

# 1 General Description of Aluminum Electrolytic Capacitors

## 1-1 The Principle of Capacitor

The principle of capacitor can be presented by the principle drawing as in Fig.1-1.

When a voltage is applied between the metal electrodes placed opposite on both surfaces of a dielectric, electric charge can be stored proportional to the voltage.

$$Q=C \cdot V$$

Q : Quantity of electricity (C)

V : Voltage (V)

C : Capacitance (F)

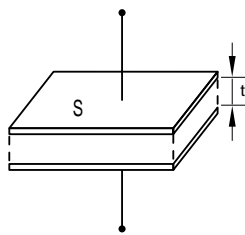


Fig.1-1

C, called the capacitance of capacitor, is expressed by the following expression with the electrode area S[m<sup>2</sup>], the electrode spacing t [m] and the dielectric constant of dielectric “ε”:

$$C[F] = \epsilon_0 \cdot \epsilon \cdot \frac{S}{t}$$

ε<sub>0</sub>: Dielectric constant in vacuum (=8.85x10<sup>-12</sup>F/m)

The dielectric constant of an aluminum oxide film is 7 to 8. Larger capacitances can be obtained by enlarging the electrode area S or reducing t.

Table 1-1 shows the dielectric constants of typical dielectrics used in the capacitor. In many cases, capacitor names are determined by the dielectric material used, for example, aluminum electrolytic capacitor, tantalum capacitor, etc.

Table 1

Dielectric	Dielectric Constant	Dielectric	Dielectric Constant
Aluminum oxide film	7 to 8	Porcelain (ceramic)	10 to 120
Mylar	3.2	Polystyrene	2.5
Mica	6 to 8	Tantalum oxide film	10 to 20

Although the aluminum electrolytic capacitor is small, it has a large capacitance. It is because the electrode area is roughened by electrochemical etching, enlarging the electrode area and also because the dielectric is very thin.

The schematic cross section of the aluminum electrolytic capacitor is as in Fig.1-2.

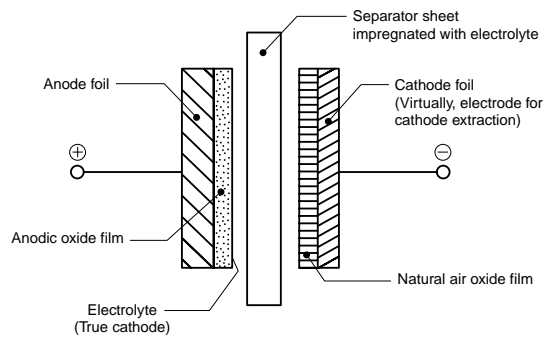
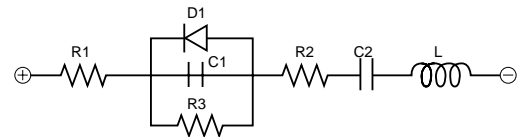


Fig.1-2

## 1-2 Equivalent Circuit of the Capacitor

The electrical equivalent circuit of the aluminum electrolytic capacitor is as presented in Fig. 2.



R1 : Resistance of terminal and electrode

R2 : Resistances of anodic oxide film and electrolyte

R3 : Insulation resistance because of defective anodic oxide film

D1 : Oxide semiconductor of anode foil

C1 : Capacity of anode foil

C2 : Capacity of cathode foil

L : Inductance caused by terminals, electrodes, etc.

# 2 About the Life of an Aluminum Electrolytic Capacitor

## 2-1 Estimation of life with minimal ripple current (negligible).

Generally, the life of an aluminum electrolytic capacitor is closely related with its ambient temperature and the life will be approximately the same as the one obtained by Arrhenius' equation.

$$L = L_0 \times 2^{\left(\frac{T_0 - T}{10}\right)} \dots\dots\dots(1)$$

Where L : Life at temperature T  
L<sub>0</sub> : Life at temperature T<sub>0</sub>

The effects to the life by derating of the applied voltage etc. are neglected because they are small compared to that by the temperature.

## 2-2 Estimation of life considering the ripple current.

The ripple current affects the life of a capacitor because the internal loss (ESR) generates heat. The generated heat will be:

$$P = I^2 R \dots \dots \dots (2)$$

Where I : Ripple current (Arms)

R : ESR ( $\Omega$ )

With increase in the temperature of the capacitor:

$$\Delta T = \frac{I^2 \cdot R}{A \cdot H} \dots \dots \dots (3)$$

Where  $\Delta T$  : Temperature increase in the capacitor core(deg.)

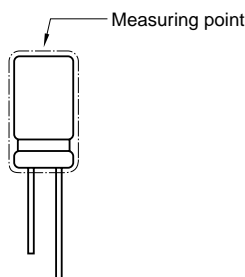
I : Ripple current (Arms)

R : ESR ( $\Omega$ )

A : Surface area of the capacitor ( $\text{cm}^2$ )

H : Radiation coefficient (Approx.  $1.5 \sim 2.0 \times 10^{-3} \text{ W/cm}^2 \times \text{C}$ )

The above equation (3) shows that the temperature of a capacitor increases in proportion to the square of the applied ripple current and ESR, and in inverse proportion to the surface area. Therefore, the amount of the ripple current determines the heat generation, which affects the life. The value of  $\Delta T$  varies depending on the capacitor types and operating conditions. The usage is generally desirable if  $\Delta T$  remains less than  $5^\circ\text{C}$ . The measuring point for temperature increase due to ripple current is shown below;



Test results:

(1) The life equation considering the ambient temperature and the ripple current will be:

$$L = L_d \times 2^{\left(\frac{T_0 - T}{10}\right)} \times K^{\left(\frac{-\Delta T}{10}\right)} \dots \dots \dots (4)$$

Where  $L_d$ : Life at DC operation (h)

K: Ripple acceleration factor

(K=2, if with in allowable ripple current)

(K=4, if exceeding allowable ripple current)

$T_0$ : Maximum guaranteed temperature ( $^\circ\text{C}$ )

T: Operating temperature ( $^\circ\text{C}$ )

$\Delta T$ : Temperature increase at capacitor core (deg.)

