MINI GLOSSARY

• Summary of electorlytic capacitors

● Principle

The ability of a capacitor to store electrical energy is a direct function of its mechanical geometry and its chemical composition. The amount of energy that it can store is given by equation :

$$Q = CV$$

where Q = the magnitude of the stored charge
C = the capacitance in farads
V = the applied voltage

The value of capacitance is directly proportional to the(anode) surface area and inversely proportional to the thickness of the dielectric layer, thus :

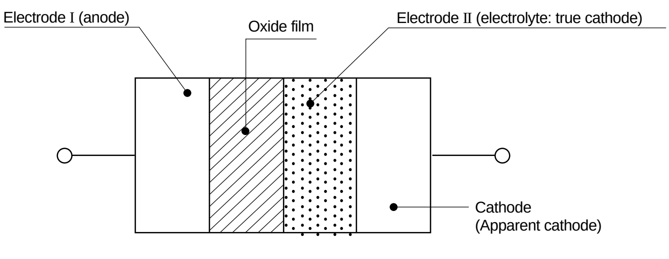
$$C = \varepsilon_r \cdot \varepsilon_0 \cdot \frac{A}{d}$$

where ε_0 = absolute permittivity(8.85 x 10^{-12} F/m)
ε_r = relative dielectric constant(dimensionless)
A = surface area (m^2)
d = thickness of dielectric (oxide layer in electrolytic capacitors)in m

The energy content of a capacitor is given by :

$$P = \frac{1}{2} C \cdot V^2$$

Electrolytic capacitors are distinguished from other capacitors by the uniqueness of their electrode materials and dielectric. This is explained in the principle diagram of the electrolytic capacitor in below.

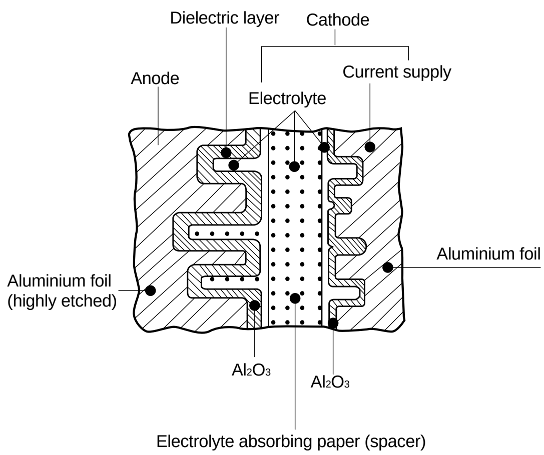


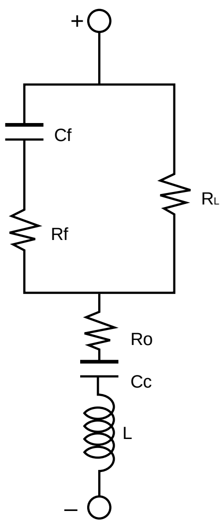
Principle Diagam of Electrolytic Capacitor

General capacitors can, in theory, use any kind of material for electrodes I and II as long as it is a conductor, and the same is true for the dielectric as long as it is a good insulator. In addition, electrode I and II can serve as the anode and cathode or vice versa without any problem.

However, this is not true with electrolytic capacitors, in which electrode I is limited to aluminum(Al), tantalum(Ta), niobium(Nb), titanium(Ti), zirconium(Zr), hafnium(Hf) and other metals (referred to as valve metals) which form a fine, highly insulative oxide film on its surface during anodic oxidation in an electrolyte solution. Currently, the only two metals in practical application are aluminum and tantalum.
The oxide film that forms on the surface of electrode I due to anodic oxidation serves as a dielectric.
The oxide film becomes an electrical insulator and functions as a dielectric only when the electrode on which it forms is the anode. Therefore, electrolytic capacitors are, in principle, capacitors with polarity.
Electrode II serves as a cathode that yields capacitance with a liquid or solid electrolyte.

