10 minutes at a maximum liquid temperature of 60℃. Find optimum condition for washing, rinsing, and drying. Be sure not to rub the marking off the capacitor by contacting any other components or the PC board. Note that shower cleaning adversely affects the markings on the sleeve.

–Non-Halogenated Solvent Cleaning
AK225AES (Asahi Glass)
Cleaning conditions:
Solvent resistant capacitors are capable of withstanding any one of immersion, ultrasonic or vapor cleaning for 5 minutes; ex-ception is 2 minutes max. for KRE, and KRE-BP series capacitors and 3 minutes for SRM series capacitors. However, from a view of the global environmental problems, these types of solvent will be banned in near future. We would recommended not using them as much as possible.

Isopropyl alcohol cleaning agents
IPA (Isopropyl Alcohol) is one of the most acceptable cleaning agents; it is necessary to maintain a flux content in the cleaning liquid at a maximum limit of 2 Wt.%.

5 Precautions for using adhesives and coating materials

a) Do not use any adhesive and coating materials containing halogenated solvent.
b) Verify the following before using adhesive and coating material.
- Remove flux and dust leftover between the rubber seal and the PC board before applying adhesive or coating materials to the capacitor.
- Dry and remove any residual cleaning agents before applying adhesive and coating materials to the capacitors. Do not cover over the whole surface of the rubber seal with the adhesive or coating materials.
- For permissible heat conditions for curing adhesives or coating materials, follow the instructions in the catalogs or the product specifications of the capacitors.
- Covering over the whole surface of the capacitor rubber seal with resin may result in a hazardous condition because the inside pressure cannot release completely. Also, a large amount of halogen ions in resins will cause the capacitors to fail because the halogen ions penetrate into the rubber seal and the inside of the capacitor.

c) Some coating materials, it cannot be implemented to the capacitor. Please note that loose luster and whitening on the surface of the outer sleeve might be caused according to the kind of solvents used for mounting adhesives and coating agents.

6 Fumigation

In many cases when exporting or importing electronic devices, such as capacitors, wooden packaging is used. In order to control insects, many times, it becomes necessary to fumigate the shipments. Precautions during “Fumigation” using halogenated chemical such as Methyl Bromide must be taken. Halogen gas can penetrate packaging materials used, such as, cardboard boxes and vinyl bags. Penetration of the halogenide gas can cause corrosion of Electrolytic capacitors.

The Operation of Devices

a) Do not touch terminals of capacitor directly with bare hands.
b) Do not short-circuit the terminal of a capacitor by letting it come into contact with any conductive object.
Also, do not spill electric-conductive liquid such as acid or alkaline solution over the capacitor.
c) Do not use capacitors in circumstance where they would be subject to exposure to the following materials exist or expose.
- Oil, water, salty water or damp location.
- Direct sunlight.
- Toxic gases such as hydrogen sulfide, sulfurous acid, nitrous acid, chlorine or its compounds, and ammonium.
- Ozone, ultraviolet rays or radiation.
- Severe vibration or mechanical shock conditions beyond the limits prescribed in the catalogs or product specification.

Maintenance Inspection

a) Make periodic inspections of capacitors that have been used in industrial applications. Before inspection, turn off the power supply and carefully discharge the electricity in the capacitors. Verify the polarity when measuring the capacitors with a volt-ohm meter. Also, do not apply any mechanical stress to the terminals of the capacitors.
b) The following items should be checked during the periodic inspections.
- Significant damage in appearance : venting and electrolyte leakage.
- Electrical characteristics: leakage current, capacitance, tanδ and other characteristics prescribed in the catalogs or product specifications.
We recommend replacing the capacitors if the parts are out of specification.

In Case of Venting

a) If a non-solid aluminum electrolytic capacitor expels gas when venting, it will discharge odors or smoke, or burn in the case of a short-circuit failure. Immediately turn off or unplug the main power supply of the device.
b) When venting, a non-solid aluminum electrolytic capacitor blows out gas with a temperature of over 100℃. (A solid aluminum electrolytic capacitor discharges decomposition gas or burning gas while the outer resin case is burning.) The gas which comes out from the pressure vent of a capacitor, it is not smoke by flammable. This is the vaporized electrolyte.Never expose the face close to a venting capacitor. If your eyes should inadvertently become exposed to the spouting gas or you inhale it, immediately flush the open eyes with large amounts of water and gargle with water respectively. If electrolyte is on the skin, wash the electrolyte away from the skin with soap and plenty of water. Do not lick the electrolyte of non-solid aluminum electrolytic capacitors.

Storage

We recommend the following conditions for storage.
a) Do not store capacitors at a high temperature or in high humidity. Store the capacitors indoors at a temperature of 5 to 35℃ and a humidity of less than 75%RH.
b) Keep capacitors in the original package.
c) Store the capacitors in places free from water, oil or salt water.

d) Store the capacitors in places free from toxic gasses (hydrogen sulfide, sulfurous acid, chlorine, ammonium, etc.)
e) Store the capacitors in places free from acidic and alkaline solvents
f) Store the capacitors in places free from ozone, ultraviolet rays or radiation.
g) Store the capacitor in place free vibrations and mechanical shocks
h) It is not applied to a regulation of JEDEC J-STD-020(Rev.C).

