1 Introduction

This data book describes fixed capacitors with plastic film dielectrics. The characteristics and application possibilities of such film capacitors, which are also termed
FK capacitors,
are effected so strongly by the dielectric used that the capacitors are grouped and designated according to the type of dielectric.

1.1 Classification of film capacitors

Short identification codes for the type of construction, describing the dielectric and the basic technology applied, are defined in DIN 41 379.
The last character in the short code indicates the type of dielectric:
T ≙ Polyethylene terephthalate (PET)
P ≙ Polypropylene (PP)
N ≙ Polyethylene naphthalate (PEN)

An M (≙ Metallization) is prefixed to the short identification code of capacitors with metallized films.

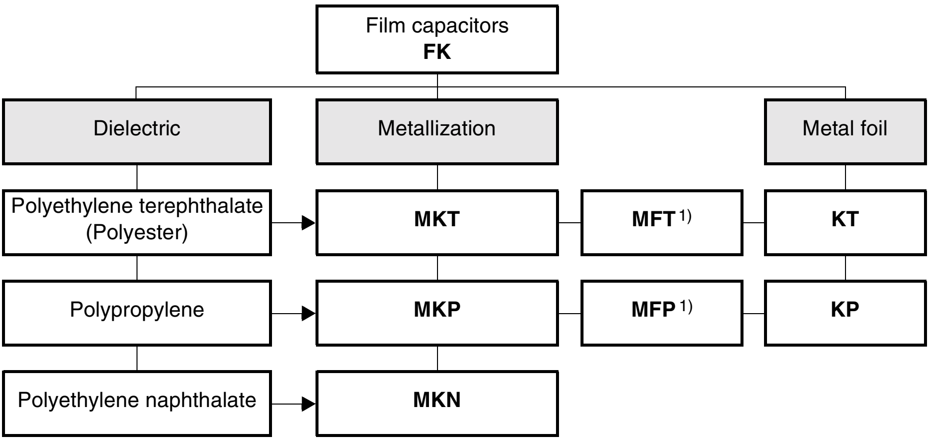


Fig. 1 Classification of film capacitors according to DIN 41 379

Our product range covers all capacitor types shown in figure 1, with the exception of KT and KP capacitors.

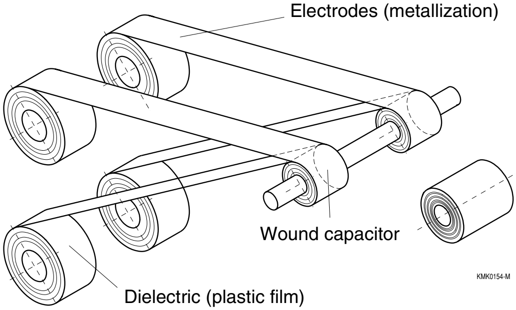
1) MFP and MFT capacitors are constructed using a combination of metal foils and metallized plastic films. They are not covered by DIN 41 379.

1.2 Basic construction

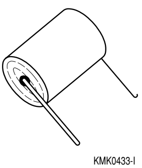
FK capacitors are produced using either winding methods or stacking methods.

1.2.1 Capacitor winding technology

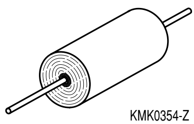
In the conventional production process, the capacitors are made by individually rolling the metallized films or the film/foils into cylindrical rolls and then covering them with an insulating sleeve or coating.



Wound capacitor, radial leads



Wound capacitor, axial leads



In the MKT, MKP and MFP type series, our production range includes capacitors with space-saving flat wound bodies with insulating coatings or in plastic cases, as well as cylindrical wound capacitors. Flat windings are produced by compressing the cylindrical rolls before they are placed in the casings, so that the casing form is optimally used.

1.2.2 Stacked-film technology

In stacked-film production technology, large rings of metallized film are wound onto core wheels (with diameters of up to 60 cm). In this way, the “master capacitors” are produced under well-defined and constant conditions.

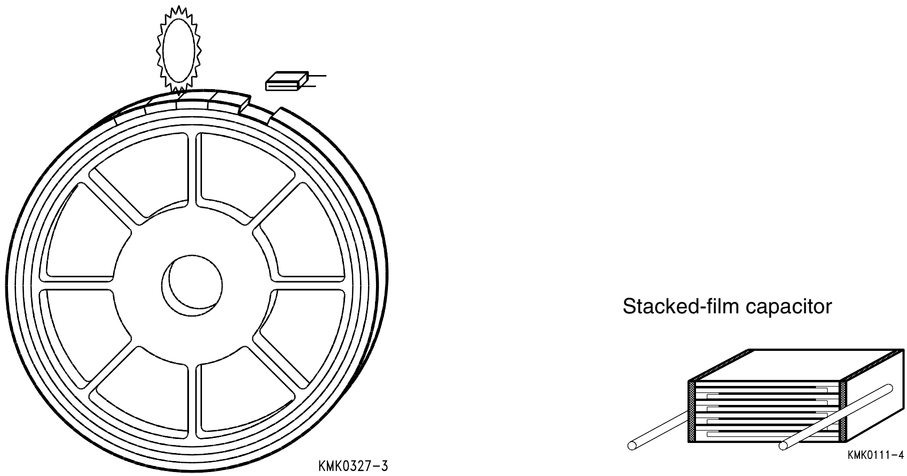


Fig. 2 Stacked-film production technology

As a result, the capacitor production lots obtained when the rings are sawed apart to produce the actual stacked-film capacitor bodies are especially homogenous.

The pulse handling capabilities of stacked-film capacitors are of particular advantage. Since each individual layer acts as a separate capacitor element, any damage to the contacts due to overloading is restricted to the respective capacitor element and does not affect the entire capacitor, as is the case for wound capacitors.

1.2.3 Foil and film arrangements

To provide a better understanding of the differences in the internal structure of the capacitors, figure 3 shows some typical foil and film arrangements.

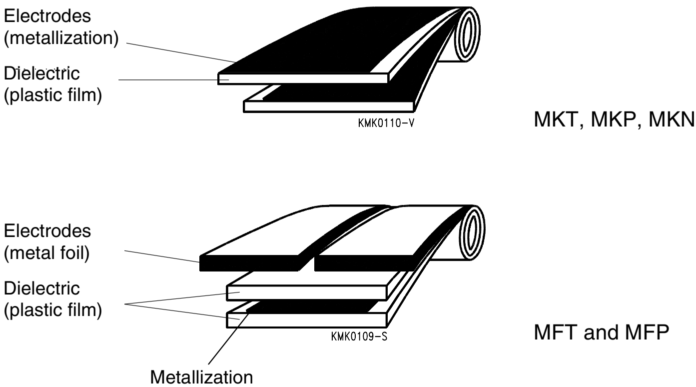


Fig. 3 Examples of typical foil and film arrangements

The relation between various foil and film arrangements and the capacitor types is shown in figure 4.

