ELECTRICAL CHARACTERISTICS

Kendeil™

LEAKAGE CURRENT (LC)

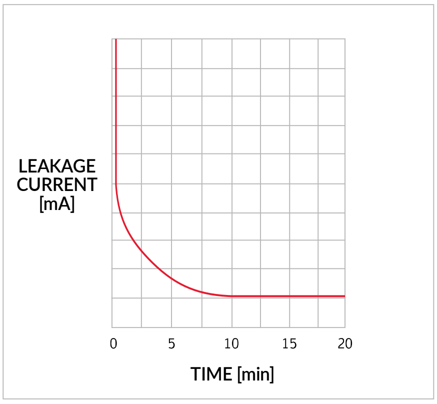
The leakage current (LC) of an electrolytic capacitor represents the loss of electrical charge through the internal parasitic resistance of the oxide that is not a perfect insulator. In other term the leakage current is the responsible of the self-discharge of a charged capacitor during time.
After the complete charge of the capacitor, once steady-state voltage and temperature conditions are reached, the leakage current decreases over long periods of time. Leakage current is a function of:

- Capacitor Design
- Voltage
- Temperature
- Time of voltage application
- Storage Conditions

Note that LC, decreasing with time, will reach a steady-state value (operating leakage current). Therefore, the specifications of LC are defined as a value measured 5 minutes after the beginning of the application of the rated voltage at 20°C.
For typical leakage current versus time, temperature and voltage, see **Fig. 3-4-5**.

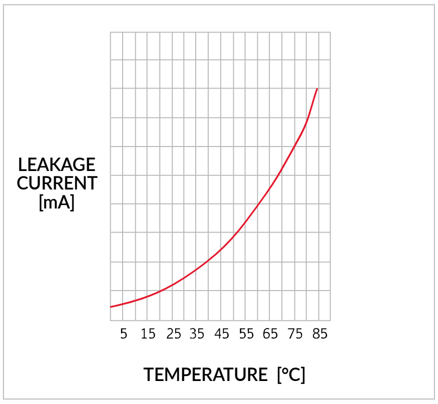
LC DRIFT VERSUS TIME

Fig. 3



LC DRIFT VERSUS TEMPERATURE

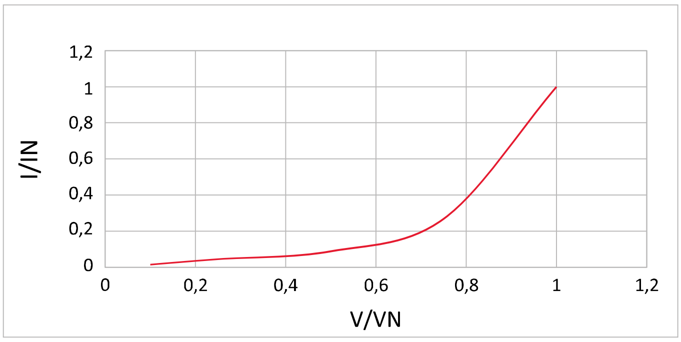
Fig. 4



LC is an increasing function of the applied voltage V, and rises quite strongly when V exceeds the rated value Vr.

LC VERSUS V

Fig. 5



REFORMING

All aluminum electrolytic capacitors need to be reformed before acceptance test. The purpose of this preconditioning is to ensure that the same initial conditions are maintained when comparing and assessing different products.
For this purpose, the rated voltage is applied to the capacitors with a current limiting a series resistance for a period of some hours.

SHELF LIFE (Voltage free storage)

Capacitors can generally be stored at temperatures up to 50°C without any reduction of their reliability.
Overall characteristics such as capacitance, ESR and impedance should show good performance with no sensitive changes while the leakage current will exhibit a slow drift upwords.

