Table of Contents

1. Principle and Basic Theory of a Capacitor
2. Types of (Fixed) Capacitors
3. Types of Film Capacitors
4. Characteristics and Performance
5. Manufacturing Process
6. Applications
7. Caution for Proper Use
8. Examples of Failure
9. Safety and Conforming to Environmental
10. Additional Information

1. Principle and Basic Theory of a Capacitor

1-1 What is a Capacitor?

When voltage is applied between facing conductors, the insulator (or space) sandwiched between them will cause dielectric polarization by electrostatic induction, thus leading to the accumulation of electric charges (charging). The capacitor is a device (part) that performs this charging and discharging of accumulated charges as its function.

1-2 Electrostatic capacity and energy

$$C=\varepsilon_0\varepsilon_r\frac{S}{d} \quad \cdots\cdots\cdots 1$$

$$Q=CV \quad \cdots\cdots\cdots 2$$

$$W=\frac{1}{2}CV^2 \quad \cdots\cdots\cdots 3$$

C : Electrostatic Capacity (F)
ε_0 : Permittivity in Vacuum
8.854×10^{-12} (F/m)
ε_r : Relative Permittivity
S : Effective Electrode area (m^2)
d : Distance between Electrodes (m)
Q : Charge (C)
V : Voltage (V)
W : Energy (J)

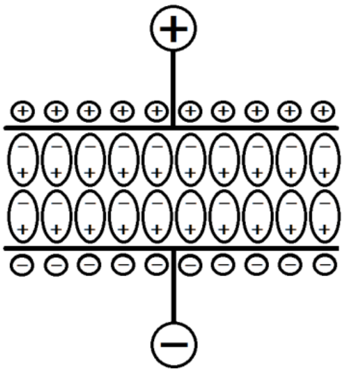


Fig.1 Conceptual Diagram of Polarization

2. Types of (fixed) capacitors

2-1 Classification

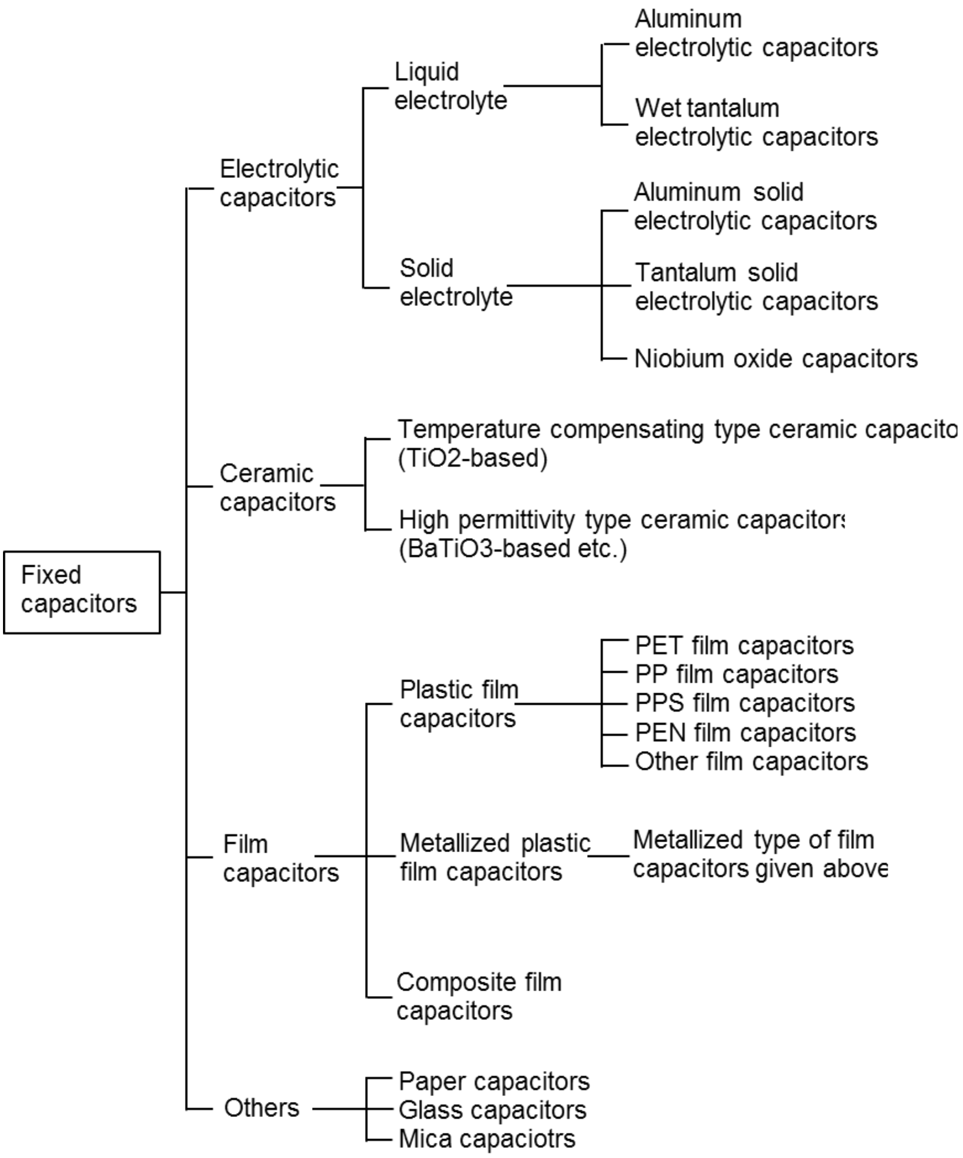


Fig.2 Capacitor classification

2-2 Comparison of Characteristics Among Various Types of Capacitors (summary)

