Characteristics and Definitions used for Film Capacitors

COMMON FILM DIELECTRICS USED IN FILM CAPACITORS PRODUCTS

PARAMETER	DIELECTRIC (1)				UNIT
	KT	KN	KI	KP	
Dielectric constant 1 kHz	3.3	3	3	2.2	-
Dissipation factor 1 kHz	50	40	3	1	10^{-4}
Dissipation factor 10 kHz	110	70	6	2	10^{-4}
Dissipation factor 100 kHz	170	100	12	2	10^{-4}
Dissipation factor 1 MHz	200	150	18	4	10^{-4}
Volume resistivity	10^{+17}	10^{+17}	10^{+17}	10^{+18}	Ωcm
Dielectric strength	400	300	250	600	V/µm
Maximum application temperature	125	150	160	125	°C
Power density at 10 kHz	50	40	2.5	0.6	W/cm^3
Dielectric absorption	0.2	1.2	0.05	0.01	%

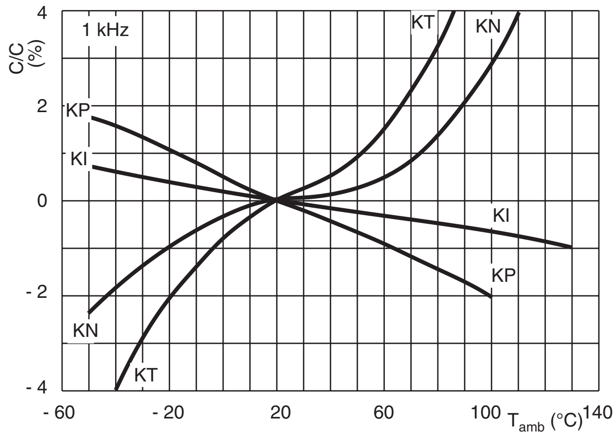
Notes

(1) According to *"IEC 60062"*: KT = polyethylene terephthalate (PETP)
KN = polyethylene naphtalate (PEN)
KI = polyphenylene sulfide (PPS)
KP = polypropylene (PP)

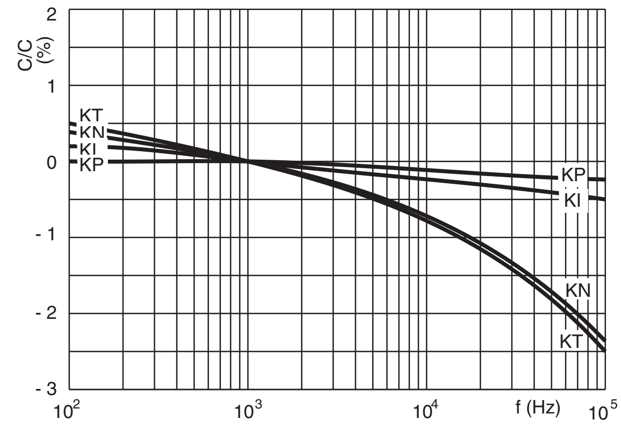
- Polyethylene terephthalate (PETP) and polyethylene naphtalate (PEN) films are generally used in general purpose capacitors for applications typically with small bias DC voltages and/or small AC voltages at low frequencies.
- Polyethylene terephthalate (PETP) has as its most important property, high capacitance per volume due to its high dielectric constant and availability in thin gauges.
- Polyethylene naphtalate (PEN) is used when a higher temperature resistance is required compared to PET.
- Polyphenylene sulfide (KI) film can be used in applications where high temperature is needed eventually in combination with low dissipation factor.
- Polypropylene (KP) films are used in high frequency or high voltage applications due to their very low dissipation factor and high dielectric strength. These films are used in AC and pulse capacitors and interference suppression capacitors for mains applications.
- Typical properties as functions of temperature or frequency are illustrated in the following chapters: "Capacitance", "Dissipation factor", and "Insulation resistance."