In practical use, we experienced the following scheme meaningful for voltage rated classes of capacitors:

SHELF LIFE	NOMINAL VOLTAGE	DIAMETER
3 years	≤ 100V DC	Ø < 76mm
2 years	≤ 100V DC	Ø ≥ 76mm
2 years	> 100V DC	All Ø
18 months	≥ 550V DC	All Ø

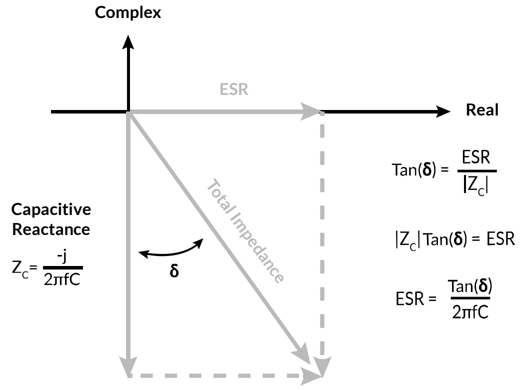
When designing application circuits, attention must be paid to the fact that after storage the leakage current may be up to 100 times higher than normal during the first few minutes following the application of power. This particular leakage current level increases with temperature and duration of storage.
After an extended storage period, the leakage current value may exceed the rated value and, before the output measurement, a reanodization process is required.
It could be realized by applying the rated voltage at room temperature for one hour.
In any case it is advisable to use a maximum charging current of 5mA or twice Ic typical value specified for each series.
Before assembling a capacitor bank, it is always recommended to:

- Use items from the same batch to have similar values of electrical parameters (capacitance, ESR, leakage current)
- Ensure equal conditions (current, voltage, temperature) are applied to all items

This will ensure balanced stresses and will reduce the risk of reduced lifetime and failures.

DISSIPATION FACTOR (tan δ)

Dissipation factor or loss angle tangent (tan **δ**) is a main electrical characteristic of an electrolyte capacitor, a measure of the deviation from an ideal capacitance value. It's represented by the tangent of the angle between the impedance and reactance phasors:



An ideal capacitor should have an ESR as low as possible and in consequence also a very small tan(**δ**).

Relationship is included in the following formula:

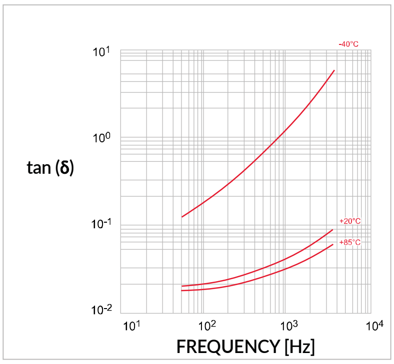
$$\tan(\delta) = 2\pi f \cdot C \cdot ESR$$

where: **F** = frequency **C** = rated capacitance

Maximum values in the datasheets have been indicated at 100Hz and 20°C.
Drift versus frequency as **Fig. 6-7**.

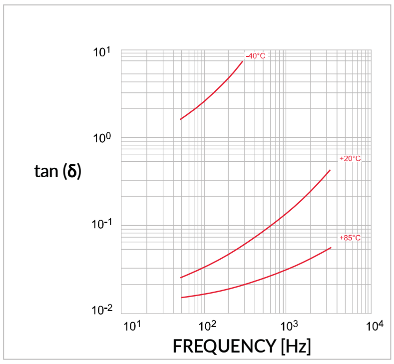
Tan(δ) DRIFT VERSUS FREQUENCY
LOW VOLTAGE (≤ 100 Vr DC)

Fig. 6



Tan(δ) DRIFT VERSUS FREQUENCY
HIGH VOLTAGE (> 100 Vr DC)

Fig. 7

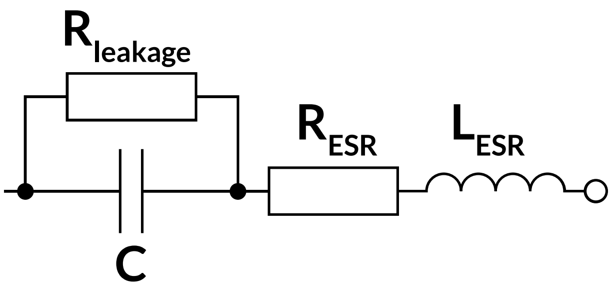


INDUCTANCE

Some inductance, mainly due to their conductive leads (tabs, terminals...) that connect the capacitor element to the circuit where it will be placed, is present in aluminium electrolytic capacitors, but values are usually less then few tens of nH.