Table1 Comparison of Characteristics

Characteristics / Type	Size	Frequency Characteristics	Temperature Characteristics	High Voltage	High Capacity	Long Life	Cost per Capacity
Film	×	◎	◎	◎	△	◎	×
Aluminum electrolytic	○	×	×	○	◎	×	◎
Aluminum solid	○	◎	○	△	◎	△	○
Tantalum electrolytic	○	○	△	×	○	△	○
MLCC	◎	△	○	◎	×	◎	×

Superior ← ◎ ○ △ × → Inferior

3. Types of Film Capacitors

3-1 Classification by Dielectrics

Table2 Classification by Dielectrics

Description of dielectrics	Abbreviation	Remarks
Polyethylene phthalate	PET	"Miler" (Du-Pont) is famous.
Polypropylene	PP	-
Polyphenylene sulfide	PPS	-
Polyethylene naphthalate	PEN	-
Others	-	-

3-2 Classification by Electrodes

Table3 Classification by electrodes

Kinds of electrodes	Material
Metal foil electrode	Aluminum, Tin, Copper, etc.
Evaporated electrode	Aluminum, Zinc, etc.

3-3 Classification by Element Structures

1) Foil Electrode Tab Structure 2) Evaporated Electrode Extended Foil Structure

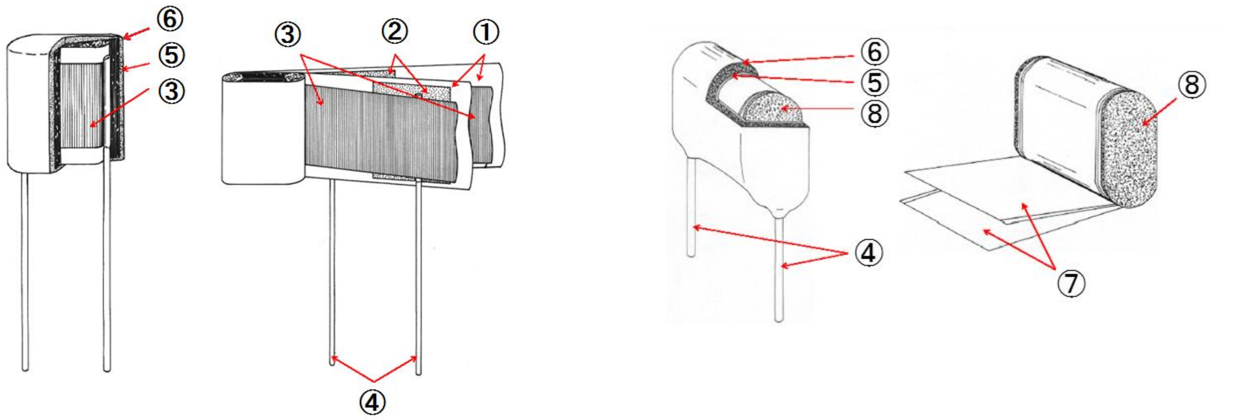


Fig.3 Element structures

① Dielectric Film
② Protective Film
③ Aluminum Foil
④ Lead Wire
⑤ Undercoating Resin
⑥ Outer coating Resin
⑦ Metallized Film
⑧ Metallicon (Metal spray)

3-4 Classification by Armoring

Resin Dipping
Tape Wrapping Resin Sealing
Non-metallic Case Resin Sealing
Metallic Case Hermetic Sealing
Resin Molding
Simple Armoring (chips for surface mounting)

4. Characteristics and Performance

4-1 Physical Properties of Dielectric Films

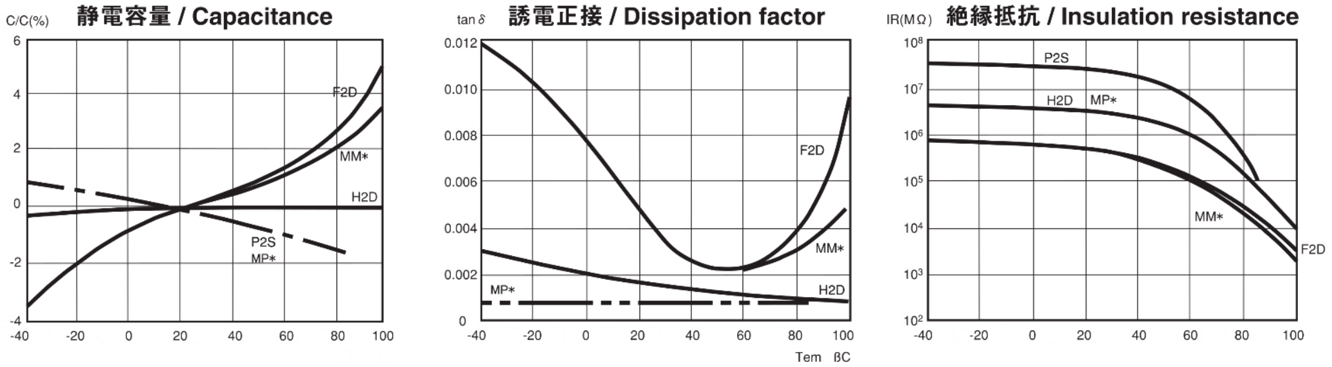
Table4 Physical Properties of Dielectric Films

Characteristics	PET	PP	PPS	PEN
Thickness (μm)	3.0 - 12	2.2 - 12	4.0 - 12	4.0 - 12
Maximum operating temperature(℃)	120 - 130	80 - 105	130 - 140	120 – 140
Relative permittivity (1kHz@ 20℃)	3.2	2.2	3	2.9
Dielectric loss tangent (1 kHz@20 ℃)	0.003	0.0002	0.0006	0.004
Volume resistivity (Ωcm)	$>10^{18}$	$>10^{17}$	$>10^{17}$	$>10^{17}$
Coefficient of water absorption (%@75%RH)	0.4	<0.01	0.05	0.3
Glass transition point (℃)	69	0	92	121
AC breakdown voltage (kV/mm)	120 - 280	200 - 400	180	300