CAPACITANCE

Capacitance change at 1 kHz as a function of temperature (typical curve)

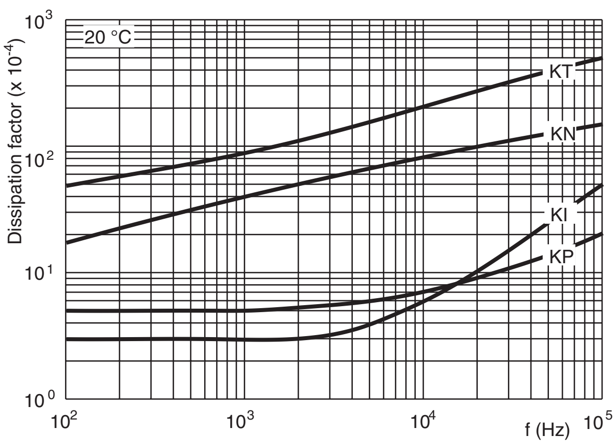


Capacitance change at 1 kHz as a function of frequency at room temperature (typical curve)

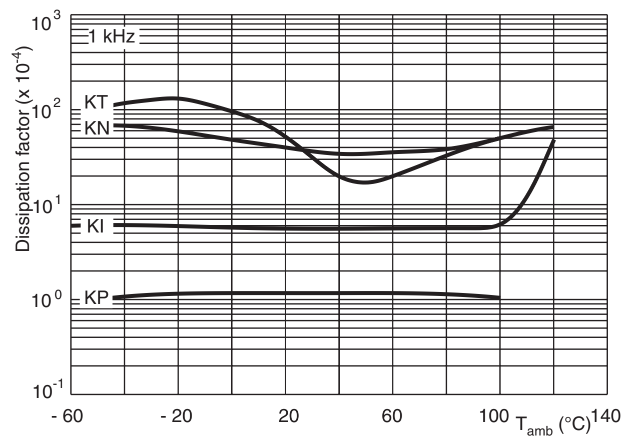


DISSIPATION FACTOR

Dissipation factor as a function of frequency at room temperature (typical curve)

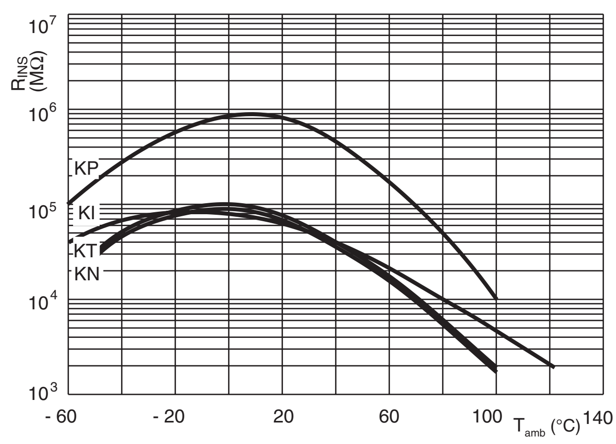


Dissipation factor as a function of temperature (typical curve)



INSULATION RESISTANCE

Insulation resistance as a function of temperature (typical curve)



CONSTRUCTION OF CAPACITORS CELLS

Film capacitors are build up by two electrodes (the capacitor plates) with plastic dielectric material in between.

The type of electrode used determines whether the capactor is a metalized film or film/foil type. In metalized types, the very thin electrode is evaporated on the plastic dielectric material. The thin metalized electrodes have a thickness of approximately 10 nm to 50 nm. The electrodes of film/foil capacitors have discrete metal foils with thicknesses of approximately 5 µm to 10 µm.

Metalized capacitors have a self-healing behavior as an intrinsic characteristic. Self healing is the ability to recover after a dielectric breakdown.

Due to their construction, very thick electrodes, film/foil capacitors can carry higher currents than metalized types, but are much larger in volume. These capacitors can not recover after a breakdown.

Therefore In some constructions double side metalized plastic film is used as electrode to replace the foil. The plastic material has only the function of carrier: the self healing properties are maintained and the current carrying capability is increased a lot in comparison with single metalized types.

Depending on the AC voltage in the application, single or series constructions are used. In a series construction two or more sections are placed internally in series in one capacitor. Single section capacitors are normally used for products with an AC rating up to 300 Vac. Series construtions are used for higher voltages.

The end connection of the capacitor cell to the outside circuit is realized by metal sprayed end connections wherein lead wires or tabs are welded.

