

1 Criteria for use

In order to scale a capacitor correctly for a particular application, the permissible ambient temperature has to be determined. This can be taken from the diagram "Permissible ambient temperature T_A vs total power dissipation P " after calculating the power dissipation (see individual data sheets). For data sheets not contained in this data book, contact the nearest office of EPCOS.

Besides calculation of power dissipation P , the following examples illustrate determination of the thermal load for continuous and intermittent operation.

2 Calculation of power dissipation P

The total power dissipation P is composed of the dielectric losses (P_D) and the resistive losses (P_R): Generally a secondary sinusoidal AC voltage can be used for calculating with sufficient accuracy.

$$P = P_D + P_R \quad (13)$$

$$P_D = \hat{u}_{ac}^2 \cdot \pi \cdot f_0 \cdot C \cdot \tan \delta_0 \quad (14)$$

\hat{u}_{ac} peak value of symmetrical AC voltage applied to capacitor (see also section 2.2.3) V
 f_0 fundamental frequency Hz
 C capacitance F
 $\tan \delta_0$ dissipation factor of dielectric

$$P_R = I^2 \cdot R_S \quad (15)$$

I rms value of capacitor current A
 R_S series resistance at maximum hot-spot temperature Ω

The R_S figure at maximum hot-spot temperature is used to calculate the resistive losses. In selection charts and data sheets the figure is stated for 20 °C capacitor temperature. The conversion factors are as follows:

MP capacitors	$R_{S70} = 1.20 \cdot R_{S20}$
MKV capacitors	$R_{S85} = 1.25 \cdot R_{S20}$
MKK capacitors	$R_{S70} = 1.20 \cdot R_{S20}$
MPK capacitors	$R_{S85} = 1.25 \cdot R_{S20}$

2.1 Calculation example for continuous operation

For data on B25855-C7255-K004, see individual data sheet, page 244.

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Electrical operating parameters

- $C_R = 2.5 \mu\text{F}$
- $U_R = \text{DC } 3000 \text{ V}$
- $\hat{u}_{ac} = 1500 \text{ V}$
- $f_0 = 300 \text{ Hz}$
- $I = 50 \text{ A}$
- $R_S(20^\circ\text{C}) = 1.4 \text{ m}\Omega$
- $R_S(85^\circ\text{C}) = 1.7 \text{ m}\Omega$
- $\tan \delta_0 = 2 \cdot 10^{-4}$

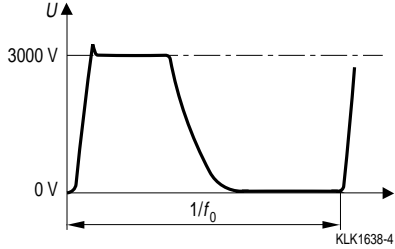


Figure 1
Voltage connected to capacitor versus time

2.1.1 Dielectric power dissipation P_D

This can be read from the upper diagram in the thermal data sheet as a function of the frequency. The diagram only applies to operation at the specified voltage \hat{u}_{ac} (peak value of the symmetrical alternating voltage applied to the capacitor)

- for DC capacitors: $\hat{u}_{ac} = 0.1 \cdot U_R$
- for AC capacitors: $\hat{u}_{ac} = U_R$
- for GTO snubber capacitors: $\hat{u}_{ac} = U_R (\text{DC}) / 2$

P_D can be calculated for all other voltages by applying equation (14):

$$P_D = \hat{u}_{ac}^2 \cdot \pi \cdot f_0 \cdot C \cdot \tan \delta_0$$

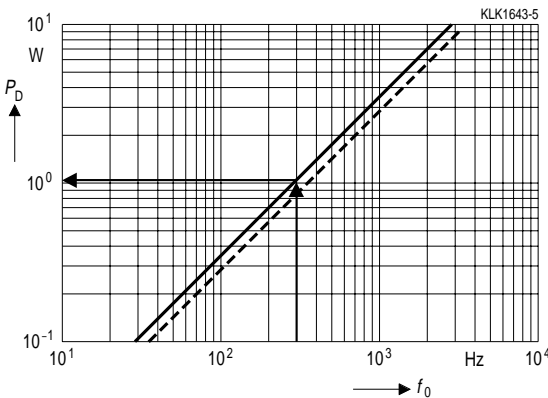


Figure 2
Dielectric power dissipation P_D versus repetition frequency f_0

$\hat{u}_{ac} = 1500 \text{ V}$ —————
 $\hat{u}_{ac} = 1350 \text{ V}$ - - - - -

for $f_0 = 300 \text{ Hz}$, we read: $P_D = 1.1 \text{ W}$

2.1.2 Ohmic power dissipation P_R

This can be read from the middle diagram as a function of the current, or can be calculated using equation (15): $P_R = I^2 \cdot R_S$