4-2 Characteristics

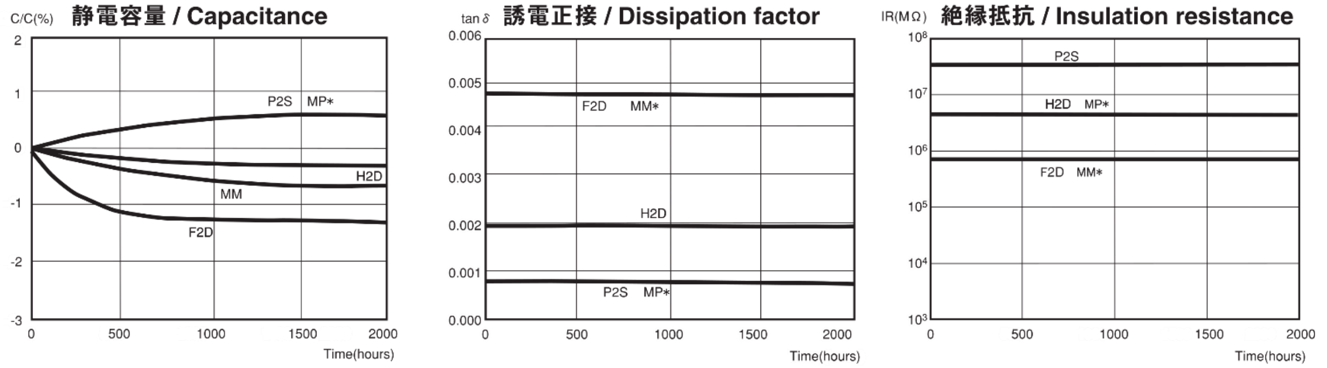
Typical characteristics are shown below. (Capacitances are 0.1uF)

◆温度特性 / TEMPERATURE CHARACTERISTICS



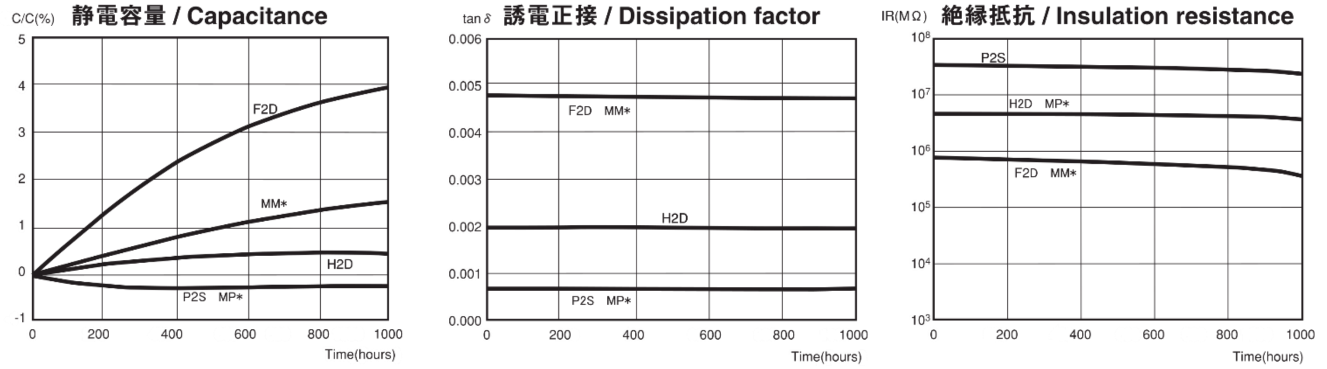
◆高温負荷（定格電圧軽減なしで使用できる最高温度中、定格電圧×1.25または1.4（F2D,P2S,H2D）倍印加）

HIGH TEMPERATURE LOADING (Temperature : 105℃ or 85℃ or 70℃, Test voltage : 140% or 125% of rated voltage)



◆耐湿負荷（40℃、95%中、定格電圧印加）

MOISTURE RESISTANCE LOADING (Temperature : 40℃, Humidity : 95%, Test voltage : rated voltage)



◆周波数特性 / FREQUENCY CHARACTERISTICS

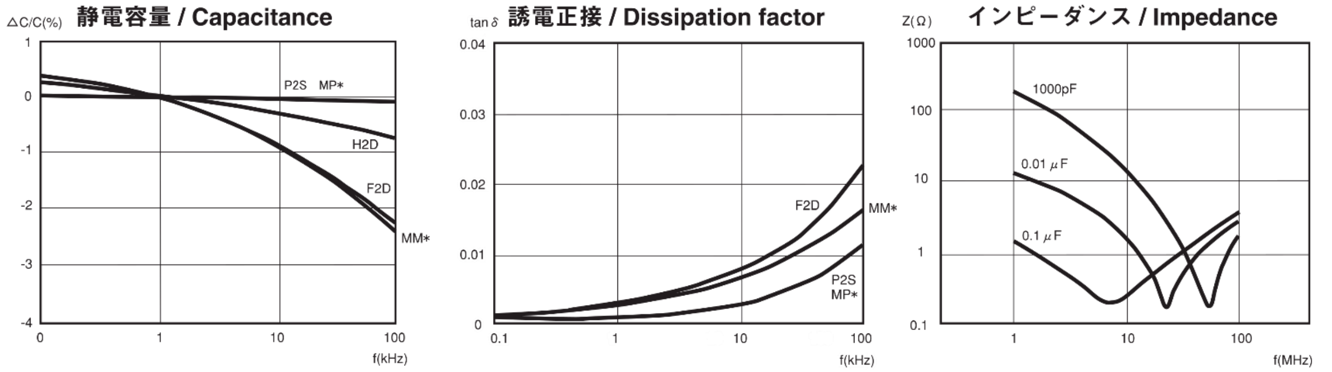


Fig.4 Characteristics

4-3 Features of Various Types of Films

Table5 Features of Dielectric Films

Item	PET	PP	PPS	PEN
Cost	◎	○	×	○
Miniaturization	◎	○	○	◎
Heat resistance	○	○	◎	◎
Moisture resistance	△	◎	○	△
Solvent resistance	○	○	○	○
Temperature characteristics	△	○	◎	△
Low loss (low tanδ)	△	◎	○	△