●Equivalent circuit of Aluminum electrolytic capacitor





Cf : capacitance of anode oxide film
Cc : capacitance of cathode
Rf : equivalent series resistance of anode oxide film
Ro : composite resistance of electrolyte and electrolytic paper
R_L : resistance of leakage current
L : inductance of electrode length, leads, etc.
R : equivalent series resistance (Rf+Ro combined resistance)

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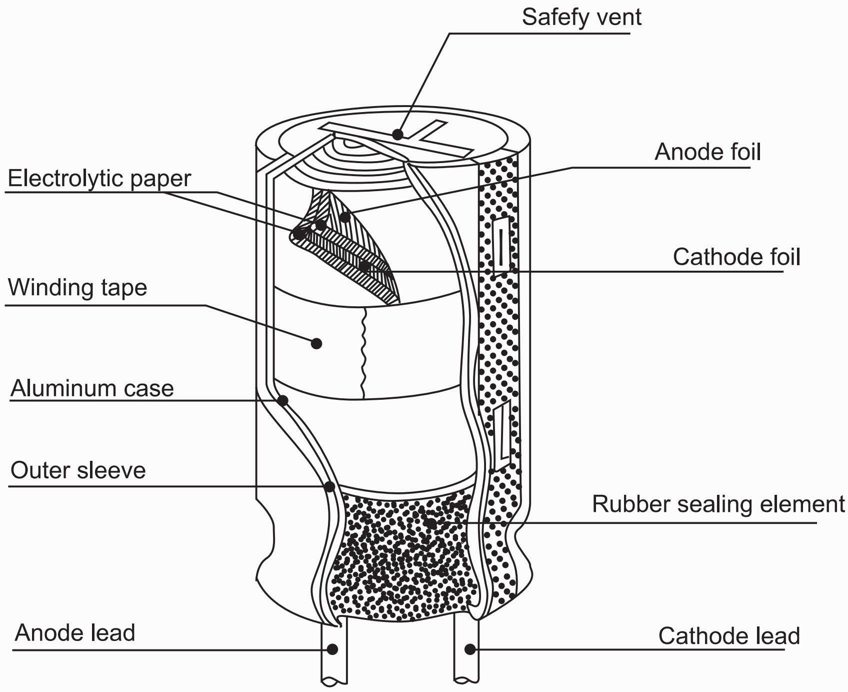
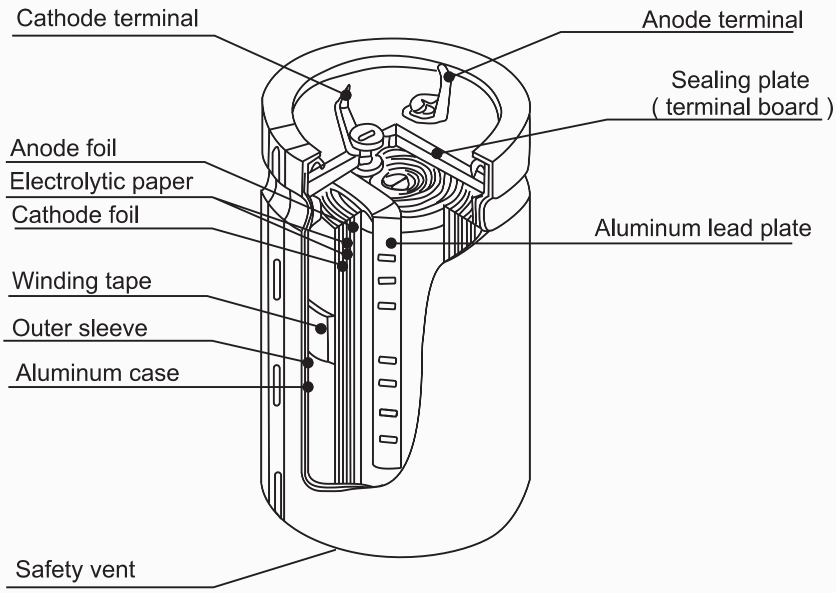
● Construction

• Radial lead type



• Snap-in type



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II Definition of the electrical parameters

1. Nominal Capacitance

The nominal capacitance of the capacitor is the value which is indicated upon it.