(2) The life equation based on the life with the rated ripple current applied under the maximum guaranteed temperature will be a conversion of the above equation (4), as below:

$$L = L_r \times 2^{\left(\frac{T_0 - T}{10}\right)} \times K^{\left(\frac{\Delta T_0 - \Delta T}{10}\right)} \dots \dots \dots (5)$$

Where  $L_r$ : Life at the maximum guaranteed temperature with the rated ripple current (h)

$\Delta T_0$ : Temperature increase at capacitor core, at the maximum guaranteed temperature (deg.)

(3) The life equation considering the ambient temperature and the ripple current will be a conversion of the above equation (5), as below:

$$L = L_r \times 2^{\left(\frac{T_0 - T}{10}\right)} \times K \left\{ 1 - \left(\frac{I}{I_0}\right)^2 \right\} \times \frac{\Delta T_0}{10} \dots \dots \dots (6)$$

Where  $I_0$ : Rated ripple current at the maximum guaranteed temperature (Arms)

I : Applied ripple current (Arms)

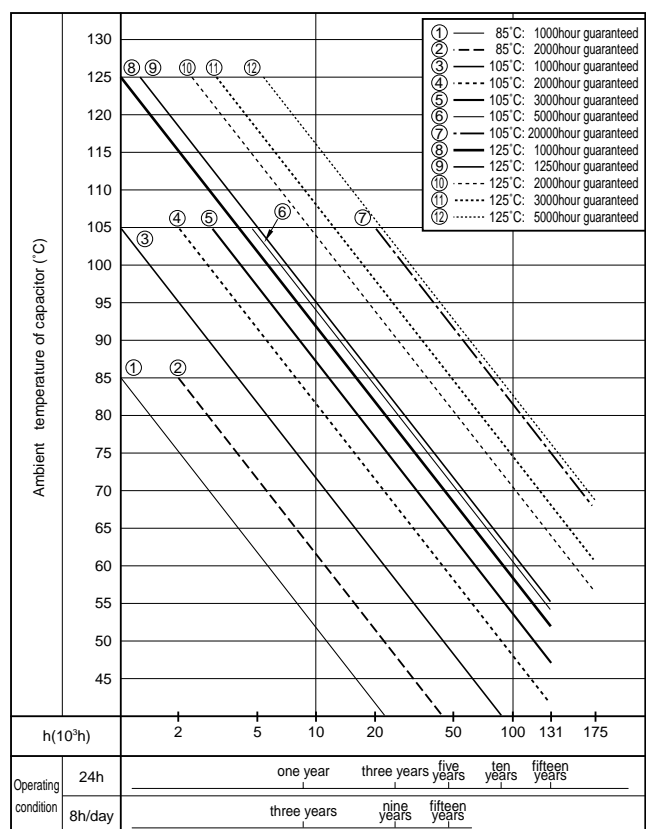
Since it is actually difficult to measure the temperature increase at the capacitor core, the following table is provided for conversion from the surface temperature increase to the core temperature increase.

Table 2-1

Case diameter	~10	12.5~16	18	22	25	30	35
Core / Surface	1.1	1.2	1.25	1.3	1.4	1.6	1.65

The life expectancy formula shall in principle be applied to the temperature range between the ambient temperature of  $+40^\circ\text{C}$  and maximum allowable working temperature. The expected life time shall be about fifteen years at maximum as a guide in terms of deterioration of the sealant.

(Table 2-1 Life Expectancy Chart)



**NOTE**  
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Ask factory for technical specifications before purchase and/or use.

2-2 Practical Examples of Life Expectancy

As practical examples of life expectancy, we introduce 250V 560 μ F in the LAG Series considering the effect of high-frequency component. Figures 2-1 to 2-3 show the simulated ripple current waveforms when the high-frequency component for switching is superimposed on the commercial frequency component.



Fig.2-1 Ripple Current Waveform of Capacitor

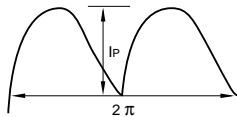


Fig.2-2 Low-frequency component

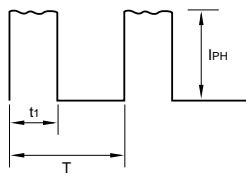


Fig.2-3 High-frequency component

Each of the above may be obtained as the effective ripple current value. Assuming that the ripple current waveform of the low-frequency component is generally approximated to the full-wave rectification waveform as shown in Fig.2-2, we obtain the effective ripple current value  $I_L$  as follows:

$$I_L = \sqrt{\frac{I_{PL}}{2}} = 0.707 \cdot I_{PL}$$

Since the ripple current waveform of the high-frequency component is approximated to the rectangular as shown in Fig.2-3, the effective current value of high-frequency component  $I_H$  is given by

$$I_H = \sqrt{\frac{1}{T} \int_0^{t_1} I_{PH}^2 dt} = I_{PH} \sqrt{\frac{t_1}{T}}$$

The reason why the ripple current affects the life is due to the heat generated by the ESR (R) of capacitor. That is,  $\Delta T$  by heat generation can be expressed by  $\Delta T \propto I^2 \cdot R$  from Expression (2).

Therefore, when ripple currents with different frequencies are handled, each current value must first be squared and then summed. That is:

$$I = \sqrt{(I_L)^2 + (I_H)^2}$$

Now, we proceed to specific examples assuming that the effective ripple current values of low-and high-frequencies have been obtained by the above methods.

Data A (Test piece and basic data)

Product name	: 250V 560 μF ø 30x40 L, Series LAG
$L_r$	=2000
K	= 4
$T_o$	=105°C
$\Delta T_o$	= 5deg
$I_o$	=1.74Arms at 105°C, 120 Hz

To verify the effect of the high-frequency component, the expected life will be calculated for each of three high-frequency ripple current conditions.