ENCAPSULATION

Finally the capacitor cells can be protected for severe environmental conditions or to withstand passive flammability. Encapsulation with epoxy materials in plastic boxes is common used for fixed outline dimensions. Epoxy dipped capacitors have a more rounded and easy to handle shape. All these encapsulations are flame retardant materials fulfilling the UL 94 classification system. Axial types are typically of the wrapped end construction. An extra wrapped film and epoxy at the end connections protects the cell.

GENERAL DEFINITIONS

Rated DC voltage (U_{Rdc})

The maximum DC voltage (in V) which may be continuously applied to a capacitor at any operating ambient temperature below the rated temperature.

Category voltage (U_C)

The maximum AC voltage (or DC voltage) that may be applied continuously to a capacitor at its upper category temperature.

Rated AC voltage (U_{Rac})

The maximum RMS voltage (in V) at specified frequency (mostly 50 Hz), that may be continuously applied to a capacitor at any operating ambient temperature below the rated temperature.

Corona starting voltage (Ionization)

In AC voltage applications or in rapid changing DC voltages (pulses) air can be ionized and partially break down.

The corona starting voltage is defined as the AC voltage at which electrical discharges resulting from the ionization of air on the surface or between the capacitor plates can be detected . Its value is dependent upon the internal design of the capacitor element, the dielectric material, and the thickness of the film. The usage of series wound capacitors increases the corona voltage level.

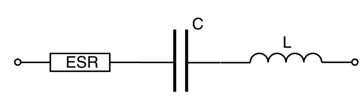
Where applicable the corona starting voltage is typically defined with a certain sensitivity in pC (Pico-Coulomb).

Impulse voltage

An impulse voltage is an a-periodic transient voltage of a defined waveform as described in IEC 60060-1

Capacitance

The capacitance of a capacitor is the capacitive part of the equivalent circuit composed of capacitance, series resistance and inductance.



Rated capacitance

The rated capacitance, normally marked on the product, is the value for which the capacitor has been designed.

Capacitance tolerance

The percentage of the allowed deviation of the capacitance from the rated capacitance. This is measured at a free air ambient temperature of 23 ± 1 °C and RH of 50 ± 2 %.

Tolerance coding in accordance with *"IEC 60062"*

PERCENTAGE OF DEVIATION	LETTER CODE
± 1.0 %	F
± 2.0 %	G
± 5.0 %	J
± 10.0 %	K
± 20.0 %	M

A letter "A" indicates that the tolerance is deviasting from the standard definitions in the type specification or customer detail specification.

Temperature coefficient and cyclic drift of capacitance

The terms characterizing these two properties apply to capacitors for which the variations of capacitance as a function of temperature are linear, or approximately linear, and can be expressed with a certain precision.

Temperature coefficient of capacitance

The rate of capacitance change with temperature, measured over the specified temperature range. It is normally expressed in parts per million per Kelvin (10^{-6}/K).

Temperature cyclic drift of capacitance

The maximum irreversible variation of capacitance observed at room temperature during or after the completion of a number of specified temperature cycles. It is usually expressed as a percentage of the capacitance related to a reference temperature. This is normally 20 °C.

Rated voltage pulse slope (dU/dt)

The maximum voltage pulse slope that the capacitor can withstand with a pulse voltage equal to the rated voltage. For pulse voltages other than the rated voltage, the maximum voltage pulse slope may be multiplied by U_{Rdc} and divided by the applied voltage or:

$$U_{signal} \times (dU/dt)_{signal} < U_{Rdc} \times (dU/dt)_R$$

For complex signals with ringing it is always a must to use following formula:

The voltage pulse slope multiplied by the capacitance gives

$$2 \times \int_0^T \left(\frac{dU}{dt}\right)^2 \times dt < U_{Rdc} \times \left(\frac{dU}{dt}\right)_{rated}$$

the peak current for the capacitor.

Dissipation factor and equivalent series resistance

The dissipation factor or tangent of loss angle (tan δ) is the power loss of the capacitor divided by the reactive power of the capacitor at a sinusoidal voltage of specified frequency.

The equivalent series resistance (ESR) is the resistive part of the equivalent circuit composed of capacitance, series resistance and inductance.

