Ferrites and accessories

General – Definitions

Date: October 2022
1  **Hysteresis**

The special feature of ferromagnetic and ferrimagnetic materials is that spontaneous magnetization sets in below a material-specific temperature (Curie point). The elementary atomic magnets are then aligned in parallel within macroscopic regions. These so-called Weiss’ domains are normally oriented so that no magnetic effect is perceptible. But it is different when a ferromagnetic body is placed in a magnetic field and the flux density \( B \) as a function of the magnetic field strength \( H \) is measured with the aid of a test coil. Proceeding from \( H = 0 \) and \( B = 0 \), the so-called initial magnetization curve is first obtained. At low levels of field strength, those domains that are favorably oriented to the magnetic field grow at the expense of those that are not. This produces what are called wall displacements. At higher field strength, whole domains overturn magnetically – this is the steepest part of the curve – and finally the magnetic moments are moved out of the preferred states given by the crystal lattice into the direction of the field until saturation is obtained, i.e. until all elementary magnets in the material are in the direction of the field. If \( H \) is now reduced again, the \( B \) curve is completely different. The relationship shown in the hysteresis loop (figure 1) is obtained.

1.1  **Hysteresis loop**

![Figure 1](image1.png)  
**Magnetization curve**  
(schematic)

![Figure 2](image2.png)  
**Hysteresis loops for different excitations and materials**

- **Magnetic field strength**  
  \[ H = \frac{I \cdot N}{L} = \text{ampere-turns} \quad \left[ \frac{A}{m} \right] \]

- **Magnetic flux density**  
  \[ B = \frac{\Phi}{A} = \text{magnetic flux} \quad \left[ \frac{Vs}{m^2} \right] = [T(\text{Tesla})] \]

- **Polarization J**  
  \[ J = B - \mu_0 H \quad \mu_0 \cdot H \ll J \Rightarrow B \approx J \]
General relationship between B and H:

\[ B = \mu_0 \cdot \mu_r(H) \cdot H \]

- \( \mu_0 \): Magnetic field constant
- \( \mu_0 = 1.257 \times 10^{-6} \) Vs/Am
- \( \mu_r \): Relative permeability

In a vacuum, \( \mu_r = 1 \); in ferromagnetic or ferrimagnetic materials the relation \( B(H) \) becomes nonlinear and the slope of the hysteresis loop \( \mu_r \gg 1 \).

1.2 Basic parameters of the hysteresis loop

1.2.1 Initial magnetization curve

The initial magnetization curve describes the relationship \( B = \mu_r \mu_0 H \) for the first magnetization following a complete demagnetization. By joining the end points of all “sub-loops”, from \( H = 0 \) to \( H = H_{\text{max}} \) (as shown in figure 1), we obtain the so-called commutation curve (also termed normal or mean magnetization curve), which, for magnetically soft ferrite materials, coincides with the initial magnetization curve.

1.2.2 Saturation magnetization \( B_S \)

The saturation magnetization \( B_S \) is defined as the maximum flux density attainable in a material (i.e. for a very high field strength) at a given temperature; above this value \( B_S \), it is not possible to further increase \( B(H) \) by further increasing \( H \).

Technically, \( B_S \) is defined as the flux density at a field strength of \( H = 1200 \) A/m. As is confirmed in the actual magnetization curves in the chapter on “Materials”, the \( B(H) \) characteristic above 1200 A/m remains roughly constant (applies to all ferrites with high initial permeability, i.e. where \( \mu \geq 1000 \)).

1.2.3 Remanent flux density \( B_R(H) \)

The remanent flux density (residual magnetization density) is a measure of the degree of residual magnetization in the ferrite after traversing a hysteresis loop. If the magnetic field \( H \) is subsequently reduced to zero, the ferrite still has a material-specific flux density \( B_R \neq 0 \) (see figure 1: intersection with the ordinate \( H = 0 \)).

1.2.4 Coercive field strength \( H_C \)

The flux density \( B \) can be reduced to zero again by applying a specific opposing field \(-H_C \) (see figure 1: intersection with the abscissa \( B = 0 \)).

The demagnetized state can be restored at any time by:

a) traversing the hysteresis loop at a high frequency and simultaneously reducing the field strength \( H \) to \( H = 0 \).

b) by exceeding the Curie temperature \( T_C \).
2 Permeability

Different relative permeabilities $\mu$ are defined on the basis of the hysteresis loop for the various electromagnetic applications.