Data B

$I_L$	=2.4Arms at 120Hz, T=45°C
$I_{H1}$	=0.36Arms at 20kHz (corresponding to 15% of the commercial frequency component)
$I_{H2}$	=0.72Arms at 20kHz (corresponding to 30% of the commercial frequency component)
$I_{H3}$	=1.2Arms at 20kHz (corresponding to 50% of the commercial frequency component)

For Data B, the currents are converted to 120 Hz by the frequency conversion factor for the cases of ignorance of the high-frequency component, and each high-frequency component condition.

$$I = 2.4/1 = 2.4$$

$$I_1 = \sqrt{(2.4)^2 + (0.36/1.18)^2} \approx 2.42A$$

$$I_2 = \sqrt{(2.4)^2 + (0.72/1.18)^2} \approx 2.48A$$

$$I_3 = \sqrt{(2.4)^2 + (1.2/1.18)^2} \approx 2.61A$$

Explained here is about the frequency conversion factor. As described above, the heat generation (or temperature rise =  $\Delta T$ ) affecting the life is proportional to the ESR of capacitor. In addition, the fundamental frequency is 120 Hz in measurement of capacitor characteristics, and the ripple current is also specified with this frequency; it is thus more convenient to calculate by converting the current value to that with the same temperature rise at 120 Hz.

The ESR of aluminum electrolytic capacitor is frequency dependent.

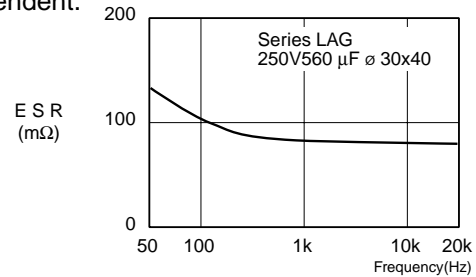


Fig.2-4 Frequency Characteristics of ESR

Figure 2-4 shows a typical example of frequency characteristics of ESR, indicating that the ESR decreases with increasing frequencies. Therefore, the high-frequency component has less effect on the heat generation of capacitor than low-frequency component. Next, we calculate the expected life according to each condition to compare with the case with no high-frequency component.

For the case with no high-frequency component:

$$L = 2000 \times 2 \left(\frac{105-45}{10}\right) \times 4 \left[1 - \left(\frac{2.4}{1.74}\right)^2\right] \times \frac{5}{10} \approx 68,470 \text{ hours}$$

For the case with high-frequency component:

$$L_1 = 2000 \times 2 \left(\frac{105-45}{10}\right) \times 4 \left[1 - \left(\frac{2.48}{1.74}\right)^2\right] \times \frac{5}{10} \approx 66,980 \text{ hours}$$

66,980/68,470 0.978, about a 2.2% reduction in life

$$L_2 = 2000 \times 2 \left(\frac{105-45}{10}\right) \times 4 \left[1 - \left(\frac{2.48}{1.74}\right)^2\right] \times \frac{5}{10} \approx 62,620 \text{ hours}$$

62,620/68,470 0.914, about an 8.6% reduction in life

$$L_3 = 2000 \times 2 \left(\frac{105-45}{10}\right) \times 4 \left[1 - \left(\frac{2.61}{1.74}\right)^2\right] \times \frac{5}{10} \approx 53,820 \text{ hours}$$

53,820/68,470 ≈ 0.786, about a 21.4% reduction in life

As described above, there may be cases where the effect of larger high-frequency component on the life cannot be ignored; thus high-frequency component exceeding 30% with respect to the current with fundamental frequency should be considered.

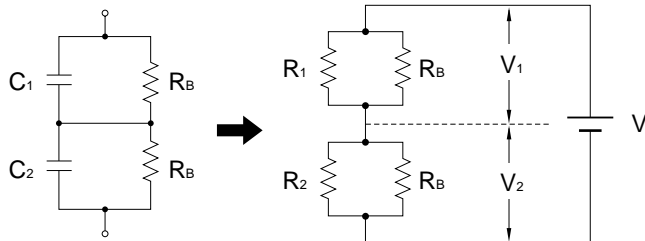
NOTE

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### 3 To calculate Balance when connecting in series

#### 3-1 Circuit layout

Circuit for connecting two capacitors (C1, C2) in series and equivalent circuit can be illustrated as below figure. Formula to calculate a balance resistance  $R_B$  of below figure is shown as follows.



Following are the preconditions of the circuit.

- ①  $V_2$  shall be the rated voltage ( $=V_0$ ). ( $V_1 < V_2$ )
- ②  $V$  shall be a times  $V_0 \times 2$ .  $V = 2aV_0$  ( $a < 1$ )
- ③  $R_2$  shall equal  $R_1 \times b$ . ( $b < 1$ ) (1)

#### 3-2 Formulas to calculate [ $R_B$ ]

3-2-1 Following formula can be established from balanced condition.

$$V_1 \left[ \frac{1}{R_1} + \frac{1}{R_B} \right] = V_2 \left[ \frac{1}{R_1} + \frac{1}{R_B} \right] \quad (2)$$

3-2-2 Following formula can be established from preconditions.

$$V_2 \leq V_0 \quad (3)$$

$$V_1 = V - V_2 \quad (4)$$

$$= 2aV_0 - V_2 \quad (4')$$

3-2-3 Put formulas (1), (3) and (4') in formula (2).

$$(2aV_0 - V_2) \left[ \frac{R_1 + R_B}{R_1 \cdot R_B} \right] = V_2 \left[ \frac{bR_1 + R_B}{bR_1 \cdot R_B} \right]$$

$$2abV_0(R_1 + R_B) = V_2 \{ b(R_1 + R_B) + bR_1 + R_B \}$$

$$2ab(R_1 + R_B) \leq 2bR_1 + (1+b)R_B$$

Accordingly, balance resistance  $R$  shall be the following formula.

$$R_B \leq 2bR_1 \frac{(1-a)}{(2a-1) \cdot b-1} \quad (5)$$

#### 3-3 Calculation Example.

Calculate the value of the balance resistance in the case of connecting two 400V 470 $\mu$ F ( LC standard value : 1.88mA) capacitors in series.

$$R_1 = \frac{400(V)}{1.88(mA)} = 213(k\Omega)$$

If  $a=0.8$ ,  $400(V) \times 2 \times 0.8 = 640(V)$  as an impressed voltage.

If  $b=2$ ,  $R_2 = b R_1 = 426(k\Omega)$ ,  $LC=0.94(mA)$ .