Superior ← ◎ ○ △ × → Inferior

5. Manufacturing Process

(Control items and influencing characteristics by types of products and processes)

5-1 Foil Electrode Tab Structure

Table6 Manufacturing Process and Control Items

Process	Control items	Influencing characteristics
Coiling	Weld strength	Capacity open Small capacity due to broken foil Short-circuiting due to weld burrs
	Offset in coiling	Short-circuiting
Application of remover	Applied condition	Soldering
Pressing	Temperature	Short-circuiting
	Pressure	Small capacity due to broken foil
Resin impregnation	Degree of vacuum	Lowering of withstand voltage due to voids
Resin curing	Temperature	Large tanδ
	Time	Large tanδ

5-2 Evaporated Electrode Extended Foil Structure (lead wire)

Table7 Manufacturing Process and Control Items

Process	Control items	Influencing characteristics
Evaporation coating	Evaporation condition	Large tanδ
Coiling	Offset margin	Capacity open Large tanδ
	Film flaws	Large tanδ
Pressing	Temperature	IR down, short-circuiting
	Pressure	IR down, short-circuiting
Metallicon	Conditions	Large tanδ Short-circuiting
	Thickness	Large tan
Voltage processing	Voltage	IR down, capacity open, large tanδ
Lead welding	Welded condition	Large tanδ Capacity open
Application of remover	Applied condition	Soldering trouble

5-3 Evaporated Electrode Extended Foil Structure (power film)

Table8 Manufacturing process and control items

Process	Control items	Influencing characteristics
Evaporation coating	Evaporation condition	Large tanδ
Coiling	Offset margin	Capacity open Large tanδ
	Film flaws	Large tanδ
Pressing	Temperature	IR down, short-circuiting
	Pressure	IR down, short-circuiting
Metallicon	Conditions	Large tanδ Short-circuiting
	Thickness	Large tan
Voltage processing	Voltage	IR down, capacity open, large tanδ
Terinal soldering	Soldering conditoin	Large tanδ Capacity open
Resin filling	Resin condition	Humidity resistance degradation

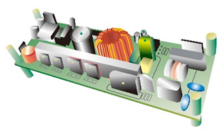
6. Applications and Features

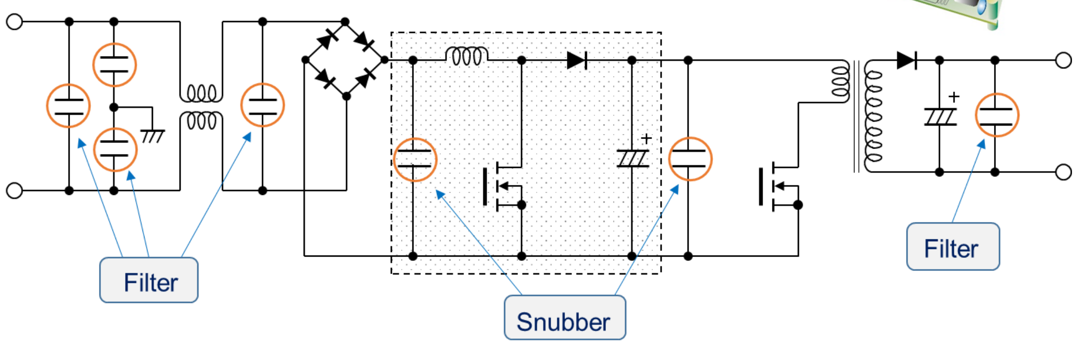
Table9 Outline of Applications by the Types of Dielectrics and Electrodes

Dielectric	Electrode	Structure	By-pass coupling	Filter	Anti-noise	Charge & Discharge	Resonance	Differential & Integral	Time constant	Oscillation	Phase compensatoin	Smoothing	Snubber
PET	Foil	Tab	○			△		○	○	○	○		
		Extended foil	○			○	○	○	○	○	○		
	Evaporation	Winding	○	○	○	△	○						
		Stacking	○			○	○						
PP	Foil	Tab	○					○	○	○	○		
		Extended foil	○			○	○	○	○	○	○		
	Evaporation	Winding	○	○	○	△	○					○	○
PPS	Foil	Tab	○					○	○	○	○		
		Extended foil	○			○	○	○	○	○	○		
	Evaporation	Winding	○			△	○						
		Stacking	○			○	○						

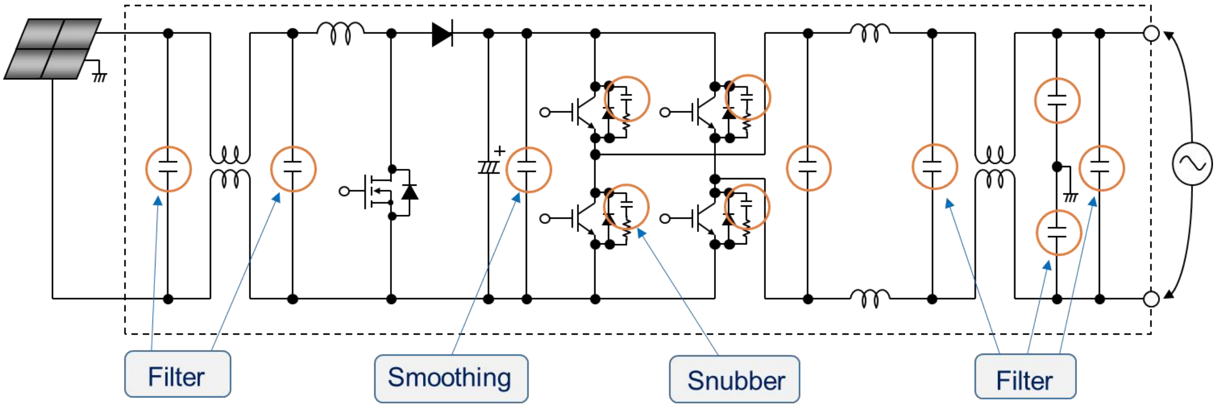
△: Designed for Exclusive Use

Power supply（Flyback circuit with PFC）





Photovoltaic generation（power conditioner）



Automotive inverter circuit (for driving)