The tan δ reflects the polarization losses of the dielectric film and the losses caused by the internal contact resistances (terminal, metal spray, electrodes) of the capacitor. Parallel losses cam in general be neglected at frequencies higher than 1 kHz, due to the high insulation resistance. The tan δ is temperature and frequency dependant.

The reciprocal value of tan δ is also known as Q-factor.

$$Q = 1/\tan \delta$$

Insulation resistance and time constant

The insulation resistance (R_{ins}) is defined by the applied DC voltage divided by the leakage current after a well defined minimum time.

The time constant is the product (in s) of the nominal capacitance and the insulation resistance between the leads.

Equivalent self inductance

The equivalent self inductance defined at resonance frequency, is calculated as the:

$$1/4 \times \pi \times f_{res}^2 \times C$$

Resonance frequency

The lowest frequency at which the impedance of the capacitor is a minimum when applying a sinusoidal voltage.

Ambient free air temperature

The ambient free air temperature is the temperature of the air surrounding the component.

Climatic category

The climatic category code (e.g. 50/100/56) indicates to which climatic category a film capacitor type belongs. The category is indicated by a series of three sets of digits separated by oblique strokes corresponding to the minimum ambient temperature of operation, the maximum temperature of operation, and the number of days of exposure to damp heat (steady state-test Ca) respectively that they will withstand.

Category temperature range

The range of ambient temperatures for which the capacitor has been designed to operate continuously. This is defined by the temperature limits of the appropriate category.

Upper category temperature

The maximum ambient temperature for which a capacitor has been designed to operate continuously at category voltage.

Lower category temperature

The minimum ambient temperature for which a capacitor has been designed to operate continuously.

Rated temperature

The maximum ambient temperature at which the rated voltage may be applied continuously.

Maximum application temperature

The equivalent of the upper category temperature.

Self-healing

The process by which the electrical properties of a metalized capacitor, after a local breakdown, are rapidly and essentially restored to the values before the breakdown.

Temperature characteristic of capacitance

The term characterizing this property applies mainly to capacitors for which the variations of capacitance as a function of temperature, linear or non-linear, cannot be expressed with precision and certainty.

The temperature characteristic of capacitance is the maximum reversible variation of capacitance, produced over a given temperature range within the category temperature range.

It is expressed normally as a percentage of the capacitance related to a reference temperature of 20 °C.

Storage temperature

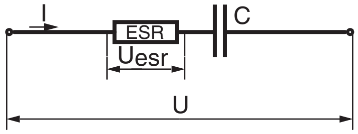
The temperature range with relative humidity RH of maximum 80 % without condensation at which the initial characteristics can be guaranteed for at least 2 years.

Maximum power dissipation

The power dissipated by a capacitor is a function of the voltage (U_{esr}) across or the current (I) through the equivalent series resistance ESR and is expressed by:

$$P = \frac{U_{esr}^2}{ESR}$$

$$P = ESR \times I^2$$



$$U_{esr}^2 = \frac{ESR^2}{ESR^2 + 1/\omega^2 C^2} \times U^2$$

Given that for film capacitors $\tan\delta = \omega^2 \times C \times ESR \ll 0.1$ the formula can be simplified to:

$$U_{esr}^2 = ESR^2 \times \omega^2 \times C^2 \times U^2$$

or with $ESR = \tan\delta/\omega C$

the formula becomes:

$$P = \omega \times C \times \tan\delta \times U^2$$

$$P = \frac{\tan\delta}{\omega \times C} \times I^2$$

For the $\tan\delta$ we take the typical value found in the specification, C is in farads and $\omega = 2\pi f$. U or I are assumed to be known.

In applications where sinewaves occur, we have to take for U the RMS-voltage or for I the RMS-current of the sinewave.

In applications where periodic signals occur, the signal has to be expressed in Fourier terms:

$$U = U_0 + \sum_{k=1}^{\infty} U_k \times \sin(k\omega t + \Phi k)$$

$$I = \sum_{k=1}^{\infty} I_k \times \sin(k\omega t + \Phi k)$$

with U_0 the DC voltage, U_k and I_k (the voltage and current of the k-th harmonic respectively) the formula for the dissipated power becomes:

$$P = \sum_{k=1}^{\infty} \frac{\tan\delta_k \times I_k^2}{2 \times k \times \omega \times C}$$

$$P = \sum_{k=1}^{\infty} k \times \omega \times C \times \tan\delta_k \times \frac{U_k^2}{2}$$

and $\tan\delta_k$ is the $\tan\delta$ at the k-th harmonic.