2. Leakage Current

The leakage current is the conduction current flowing through a capacitor, when a DC voltage equal to the rated voltage is applied to the capacitor.

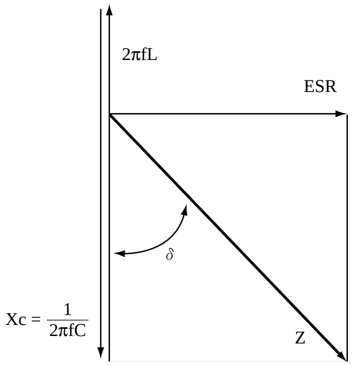
3. Tangent of Loss Angle(Tanδ)/Dissipation Factor

The power loss of the capacitors divided by the reactive power of the capacitor at a sinusoidal voltage of specified frequency.

$$\tan\delta = \frac{ESR}{Xc}$$

Where ESR : Equivalent series resistance(Ω) of capacitor
Xc : Reactance(Ω) of capacitor

D.F.= ESR/Xc x 100(%)



Vector diagram showing the AC parameters of a capacitor.

Note : Equivalent series resistance (E.S.R) may also be used as a means to define a single resistance representing all the ohmic losses in the capacitor.

$$ESR(\Omega) = \frac{\tan\delta}{2\pi fC} = \frac{D.F.}{2\pi fC \times 100}$$

where f = measured frequency in Hz
C= measured capacitance in farads

4. Operating Temperature Range

The operating temperature range is the range of ambient temperature for which the capacitor has been designed to operate continuously.

5. Rated Voltage / Working Voltage

The rated DC voltage is the maximum operating voltage which is the sum of the DC voltage and peak AC voltage applied to the capacitors and which may be applied continuously to the capacitors at temperature within the operating temperature range.

6. Capacitance Tolerance

The tolerance for capacitance stated in percent of the nominal capacitance.

7. Surge Voltage

The surge voltage is the maximum DC voltage to which the capacitor may be subjected at normal room temperature for 30 seconds at infrequent intervals of not less than 5 minutes. The rated surge voltages are as follows :

Rated Voltage (V)	4	6.3	10	16	25	35	40
Surge Voltage (V)	5	8	13	20	32	44	50

Rated Voltage (V)	50	63	80	100	160	180	200
Surge Voltage (V)	63	79	100	125	200	225	250

Rated Voltage (V)	250	315	350	400	450
Surge Voltage (V)	300	365	400	450	500

8. Ripple Current

Any pulsating voltage(or ripple voltage superimposed on DC bias) across a capacitor results in an alternating current through the capacitor.
Because of ohmic and dielectric losses in the capacitor, this alternating current produces an increase of temperature in the capacitor cell.
The heat generation depends on frequency and wave form of the alternating current.
The maximum RMS value of this alternating current, which is permitted to pass through the capacitor during its entire specified useful life(at defined frequency and defined ambient temperatrue), is called rated ripple current (I_R).
Usually the rated ripple current will cause a temperature increase of the capacitor's surface compared with ambient temperature.

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This temperature rise is the result of the balance between heat generated by dielectiric losses :

$P = I_R^{\,2} \cdot ESR$ equation 1)

and the carried off heat by radiation, convection and conduction :

$P = \Delta T \cdot A \cdot \beta$ equation 2)

from equation 1) and 2)

$$I_R = \sqrt{\frac{\beta \cdot A \cdot \Delta T}{ESR}} = \sqrt{\frac{2\pi fC \cdot \beta \cdot A \cdot \Delta T}{\tan\delta}}$$

$\Delta T = I_R^{\,2} \cdot ESR / \beta \cdot A$

Where

ΔT = Difference of temperature between ambient and case surface
β = Heat transfer constant
A = Geometric surface area of the capacitor
I_R = Ripple current
ESR = Equivalent series resistance