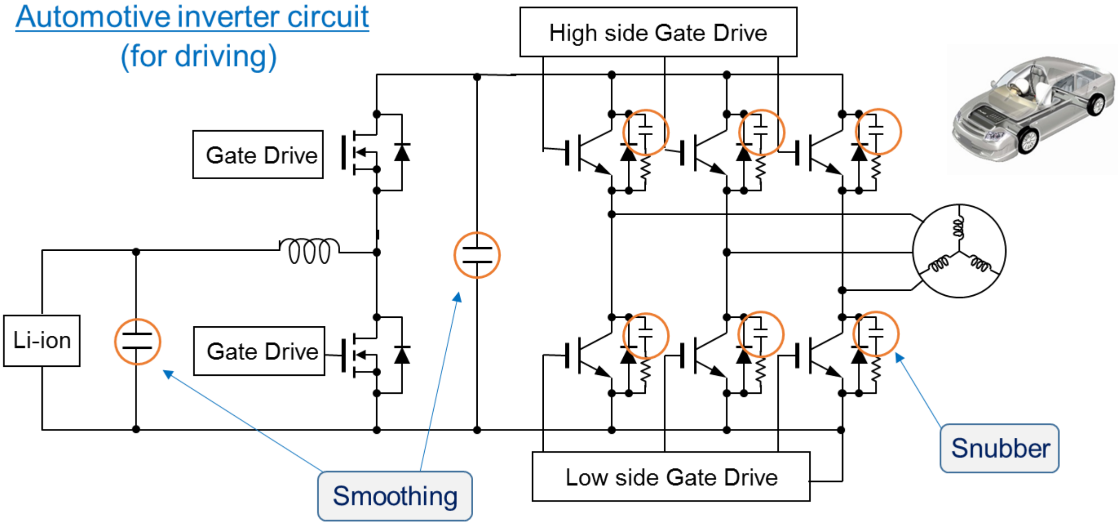
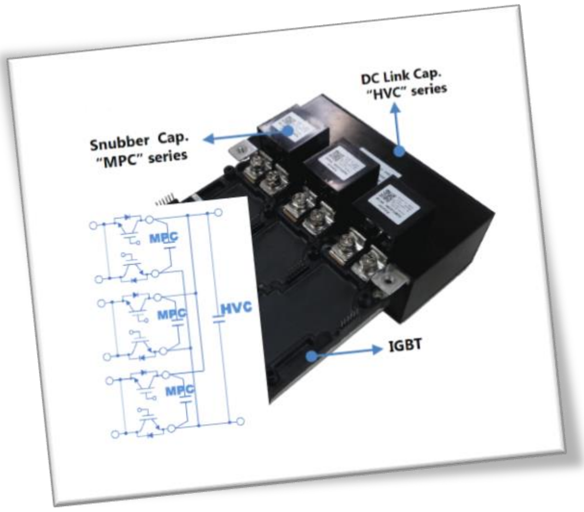


Fig.5 Example of use

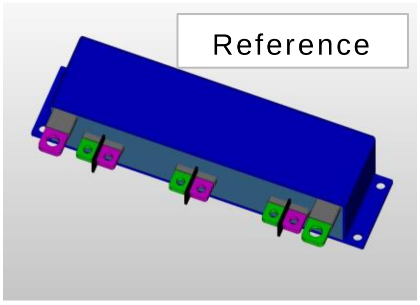
6-1 Optimization of Internal Elements

The internal element of the capacitor is polypropylene, which has been conventionally used to handle high currents. In addition, in response to the market demand for high heat resistance, we are developing a module with a high-voltage PMLCAP internal element that can withstand 125°C or higher.

- High current → Built-in Element: Polypropylene Film Capacitor



- High Heat Resistance and Ultra-Small size → Built-in element: PMLCAP



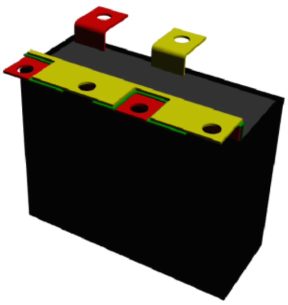
Example) 800VDC/200μF/250Arms/0.28L
Energy density 225J/L
Operating temperature range is -40 to +125°C