Disposal

Please consult with a local industrial waste disposal specialist when disposing of aluminum electrolytic capacitors.

Catalogs

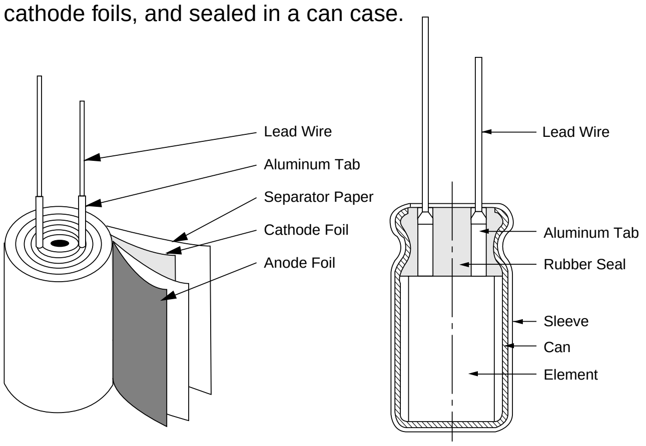
Specifications in catalogs may be subject to change without notice. Catalog data are typical. This value does not guarantee the performance. For more details of precautions and guidelines for aluminum electrolytic capacitors, please refer to Engineering Bulletin No. 634A.

Regarding compliance for EU REACH Regulation

a) According to the content of REACH handbook (Guidance on requirements for substances in articles which is published on May 2008), our electronic components are "articles without any intended release". Therefore they are not applicable for "Registration" for EU REACH Regulation Article 7 (1).
   Reference: Electrolytic Condenser Investigation Society
   "Study of REACH Regulation in EU about Electrolytic Capacitor" (publicized on 13 March 2008)
b) DEHP (CAS No.117-81-7) is a high concern substance (SVHC) in the EU REACH rules. DEHP is contained as a plasticizer in PVC sleeve covering material etc.. Nippon Chemi-Con will abolish use of DEHP by June, 2011. Please consult with us about an alternate product.

Structure of Aluminum Electrolytic Capacitors

The aluminum electrolytic capacitor contains an internal element of an anode foil, a cathode foil and paper separator rolled together, impregnated with an electrolyte, then attached to external terminals connecting the tabs with the anode or the cathode foils, and sealed in a can case.



Among various types of capacitors, an aluminum electrolytic capacitor offers large CV to volume and features low cost. The capacitance (C) of aluminum electrolytic capacitors, as well as other capacitors, is expressed by the following equation:

$$C=8.854\times10^{-12}\times\frac{\varepsilon S}{d}\ (F)$$

Where : ε=Dielectric constant
S=Surface area of dielectric (m^2)
d=Thickness of dielectric (m)

This equation shows that the capacitance increases in proportion as the dielectric constant becomes high, its surface area becomes large and the thickness of dielectric becomes thin. In aluminum electrolytic capacitors the dielectric constant of an aluminum oxide (Al_2O_3) layer is 8 to 10, which is not as high as compared with the other types of capacitors. However, the dielectric layer of the aluminum oxide is extremely thin (about 15Å per volt) and the surface area is very large. An electrochemical formed electrode foil makes the dielectric on the etched surface of aluminum electrode foil. Electrochemical etching creates 20 to 100 times more surface area as plain foil. Therefore, an aluminum electrolytic capacitor can offer a large capacitance compared with other types.

Primary of Composition Material

Anode aluminum foil:
First, the etching process is carried out electromechanically with a chloride solution which dissolves metal and increases the surface area of the foil; forming a dense network like innumerable microscopic channels. Secondly, the formation process is carried out with a solution such as ammonium borate which forms the aluminum oxide layer (Al_2O_3) as a dielectric at a thickness of about 1.1 to 1.5nm / volt. The process needs to charge more the rated voltage into the foil.

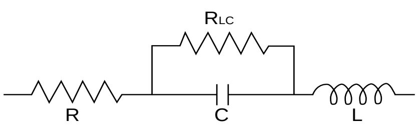
Cathode aluminum foil:
As in the first manufacturing process of the positive foil, the cathode foil requires etching process. Generally, it does not require the formation process; therefore, the natural oxide layer of Al_2O_3, which gives a characteristic dielectric voltage of 1.0 volts, is formed.

Electrolyte and separator:
In a non-solid aluminum electrolytic capacitor, the electrolyte, an electrically conductive liquid, functions as a true cathode by contacting the dielectric oxide layer. Accordingly, the “cathode foil” serves as an electrical connection between the electrolyte and terminal.
The separator functions to retain the electrolyte and prevent the anode and cathode foils from short-circuiting.