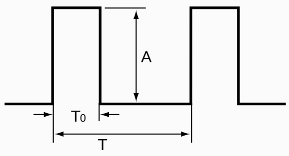
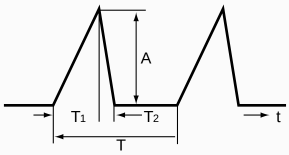
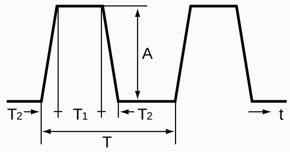
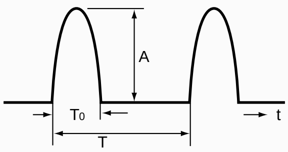
The heat, generated by ripple current, is an important factor of influence for non-solid electrolytic capacitors for calculating the useful life under certain circumstances.
The flow of ripple current over the permissible ripple current will cause heat of the capacitor, which may decrease the capacitance and damage the capacitor.
Ripple current on the capacitor must be at or below allowable level. (The sum of DC voltage and peak voltage shall not exceed the rated DC voltage)

● Ripple current coefficient

When the capacitor is operated in other condition of temperature and frequency which are specified in relevant specification, ripple current multiplied by the factor(coefficient) which is specified in relevant specification can be applied as maximum permissible ripple current.

● Calculation of the applicable RMS ripple current

Non-sinusoidal ripple current (if not accessible by direct measurement) have to be analyzed into a number of sinusoidal ripple currents by means of Fourier-analysis; the sum of the currents thus found may not excced the applicable ripple current.
For some frequently occurring waveforms, approximation formulae are stated in next for calculating the corresponding RMS value.

WAVE FORM	RMS VALUE
	$A\sqrt{\frac{t_0}{T}}$
	$A\sqrt{\frac{3t_1+2t_2}{3T}}$
	$A\sqrt{\frac{2t_1+3t_2}{3T}}$
	$A\sqrt{\frac{t_0}{2T}}$

Approximation formulae for RMS values of nonsinusoidal ripple currents.

9. Impedance

The impedance(Z) of an electrolytic capacitor is given by capacitance, ESR and ESL according to the following equation :

$$Z_C = \sqrt{ESR^2 + (X_L - X_C)^2}$$

where

$$X_C = \frac{1}{2\pi fC}$$

$X_L = 2\pi fL$
f = Frequency, C = Farads, L = Henries

where the ESR, capacitance and inductance are the values specified in the manufacturer's literature.
From above equations, the resonant frequency is

$$Freq. = \frac{1}{2\pi\sqrt{LC}}$$

At resonant frequency, the impedance is equal to the ESR.

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10. Life and failure rate

- Impress the rated voltage (or superpose prescribed ripple current) for a prescribed time period at the maximum operating temperature.
  The test duration, conditions and acceptable drift of electrical parameters after the life test are stated in the relevant detail specification (individual specification).

- Influence of temperature and ripple current on life

The influence of temperature on life is indicated by the so-called doubling 10˚C-rule. The doubling 10˚C-rule means that each time the temperature increases 10˚C, the life of the capacitor decreases by half. This relation is described in next equation.

$$L = L_0 \times 2^{\frac{T_0 - T}{10}}$$

where T_o : maximum use temperature (˚C)
L_o : guaranteed life time (h)
T : ambient temperature(˚C)
L : estimated life (h) at T(˚C)