Fig.6 Example of use

6-2 Optimal Design

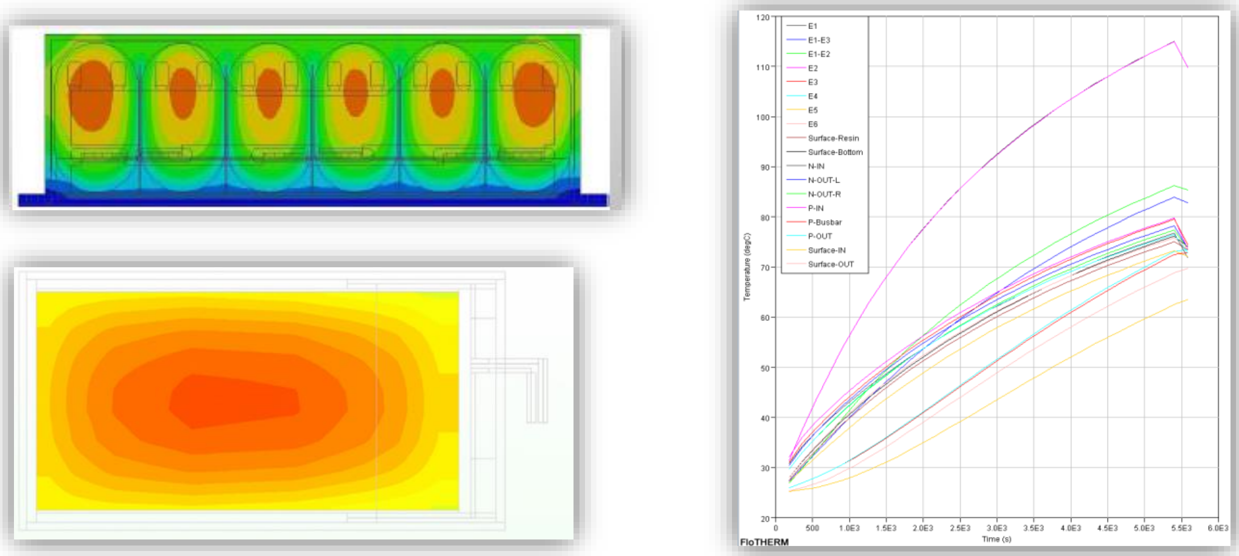
We conduct simulations and experiments of electromagnetic field, heat, and structure to design optimal products to meet customer requirements.

- Low Inductance Design



Example) 450VDC/200μF/4.1nH at 10MHz

- Thermal Simulations



- Product Strength/Seismic Simulations

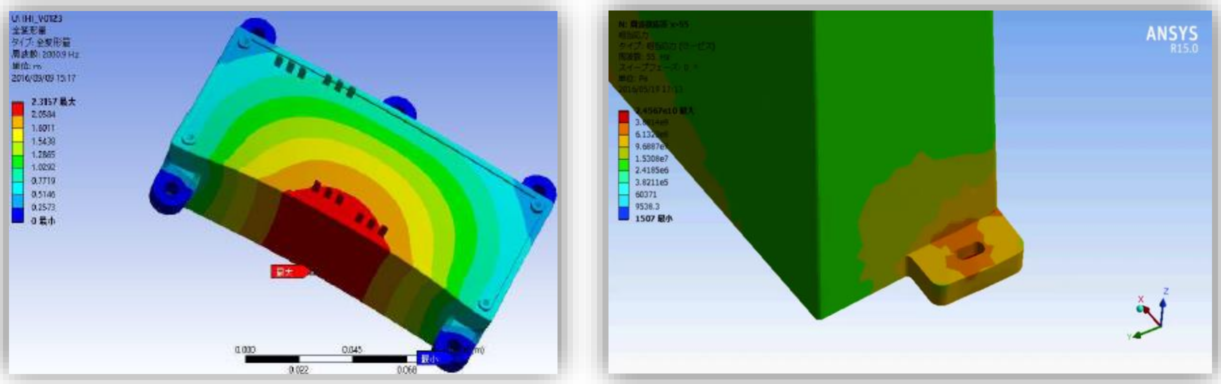


Fig.7 Design and Simulation Example

7. Caution for Proper Use

Please refer here with regard to caution for proper use of film capacitors.

8. Examples of Failure Modes

Table10　Probable Causes of Failure and Failure Mode of Film Capacitors

Failure mode	Probable causes of failure	
	Foil electrode	Evaporated electrode
Short- circuiting	･Dielectric breakdown of dielectric film by application of overvoltage and/or high pulse voltage. ･Self-heating due to overcurrent ･High temperature environment ･Moisture absorption by film →Dielectric breakdown of dielectric film due to withstand voltage degradation.	—
Short- circuiting with resistance (*)(**)	—	･Dielectric breakdown of dielectric film by appling overvoltage and/or high pulse voltage. ･Self-heating due to overcurrent ･High temperature environment ･Moisture absorption by film →Dielectric breakdown of dielectric film due to withstand voltage degradation.
Open	･Self-heating due to overcurrent ･High temperature environment →Connection instability by heat contraction of a dielectric film.	The connected portion between the evaporated electrode metal and metallicon metal is heated and dispersed instantaneously by high pulse current. ･Self-heating due to overcurrent ･High temperature environment →Connection instability by heat contraction of a dielectric film. Reduction in electrode area caused by oxidation of evaporated metal due to moisture absorption (capacity decrese → open)

*) In case of the metallized film capacitors (evaporated metal electrode type), if voltage in excess of the withstand voltage (or apparently in excess of the withstand voltage due to the lowering of withstand voltage) is applied, self-healing will happen continuously. Upon such occasion, the film may be melted and carbonized by discharging energy, thus leading not to complete short-circuiting, but to short-circuiting with resistance value.

**) Upon occurrence of short-circuiting with resistance value, if some of the conditions deemed to be its probable causes are combined with each other or critical, it may sometimes lead to fuming and/or ignition.　Particularly for the laminated type, it is necessary to pay due attention to overvoltage because the withstand voltage in the portion having been cut upon formation of capacitor elements is low.

･Concrete example
The product of evaporated electrode with extended foil structure became open after 8 years operation in the field.
→ Results of analysis: Judging from the fact that the evaporated metal has been almost lost, it is supposed to have been used in high humidity environment.