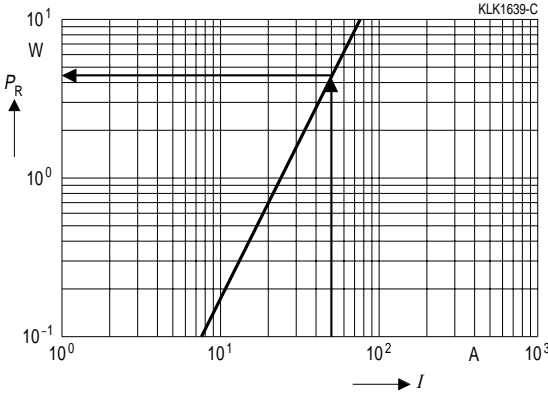


Figure 3

Ohmic power dissipation P_R versus rms current value I

$R_S (85^\circ\text{C}) = 1.7\text{ m}\Omega$

for $I = 50\text{ A}$, we read: $P_R = 4.3\text{ W}$

2.1.3 Permissible ambient temperature

This can be read from the lower diagram as a function of the total power dissipation. Total power dissipation (equation (13)): $P = P_D + P_R = 5.4\text{ W}$

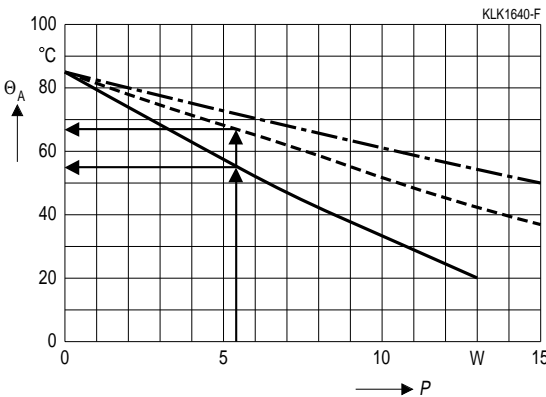


Figure 4

Permissible ambient temperature T_A versus total power dissipation P

Natural cooling ———
 Forced cooling 2 m/s - - - - -
 Permissible capacitor temperature ·····

Upright mounting position

In the example, the following permissible ambient temperature is obtained:

For natural convection cooling: $T_{Amax} = 55^\circ\text{C}$
 For forced convection cooling (2 m/s): $T_{Amax} = 67^\circ\text{C}$

2.2 Permissible ambient temperature in intermittent operation

The effective mean power dissipation \bar{P} has to be determined for intermittent operation. The maximum hot-spot temperature T_{HS} is also the scaling limit in intermittent operation.

$$\bar{P} = \frac{1}{t} \int_0^t P(t) dt \quad (16)$$

\bar{P}	mean power dissipation	W
$P(t)$	power dissipation vs time	W
dt	time element	s
t	time	s

In intermittent operation the calculation is simplified by introduction of the duty factor $t_1 / (t_1 + t_2)$ to become

$$\bar{P} = \frac{t_1}{t_1 + t_2} \cdot P \quad (17)$$

\bar{P}	mean power dissipation	W
t_1	on time	s
t_2	off time	s
P	total power dissipation	W
$t_1 + t_2$	cycle duration	s
$t_1 / (t_1 + t_2)$	duty factor	

Calculation example

Given:

$t_1 = 1650$ s	(on time)
$t_2 = 2000$ s	(off time)
$P = 5.4$ W	(total power dissipation)

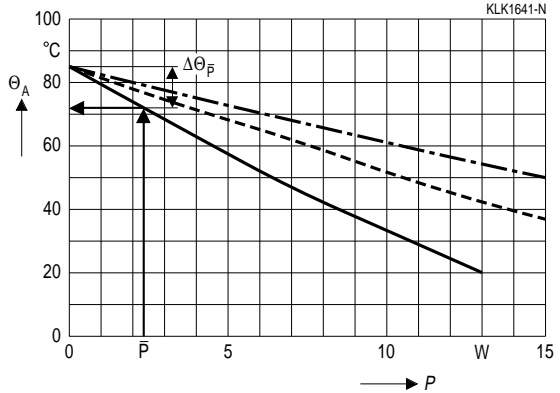
With equation (17) this becomes:

$$\bar{P} = \frac{1650}{(1650 + 2000)} \cdot 5.4 = 2.44 \text{ W}$$

Figure 5

Permissible ambient temperature T_A
versus total power dissipation P

Natural cooling _____
Forced cooling 2 m/s - - - - -
Permissible capacitor
temperature - - - - -



Reading from the diagram

$T_{Amax} = 72 \text{ °C}$ permissible ambient temperature for natural cooling in intermittent operation
 $\Delta T_{\bar{P}} = 13 \text{ K}$ mean temperature difference in intermittent operation

2.2.1 Check of thermal scaling in intermittent operation

It is necessary to ensure that the temperature limit Θ_{HS} is not exceeded.