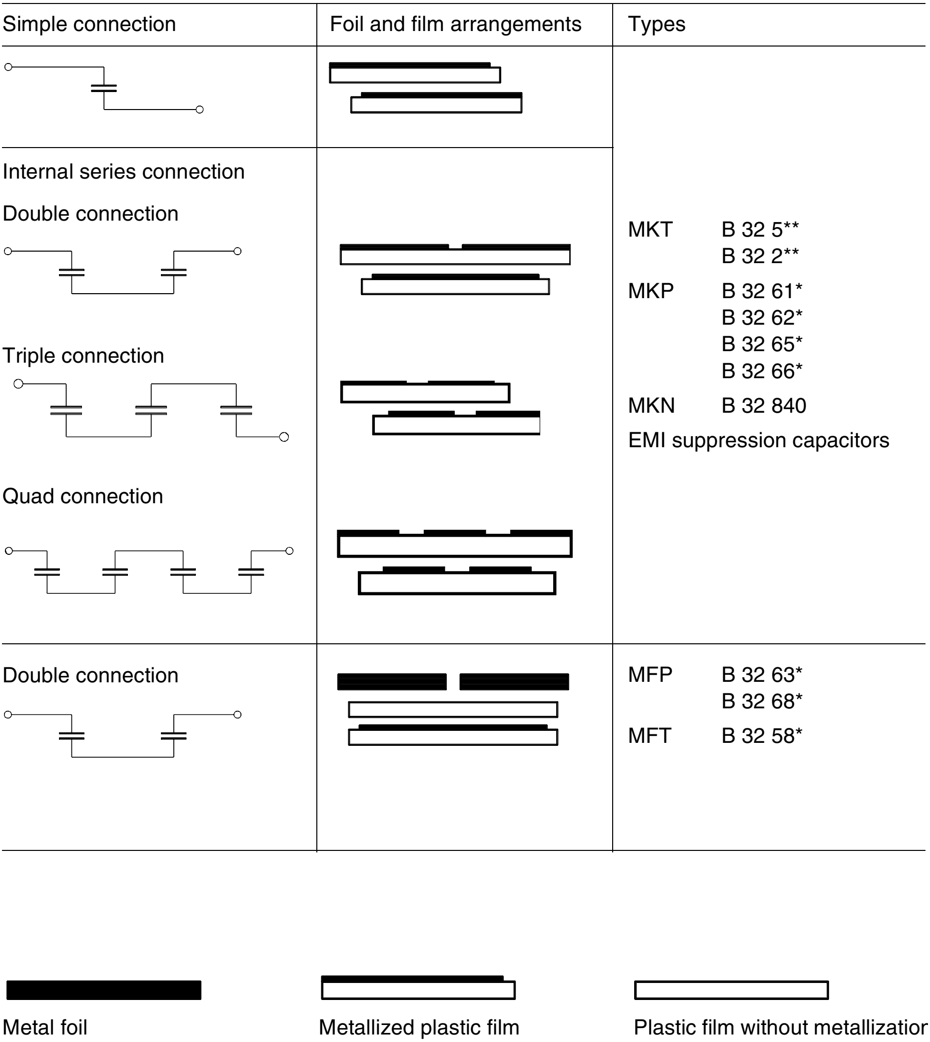


Fig. 4   Schematic foil and film arrangements of various capacitor types

1.2.4 Metallized film capacitors

Capacitors with metallized plastic film have a decisive advantage over capacitors with metal foil electrodes: they have self-healing properties.

- These self-healing properties permit utilization of the full dielectric strength of the dielectric materials of metallized film capacitors, whereas metal-foil electrode capacitors must always be designed with a safety margin to allow for any possible faults in the dielectric.
- Metallized types thus have a distinct size advantage, which is particularly apparent with the larger capacitance ratings.
- With metallized-film designs, it is also possible to implement even complicated capacitor arrangements, e.g. multiple internal series connection to cope with high dc voltages coupled with high ac load capabilities.
- The combination of metal foils, metallized and plain film used in MFP and MFT capacitors gives an extremely high current carrying capability together with self-healing properties.

1.2.5 Self-healing

The metal coatings, which are vacuum-deposited directly onto the plastic film, have a thickness of only 20 … 50 nm. If the dielectric breakdown field strength is exceeded locally at weak points, at pores or impurities in the dielectric, a dielectric breakdown occurs. The energy released by the arc discharge in the breakdown channel is sufficient to totally evaporate the thin metal coating in the vicinity of the channel. The rapid expansion of the plasma in the breakdown channel causes it to cool after a few microseconds, thus quenching the discharge. The insulated region thus resulting around the former faulty area will cause the capacitor to regain its full operation ability.

Since the absence of any form of pressure in the individual dielectric layers and a good homogeneity improves the self-healing properties, stacked-film capacitors have better self-healing properties than wound capacitors.

Note:

At low voltages, anodic oxidation of the metal coatings leads to an electrochemical self-healing process.

1.3 Characteristic properties

Different dielectrics and various foil and film arrangements enable a wide variety of characteristics to be achieved. A table of general typical values for comparison purposes is shown on page 10.

1.4 Capacitor designs and types of terminal

A variety of standard designs with corresponding types of terminal are available to suit different applications and operating environments.

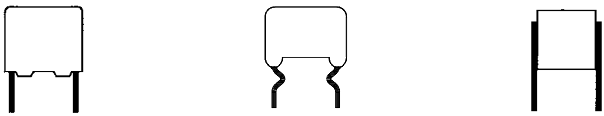
Stacked-film capacitors and wound capacitors, radial leads:

sealed in plastic case

coated (powder dipped)

Stacked-film capacitors, radial leads:

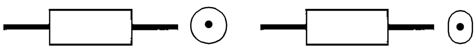
uncoated (SilverCap)



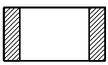
Wound capacitors, axial leads:

cylindrical winding

flat winding



Surface-mount capacitors (SMD)



Customized capacitors

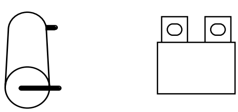


Fig. 5 Capacitor designs

Stacked-film capacitors (partially coated or uncoated) with special dimensions

These components have the special advantage that they can be adapted to the customer's design requirements in an almost unlimited range of sizes without having to take consideration of case size standards or provide special tools for special casings.

Design rules:
The lead spacing (capacitor length *l*) is determined by the dielectric film cut-off width. However, the width *b* and height *h* can be adjusted within the following value range:

Lead spacing e mm		7,5	10	15	22,5	27,5
Width (*b*) (mm)	min.	1,5	1,5	2,5	4	4
	max.	11	11	16	18	18
Height (*h*) (mm)	min.	3,5	3,5	4	6	6
	max.	13	13	20	25	25

In so doing the volume must remain approximately the same.

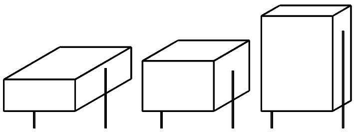


Fig. 6 Examples of special capacitors dimensions for same capacitance and voltage rating

2 Capacitance

2.1 Rated capacitance / measuring conditions

The rated capacitance C_R of a capacitor is the value which is indicated upon it.

The capacitance is measured under standard ambient conditions in accordance with IEC 60068-1, section 5.3. In case of doubt, the measurements have to be carried out under the referee climate conditions in accordance with IEC 60068-1, section 5.2.

The measuring frequency is chosen in accordance with section 4.2.2 of the respective sectional specification. The reference temperature is 20 °C (according to IEC 60068-1, section 5.1).

Measuring conditions	Standard conditions	Referee conditions
Temperature	15 °C … 35 °C	(23 ± 1) °C
Relative humidity	45 % … 75 %	(50 ± 2) %
Ambient atmos. pressure	86 kPa … 106 kPa	86 kPa … 106 kPa
Frequency	1 kHz	1 kHz
Voltage	$0{,}03 \cdot V_R$ (max. 5 V)	$0{,}03 \cdot V_R$ (max. 5 V)

Prior to being measured, a capacitor must be stored under measuring conditions until the entire capacitor has reached the measuring temperature and humidity.

2.2 Variation of capacitance with temperature

The capacitance of an FK capacitor will undergo a reversible change within a range of temperatures between the upper and lower category temperatures. The gradient of the capacitance/temperature curve is given by the temperature coefficient α_c of the capacitance. This is essentially determined by the properties of the dielectric and of the electrode foils, as well as by the capacitor construction and the manufacturing parameters. Polypropylene capacitors have negative temperature coefficients, i.e. the capacitance decreases with increasing temperature, polyester capacitors have positive temperature coefficients.

The temperature coefficient α_c is defined as the average capacitance change, in relation to the capacitance measured at (20 ± 2) °C, occurring within the temperature range $T_1 \dots T_2$. It is expressed in units of 10^{-6}/K.

$$\alpha_C = \frac{C_2 - C_1}{C_3 \cdot (T_2 - T_1)}$$

C_1 Capacitance measured at temperature T_1

C_2 Capacitance measured at temperature T_2

C_3 Reference capacitance measured at (20 ± 2) °C [1)]

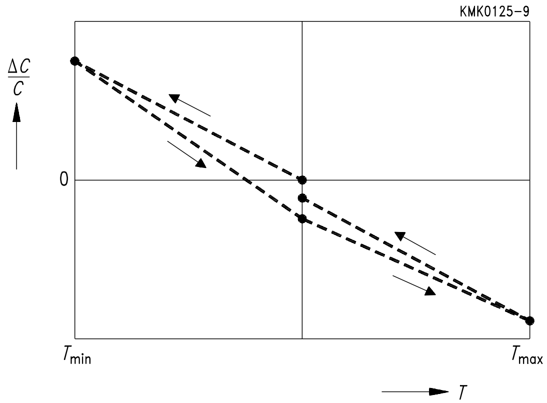


Fig. 7 Capacitance change versus temperature (schematic curve)

1) In accordance with IEC 60384-1, section 4.24.1 and CECC 30 000, section 4.24.1

If a capacitor is subjected to a temperature cycle from the reference temperature to T_{min}, up to T_{max} and back to the reference temperature, small differences may be observed between the initial and the final capacitance (cf. figure 7).

This temperature-curve deviation is designated as the capacitance drift in sections 4.24.3 of both IEC 60384-1 and CECC 30000.

Generally, when making the measurements, it must be taken into consideration that every temperature change is accompanied by a relative humidity change, which will affect the measurement with the humidity effect time constant, depending on the capacitor type (also refer to chapter 2.4). The change in α_c caused by the humidity variations remain within the scatter limits specified for α_c if measurements are carried out under standard conditions and the temperature cycles are not too long.