9. Safety and Conforming to Environmental

9-1 Safety

Countermeasures against fuming and ignition of evaporated electrode type

・Improvement in screening accuracy by charging/discharging test and tanδ measurement at higher frequency
・Improvement of safety by attaching security mechanism to vapor deposition pattern.(for electrical equipment and anti-noise)

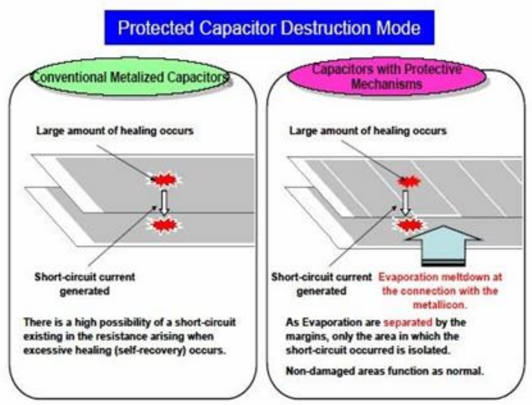


Fig.8 Structure and destruction mode of security mechanism

9-2 Conforming to Environmental

Please refer here with regard to conforming to environmental of film capacitors.

10. Additional Information

10-1 Service Life of Capacitors

(1) Failure rate calculation

Since electrolyte is not used in film capacitors, there is no lifetime due to dry-up like aluminum electrolytic capacitors, and therefore it is considered reasonable to express by failure rate in general. Failure rate has a dependence on temperature and voltage, and according to the literature, it is calculated following relational expression (formula 4), but the numerical value calculated by these is an estimated value, and it does not guarantee this.

$$\lambda = \lambda_0 \cdot \left(\frac{V_{op}}{V_{ref}} \right)^{\gamma} \cdot 2^{\frac{T_{op}-T_{ref}}{10}} \qquad \cdots\cdots\cdots 4$$

λ	: Failure rate under operating condition	
λ_0	: Failure rate under reference condition	
V_{op}	: Operating voltage	(Vdc)
V_{ref}	: Reference voltage (Test voltage)	(Vdc)
γ	: Voltage coefficient	
T_{op}	: Operating temperature	(°C)
T_{ref}	: Reference temperature (Test temperature)	(°C)

(2) Life Calculation for Film Capacitors

For the life of a film capacitor, the Mean Time To Failure(MTTF), which is calculated by the inverse of the failure rate, is used as the basis for the life calculation.

(3) Derating of the Rated Voltage based on the Operating Temperature

If a capacitor is used at high temperatures, its service life will be shortened due to thermal deterioration. In case when a capacitor is to be used at high temperatures, please derate the operating voltage in accordance with the graphs as given below.

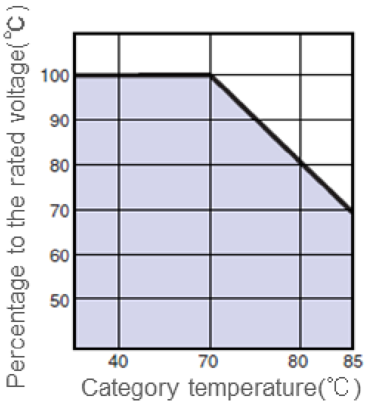


Fig.9-1

Application series

P2S

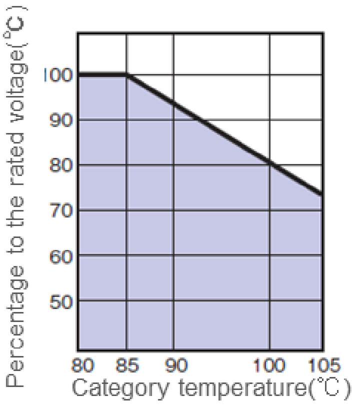


Fig.9-2

Application series

MPK, PCK, MMB, MMG, MMK, F2D

(4) Ripple Current and Service Life

In the case when ripple current is applied on a capacitor, Joule heat will be generated. The capacitor temperature rise on this occasion is given by the Formula 7.

$$\Delta T = \frac{1}{\beta \cdot S} \cdot \frac{I^2 \cdot \tan\delta}{\omega \cdot C} \qquad \cdots\cdots\cdots 5$$

ΔT	: Surface temperature rise of capacitor	(°C)
β	: Radiation coefficient	(W/°C・cm²)
S	: Surface area of capacitor	(cm²)
ω	: Angular frequency(= 2πf)	(rad/s)
C	: Electrostatic capacity of capacitor	(μF)
I	: Ripple current	(Arms)
tanδ	: Dissipation factor of capacitor	

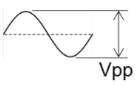
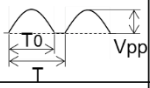
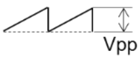
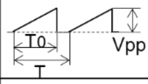
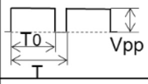
Since significant self-heating of the capacitor may lead to the deterioration and/or damage to the capacitor, self-temperature rise of capacitor should be limited to lower than 15°C for polyester film capacitors and to lower than 10°C for polypropylene film capacitors. When used at high temperature/high frequency, the voltage derating factor is different from that of DC voltage. This is partly due to heating by ripple current is more severe vs. the Arrhenius 10°C Law and for polyester film capacitors etc. the dissipation factor may change with temperature thus leading to the change in self temperature rise.

(5) Allowable Voltage in Various Voltage Waveforms

Allowable voltage in various voltage waveforms varies with the kinds of waveforms and frequency. Allowable voltage shall be the value obtained by multiplying sine wave allowable voltage at each frequency by any of the coefficient as given below. Moreover, in case of the voltage containing DC bias component, the AC voltage obtained by subtracting the bias voltage from the DC rated voltage shall be the allowable value. Then, this voltage should be derated for use depending on the respective frequencies and waveforms.

(In case when the voltage values on the voltage derating curves for various kinds of products are given by effective values, the value obtained by increasing the allowable voltage value by 2 √ 2 shall be the Vp-p value. Then, the value obtained by multiplying it by any of the coefficients as given below shall be the allowable voltage value Vp-p at the frequency of the relevant waveform.)