Balance resistance  $R_B$  will be.

$$R_B \leq 2 \times 2 \times 213(k\Omega) \frac{(1-0.8)}{(2 \times 0.8) \times 2 - 1} = 852(k\Omega)$$

### 4 Regarding Recovery Voltage

• After charging and then discharging the aluminum electrolytic capacitor, and further causing short-circuit to the terminals and leave them alone, the voltage between the two terminals will rise again after some interval. Voltage caused in such case is called recovery voltage. Following is the process that causes this phenomenon:

• When the voltage is impressed on a dielectric, electrical transformation will be caused inside the dielectric due to dielectric action, and electrification will occur in positive-negative opposite to the voltage impressed on the surface of the dielectric. This phenomenon is called polarization action.

• After the voltage is impressed with this polarization action, and if the terminals are discharged till the terminal voltage reaches 0 and are left open for a while, an electric potential will arise between the two terminals and thus causes recovery voltage.

• Recovery voltage comes to a peak around 10 to 20 days after the two terminals are left open, and then gradually declines. Recovery voltage has a tendency to become bigger as the component (stand-alone base type) becomes bigger.

• If the two terminals are short-circuited after the recovery voltage is generated, a spark may scare the workers working in the assembly line, and may put low-voltage driven components (CPU, memory, etc.) in danger of being destroyed. Measures to prevent this is to discharge the accumulated electric charge with resistor of about 100 to 1k $\Omega$  before using, or ship out by making the terminals in short-circuit condition by covering them with an aluminum foil at the production stage. Please consult us for adequate procedures.

5 Electrode Foil Development Technology

5-1 Corrosion inhibition of cathode foil

Inactive treatment is implemented to ensure long life by inhibiting natural corrosion of the cathode foil. Fig. 3-1 shows its effects with values of the polarization resistance inversely proportional to the corrosion rate using the AC impedance method(FRA).This indicates that the cathode foil used in the “Safety’s” capacitors has the polarization resistance higher than that of the conventional capacitors owing to corrosion inhibition.

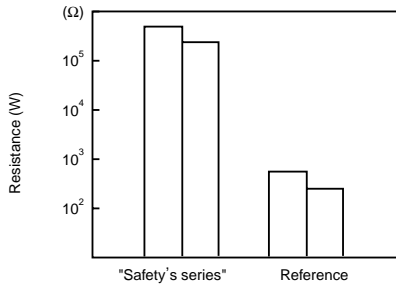


Fig. 3-1

5-2 Sealing material permeability of electrolyte

To ensure long life, a low permeable lactone solvent for the sealing material is used as the main solvent of the electrolyte of the “Safety’s” capacitor. Fig. 3-2 shows the test results on the permeability obtained by changing the weight of the capacitors produced with different types of electrolytes at a high temperature.

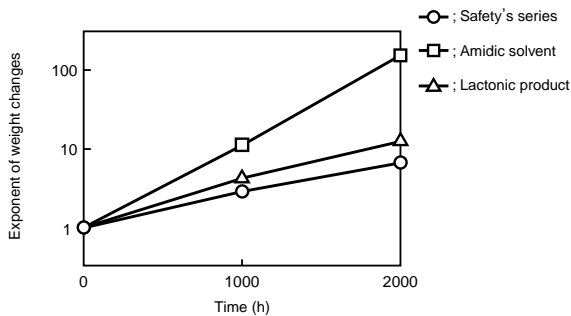


Fig. 3-2

5-3 Airtightness of sealing material

Since the electrolyte is stable for hours, the key element for capacitor’s life is the sealing material. By optimizing the crosslinking density of the sealing material polymer, the sealing material of the “Safety’s” capacitor attains its long life with electrolyte permeability less than that of the conventional capacitors.

Fig. 3-3 shows the test results on the airtightness of the sealing material obtained by changing the weight of the capacitors at a high temperature, producing capacitors with the conventional sealing material and improved one both containing the electrolyte used in the “Safety’s” capacitor.

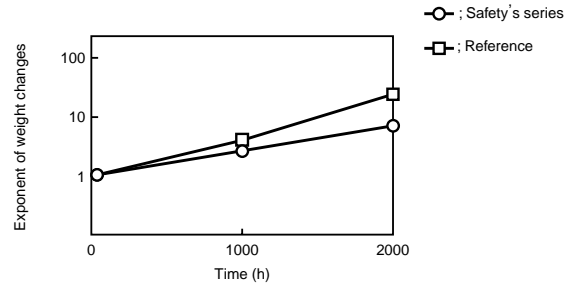


Fig. 3-3

5-4 Long-time stability of electrolyte

The electrolyte used in the “Safety’s” capacitor is stable with low initial resistivity and small secular changes at a high temperature. Fig. 3-4 shows change in resistivity at 105°C.

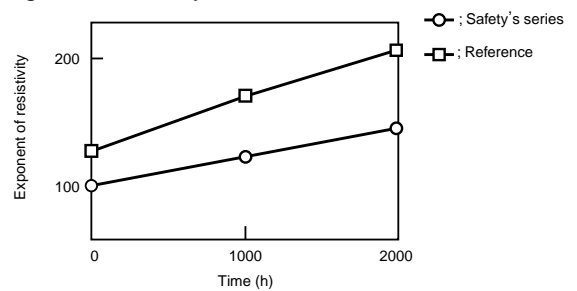


Fig. 3-4

5-5 Dielectric formation voltage and leakage current characteristics of anode foil

To increase the operating life by controlling the gas generation inside capacitor because of 1.5 to 2 times the rated voltage, while that of the previous capacitor is about 1.3 times the rated voltage.