TEST INFORMATION

Robustness of leads

Tensile strength of leads (Ua) (load in lead axis direction)
Lead diameter 0.5 mm, 0.6 mm and 0.8 mm: load 10 N, 10 s.
Bending (Ub)
Lead diameter 0.5 mm, 0.6 mm and 0.8 mm: load 5 N, 4 x 90°.
Lead diameter 1.0 mm: load 10 N, 4 x 90°.
Torsion (Uc) (for axial capacitors only)
Severity 1: three rotations of 360°.
Severity 2: two rotations of 180°.

Rapid change of temperature (Na)

The rapid change of temperature test is intended to determine the effect on capacitors of a succession of temperature changes and consists of 5 cycles of 30 min at lower category temperature and 30 min at higher category temperature.

Dry heat (Ba)

This test determines the ability of the capacitors to be used or stored at high temperature. The standard test is 16 h at upper category temperature.

Damp heat cyclic (Db)

This test determines the suitability of capacitors for use and storage under conditions of high humidity when combined with cyclic temperature changes and, in general, producing condensation on the surface of the capacitor.
One cycle consists of 24 h exposure to 55 °C and 95 % to 100 % relative humidity (RH).

Cold (Aa)

This test determines the ability of the capacitors to be used or stored at low temperature. The standard test is 2 h at the lower category temperature.

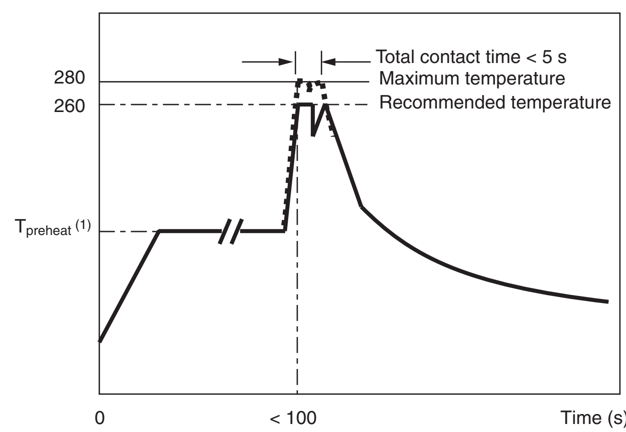
Damp heat steady state (Ca)

This test determines the suitability of capacitors for use and storage under conditions of high humidity.
The test is primarily intended to permit observation of the effects of high humidity at constant temperature over a specified period.
The capacitors are exposed to a damp heat environment, which is maintained at a temperature of 40 °C and an RH of 90 % to 95 % for the number of days specified by the third set of digits of the climatic category code.

Soldering conditions and recommended wave soldering profile

With regard to the resistance to soldering heat and the solderability, our products comply with *"IEC 60384-1"* and the additional type specifications.
For precision capacitors where capacitance stability is important, we refer to the paragraph "Soldering Conditions" in the type specification.
Recommended wave soldering profile for our leaded components:

Temperature (°C)



Note
(1) The preheating temperature must be restricted to the maximum application temperature of the component

Solvent resistance of components

Soldered capacitors may be cleaned using appropriate cleansing agents, such as alcohol, fluorhydro-carbons or their mixtures. Solvents or cleansing agents based on chlorohydrocarbons or ketones should not to be used, as they may attack the capacitor or the encapsulation.
After cleaning it is always recommended to dry the components carefully.

Passive flamability

The ability of a capacitor to burn with a flame as a consequence of the application of an external source of heat according to IEC 60384-1 and IEC 60695-2-2.

Category of flammability	Severities flame exposure time (s) for capacitor volume (V) (mm^3)				Maximum permitted burning time (s)	Additional requiremented
	V = 250	250 < V = 500	500 = < V = 1750	V = 1750		Burning droplets or glowing parts falling down shall not ignite the tissue paper
A	15	20	60	120	3	
B	10	20	30	60	10	
C	5	10	20	30	30	

Active flammability

The ability of the capacitor to burn with a flame as a consequence of electrical loading (self heating effect).