Table11　Allowable Voltage Coefficient

Kind	1	2	3	4	5	6	7
Waveform							Others
Coefficient	1.0	0.5	$0.5\sqrt{T/T_0}$	0.61	$0.5\sqrt{3T/2T_0}$	$0.5\sqrt{T/2T_0}$	0.5

10-2 Self-Healing (Clearing)

Since an electrode is evaporated as a very thin metal film (about 150 to 400Å) on the dielectric, even if dielectric breakdown is caused on the weakest portion in the dielectric, only the weakest portion and its peripheral portion will be dispersed instantaneously by large current energy and the functions as a capacitor will not be still lost. This phenomenon is called the self-healing.

Higher evaporation resistance and thinner evaporated film bring better self-healing properties. However, this may lead to the poor connection with metallicon and an increase in the ESR in the high frequency zone. Therefore, full investigations should be made on the applications upon its design.

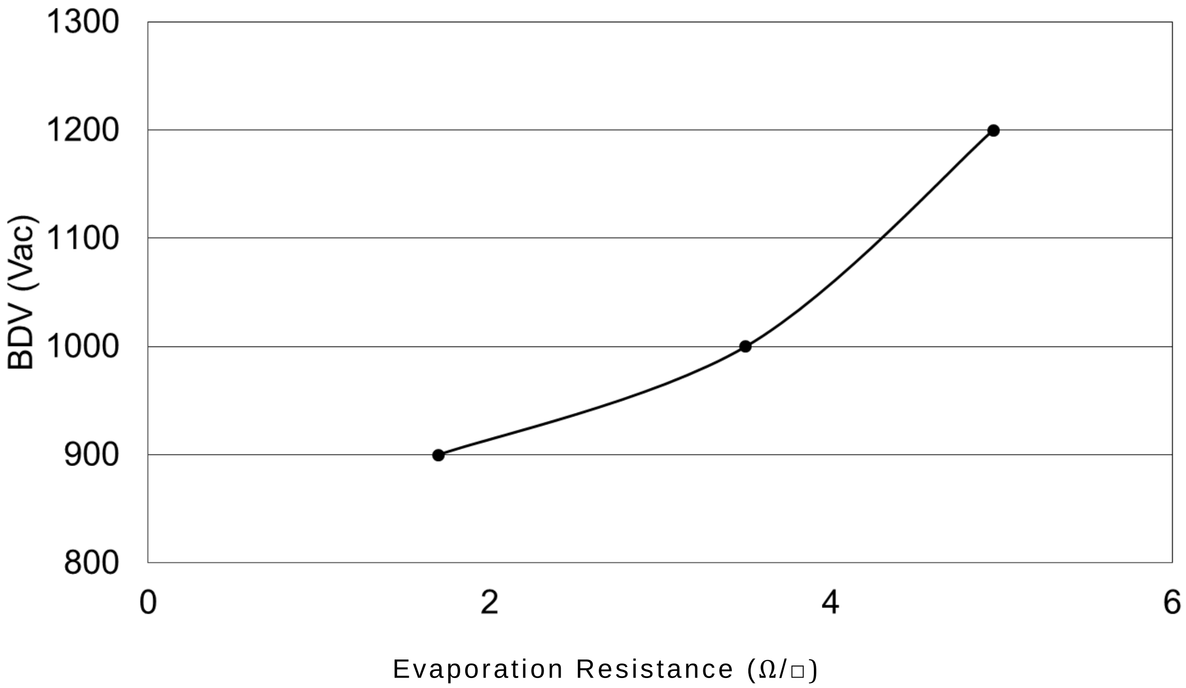


Fig.10 Evaporation Resistance and AC Break-down Voltage

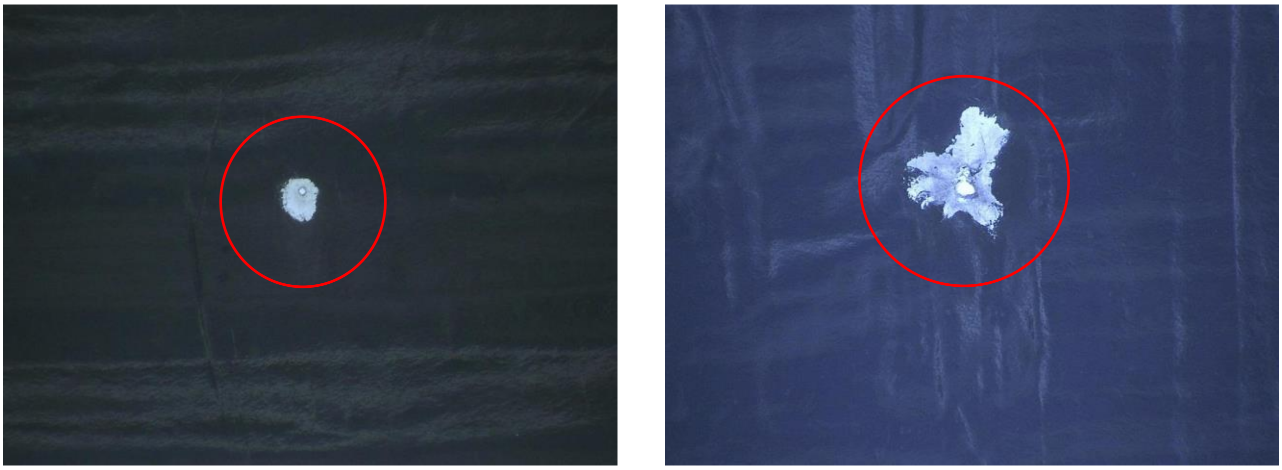


Photo1 Self-Healing Point

Self-healing means the recovery of capacitor insulation. It does not mean that the disappeared evaporated metal film regenerates and recovers (Insulation is recovered by local disappearance of the deposited metal film around the insulation defect portion.).