Figure 8 shows typical temperature characteristics of the capacitances of different capacitor styles.

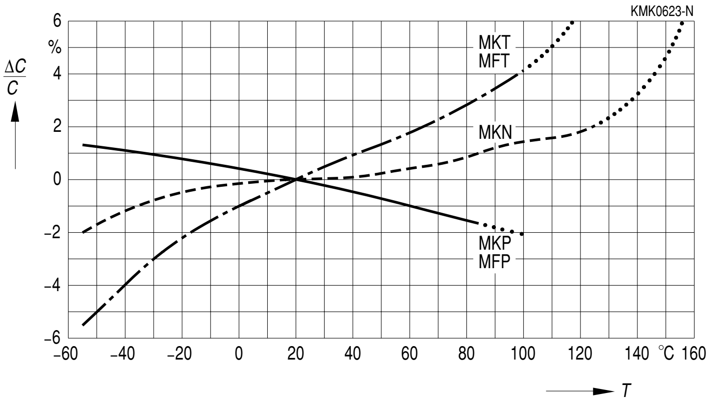


Fig. 8 Relative capacitance change ΔC/C versus temperature *T* (typical values)

2.3 Variation of capacitance with humidity

The capacitance of a plastic film capacitor will undergo a reversible change of value in relation to any change in the ambient humidity. Depending on the type of capacitor design, both the dielectric and the effective air gap between the films will react to changes in the ambient humidity and will thus affect the measured capacitance.

The humidity coefficient β_c is defined as the relative capacitance change determined for a 1 % change in the humidity (at a constant temperature).

$$\beta_c = \frac{2 \cdot (C_2 - C_1)}{(C_2 + C_1) \cdot (F_2 - F_1)}$$

C_1 capacitance value at relative humidity F_1
C_2 capacitance value at relative humidity F_2

The following typical values apply to the humidity coefficients:

Style	Relative humidity range	Humidity coefficient β_c
MKP, MFP capacitors	50% … 95%	+ (40…100) · 10^{-6}/% rel. hum.
MKT, MFT capacitors	50% … 95%	+ (500…700) · 10^{-6}/% rel. hum.
MKN	50% … 95%	+ (700…900) · 10^{-6}/% rel. hum.

Figure 9 shows typical capacitance/humidity characteristics of the different capacitor styles.

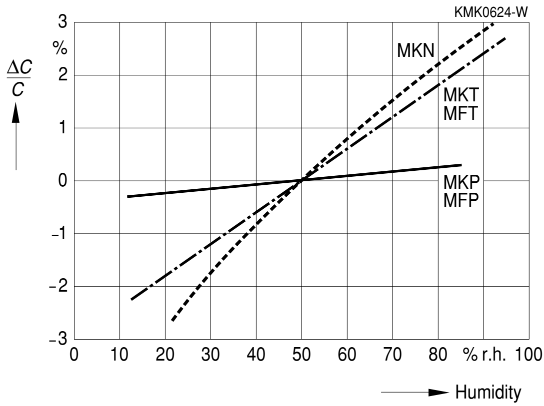


Fig. 9 Relative capacitance change Δ*C/C* versus relative humidity (typical values)

The rate of the moisture absorption and drying processes will vary with time, depending on the water vapor diffusion. The time constant depends on the capacitor type and varies between 1/2 a day (e.g. for capacitors without coating) and several weeks (e.g. for capacitors with plastic cases).

At relative humidities below 30 %, the humidity coefficient is relatively low. Wide variations are to be expected at relative humidities above 85 %.

2.4 Variation of capacitance with frequency

MKT , MFT and MKN capacitors:

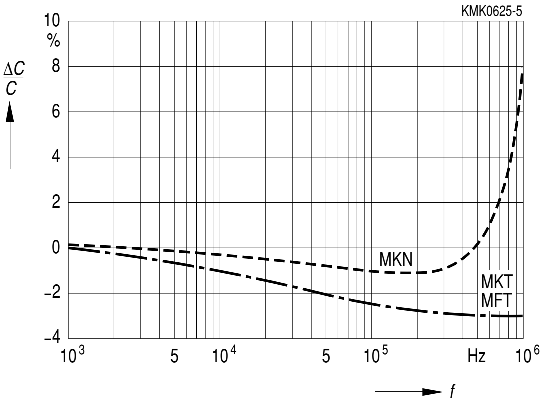


Fig. 10 Relative capacitance change $\Delta C/C$ versus frequency f for MKT, MFT and MKN capacitors (typical example)

MKP and MFP capacitors:

Up to a frequency of 1 MHz, the capacitance remains virtually unaffected by the frequency.

In the vicinity of the natural resonance frequency of the capacitors, the self-inductance leads to an additional decrease of the impedance. This has the same effect as an increase in the capacitance (also refer to the equivalent circuit diagram in chapter 4).

2.5 Variation of capacitance with time

The values stated for the time instability of the capacitance, the capacitance drift $i_z = |\Delta C/C|$ do not take into consideration the reversible effects of temperature changes (α_c) and changes in relative humidity (β_c) and are based on a two-year period.

The capacitance drift may exceed the specified values if the capacitor is subjected to frequent, large temperature changes in the vicinity of the upper category temperature and relative humidity limits.

The following i_z values can be applied as typical values for the various capacitor styles:

Style	MKT, MFT	MKN	MKP, MFP
Capacitance drift i_z (typical values)	3 %	3 %	2 %

3 Voltage and current

3.1 Rated voltage

The rated voltage V_R is the maximum dc voltage which may be applied continuously to the terminals of a capacitor at any temperature between the lower category temperature T_{min} and the rated temperature T_R.

3.2 DC test voltage

The dc test voltage to which the capacitor is subjected in the course of the final inspection test in production (100% electrical inspection) is stated for each type. The test may be repeated once as an incoming goods inspection test.

This dc test voltage also applies to the qualification approval test (duration: 60 s) and to the lot-by-lot quality conformance inspection (duration ≤ 2 s). An exception is made in the case of EMI suppression capacitors, for which the (lower) test voltages specified in the respective standards apply.

For details on the test circuit and equipment, refer to CECC 30 000 or IEC 60384-1, section 4.6 in both documents.

3.3 Maximum continuous voltage (category voltage)

The maximum voltage which may be applied continuously to a capacitor in the temperature range between the lower category temperature T_{min} and the rated temperature T_R is equal to the rated dc voltage V_R. In the temperature range between the rated temperature T_R and the upper category temperature T_{max} a voltage derating as shown in figure 11 and figure 12 must be applied. At the upper category temperature, the maximum continuous voltage is equal to the category voltage V_C.

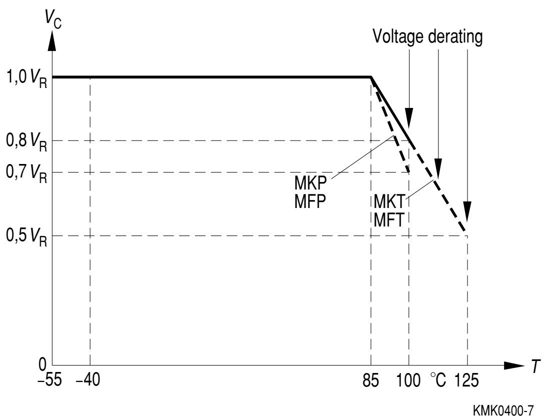


Fig. 11 Maximum permissible continuous voltage in relation to the temperature T for MKT, MFT, MKP and MFP capacitors

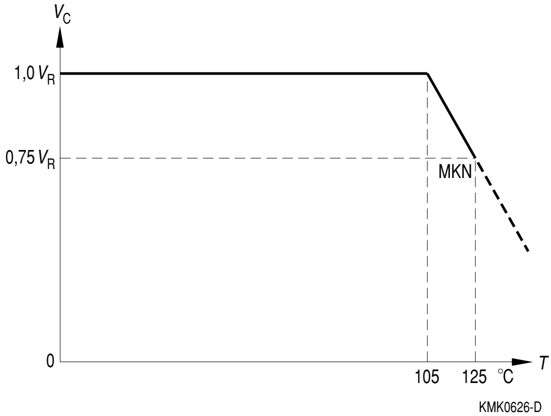


Fig. 12 Maximum permissible continuous voltage in relation to the temperature T for MKN capacitors

3.4 Alternating voltage, alternating current

The ability of a capacitor to withstand a continuous (sine-wave) alternating voltage load V_{rms} or alternating current I_{rms} is a function of the frequency and is limited by three different factors (refer to figure 13):