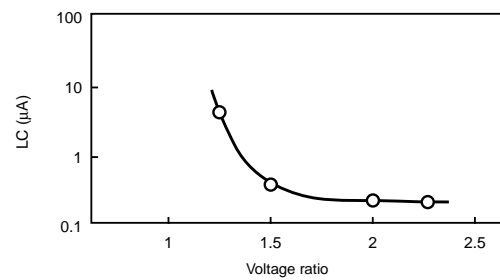


Fig. 3-5

5-6 Lowered ESR of Electrode Foil

To reduce the ESR of electrolytic capacitor, we have improved our chemical conversion technology for anode foil to develop lower ESR electrode foil compared to the conventional product as shown in Fig. 3-6

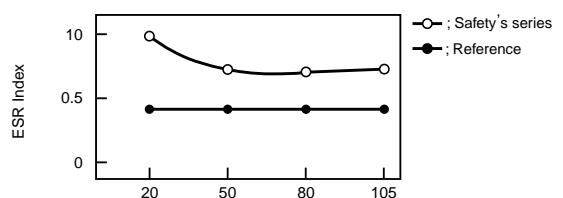
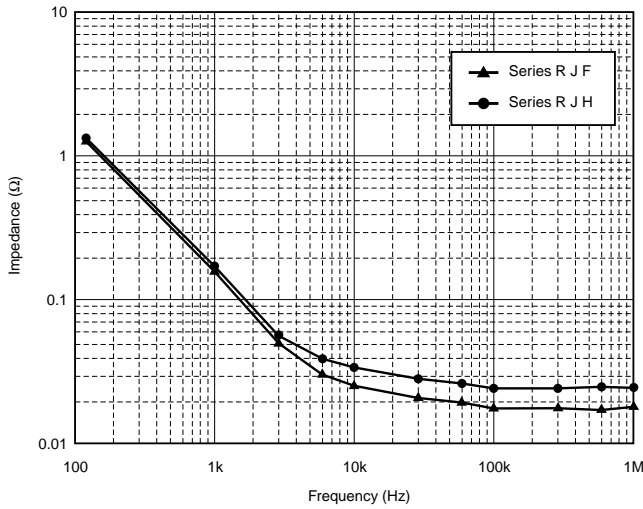


Fig. 3-6 ESR Index of Anode Foil

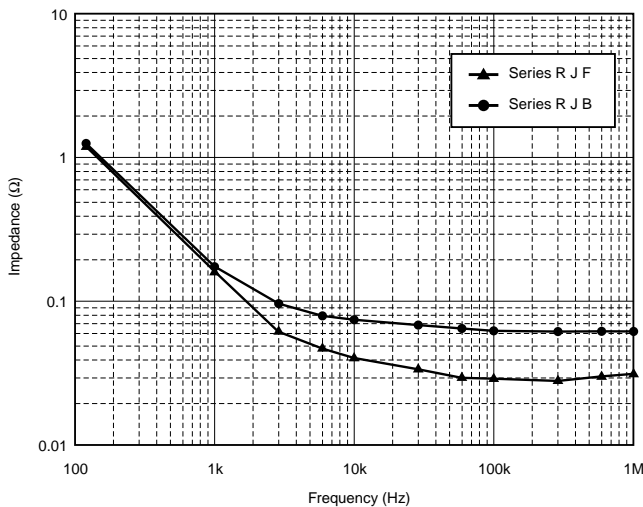
### 6. Electric Characteristics Data

#### 6-1 Series RJF, RJB, RJH

#### Frequency characteristics at 20°C

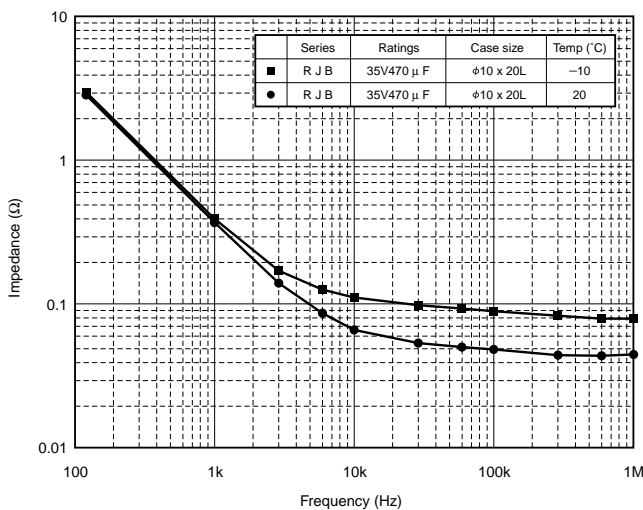


Performanse \ Series	R J F	R J H
Rated Voltage	25V	25V
Capacitance	1000 $\mu$ F	1000 $\mu$ F
Size( $\phi$ x L )	12.5 x 20	12.5 x 25
Impedance Spec (20°C, 100kHz)	0.021 $\Omega$	0.034 $\Omega$

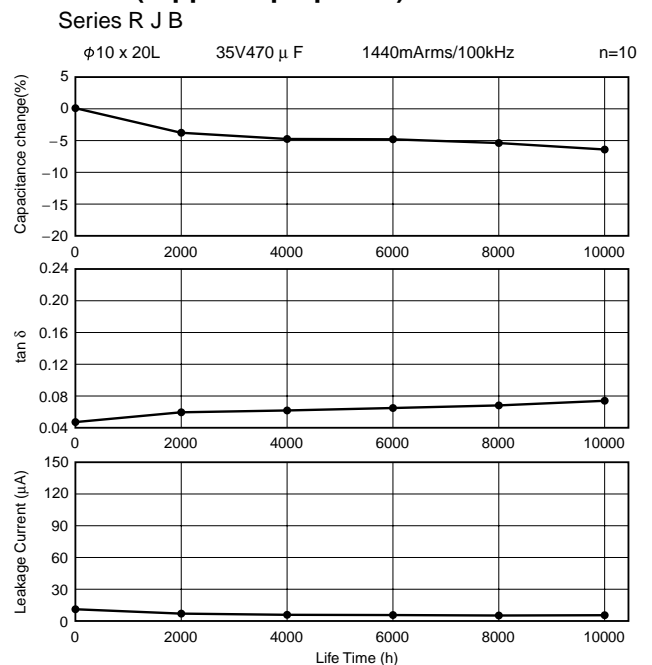


Performanse \ Series	R J F	R J B
Rated Voltage	10V	10V
Capacitance	1000 $\mu$ F	1000 $\mu$ F
Size( $\phi$ x L )	10 x 16	10 x 16
Impedance Spec (20°C, 100kHz)	0.038 $\Omega$	0.080 $\Omega$