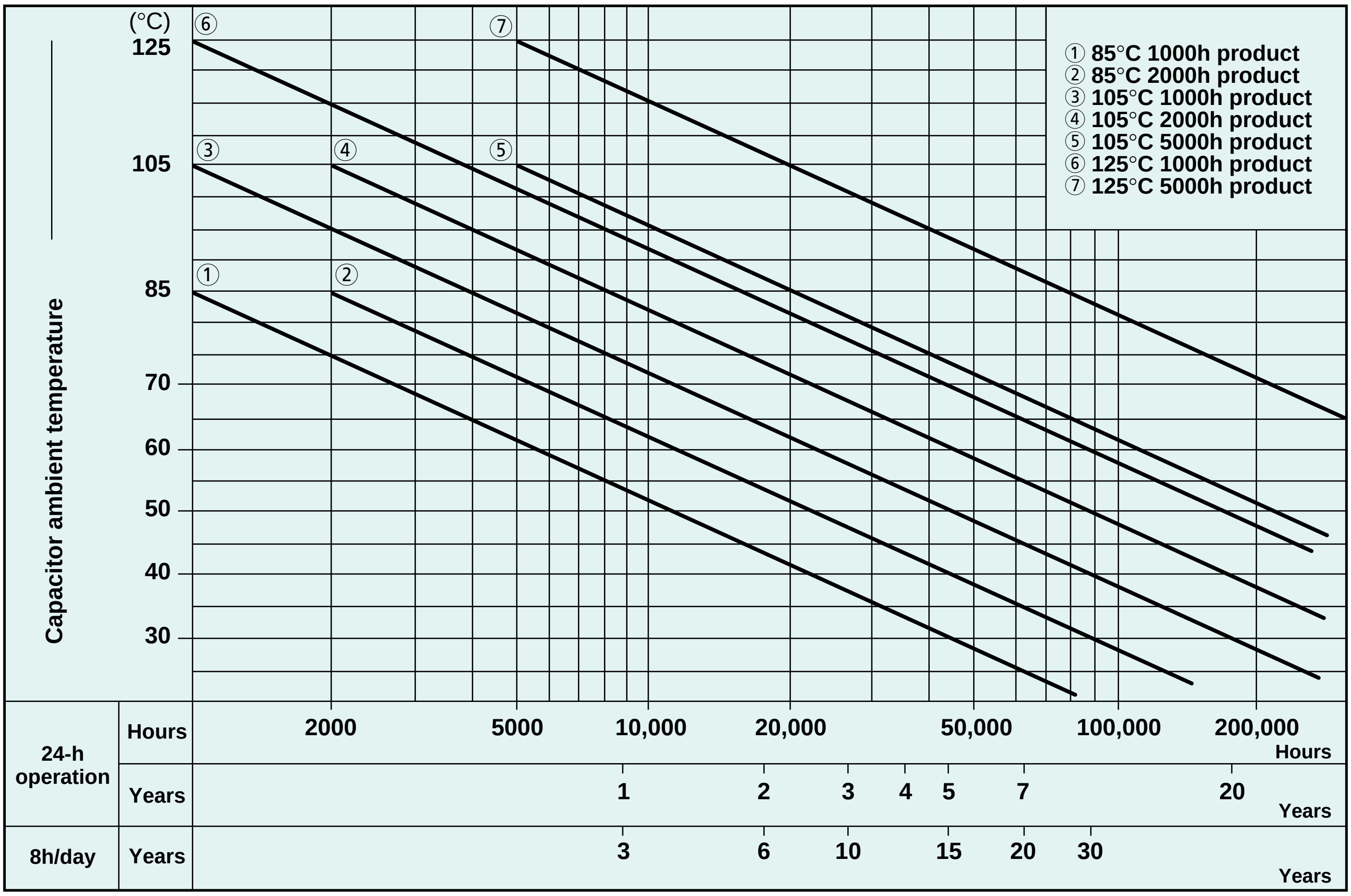
When capacitor is used with ripple current, temperature rises due to this ripple current effects the life of the capacitor, the allowable ripple current at which aluminum electrolytic capacitors can stand up for the guaranteed maximum temperature rise can be treated in the same way as that due to ambient temperature, and an equation which adds the temperature rise due to ripple current to the ambient temperature is sufficient.

$$L = L_0 \times 2^{\frac{T_o - (T + \Delta T)}{10}}$$

where
ΔT = Temperature rise by ripple current

When used with ripple currents exceeding the allowable ripple current, the "doubling 10˚C-rule" dose not hold valid for life acceleration and the life of the capacitor may be markedly shortened and the failure mode changed.

ALUMINUM ELECTROLYTIC CAPACITORS Life Estimate Chart



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Failure rate (λ)

The failure rate is defined by the number of components failing within a unit of time, related to the total quantity of components observed :

$$\lambda = \frac{\text{number of failures (statistical upper limit 60\%)}}{\text{total number of components} \times \text{duration}}$$

The failure rate(λ) is generally expressed in so-called "fit"(failure in time) = 10^{-9} /hours with an upper confidence level(UCL) of 60%. It is calculated from results of periodical tests in the quality laboratories or derived from field observations respectively.