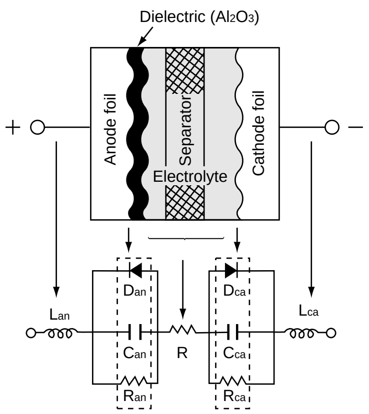
Can case and sealing materials:
The foils and separator are wound into a cylinder to make an internal element, which is impregnated with the electrolyte, inserted into an aluminum can case and sealed. During the service life of a capacitor, electrolyte slowly and naturally vaporizes by electrochemical reaction on the boundary of the aluminum foils. The gas will increase the pressure inside the case and finally cause the pressure relief vent to open or the sealing materials to bulge. The sealing material functions not only to prevent electrolyte from drying out but also to allow the gas to escape out of the can case in a controlled manner.

The Equivalent Circuit

As the equivalent circuit of an aluminum electrolytic capacitor is shown below, it forms a capacitance, a series resistance, an inductance, and a parallel resistance.



R =Equivalent series resistance (ESR)
R_{LC} =Resistance due to leakage current
C =Capacitance
L =Equivalent series inductance

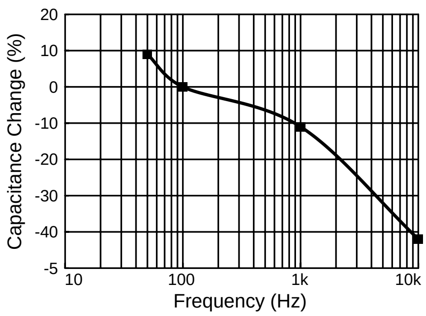


From a composition material point wise, the equivalent circuit is subdivided as follows.

C_{an}, C_{Ca}=Capacitance due to anode and cathodes foils
R =Resistance of electrolyte and separator
R_{an}, R_{Ca}=Internal resistance of oxide layer on anode and cathode foils
D_{an}, D_{Ca}=Diode effects due to oxide layer on anode and cathode foils
L_{an}, L_{Ca} =Inductance due to anode and cathode terminals

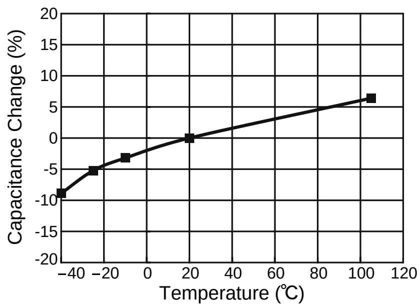
Basic Electrical Characteristics

Capacitance:
The capacitance of capacitor is expressed as AC capacitance by measuring impedance and separating factors. Also, the AC capacitance depends upon frequency, voltage and other measuring methods. In fact, JIS C 5101 prescribes that the series capacitive factor of an equivalent series(o—||—/\/\/—o) circuit shall be the capacitance measured at a frequency of 120Hz and applying a maximum AC voltage of 0.5V rms with a DC bias voltage of 1.5 or 2.0V to aluminum electrolytic capacitors. The capacitance of an aluminum electrolytic capacitor becomes smaller with increasing frequency. See the typical behavior shown below.



Capacitance VS. Frequency

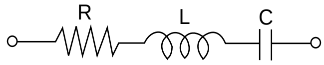
The capacitance value is highly dependent upon temperature and frequency. As the temperature decreases, the capacitance becomes smaller. See the typical behavior shown below.

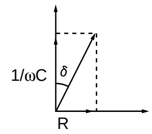


Temperature Characteristics of Capacitance

On the other hand, DC capacitance, which can be measured by applying a DC voltage, shows a slightly larger value than the AC capacitance at a normal temperature and has the flatter characteristic over the temperature range.

tanδ(tangent of loss angle or dissipation factor):
The tanδ is expressed as the ratio of the resistive component (R) to the capacitive reactance (1/ωC) in the equivalent series circuit. Its measuring conditions are the same as the capacitance.

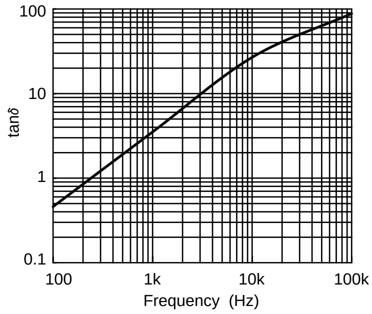




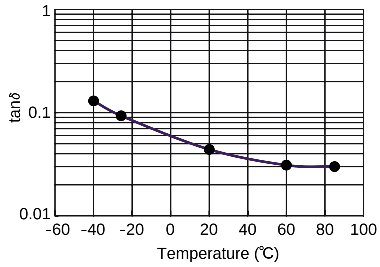
$\tan\delta = R/(1/\omega C) = \omega CR$

Where : R=ESR at 120Hz
$\omega = 2\pi f$
f=120Hz

The tanδ shows higher values as the measured frequency increases and the measured temperature decreases.



tanδ VS. Frequency



Temperature Characteristics of tanδ

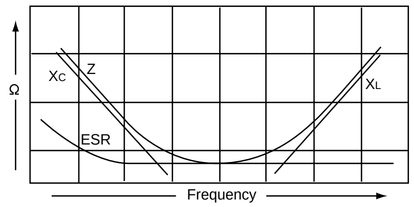
Equivalent series resistance (ESR):
The ESR is the series resistance consisting of the aluminum oxide layer, electrolyte/separator combination, and other resistance related factors, foil length, foil surface area and others.
The ESR value depends upon the temperature. Decreasing the temperature makes the resistivity of the electrolyte increase and leads to increasing ESR.
As the measuring frequency increases, the ESR decreases and reaches an almost constant value that mainly dominates the frequency-independent resistance relating electrolyte/separator combination.