IMPEDANCE (Z)

Due to all these unwanted parasitic (ESR, inductance, LC) the equivalent model of the real aluminum electrolytic capacitor has this electrical scheme:



the impedance of this two-pole will be:

$$Z(j\omega) = \left(\frac{1}{j\omega C} // R_{leak}\right) + R_{ESR} + j\omega L_{ESL}$$

If we ignore R_{leak}, usually in the order of MΩ, we get:

$$|Z(j\omega)| = \sqrt{ESR^2 + (\omega L - \frac{1}{\omega C})^2} = \sqrt{ESR^2 + (X_L - X_C)^2}$$

Impedance is dominated by the capacitive reactance (X_C) at low frequencies and by the inductive reactance (X_L) at high frequencies. At the point of series resonance Z=ESR.
The variation with frequency of individual resistive and reactive values determines the total impedance characteristic of the capacitor. Capacitive reactance predominates at low frequencies.
Fr is the self-resonant frequency. Defined as the frequency where XL and XC are equal.

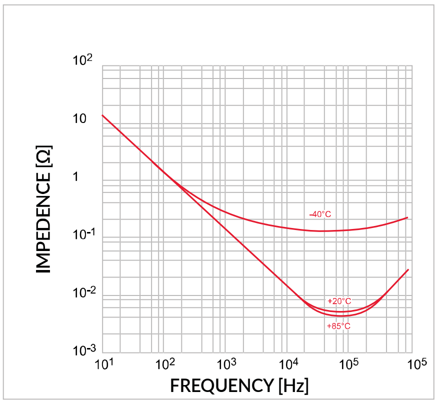
$$f_r = \frac{1}{2\pi \cdot \sqrt{LC}}$$

- When frequency goes from 0 up to the resonance Fr, the capacitive reactance (XC = 1/ϖCS) decreases until it reaches the order of magnitude of the electrolyte resistance
- At even higher the resistance of the electrolyte is the predominant term
- Resonance frequency is reached when capacitive and inductive reactance mutually cancel each other.
- Above the self-resonant frequency the inductive component is dominant and the capacitor behaves more like an inductor
- The resistance of the electrolyte increases strongly with decreasing temperature.

Specific impedance values are given in the individual data sheets. Typical impedance drift versus frequency, see **Fig. 8-9**.

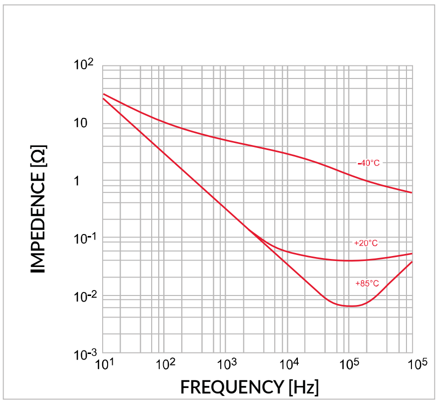
Z DRIFT VERSUS FREQUENCY
LOW VOLTAGE (≤ 100 Vr DC)

Fig. 8



Z DRIFT VERSUS FREQUENCY
HIGH VOLTAGE (> 100 Vr DC)

Fig. 9



RIPPLE CURRENT (RC)

It is defined as the superimposed alternated ripple current (sinusoidal alternating current at 100 Hz).
It depends mostly on an allowable temperature rise within a capacitor section due to the power relation formula: $I^2 \times R$. Heating occurs, due to an alternating current flowing through the equivalent series resistance of capacitor. Actual power must be considered when defining ripple current capability. Since the ripple current raises the temperature of the capacitor it has a significant effect on the operational life of the component. A diagram of useful life specifies life under given operating conditions of different temperatures values and ripple current values.