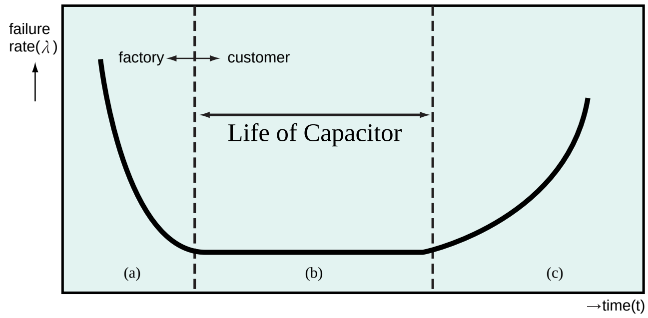
Usually the faiture rate during time shows the well known "bathtub" curve (see next)

There are 3 periods in a typical capacitor life cycle :

a) Initial failure period, showing a rapidly decreasing failure rate. During production of DAEWOO electrolytic capacitors, initial failures are removed after re-forming(which is short aging) : all capacitors shipped, have passed aging.

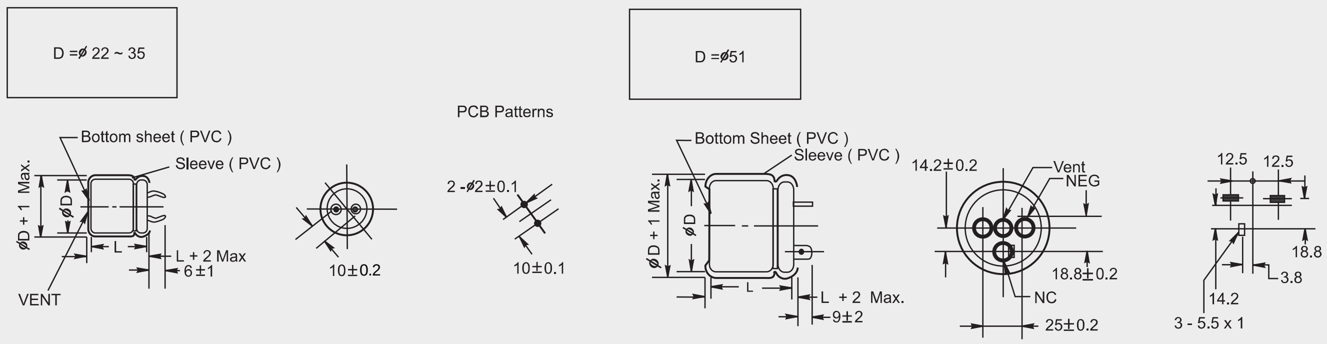
b) Random failure period, showing a low and constant failure rate. This period is identical with "useful life". The sum total of all (drift and accident) failures during this period, related to the total number of observed capacitors, is called "failure percentage".

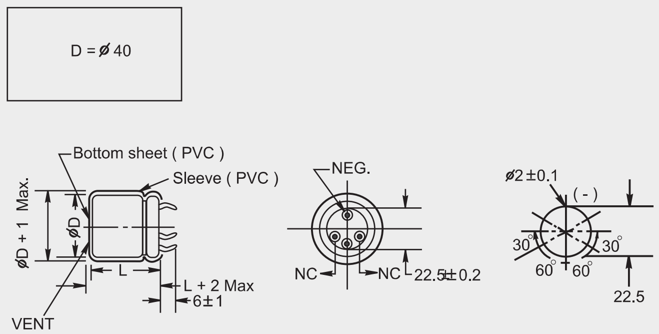
c) Wear-out failure period, showing an increasing failure rate due to gradual deterioration.



a) initial failure period ("infant mortality")
b) random failure period (=useful life period)
c) wear-out failure period

●Standard PCB patterns of PCB mounting type





Remark;
the lands for N.C. terminals have to be free from the circuit wiring.