#### Frequency characteristics at 20°C, -10°C



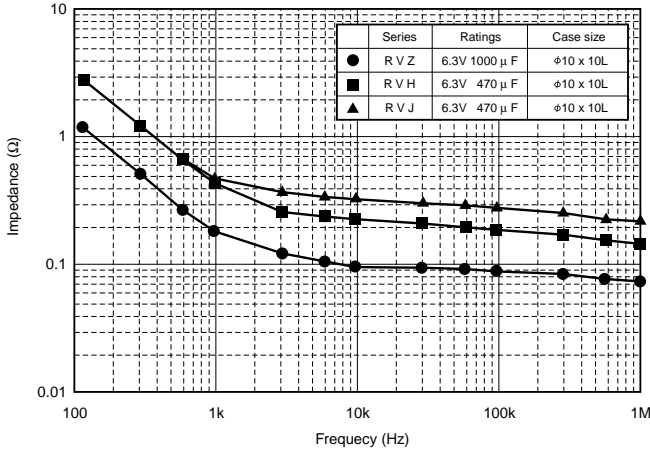
#### Endurance(Ripple superposed)at 105°C



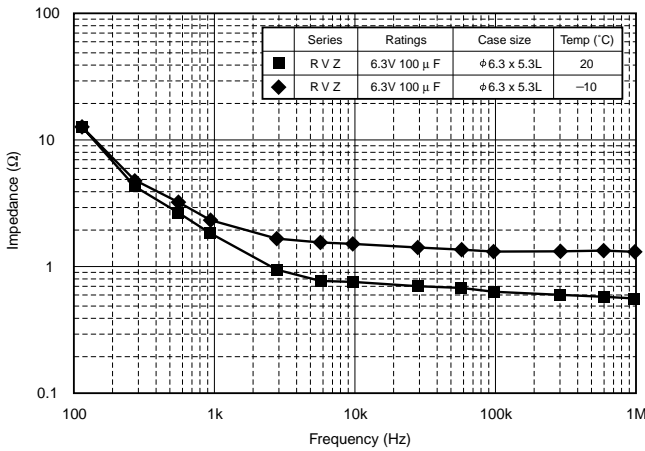
Notice: The mesurment values are not guaranteed values, but measurements.