Impedance (Z):
The impedance is the resistance of the alternating current at a specific frequency. It is related to capacitance (C) and inductance (L) in terms of capacitive and inductive reactance, and also related to the ESR. It is expressed as follows:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

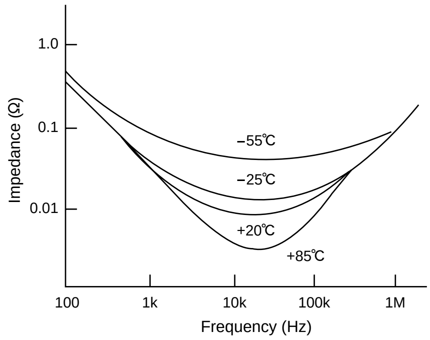
Where : R =ESR
$X_C = 1/\omega C = 1/2\pi fC$
$X_L = \omega L = 2\pi fL$

As shown below, the capacitive reactance (Xc) dominates at the range of low frequencies, and the impedance decreases with increasing frequency until it reaches the ESR in the middle frequency range. At the range of the higher frequencies the inductive reactance (XL) comes to dominate, so that the impedance increases when increasing the measuring frequency.



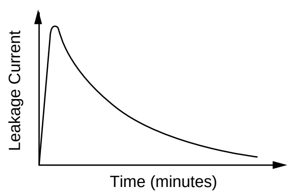
Impedance VS.Frequency

As shown at the next page, the impedance value varies with temperature because the resistance of the electrolyte is strongly affected by temperature.



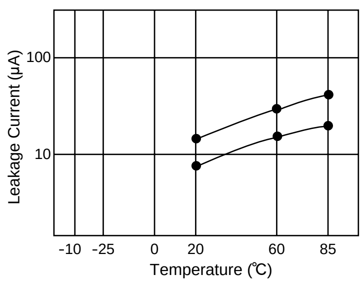
Temperature Characteristics of Impedance

Leakage current:
The dielectric of a capacitor has a very high resistance that does not allow DC current to flow. However, due to the characteristics of the aluminum oxide layer that functions as a dielectric in contact with electrolyte, a small amount of current, called leakage current, will flow to reform and repair the oxide layer when a voltage is being applied. As shown below, a high leakage current flows to charge voltage to the capacitor for the first seconds, and then the leakage current will decrease and reach an almost steady-state value with time.



Leakage Current VS. Time

Measuring temperature and voltage influences the leakage current. The leakage current shows higher values as the temperature and voltage increase.

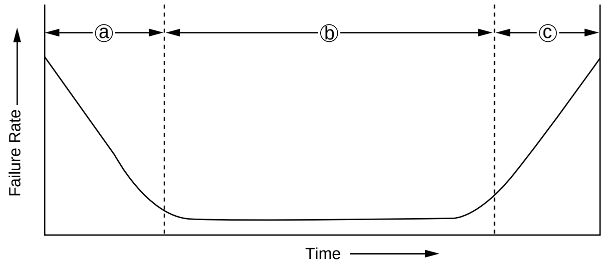


Typical Temperature Characteristics

In general, the leakage current is measured at 20℃ by applying the rated voltage to capacitor through a resistor of 1000Ω in series. The leakage current is the value several minutes later after the capacitor has reached the rated voltage. The catalog prescribes the measuring temperature and time.

Reliability

The bathtub curve:
Aluminum electrolytic capacitors feature failure rates shown by the following bathtub curve.



a) Infant failure period
This initial period accounts for the failures caused by deficiencies in design, structure, the manufacturing process or severe misapplications. In other words the initial failures occur as soon as the components are installed in a circuit. In the case of aluminum electrolytic capacitors, these failures do not occur at customers' field because aging process reforms an incomplete oxide layer, or eliminate the defective parts at the aging process and the sorting process.
Misapplication of the capacitor such as inappropriate ambient conditions, over-voltage, reverse voltage, or excessive ripple current should be avoided for proper use of the capacitor in a circuit.

b) Useful life period
This random failure period exhibits an extremely low failure rate. These failures are not related to operating time but to application conditions. During this period, non-solid aluminum electrolytic capacitors lose a small amount of electrolyte. The electrolyte loss shows as a slow decrease in capacitance and a slow increase in tanδ and ESR. Non-solid aluminum electrolytic capacitors still exhibit lower catastrophic failures than semiconductors and solid tantalum capacitors.

c) Wear-out failure period
This period reflects a deterioration in the component properties of the capacitor ; the failure rate increases with time. Non-solid aluminum electrolytic capacitors end their useful life during this period.

Failure types:
The two types of failures are classified as catastrophic failures and wear-out failures as follows.

1) Catastrophic failures
This is a failure mode that destroys the function of the capacitor like a short circuit or open circuit failure.