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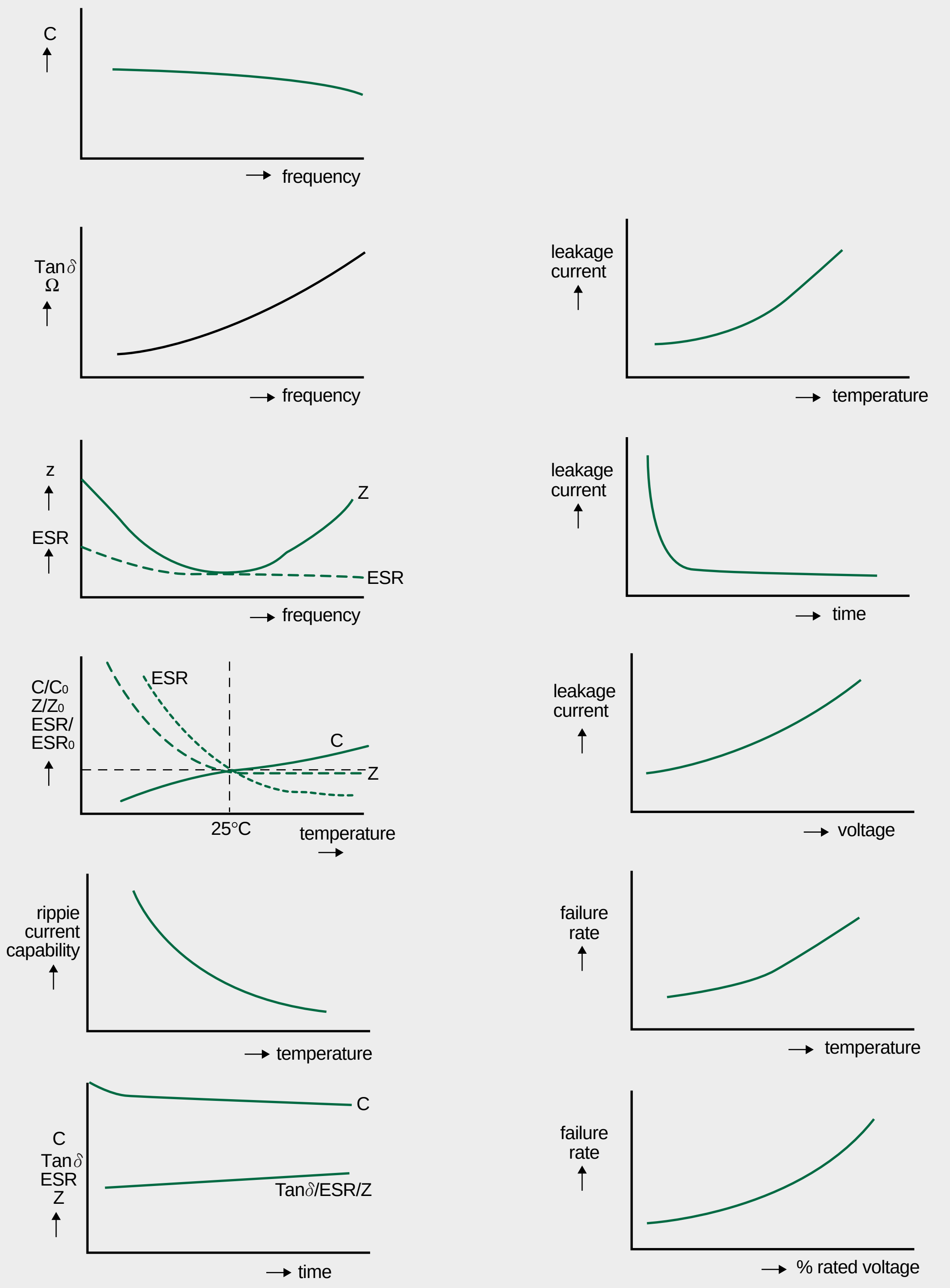
ELECTRICAL CHARACTERISTICS

Characteristics of electrolytic capacitors vary temperature, frequency, time and applied voltage.



Typical variation of electrical paramenters as a function of frequency, ambiebt temperature, voltage and time.