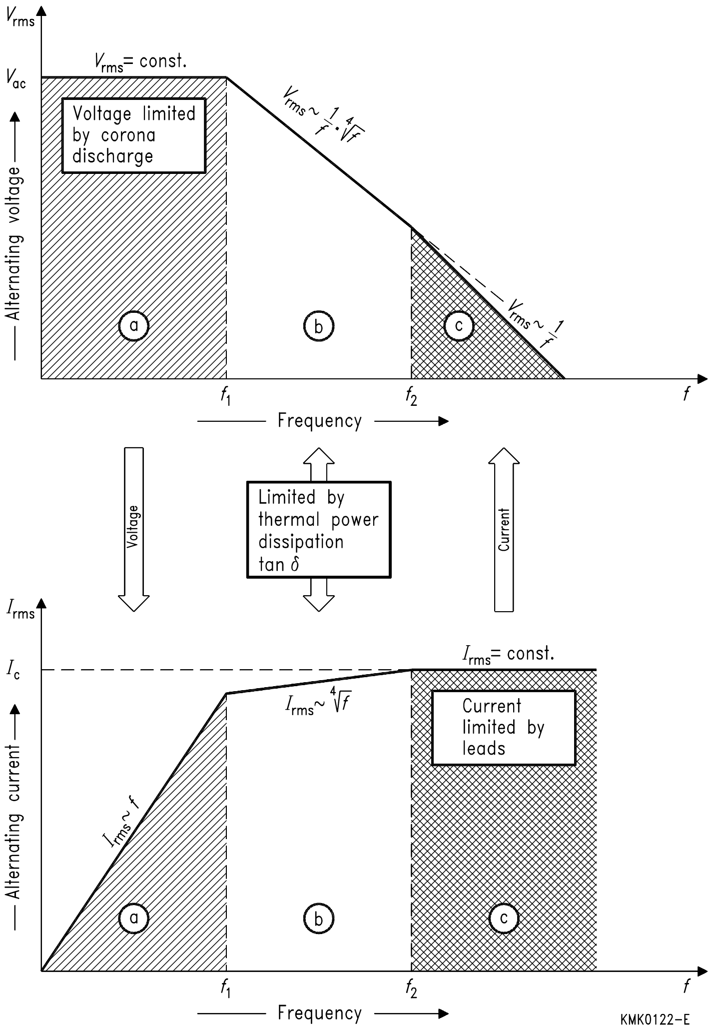


Fig. 13 Alternating voltage and alternating current load limits

Region ⓐ: Limit at which corona discharges start to occur, V_{CD}:

Below a certain frequency limit f_1 the applied ac voltage V_{rms} should not exceed the threshold voltage V_{CD} at which corona discharges (partial discharges) would start to occur with some intensity in air pockets in the capacitor and thus eventually endanger its dielectric strength. The following relation must be taken into consideration:

$V_{rms} \leq V_{CD}$ i.e. $I_{rms} \leq V_{CD} \cdot 2\Pi \cdot f \cdot C$

This voltage limit is determined, above all, by the internal construction of the capacitors (which determines the field strength at the edges); it also depends, to a lesser extent, on the thickness of the dielectric. This voltage limit can be raised, in particular, by using internal series connection designs.

Region ⓑ: Limit due to thermal power dissipation:

Above the frequency limit f_1 the permissible alternating voltage load must be reduced with increasing frequency in order to keep the power dissipation P_E resulting in the capacitor body:

$P_E = V_{rms}{}^2 \cdot 2\Pi \cdot f \cdot C \cdot \tan\delta$

below the power P_A which can be dissipated in the form of thermal energy by the surface area A of the capacitor:

$P_A = \alpha \cdot A \cdot \Delta T$

where: α = heat transfer coefficient.

In order to prevent permanent damage to the capacitor, the steady-state overtemperature ΔT attained at the hottest part of the capacitor surface in relation to the surrounding atmosphere must not exceed a certain value.

By equating the power generated and the power that can be dissipated as thermal energy:

$P_E = P_A$

the conditions for the maximum permissible alternating voltages and alternating currents in this region can be deduced as:

$$V_{rms} \leq \sqrt{\frac{\alpha \cdot A \cdot \Delta T}{2\Pi \cdot f \cdot C \cdot \tan\delta}} \text{ or } I_{rms} \leq \sqrt{\frac{2\Pi \cdot f \cdot C \cdot \alpha \cdot A \cdot \Delta T}{\tan\delta}}$$

This can be simplified by the following close approximation:

$$V_{rms,\,max} \sim \frac{1}{f} \cdot \sqrt[4]{f} \text{ or } I_{rms,\,max} \sim \sqrt[4]{f}$$

The frequency limit f_1 is the maximum frequency at which the full permissible ac voltage V_{ac} may be applied to the capacitor without the maximum permissible power dissipation being exceeded.

$$f_1 = \frac{\alpha \cdot A \cdot \Delta T}{V^2_{rms,\,max} \cdot 2\Pi \cdot C \cdot \tan\delta} \text{ or } f_1 = \frac{I^2_{rms,max} \cdot \tan\delta}{2\Pi \cdot C \cdot \alpha \cdot A \cdot \Delta T}$$

Thus, within a certain voltage series, the frequency limit f_1 is inversely proportional to the respective capacitance value:

$$f_1 \sim \frac{1}{C}$$

Region ⓒ: Limit due to maximum current handling capability

Above the frequency limit f_2 the permissible ac voltage load is limited by the current limit I_C which is the maximum current that can pass through the terminals effective electrical cross-section of the leads, the metal layers, the sprayed-on metal terminations, contact resistance of soldered and welded joints etc.) without causing overheating due to associated resistive losses.

$$V_{rms} \leq \frac{I_C}{2\Pi \cdot f \cdot C} \text{ or } I_{rms} \leq I_C$$

The frequency limit f_2 is calculated by applying the limit condition:

$$f_2 = \frac{I_C^2 \tan\delta}{2\Pi \cdot C \cdot \alpha \cdot A \cdot \Delta T}$$

In the data sheets for the individual types, several exemplary graphs of the permissible ac loads are shown for various voltage ranges and capacitor sizes.

Usually, practical applications will not involve loads with perfect sine-wave functions. In most cases, however, it is possible to estimate the loads accurately enough by approximating them to sine waves. In extreme cases, the voltage or current curves must be assessed by means of Fourier-analyses. If we are to assist in such cases, please send us scaled graphs.

It must be stated here, though, that the ac load capability figures given in the data sheets are based on very generalized assumptions which do not enable any clear statements to be deduced in critical cases, where this is especially important. In such cases the final decision should always be based on practical testing in the particular circuit.

Note:

Even if the graphs shown for the ac load capability of the capacitors cover the line voltage range, standard film capacitors are basically not suitable for operation in direct connection to public power networks. In this context, we would like to point out the EMI suppression capacitors of the type series B81***/B3292*, which are specially designed for power line applications (refer to chapter on “EMI suppression capacitors”).

3.5 Pulse handling capability, pulse characteristic

Voltage pulses with rapid voltage changes d*V*/d*t* (i.e. high rates of voltage rise) will lead to strong currents *i* (peak current) in the capacitor.

Rate of voltage rise: $\frac{dV}{dt} \approx \frac{V_{pp}}{\tau}$

Peak current: $i = C \cdot \frac{dV}{dt}$

V_{pp} Peak-to-peak voltage
τ Voltage rise or decay time
C Capacitance of capacitor

This current will generate heat in the contact regions between the sprayed-on metal terminations and the metal layers. The heat energy Q generated is calculated by the equation:

$$Q = \int i^2 \cdot R_i \cdot dt$$

R_i Internal resistance

Pulse characteristic k_0

By inserting construction-related parameters of the respective capacitor, a characteristic factor k_0 can be deduced for the capacitor. This so-called pulse characteristic k_0 is:

$$k_0 = 2\int\left(\frac{dV}{dt}\right)^2 dt$$

A good approximation is provided by:

$$k_0 \approx 2\left(\Delta V_1 \cdot \frac{\Delta V_1}{\Delta t_1} + \Delta V_2 \frac{\Delta V_2}{\Delta t_2} + \ldots\right)$$

From this equation, it is clear that the thermal load on the contact areas does not depend on the rate of voltage rise $\Delta V/\Delta t$ alone, but is determined by the product of $\Delta V/\Delta t$ and ΔV.