2) Wear-out failures
This is a failure mode where gradually deteriorates; the electrical parameters of the capacitor. The criteria of judging the failures, vary with application and design factors. Capacitance decreases and tanδ increases are caused by the loss of electrolyte in the wear-out failure period. This is primary due to loss of electrolyte by diffusion (as vapor) through the sealing material. Gas molecules can diffuse out through the material of the end seal. High temperature increase the electrolyte vapor pressure within the capacitor and the diffusion rate is therefore increased. This increases internal pressure may cause the seal to bulge caused by elevated temperatures. This bulging may accelerate diffusion and mechanically degrade the seal. Factors that can increase the capacitor temperature, such as ambient temperature and ripple current, can accelerate the wear-out phase of a capacitor.

Failure modes:
Aluminum electrolytic capacitors show various failure modes in different applications. (See Table 1.)

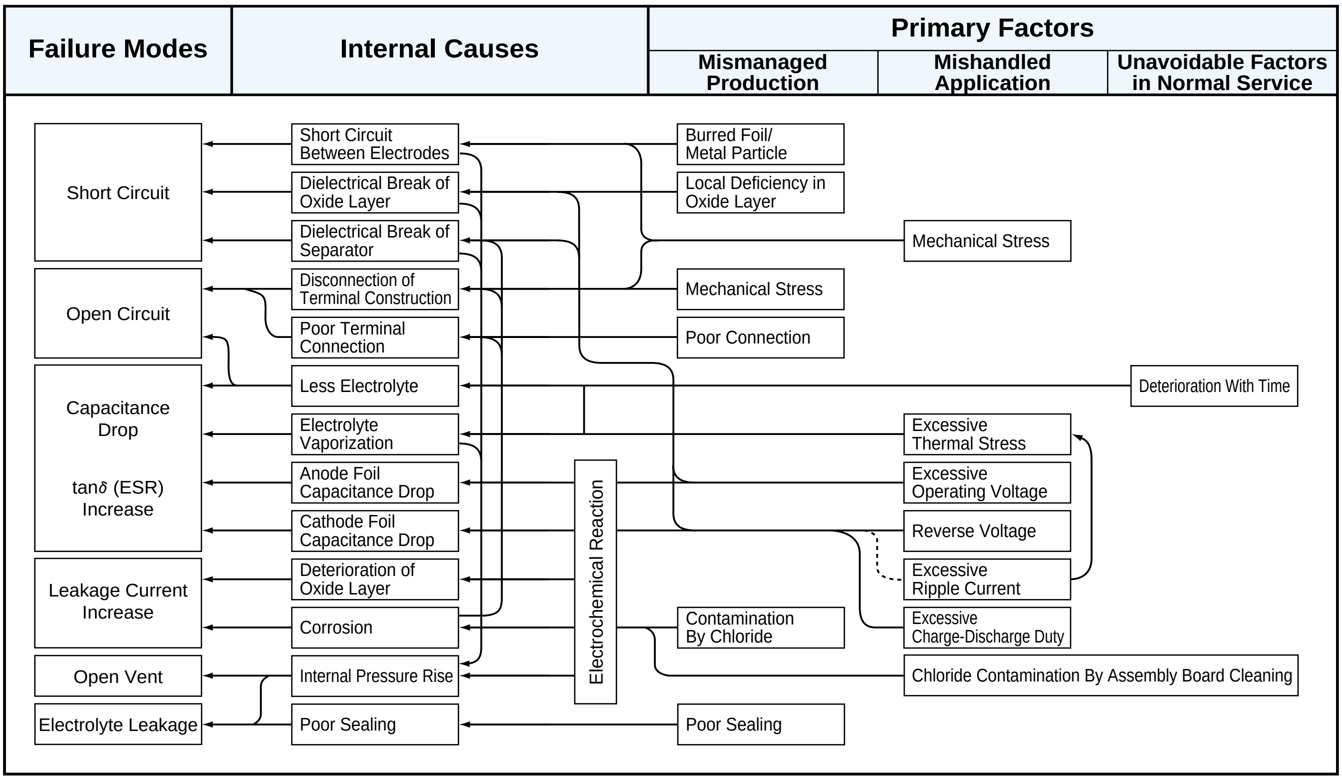


Table1

Life of Aluminum Electrolytic Capacitors

The life of aluminum electrolytic capacitors is largely dependent on environmental and electrical factors. Environmental factors include temperature, humidity, atmospheric pressure and vibration. Electrical factors include operating voltage, ripple current and charge-discharge duty cycles. The factor of temperature (ambient temperature and internal heating due to ripple current) is the most critical to the life of aluminum electrolytic capacitors.