6-2 Series RVZ

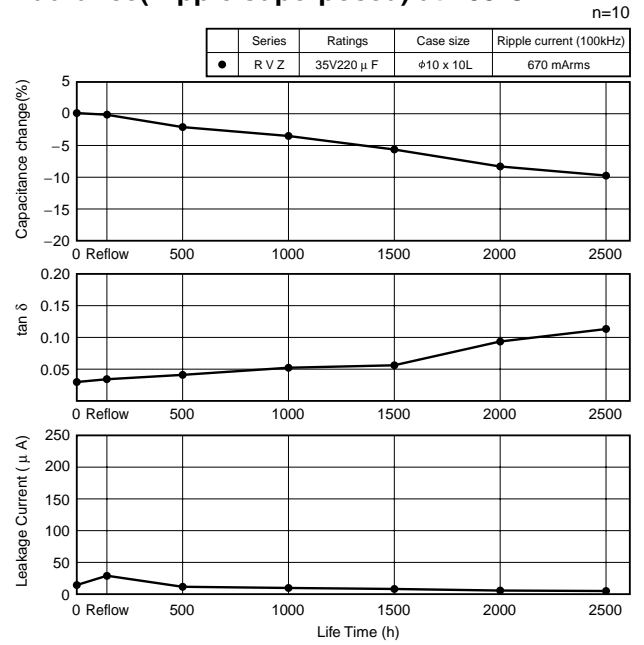
Frequency characteristics at 20°C



Frequency characteristics at 20°C, -10°C

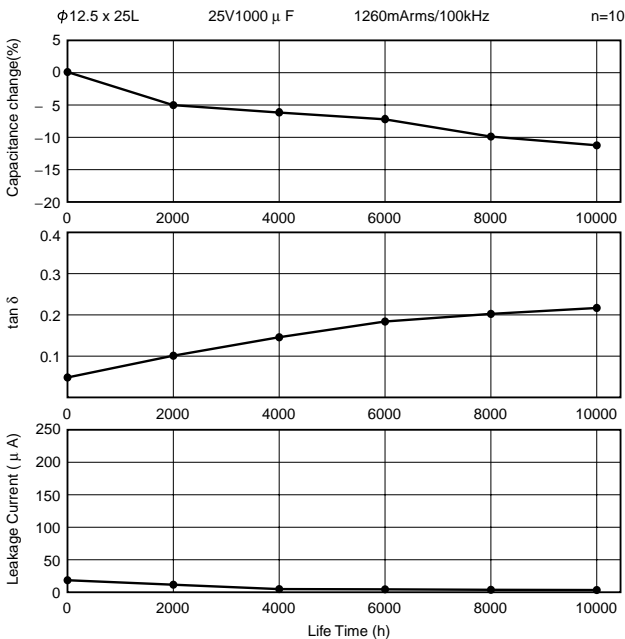


Endurance(Ripple superposed) at 105°C

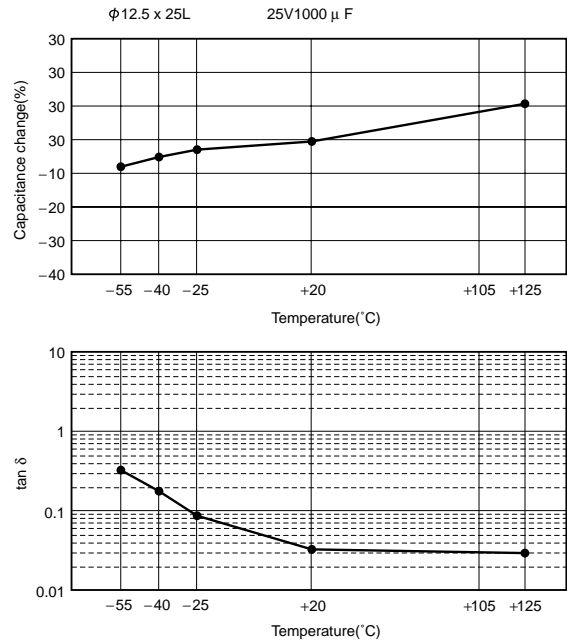


6-3 Series RK

Endurance Test (Ripple superposed) at 105°C



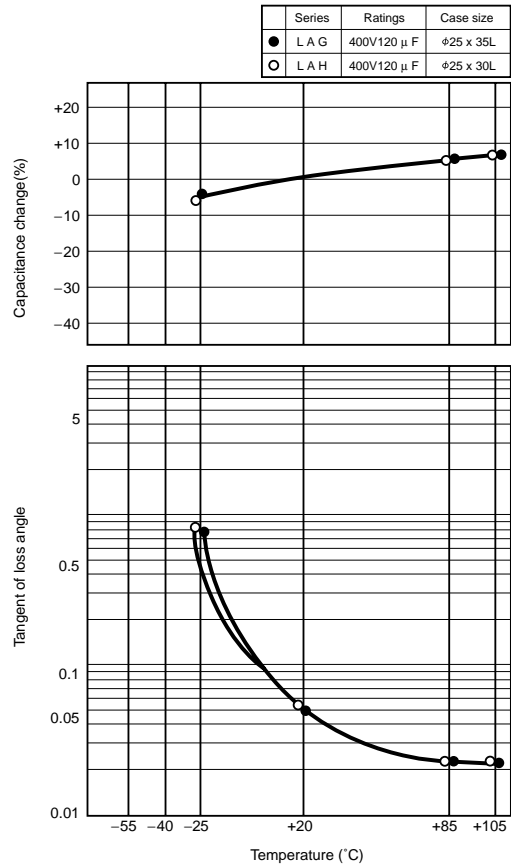
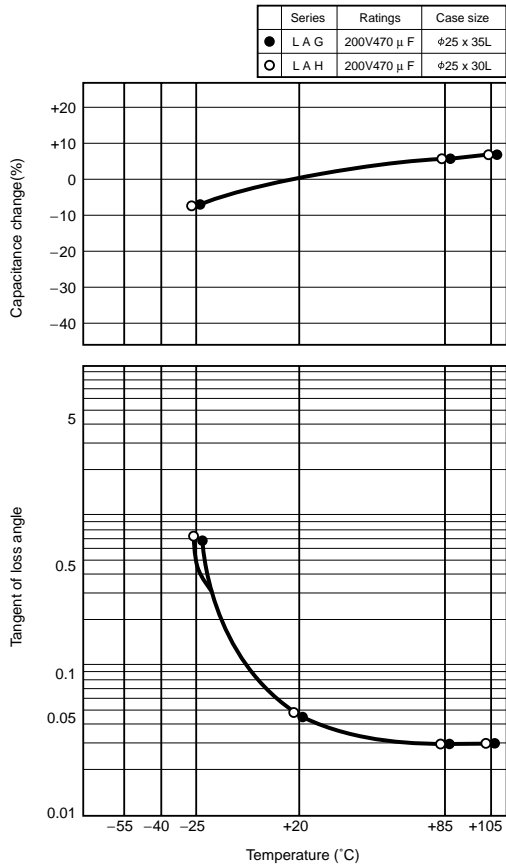
Temperature Characteristics



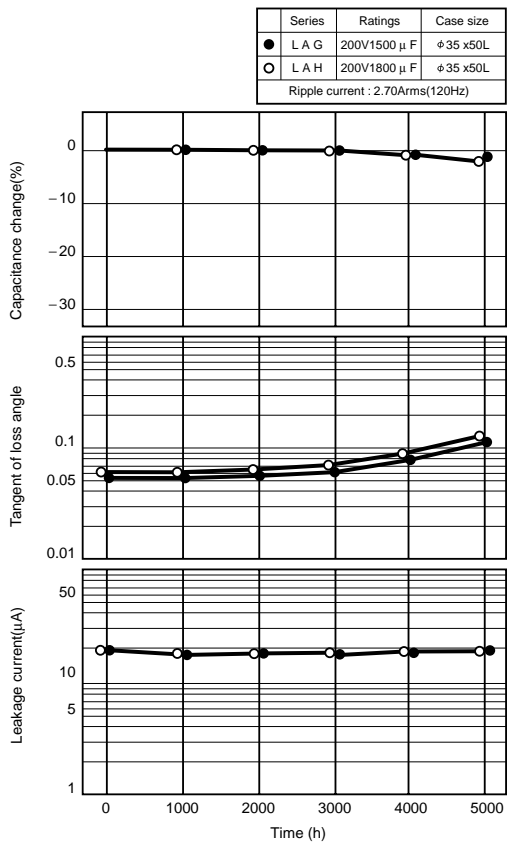
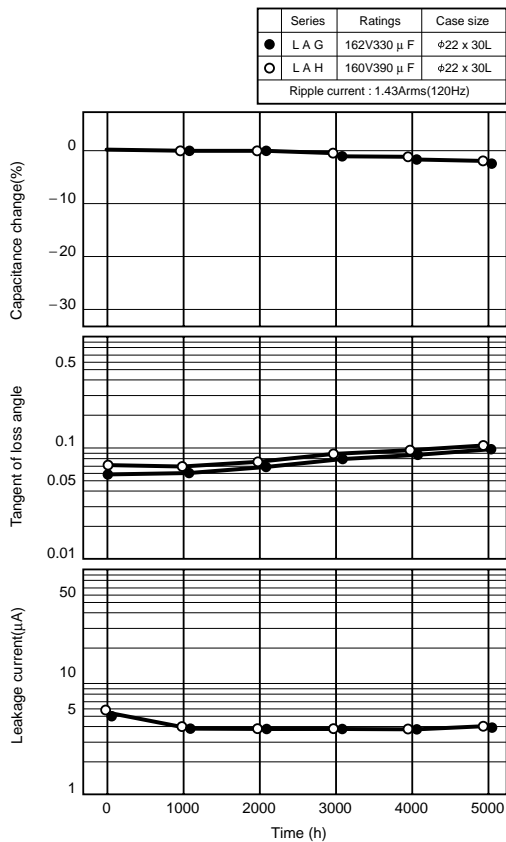
Notice: The measurement values are not guaranteed values, but measurements.