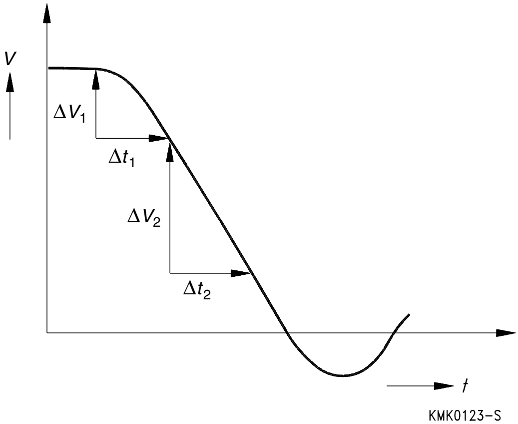


Fig. 14 Voltage-time curve across capacitor

ΔV_1, Δt_1, etc. are the related voltage and time stages of a straight-line polygon approximation of the voltage pulse.

It is also possible to use oscillograms to calculate the pulse characteristic for the respective pulse load waveform to be analysed, as follows:

For pulse-type voltages with straight-line transients (trapezoidal, sawtooth pulses):

$$k_0' = 2 \cdot \frac{V_{pp}^2}{\tau}$$

V_{pp} Peak-to-peak voltage
τ Rise time or decay time of the voltage

For passive and short-circuit-type discharging:

$$k_0' = \frac{V_{ch}^2}{R \cdot C}$$

V_{ch} Charging voltage
R Ohmic resistance of discharge circuit
C Capacitance

The pulse characteristic calculated in this way, k_0', can now be compared to the maximum permissible pulse characteristic k_0 given in the data sheets.

Maximum rate of voltage rise V_{pp}/τ

For the special application case where the capacitor is discharged from the full rated voltage, the maximum permissible rate of voltage rise V_{pp}/τ is given in addition to the respective pulse characteristic k_0.

Example:

MKT stacked-film capacitor B 32 520/lead spacing 7,5 with V_R = 250 V_{dc}:
The maximum permissible pulse characteristic is given as: k_0 = 100 000 $V^2/\mu s$

The maximum permissible rate of voltage rise (rise rate or decay rate) for discharge from the full rated voltage ($V_{pp} = V_R$) is then:

$$\frac{V_{pp}}{\tau} = \frac{k_0}{2 \cdot V_{pp}} = \frac{100000\,\mathrm{V}^2/\mu\mathrm{s}}{2 \cdot 250\,\mathrm{V}} = 200\ \mathrm{V}/\mu\mathrm{s}$$

From the pulse characteristic k_0, it is also possible to calculate the (higher) permissible rate of voltage rise for lower peak-to-peak voltages.

For a lower peak-to-peak voltage, of e.g. V_{pp} = 100 V_{dc} , we obtain:

$$\frac{V_{pp}}{\tau} = \frac{k_0}{2 \cdot V_{pp}} = \frac{100000\,\mathrm{V}^2/\mu\mathrm{s}}{2 \cdot 100\,\mathrm{V}} = 500\ \mathrm{V}/\mu\mathrm{s}$$

Both types of discharge have the same pulse load effect (i.e. the same pulse characteristic k_0!), although the maximum permissible rates of voltage rise are clearly different.

The pulse handling capability of a capacitor is determined, in particular, by the internal structure of the capacitor element. (Construction variants are shown in figure 4.)

Apart from the layer structure variants, stacked-film capacitors have basic advantages over wound capacitors in terms of pulse-handling capabilities. Since, in principle, a stacked-film capacitor comprises a large number of independent capacitors in parallel, any contact weakness occurring can only affect the individual capacitor element.

3.6 Dielectric strength at low air pressure (altitude safety)

The flashover safety at the capacitor terminations is reduced as the atmospheric pressure drops.

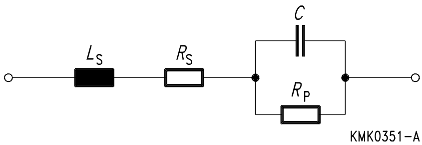
The capacitors can be used at pressures down to 40 kPa without a voltage derating being necessary. This corresponds to an altitude of 7000 m (approx. 23 000 ft) above mean sea level.

Capacitors for use at altitudes above 7000 m are available upon special request.

4 Dissipation factor

The dissipation factor tan δ is the ratio of the equivalent series resistance to the capacitive resistance in the equivalent series circuit or of effective power (power dissipation) to reactive power for sine-wave loads.

Equivalent circuit diagram



L_S Series inductance
R_S Series resistance (leads and contacts)
R_p Parallel resistance (insulation resistance)
C Capacitance

4.1 Measuring conditions

The generic standards and the sectional standards specify the same measuring conditions for measuring the dissipation factor tan δ as for measuring the capacitance (refer to chapter 2.1). For MKT, MFP and MKP capacitors, an additional measuring frequency of 10 kHz is used for determining the dissipation factor for capacitors with $C_R \leq 1\mu F$.

4.2 Variation of dissipation factor with frequency

If the inductance L_S is neglected and for frequencies $f \ll f_r$ where $f_r = 1/(2\Pi\sqrt{L_S \cdot C})$ is the natural resonance frequency) the dissipation factor tan δ is a combination of a parallel component $\tan\delta_P$, a series component $\tan\delta_S$ and a dielectric component $\tan\delta_D$:

$$\tan\delta = \tan\delta_P + \tan\delta_S + \tan\delta_D \qquad \tan\delta_P = \frac{1}{R_P \cdot 2\Pi f \cdot C}$$

$$\tan\delta_S = R_S \cdot 2\Pi f \cdot C$$

$\tan\delta_D$ = a characteristic of the dielectric

The parallel component $\tan\delta_P$ is negligible in the entire frequency range since it contributes virtually nothing to the overall dissipation factor even at very low frequencies ($f <<$ 1 kHz) due to the extremely high insulation resistance (parallel resistance R_P). Because of this, the dissipation factor tan δ at low frequencies is solely determined by the dielectric component $\tan\delta_D$, which, for MKP and MFP capacitors is independent of the frequency up to frequencies far into the multi-MHz-range and will typically result in a value of approximately 10^{-4}.

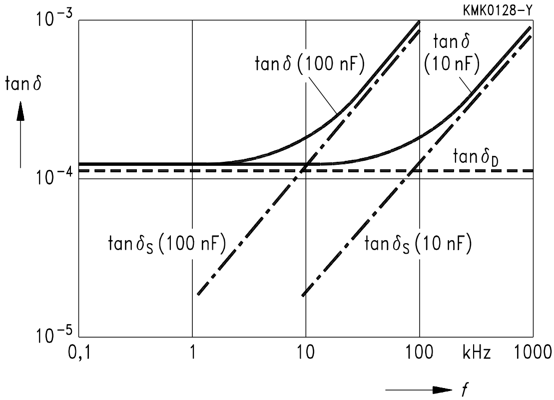


Fig. 15 Dissipation factor versus measuring frequency (schematic representation using two polypropylene capacitors of different capacitances as examples)

However, with rising frequency (f >1 kHz), the series component tan δ_s of the dissipation factor, which is proportional to the capacitance, increases more and more rapidly, until it is the dominating component in the dissipation factor curve. The measured value of the series component is determined by the series resistance R_s, which represents the sum of the contact resistances (terminations) and the resistances of leads, metal layers and electrode foils.

Because the dielectric of MKT capacitors contributes a considerably greater dielectric component tan δ_D, MKT capacitors display a noticeably higher overall dissipation factor, especially at lower frequencies, than, for example, MKP and MKN capacitors (cf. figure 16).

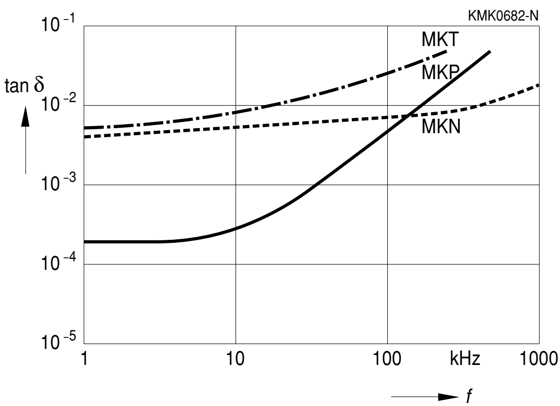


Fig. 16 Frequency dependence of the dissipation factor, e.g. for C_R = 0,10 µF (typical behavior)

4.3 Variation of dissipation factor with temperature, humidity and voltage

The dissipation factor of capacitors with polypropylene dielectrics is largely unaffected by the temperature, whereas MKT and MFT capacitors show a characteristic dissipation factor minimum at approximately 70 °C.