General formula to estimate lifetime:

The lifetime of non-solid aluminum electrolytic capacitors is generally expressed by using three elements representing the effects of ambient temperature, applying voltage and ripple current, which is shown by the following equation:

$$L_X = L \cdot K_{Temp} \cdot K_{Voltage} \cdot K_{Ripple}$$

Where : L_X =Lifetime of capacitor to be estimated
L_o =Base lifetime of capacitor
K_{Temp} =Ambient temperature accelation term
$K_{Voltage}$=Voltage accelation term
K_{Ripple} =Ripple current accelation term

K_{Temp} (Effects of ambient temperature on life):

Because an aluminum electrolytic capacitor is essentially an electrochemical component, increased temperatures accelerate the chemical reaction producing gas within the capacitor which is diffused through the end seal, and consequently accelerates a gradual decrease in capacitance and a gradual increase in tanδ and ESR. The following equation has been experimentally found to express the relationship between the temperature acceleration factor and the deterioration of the capacitor.

$$L_X = L_O \cdot K_{Temp} = L_O \cdot B_T^{\ (T_O - T_X)/10}$$

$$K_{Temp} = B_T^{\ (T_O - T_X)/10}$$

Where : L_X =Lifetime (hour) of capacitor to be estimated
L_o =Base lifetime (hour) of capacitor
T_o =Maximum rated category temperature (℃) of capacitor shown in catalog
T_X =Actual ambient temperature (℃) of capacitor
B_T =Temperature accelation factor (≒2)

Factor B_T will vary depending on range of ambient temperature or products type.

This equation is similar to Arrhenius' equation that expresses a relationship between chemical reaction rates and temperature, and called Arrhenius' rule of aluminum electrolytic capacitors. The temperature acceleration factor (B_T) is approximately 2 over an ambient temperature range (Tx) from 40℃ to the maximum rated category temperature of each capacitor. It means that the lifetime is approximately halved with every 10℃ rise in ambient temperature and can be extended by using the capacitors at low temperatures. For an ambient temperature range (Tx) of 20℃ to 40℃, the factor B_T will be close to 2, and the lifetime will actually be extended. However, operating and surrounding conditions, especially the operating conditions influence ambient temperatures mutually. The ambient temperature in this range will be very changeable; therefore, lifetime estimation under 40℃ should use 40 as Tx.

$K_{voltage}$ (Effects of applying voltage to life):

350V and higher screw-mount terminal types of capacitors for customer-use power electronics applications allow the life time to extend by applying low voltage, relating to the characteristics of their aluminum oxide layer. For $K_{voltage}$ values of these products, please contact a representative of Nippon Chemi-Con.

K_{ripple} (Effects of ripple current to life):

Aluminum electrolytic capacitors have higher tanδ than any other types of capacitors; therefore, the ripple current gives aluminum electrolytic capacitors higher internal heat. Be sure to check the rated ripple current which is specified in the catalog for assuring the life.

The ripple current through the capacitor produces heat by dissipating power from the capacitor. This leads to temperature increase. Internal heating produced by ripple currents can be expressed by:

$$W = I_R^2 \cdot R + V \cdot I_L$$

Where : W =Internal power loss
I_R =R.M.S. ripple current
R =Internal resistance (ESR) at ripple frequency
V =Applied voltage
I_L =Leakage current

Leakage current may be 5 to 10 times higher than the values measured at 20℃, but compared with I_R , the leakage current value is very small and negligible.
Thus, the above equation can be simplified:

$$W=I_R^2 \cdot R$$

The following equation gives the internal heat rise; it is heat rise to stable condition. (It is necessary to input several factors.):

$$I_R^2 \cdot R=\beta \cdot A \cdot \Delta T$$

Where : β =Heat transfer constant
A =Surface area of can case
$A=(\pi/4) \cdot D \cdot (D+4L)$
Where : D=Can diameter
L=Can length
ΔT=An increase in core temperature by internal heating due to ripple current
(ΔT=Core temperature−Ambient temperature)

From the above equation, internal temperature rise (ΔT) produced by ripple current is given by:

$$\Delta T=I_R^2 \cdot R/ (\beta \cdot A)$$

When the ripple frequency is 120Hz, R at 120Hz is expressed by

$$R=\tan\delta/ (\omega \cdot C)$$

$$\Delta T=I_R^2 \cdot \tan\delta/ (\beta \cdot A \cdot \omega \cdot C)$$

Where : $\tan\delta$=120Hz value
ω $=2\pi \cdot f=2\pi \cdot 120$Hz
C =120Hz capacitance value

As above equation, ΔT varies with frequency of ripple, frequency and temperature dependent ESR, and application dependent (even ripple current is constant). We really recommend that customers measure ΔT with a thermocouple at the actual operating conditions of the application in lieu of using the above equation. (Another approximation of ΔT will be stated later.)
As mentioned in the paragraph of K_{Temp}, aluminum electrolytic capacitors will slowly increase in $\tan\delta$ and ESR during their service life. The application without ripple current has no influence on the life of the capacitor even though the ESR will increase during life. In other words, the application with ripple current makes ΔT increase; furthermore, a ΔT increase results in ESR increase. The ESR increase then makes ΔT increase. It is a chain reaction. Theoretically, the ripple current acceleration term (K_{Ripple}) cannot be simply expressed like the ambient temperature acceleration term (K_{Temp}). Practically, the ripple current acceleration term (K_{Ripple}) can be approximately expressed by an equation using a ΔT initially measured. The following table shows the ripple current acceleration term (K_{Ripple}) for each capacitor design group.