## 6-4 Series LAG • LAH

### Temperature characteristics, Series LAG • LAH



### Endurance(Ripple superposed) at 105°C of Series LAG • LAH

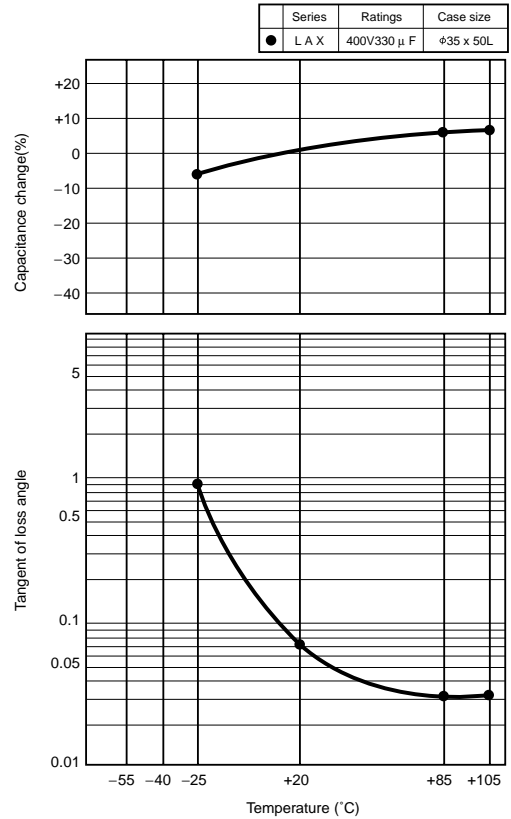
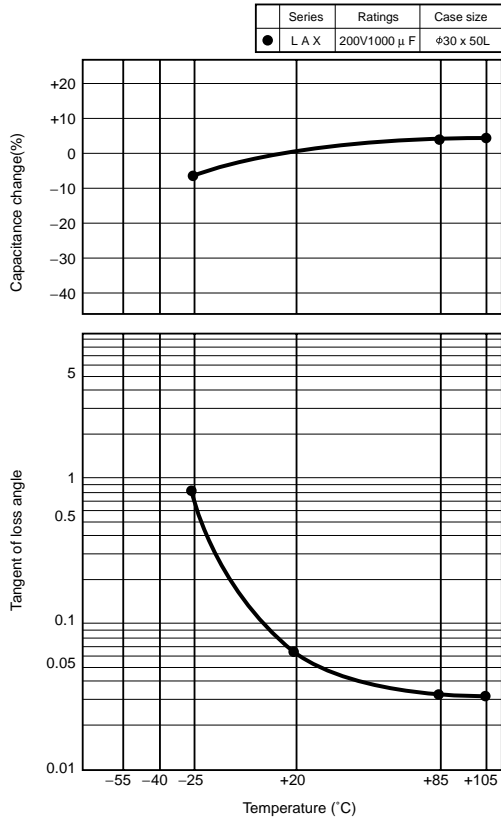


Notice: The measurement values are not guaranteed values, but measurements.

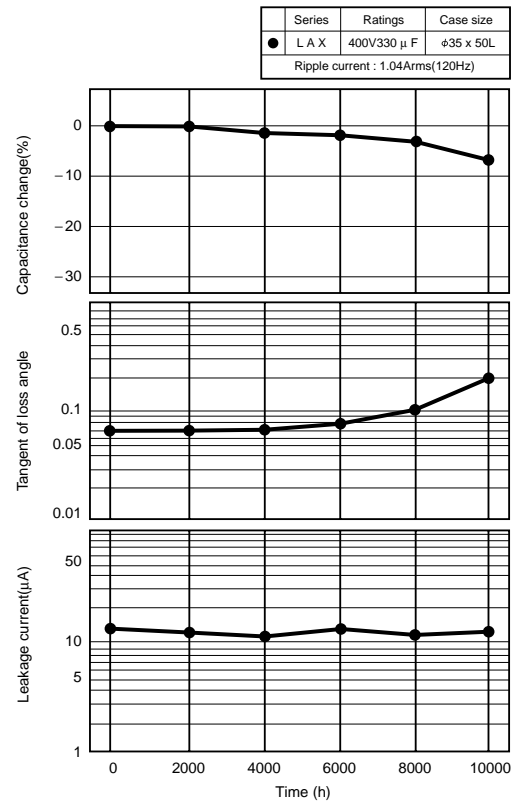
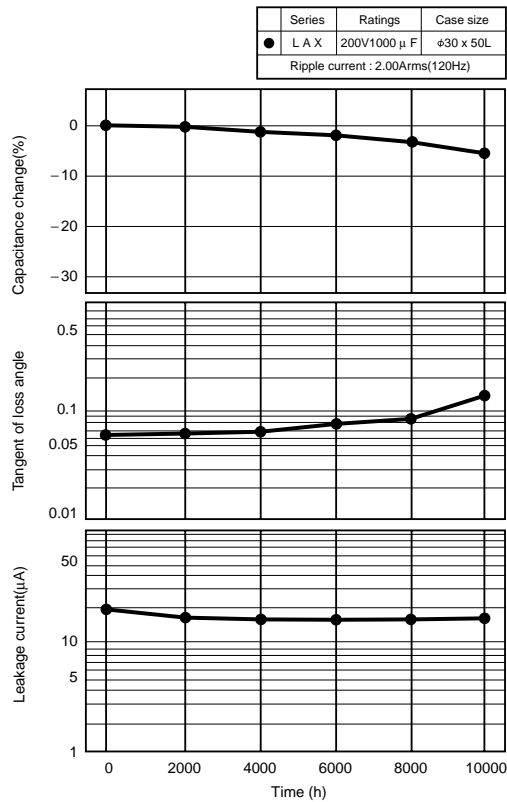


6-5 Series LAX

Temperature characteristics, Series LAX



Endurance (Ripple superposed) at 105°C of Series LAX



Notice: The measurement values are not guaranteed values, but measurements.