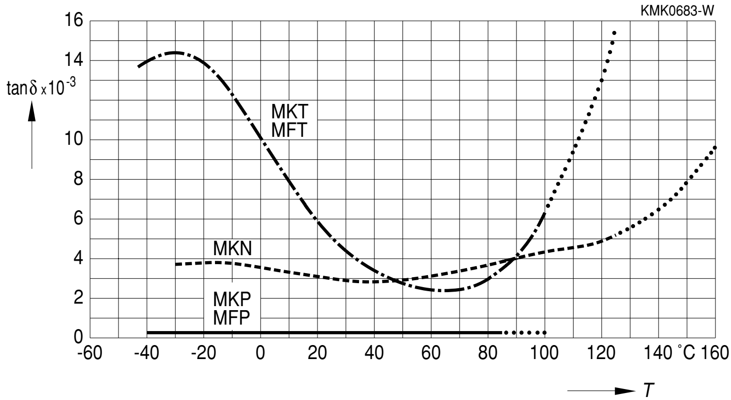


Fig. 17 Dissipation factor tan δ versus temperature T for f = 1 kHz (typical values)

The dissipation factor values may increase under humid conditions. It is virtually impossible to detect any variation of the dissipation factor with voltage.

5 Insulation resistance

5.1 Measuring conditions

The insulation resistance R_{is} is measured by determining the ratio of the applied dc voltage to the current flowing through the capacitor after a period of 1 min ± 5 s.

As specified by section 4.5.2. of both CECC 30 000 and IEC 60384-1, the measuring voltage is:

Rated voltage V_R of capacitor	Measuring voltage
10 V ≤ V_R < 100 V	(10 ± 1) V[1)]
100 V ≤ V_R < 500 V	(100 ± 15) V
500 V ≤ V_R	(500 ± 50) V

1) When it can be demonstrated that the voltage has no influence on the measuring result, or that a known relationship exists, measurements can be carried out at any voltages up to the rated voltage V_R. (In case of referee measurements, 10 V shall be used).

If the measurement is made at temperatures other than 20 °C a correction shall be made to the measured value to obtain the equivalent value for 20 °C by multiplying the measurement result by the appropriate correction factor.

Measuring temperature in °C	Correction factors (average values) according to the sectional specification MKT, MFT	MKN	MKP, MFP
15	0,79	0,79	0,75
20	1,00	1,00	1,00
23	1,15	1,15	1,25
27	1,38	1,38	1,50
30	1,59	1,59	1,75
35	2,00	2,00	2,00

In case of doubt a referee measurement at 20 °C and (50 ± 2) % relative humidity is decisive.

In the data sheets for the individual types, the insulation resistance R_{is} is given as a minimum as-delivered value and as a limit value attained after the “damp heat, steady-state” test.

For capacitors with capacitance ratings > 0,33 µF the insulation is given in terms of a time constant $\tau = R_{is} \cdot C_R$ in s.
(Conversion tip: $1\ \mathrm{M\Omega} \cdot \mu\mathrm{F} \mathrel{\hat{=}} 1\ \mathrm{s}$)

5.2 Factors affecting the insulation resistance

As could already be deduced from the correction factor tables (chapter 5.1), the insulation resistance is affected by the temperature. In figure 18 the typical behavior of individual types is shown.

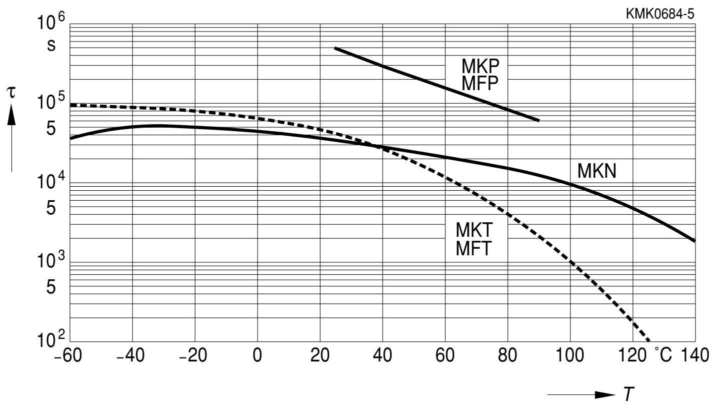


Fig. 18 Insulation as self-discharge time constant τ (= $R_{is} \cdot C_R$) in s ($\mathrel{\hat{=}}$ MΩ · µF) versus temperature T (typical values)

The insulation resistance is also affected by humidity (the humidity coefficient of the insulation resistance is negative).

6 Climatic stress

6.1 Upper and lower category temperature

In the respective generic specification, the upper category temperature T_{max} and the lower category temperature T_{min} are defined as the maximum and the minimum ambient temperature for which a capacitor has been designed to operate continuously.

Note:

Due to the associated self-heating, a capacitor's surface temperature may be higher than the ambient temperature when it is operated with ripple current loads.

6.2 Rated temperature

The rated temperature T_R is defined as the maximum ambient temperature at which the rated voltage V_R may be applied continuously.

In the respective sectional specifications, a single rated temperature is specified for MKT, MFT, MKP and MFP capacitors listed in this data book:

T_R = 85 °C

For MKN capacitors:

T_R = 105 °C

6.3 Reference temperature for measurements

According to IEC 60068-1, Section 5.1, the reference temperature for all electrical measurements is defined as 20 °C . If required, measurement results obtained at different temperatures can be converted to the reference temperature. For conversion factors for insulation resistance, refer to table on page 306.

6.4 Reference temperature for reliability specifications

In the reference conditions for reliability specifications, DIN 40 039 an ambient temperature of 40 °C is defined as the reference temperature. For a table of conversion factors for the failure rate, refer to the chapter on quality.

6.5 Storage temperature

All capacitors listed in this data book can be stored at any temperature within the entire category temperature range.

Criteria for taped capacitors:

- storage temperature −20 °C to +40 °C,
- maximum relative humidity 80 %,
- duration max. 12 months.

6.6 Climatic category

The climatic category is identified by three groups of figures, separated by slashes, as specified in IEC 60068-1, Appendix A.

Example: 55/085/56

–55 °C
+85 °C
56 days

1st group of figures:

Absolute value of the lower category temperature T_{min} as test temperature for
test Aa (cold) in accordance with IEC 60068-2-1

2nd group of figures:

Upper category temperature T_{max} as test temperature for
test Ba (dry heat) in accordance with IEC 60068-2-2
duration of test: 16 h

3rd group of figures:

Number of days, duration of
test Ca (damp heat, steady state) in accordance with IEC 60068-2-3
at (93 +2/–3) % rel. humidity and 40 °C ambient temperature

The limit values permissible after the damp heat test are given in the data sheets for the respective capacitor types. Capacitance changes due to the effects of humidity are reversible.

7 Notes on processing and applications

7.1 Soldering

Solderability of leaded capacitors

The solderability of the terminal leads is tested in accordance with IEC 60068-2-20, test Ta, method 1.

Before the solderability test is carried out, the terminals are subjected to an accelerated ageing procedure (in accordance with IEC 60068-2-2, test Ba: 4 hours exposure to dry heat at 155 °C). Since the ageing temperature is far higher than the upper category temperature of the capacitors, the terminal wires should be cut off from the capacitor before the ageing procedure in order to prevent the solderability being impaired by the products of any capacitor decomposition that might occur.

Solder bath temperature: (235 ± 5) °C
Immersion time: (2,0 ± 0,5) s
Immersion depth: distance from standoff surface or capacitor body: (2,0+0/-0,5) mm
Evaluation criterion: wetting of wire surface by new solder ≥ 90%,
free-flowing solder.

Solderability of SMD capacitors

The solderability of the terminals is tested in accordance with IEC 60068-2-58, test Td and CECC 00 802.

Before the solderability test is carried out, the terminals are subjected to an accelerated ageing procedure (in accordance with IEC 60068-2-2, test Ba: 4 hours exposure to dry heat at 155 °C).

Solder bath temperature: 215 °C
Immersion time: (3,0 ± 0,3) s
Evaluation criterion: wetting of wire surface by new solder ≥ 90%,
free-flowing solder.

Resistance to soldering heat for leaded capacitors

The resistance to soldering heat is tested in accordance with IEC 60068-2-20, test Tb, method 1A.

Solder bath temperature: (260 ± 5) °C
(For uncoated and partially coated capacitors, refer to note on next page.)
Shield: heat-absorbing board, (1,5 ± 0,5) mm thick, betweeen capacitor body and liquid solder
Soldering time: MKT capacitors, except types with case (2,5×6,5×7,2) mm: (10 ± 1) s
all others: (5 ± 1) s
Immersion depth: (2,0+0/-0,5) mm from standoff surface or capacitor body
Evaluation critera: No visible damage
tan δ as specified in sectional specification

Permissible capacitance change	Type
2 %	MKT/MFT/MKP/MFP
5 %	EMI suppression capacitors

General notes on soldering

Permissible heat exposure loads on film capacitors are characterized by the upper category temperature T_{max} . Long exposure to temperatures above this type-related temperature limit can lead to changes in the plastic dielectric and thus change a capacitor's electrical characteristics irreversibly.