K_{Ripple}	Products	
	Type	Series
$2^{(-\Delta T/5)}$	Surface Mount	MVS MVA MV MVE MVK MZJ MZA MVY MZF MZE MZK MLA MLF MLE MLK MVL MVJ MVH MHB MKB MV-BP MVK-BP
	Radial	SRM SRE KRE SRA KMA SRG KRG SMQ SMG SME-BP KME-BP LLA
$2^{(\Delta To-\Delta T)/5}$	Radial	KMQ KMG KZM KZH KZE KY LZA LXZ LXY LXV KXJ KXG SMH KMH PAG KLJ KLG FL GPA GXE GXL GXH LBG
	Snap-in	SMQ KMW KMR KMQ KMT SMM KMS KMM SMH KMH SLM KLM LXM LXS LXQ LXG CHA LXH
	Screw-Mount (Less than 350Vdc)	SME KMH LXA
$2^{(-2+(25-\Delta T)/b)}$	Screw-Mount (350Vdc and higher)	RWG RWF RWQ RWE RWY RWL LXA LXR

Note :ΔT = An increase (deg) in core temperature produced by internal heating due to actual operating ripple current. The ΔT is the difference between the core temperature and ambient temperature measured at the actual operating conditions.
ΔTo = An increase (deg) in core temperature by internal heating due to rated ripple current.
b = Factor b varies from 5 to 10 by the conditions of ripple frequency and ΔT. Please contact a representative of Nippon Chemi-Con for the details

Note that a ΔT over a certain maximum limit may over-heat the capacitors, though the lifetime estimation will not give you practical lifetime. For instance, the following shows a guide limit of ΔT at each ambient temperature for 105℃ maximum rated products.

Ambient temperature Tx (℃)	85	105
Guide limit of ΔT (deg)	15	5
Core temperature (=Tx+ΔT)	100	110

Approximation of ΔT

You can roughly estimate a ΔT by using the following equation without need to measure.

$$\Delta T=\Delta T_0 \cdot (Ix/Io)^2$$

Where : ΔT_0=Please contact a representative of Nippon Chemi-Con for details.
Io =Rated ripple current (A_{RMS}) : if its frequency is different from operating ripple current Ix, it needs converting by using a frequency multiplier prescribed in the catalog.
Ix =Operating ripple current (A_{RMS}) actually flowing into a capacitor

Like switching power supplies, if the operating ripple current consists of commercial frequency element and switching frequency element(s), an internal power loss is expressed by the following equation.

$$W= I_{f1}^2 \cdot R_{f1}+ I_{f2}^2 \cdot R_{f2}+\cdots+ I_{fn}^2 \cdot R_{fn}$$

Where : W =Internal power loss
$I_{f1} \cdots I_{f1}$ =Ripple currents at every frequencies f1‥fn
$R_{f1} \cdots R_{fn}$=ESR's at every frequencies f1‥fn

The above equation can be transformed into another equation to get a ripple current value in accordance with the frequency of the rated ripple current, each of $R_{f1}, \cdots R_{fn}$ is approximately equal to R_{f0} divided by square value of the frequency multiplier ($F_{f1} \cdots F_{fn}$). Here R_{f0} is the value at the frequency of the rated ripple current and $F_{f1} \cdots F_{fn}$ is a conversion coefficient from one frequency to another in accordance with the frequency f1···fn.

$$R_{f1}=R_{f0}/F_{f1}$$
$$\vdots \qquad \vdots$$
$$R_{fn}=R_{f0}/F_{fn}$$

Relationship of $W=I_R^2 \cdot R$ leads I_{f0} as follows:

$$I_{f0}=\sqrt{W/R_{f0}}$$

The above is rewritten in the following equation:

$$I_{f0}=\sqrt{(I_{f1}/F_{f1})^2+(I_{f2}/F_{f2})^2+\cdots\cdots(I_{fn}/F_{fn})^2}$$

Where : I_x =Ripple current in accordance with the frequency of the rated ripple current
$I_{f1} \cdots\cdots I_{fn}$ =Operating ripple currents at every frequencyf1···fn
$F_{f1} \cdots\cdots F_{fn}$=Frequency multipliers for every frequencyf1···fn prescribed in the catalog, based on the fact that the internal resistance of a capacitor varies with frequency.

The result calculated by the estimated life expectancy formula, it is not guaranteed lifetime.
When designer calculate the lifetime of apparatus, please include an extra margin in consideration of the estimated lifetime of a capacitor. When the result calculated by the estimated life expectancy formula exceeds 15 years, please consider 15 years to be a maximum.

Cleaning Agents

a. Cleaning agents penetrate into a capacitor.
Solvent contacts the rubber seal of a capacitor. Some percentage of solvent does not penetrate but a percentage suceeds in entering and defusing inside the capacitor.
b. Cleaning agents decompose and release halogen ions.
In the electrolyte of the inside element, the halides in the cleaning agents become hydrolyzed and release halogen ions as follows,

$$RX+H_2O \rightarrow ROH+H^++X^-$$

RX : Halide
X^- : Halogen ion

c. Corrosion
The halogen ions attack the aluminum foil by the following anodic half-cell reaction:

$$Al+3X^- \rightarrow AlX_3+3e$$

The AlX3 further becomes hydrolyzed and release the halogen ion again:

$$AlX_3+3H_2O \rightarrow Al\,(OH)^3+3H^++3X^-$$

The halogen ions release by this hydrolysis reaction further attacks the aluminum according to the previous reaction formula, and these reactions are repeated and accelerated when voltage and temperature is applied. Also, the hydrogen ions increase the local acidity which causes the oxide dielectric to dissolve. Thus, localized corrosion accelerates to corrode both the aluminum metal and the dielectric. In addition, a terpene or petroleum system cleaning solvent will be absorbed into the rubber seal of the capacitor. The rubber seal finally weakens. An alkaline saponification detergent will damage the aluminum metal and marking. In summary, recommended cleaning agents are halogen free. Terpene, petroleum, alkali detergent and any solvent making the rubber seal material deteriorate are not recommended.