Calculation of thermal resistance R_{th} and thermal time constant τ_{th} :

$$R_{th} = \frac{\Delta T_{\bar{P}}}{\bar{P}} \quad (18)$$

$\Delta T_{\bar{P}}$ mean temperature difference
in intermittent operation K
 \bar{P} mean power dissipation W

The relationship between R_{th} and τ_{th} is given by equation (11).

$$\tau_{th} = m \cdot c_{thcap} \cdot R_{th}$$

Calculation example

Given:

$\Delta T_{\bar{P}} = 13 \text{ K}$ (from diagram, figure 5)
 $\bar{P} = 2.44 \text{ W}$ (calculated with equation (17), see page 48)
 $c_{thcap} \approx 1.3 \frac{\text{Ws}}{\text{K} \cdot \text{g}}$ (specific thermal capacitance for selected capacitor)
 $m = 900 \text{ g}$ (from data sheet)

Thermal design of capacitors for power electronics

Equation (18) produces

$$R_{th} = \frac{\Delta T_{\bar{P}}}{\bar{P}} = \frac{13}{2,44}$$

And equation (11) produces

$$\tau_{th} = m \cdot c_{thcap} \cdot R_{th} = 900 \cdot 1.3 \frac{Ws}{K \cdot g} \cdot 5.3 \frac{K}{W} = 6200$$

The generally valid correction factor β (figure 6) can be used for final calculation of the permissible ambient temperature in intermittent operation T_{Amax} , allowing for the particular application.

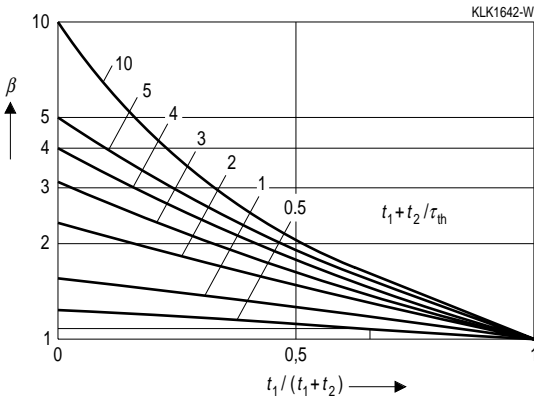


Figure 6
Correction factor β vs
duty factor $t_1/(t_1 + t_2)$

$$T_{Amax} \leq T_{HS} (1 - \beta) + \beta T_{AP} \tag{19}$$

T_{Amax}	permissible ambient temperature in intermittent operation	°C
T_{HS}	max. hot-spot temperature	°C
β	correction factor	
T_{AP}	mean ambient temperature in intermittent operation	°C

Calculation example

The on and off times stated on page 48 and the thermal time constant τ_{th} calculated on page 50 produce:

$$\frac{t_1}{(t_1 + t_2)} = \frac{1650}{(1650 + 2000)} = 0.45 \quad (\text{duty factor})$$

$$\frac{t_1 + t_2}{\tau_{th}} = \frac{(1650 + 2000)}{6200} = 0.6 \quad (\text{parameter in figure 6})$$

The correction factor $\beta \approx 1.15$ can be read from figure 6.

Equation (19) produces:

$$T_{Amax} \leq 85 (1 - 1.15) + 1.15 \cdot 72$$

$$T_{Amax} = 70 \text{ }^\circ\text{C} \quad (\text{for natural cooling})$$

3 Load duration t_{LDT} as a function of temperature T

The load duration of capacitors with organic dielectrics depends among other things on the hot-spot temperature produced in operation. By derivation from the Arrhenius equation (this describes temperature-dependent aging processes) a relation can be produced for the load duration on the basis of the maximum hot-spot temperature in a not too considerable temperature interval ($T_{hs} = T_{HS} \dots T_{HS} - 7 \text{ K}$).

$$t_{LDT_{hs}} = t_{LDT_{HS}} \cdot 2^{\left(\frac{T_{HS} - T_{hs}}{c}\right)} \quad (20)$$

$t_{LDT_{hs}}$	load duration at hot-spot temperature at operating point	h
$t_{LDT_{HS}}$	load duration at maximum hot-spot temperature	h
T_{HS}	maximum hot-spot temperature	$^\circ\text{C}$
T_{hs}	hot-spot temperature at operating point	$^\circ\text{C}$
c	Arrhenius coefficient	$7 \text{ }^\circ\text{C}$

4 Load duration t_{LDU} as a function of voltage U

This produces, in analogous fashion to the temperature-dependent load-duration forecast, results that are only useful within relatively narrow limits ($U = 0.9 \dots 1.1 \cdot U_R$). The voltage-dependent load duration of the capacitors can be approximated by a law of exponents:

$$t_{LDU} = t_{LDU_R} \left(\frac{U_R}{U}\right)^n \quad (21)$$

t_{LDU}	load duration at operating voltage	h
t_{LDU_R}	load duration at rated voltage	h
U_R	rated voltage	V
U	operating voltage	V
n	exponent which depends on the technology used	