High temperatures are encountered during soldering, but these are only applied briefly.

Apart from being dependent on the solder bath temperature and the soldering time, the thermal load is also affected by the initial (pre-heating) and the post-soldering (cooling) temperatures. Shadowing by neighboring components or subsequent heating due to heat dissipation by these has a similar effect.

Since the soldering heat is transmitted into the components mainly via the leads, the thermal resistance of the terminals is the deciding factor for the heat transmitted, especially for smaller capacitor sizes. Thus a poor thermal conductivity is desirable from this aspect, however, this is contrary to the good electrical conductivity required in order to achieve low dissipation factors (refer to explanation of series resistance R_S in section 4), since the electrical conductivity is generally proportional to the thermal conductivity.

Usually, the utilization of suitable measures, e.g.
– maximum possible distance from the solder bath,
– cooling by forced ventilation,
– use of solder-resist coatings, etc.

enables even sensitive types to be soldered for the solder periods stated above at solder bath temperatures of up to 265 °C. If pre-heating cannot be avoided, the soldering conditions may possibly have to be re-adjusted (especially the cooling process immediately following soldering).

Uncoated capacitors:

For uncoated MKT capacitors with lead spacings ≤ 10 mm
(B 32 560/B 32 561) the following measures are recommended:

- pre-heating to not more than 80 °C in the preheater phase,
- maximum solder bath temperature 245 °C,
- maximum soldering time 4 s
- rapid cooling after soldering.

For SMD capacitors refer to respective data sheet.

7.2 Cleaning

To determine whether the following solvents, often used to remove flux residues and other substances, are suitable for the capacitors described, refer to the table below:

<table>
<tr><th>Type</th><th>Ethanol,
isopropanol,
n-propanol</th><th>n-propanol-water mixtures,
water with surface tension-reducing tensides (neutral)</th><th>Solvent from table A</th><th>Solvent from table B</th></tr>
<tr><td>MKT, MKP
(uncoated)</td><td rowspan="3">suitable</td><td rowspan="2">unsuitable</td><td rowspan="2">in part suitable</td><td rowspan="3">unsuitable</td></tr>
<tr><td>MKT, MKN
(chip capacitors)</td></tr>
<tr><td>MKT, MKP, MFP, MFT
(in plastic case)</td><td>suitable</td><td>suitable</td></tr>
</table>

Table A
Manufacturers' designations for trifluoro-trichloro-ethane -based cleaning solvents (selection)

Trifluoro-trichloro-ethane	Mixtures of trifluoro-trichloro-ethane with ethanol and isopropanol	Manufacturer
Freon TF	Freon TE 35; Freon TP 35; Freon TES	Du Pont
Frigen 113 TR	Frigen 113 TR-E; Frigen 113 TR-P; Frigen TR-E 35	Hoechst
Arklone P	Arklone A; Arklone L; Arklone K	ICI
Kaltron 113 MDR	Kaltron 113 MDA; Kaltron 113 MDI; Kaltron 113 MDI 35	Kali-Chemie
Flugene 113	Flugene 113 E; Flugene 113 IPA	Rhone-Progil

Table B
Manufacturers' designations of unsuitable cleaning solvents (selection)

Mixtures of chlorinated hydrocarbons and ketones with fluorated hydrocarbons	Manufacturer
Freon TMC; Freon TA; Freon TC	Du Pont
Arklone E	ICI
Kaltron 113 MDD; Kaltron 113 MDK	Kali-Chemie
Flugene 113 CM	Rhone-Progil

Even when suitable solvents are used, a reversible change of the electrical characteristics may occur in uncoated capacitors immediately after they are washed.
Such capacitors should be dried (e.g. 4 hours at 70 °C) before being subjected to subsequent electrical testing.

Note:

The use of all chlorinated and fluorated hydrocarbons, as well as mixtures containing these (tables A and B), should be avoided for environmental reasons. The use of these substances is no longer permitted in Germany.

7.3 Mechanical robustness of leads

The mechanical robustness of the leads is tested in accordance with IEC 60068-2-21.

Tensile strength: (Test Ua1)	Wire diameter d_1 in mm	Tensile force
	$0,3 < d_1 \leq 0,5$	5 N
	$0,5 < d_1 \leq 0,8$	10 N
	$0,8 < d_1 \leq 1,25$	20 N
Bending strength: (Test Ub)	Procedure 1: 2 consecutive bends by 90°, in opposite directions	
	wire diameter d_1 in mm	Bending force
	$0,3 < d_1 \leq 0,5$	2,5 N
	$0,5 < d_1 \leq 0,8$	5 N
	$0,8 < d_1 \leq 1,25$	10 N
Torsional strength: (Test Uc)	Procedure A, severity 2: 2 successive rotations of 180° each	

Tests Ub and Uc are only carried out on types having axial wire leads.

7.4 Resistance to vibration

The capacitor's ability to withstand vibration e.g. as occurs in applications involving rotating machinery, is tested in accordance with IEC 60068-2-6.

The test procedure used here involves continuous vibration with continuously varying frequency and the following severities:

Test Fc: vibration, sinusoidal	Test conditions
Amplitude of displacement (below the 57,6 Hz transition frequency)	0,75 mm
Amplitude of acceleration (above the 57,6 Hz transition frequency)	98 m/s^2 ($\hat{=}$ 10 *g*)
Frequency range	10 Hz … 500 Hz
Test duration (in three orthogonal axes)	3 · 120 minutes

7.5 Flammability

7.5.1 Passive flammability

The passive flammability test is applied to ensure that components bearing the corresponding qualification contribute less energy to the combustion behavior of their immediate vicinity than is required to ignite them. This measure is meant to contain any localized fire which may occur.

In the respective tests, the capacitors are subjected to a standardized flame in order to be able to evaluate the combustion behavior by checking whether the flame persists longer than a maximum permissible period or not. The test severity is essentially determined by the test flame and the exposure time. In principle, the smaller the capacitor, the more easily flammable it is (see table: this fact is taken into consideration in the IEC 60040 (CO) 752 flammability categories). The following tests are used:

Specifications	Flame height mm	Severity: time of exposure to flame s				Flame persistence s
UL 1414 7. Enclosure Test	19	Three-stage flame test: 1st period: 15 2nd period: 15 3rd period: 15				 15 15 60
IEC 60695-2-2	12 ± 1	Preferred values: 5, 10, 20, 30, 60, 120				30
IEC 60040 (CO) 752 (Amendment to IEC 60384-1)	12 ± 1	Capacitor volume mm^3				
		≤ 250	> 250	> 500	> 1750	
Category A		15	30	60	120	3
Category B		10	20	30	60	10
Category C		5	10	20	30	30

Unless the detail specifications specifiy otherwise, EMI suppression capacitors are tested in accordance with CECC 32 400, section 4.17, test severity category C.

7.5.2 Active flammability

For an explanation of the active flammability of EMI suppression capacitors, refer to page 227.

7.5.3 Flammability of materials

In some cases, specifications regarding the flammability of materials in accordance with UL 94 are requested in addition to the results of capacitor flammability tests. The UL 94 safety standards describe a material test carried out on test specimens for classifying the flammability of plastics. In the test according to UL 94 V, the test specimens (length 127 mm / 5", 12,7 mm / 0.5") are arranged vertically and exposed to a flame twice; they are then classified into flammability categories:

Flammability category	UL 94 V-0	UL 94 V-1	UL 94 V-2
Material burning persistence (s): Individual flame exposure Total of ten flame exposures (5 specimens)	 ≤ 10 ≤ 50	 ≤ 30 ≤ 250	 ≤ 30 ≤ 250
Ignition of supporting layer by dropping burning particles	not permitted		permitted

The thickness of the test specimens must always be stated in order to enable evaluation of the flammability category!
E.g.: UL 94 V-0 (3,2 mm) does not imply that the material will also comply with UL 94 V-1 (1,6 mm).

The sole object of UL 94 is to enable comparison of the relative flammability of various materials. It does not provide any information on the actual combustion characteristics of a capacitor.

7.6 Embedding of capacitors in finished assemblies

In many applications, finished circuit assemblies are embedded in plastic resins. In this case, both chemical and thermal influences of the embedding (“potting”) and curing processes must be taken into account.

Our experience has shown that the following potting materials can be recommended: non-flexible epoxy resins with acid-anhydride hardeners; chemically inert, non-conducting fillers; maximum curing temperature 100 °C.

Caution:

Please consult us first if you wish to also embed other uncoated component types!

8 Self-inductance, resonant frequency

At high frequencies the self-inductance of a capacitor causes it to have a natural resonance which can have an undesirable effect when designing circuits. The self-inductance is influenced by the contact paths to the electrodes and the structure of the windings. As far as possible, all capacitors described in this data book are constructed with low-inductance bifilar electrode current paths or extended-foil contacts. A general rule for deducing the self-inductance states that the maximum value is 1 nH per mm lead length and capacitor length.