Compatible cleaning agents:
In line with recent global environmental warnings (Greenhouse effect and other environmental destruction by depletion of the ozone layer), new types of cleaning agents have been commercialized and substituted as CFC-113,1,1,2-trichloroethlene and 1,1,1-trichloroethylene. The following are recommended cleaning conditions for some of new cleaning agents.

Higher alcohol system cleaning agents
Recommended cleaning agents:
Pine Alpha ST-100S (Arakawa Chemical)
Clean Through 750H, 750K, 750L, and 710M (Kao)
Technocare FRW-14 through 17 (GE Toshiba Silicones)
Cleaning conditions:
1) Capacitors are capable of withstanding immersion or ultrasonic cleaning for 10 minutes at a maximum liquid temperature of 60℃ using the above cleaning agents. Find the optimum conditions for washing, rinsing, and drying. Be sure not to rub the marking off the capacitor by contact with any other components on the PC board. Note that shower cleaning adversely affects the marking.
2) To rinse by water, control the conditions such as temperature and water pressure to avoid sleeve shrinking or swelling.
3) Clean Through 750H and similar are weak-alkaline solvents. Do not leave the alkaline on the capacitor after cleaning process.

CFCs substitute solvents (HCFC system)
Asahi Glass AK225AES solvent is usable only with solvent resistant type capacitors, which are designed with reinforced seal constructions and modified electrolyte. This product does not penetrate the capacitor and deactivate halogen ions. However, AK225AES is one of the solvents which will have a restricted usage in future from the environmental point of view.

Non-Halogenated Solvent Cleaning

HCFC solvents: AK225AES (Asahi Glass)
Cleaning conditions:
Solvent resistant type capacitors are capable of withstanding immersion, ultrasonic or vapor cleaning for 5 minutes; exception is 2 minutes max. for KRE and KRE-BP series capacitors for 3 minutes and SRM series capacitors.
Applicable series (only for solvent resistant products):
Surface mount : PXK, PXS, PXF, PXE, PXA, PXH, MVS, MVA(4 to 63Vdc), MV, MVE(6.3 to 63Vdc), MVK, MZJ, MZA, MVY(6.3 to 63Vdc), MZF, MZE, MZK, MLA, MLF, MLE, MLK, MVL, MVJ, MVH(10 to 50Vdc), MHB, MV-BP, MVK-BP
Radial lead : PSK, PSF, PSE, PSC, PSA, PS, SRM, KRE, KMA, SRG, KRG, KMQ(6.3 to 100Vdc),SMG(6.3 to 250Vdc), KMG(6.3 to 250Vdc), SME-BP, KME-BP, LXZ, LXY, LXV, FL, GPA, GXE(10 to 50Vdc), GXL, GXH, LBG, LLA

Isopropyl alcohol cleaning agents
IPA (Isopropyl Alcohol) is one of the most acceptable cleaning agents; it is necessary to maintain a flux content in the

cleaning liquid at a maximum limit of 2 Wt. %, because chlorides in flux dissolves in the cleaning liquid during the cleaning process.
Xylene -additive IPA may make the rubber seal deteriorate.

Non-clean flux
Both ionic halogen and non-ionic halogens damage the capacitor when they penetrate in through the rubber seal. Note that some of the fluxes called non-halogenated flux contains less ionic halogen activator but actually a large amount of non-ionic halogen.
Per our analysis, AHQ3100K(Asahi) and POZ6(Senjyu) minimize ionic and non-ionic halogens.

Other Precautions to wash capacitors
a) Monitor conductivity, pH, specific gravity and water content of cleaning agents. Contamination adversely affects the characteristics.
b) The solvent may stay between the end seal and the PC board if the capacitor is mounted directly onto the PCB without a small gap. The residual solvent can cause defects. Also, washing for more than the specified time causes solvent residual. Therefore, wash the assembly board for at least 10 minutes at the recommended temperature. Be sure not to expose the capacitors under solvent rich conditions or keep capacitors inside a closed container.
c) Reforming the leads of the capacitor to fit lead spacing on the PC board causes cleaning agents to get into the inside capacitor. This may result in corrosion to the foil. Therefore, use the capacitors, which fit the hole spacing on the PC board or reform the lead wires in a manner which will not cause mechanical stress to the capacitor body.

Recovery Voltage

After discharged aluminum electrolytic capacitor, the voltage will be increasing again. This phenomenon is called by "Recovery Voltage". It happens very often and commonly for all aluminum electrolytic capacitors. In this case, discharge through a 1kΩ resistance before use at your process, because you may have trouble on sensitive devices and frighten a person working with the capacitor.