The frequency range of the natural resonance (also termed self-resonance) as a function of the capacitance can be read off the following diagram.

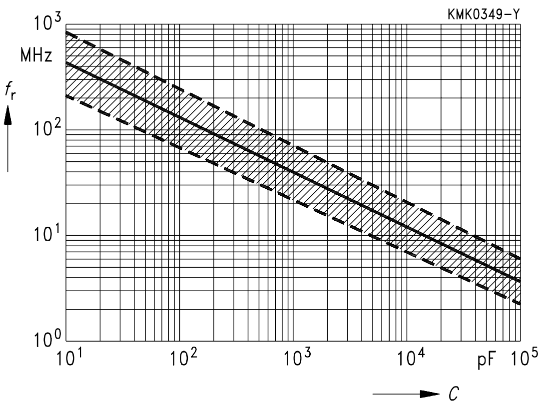


Fig. 19 Resonant frequency versus capacitance (typical values)

9 Capacitor markings

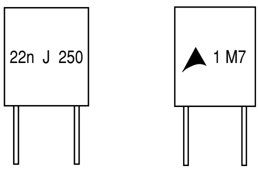
The individual data sheets state what information is provided by the identification markings on the capacitors. Depending on the capacitor size, the markings are positioned either on the side and/or the top of the component. The coded forms specified in IEC 60062 are used to indicate the rated capacitance, capacitance tolerance and date of manufacture (date code).

All radial capacitors in plastic case with lead spacings 10 to 37,5 mm as well as EMI suppression capacitors are marked with a lot number (production batch number). This ensures unique identification of a particular capacitor and allows, together with the date of manufacture, exact assignment to the process data of the entire production run (traceability).

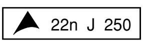
MKT, MKP and MFP capacitors (examples):

Boxed

MKT, lead spacing = 5 mm
(side stamping)

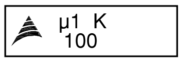


MKT, LS 7,5 and 7,5/5 mm
(top stamping, with or without date code)



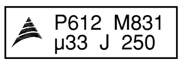
Dipped

MKT, lead spacing = 10 mm



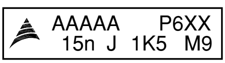
KMK0634-4

MKP/MFP/MKT, lead spacing ≥ 15 mm



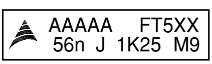
KMK0652-2

MKT/MKP,
lead spacing ≥ 10 mm



KMK0630-6

MFT/MFP,
lead spacing ≥ 15 mm



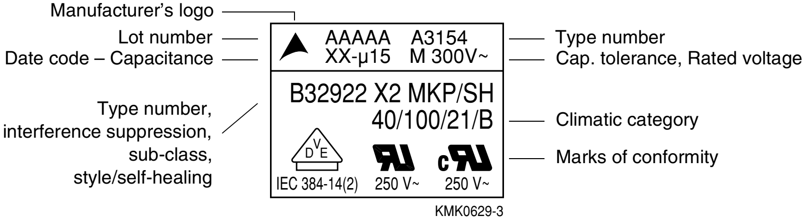
KMK0631-E

Explanation of first line (capacitors in plastic case):

AAAAA	batch number (up to 5 figures)
T5XX	MKT capacitor B325**
P6XX	MKP capacitor B326**
FT5XX	MFT capacitor B325**
FP6XX	MFP capacitor B326**
TSXX	MKT special capacitor B325**-S****
PSXX	MKP special capacitor B326**-S****
FTSXX	MFT special capacitor
FPSXX	MFP special capacitor

Imprinted in code in the second line of the stamp are rated capacitance, rated tolerance, rated voltage and date of manufacture (year, month) as defined by IEC 60062.

Example for EMI suppression capacitors:



Codes for rated capacitance

Rated capacitance	In accordance with IEC 60062	Short code
100 pF	100p	n1
150 pF	150p	n15
1 nF	1n0	1n
1,5 nF	1n5	
10 nF	10n	
100 nF	100n	µ1
150 nF	150n	µ15
1 µF	1µ0	1µ
1,5 µF	1µ5	
10 µF	10µ	

Codes for capacitance tolerance

Capacitance tolerance	Code letter
– 1)	A
± 5 %	J
± 10 %	K
± 20 %	M

1) Capacitance tolerances for which no code letter is defined can be indicated by an A . The meaning of code A must then be mutually specified in other documentation.

Codes for date of manufacture (acc. DIN 41 314)

Year	Code letter	Month	Code numeral	Month	Code numeral/ letter
1996	H	January	1	July	7
1997	J	February	2	August	8
1998	K	March	3	September	9
1999	L	April	4	October	O
2000	M	May	5	November	N
2001	N	June	6	December	D
2002	P				
2003	R				
2004	S				
2005	T				

E.g.: M9 ≙ 2000 September

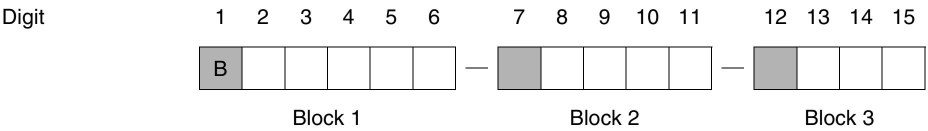
10 How to determining the ordering code

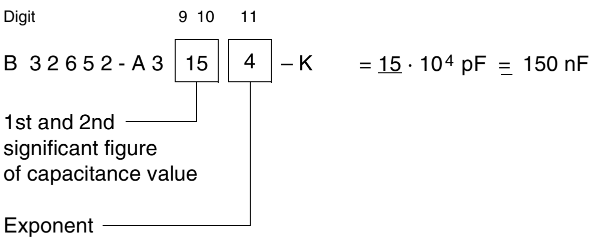
A component and the packing in which it is to be delivered are unambiguously defined by the ordering code (part number), which has up to 15 digits.

For all capacitors the ordering codes are explicitly stated (together with the corresponding tolerance and/or packing variants) in the data sheets.

Should there be any doubt about the coding system, however, then it is better to order the capacitor using a plain text description (i.e. without a code). In this case, the translation into the part number, which is required for internal handling of the order, will be done by us. The components are delivered by part numbers only.

Basic structure of the ordering code:



Digit	Meaning
1	B = Passive components
2, 3	32 = Metallized film capacitors 81 = EMI suppression capacitors
4 … 6	Type (Block 1 is termed the “type number”)
7	Revision status
8	Rated dc voltage, coded (not for EMI suppression capacitors)
9 … 11	Rated capacitance (coding method for value in pF) Examples: 
12	Capacitance tolerance, code letter
13 … 15	Codes for lead and taping parameters (refer to respective data sheet)

11 Standards and specifications

The capacitors described in this data book largely comply with German and international standards and regulations. For all specifications listed (DIN, CECC, IEC) the editions or issues valid on the 1st October 1994 apply.

11.1 Generic specifications

DIN 45 910Generic specification: Fixed capacitors
September 1985 (only available in German)

CECC 30 000Generic specification: Fixed capacitors
Issue 3, 1983

IEC 60384-1Fixed capacitors for use in electronic equipment
Part 1: Generic specification. Second edition 1982

11.2 Sectional specifications

Style	DIN	CECC	IEC
MKT	DIN 45 910-11 September 1985	CECC 30 400 Issue 2 1984	IEC 60384-2 2nd edition 1982
MKP	DIN 45 910-23 January 1983	CECC 31 200 Issue 1 1981	IEC 60384-16 1st edition 1982
MFP	—	CECC 31 900 WG3 (Secr) 239A	IEC 60384-17 1st edition 1987
EMI suppress- ion capacitors	—	CECC 32 400 Issue 1 1992 EN 132400	IEC 60384-14 2nd edition 1993

11.3 Detail specifications

Style	Type	Specification
MKT	B 32 231	DIN 44 113 (August 1967): Metallized polyethylene terephthalate film capacitors 100 to 1000 V dc
	B 32 232	DIN 45910-112 (September 1991)
	B 32 560 - 564	Manufacturer's detail specification: Metallized polyethylene terephthalate film capacitors, DC 100 to 400 V, general-purpose grade, climatic category 55/100/21
MKT	B 32 520 - 529	DIN 45 910 - 113 (September 1991), Manufacturer's detail specification: Metallized polyethylene terephthalate film capacitors, DC 63 to 630V, general purpose-grade, climatic category 55/100/56
MKT-SMD MKN-SMD	B 32 540 B 32 840	IEC 60384-19 (1993) CECC 32200

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