2.1 Initial permeability $\mu_i$

$$\mu_i = \frac{1}{\mu_0} \cdot \frac{\Delta B}{\Delta H} \quad (\Delta H \rightarrow 0)$$

The initial permeability $\mu_i$ defines the relative permeability at very low excitation levels and constitutes the most important means of comparison for soft magnetic materials. According to IEC 60401-3, $\mu_i$ is defined using closed magnetic circuits (e.g. a closed ring-shaped cylindrical coil) for $f \leq 10 \text{ kHz}$, $B < 0.25 \text{ mT}$, $T = 25 \text{ °C}$.

2.2 Effective permeability $\mu_e$

Most core shapes in use today do not have closed magnetic paths (only ring, double E or double-aperture cores have closed magnetic circuits), rather the circuit consists of regions where $\mu_i \neq 1$ (ferrite material) and $\mu_i = 1$ (air gap). Figure 3 shows the shape of the hysteresis loop of a circuit of this type.

In practice, an effective permeability $\mu_e$ is defined for cores with air gaps.

$$\mu_e = \frac{1}{\mu_0 N^2} \sum \frac{1}{A} \quad \sum \frac{1}{A} \quad \text{Form factor}$$

$$L \quad \text{Inductance}$$

$$N \quad \text{Number of turns}$$

It should be noted, for example, that the loss factor $\tan \delta$ and the temperature coefficient for gapped cores reduce in the ratio $\mu_e/\mu_i$ compared to ungapped cores.

Figure 3
Comparison of hysteresis loops for a core with and without an air gap
The following approximation applies for an air gap $s \ll l_e$:

$$
\mu_e = \frac{\mu_i}{1 + \frac{s}{l_e} \cdot \mu_i}
$$

$s$ Width of air gap

$l_e$ Effective magnetic path length


### 2.3 Apparent permeability $\mu_{app}$

$$
\mu_{app} = \frac{L}{L_0} = \frac{\text{inductance with core}}{\text{inductance without core}}
$$

The definition of $\mu_{app}$ is particularly important for specification of the permeability for coils with tubular, cylindrical and threaded cores, since an unambiguous relationship between initial permeability $\mu_i$ and effective permeability $\mu_e$ is not possible on account of the high leakage inductances. The design of the winding and the spatial correlation between coil and core have a considerable influence on $\mu_{app}$. A precise specification of $\mu_{app}$ requires a precise specification of the measuring coil arrangement.

### 2.4 Complex permeability $\mu^*$

To enable a better comparison of ferrite materials and their frequency characteristics at very low field strengths (in order to take into consideration the phase displacement between voltage and current), it is useful to introduce $\mu$ as a complex operator, i.e. a complex permeability $\mu^*$, according to the following relationship:

$$
\mu^* = \mu_s' - j \cdot \mu_s''
$$

where, in terms of a series equivalent circuit, (see figure 5)

- $\mu_s'$ is the relative real (inductance) component of $\mu$
- $\mu_s''$ is the relative imaginary (loss) component of $\mu$.

Using the complex permeability $\mu^*$, the (complex) impedance of the coil can be calculated:

$$
\bar{Z} = j \omega \mu^* L_0
$$

where $L_0$ represents the inductance of a core of permeability $\mu_r = 1$, but with unchanged flux distribution.

(cf. also section 4.1: information on $\tan \delta$)
Figure 4 shows the characteristic shape of the curves of $\mu_s'$ and $\mu_s''$ as functions of the frequency, using N48 material as an example. The real component $\mu_s'$ is constant at low frequencies, attains a maximum at higher frequencies and then drops in approximately inverse proportion to $f$. At the same time, $\mu''$ rises steeply from a very small value at low frequencies to attain a distinct maximum and, past this, also drops as the frequency is further increased.

The region in which $\mu'$ decreases sharply and where the $\mu''$ maximum occurs is termed the cut-off frequency $f_{\text{cutoff}}$. This is inversely proportional to the initial permeability of the material (Snoek’s law).

### 2.5 Reversible permeability $\mu_{\text{rev}}$

$$\mu_{\text{rev}} = \frac{1}{\mu_0} \lim_{\Delta H \to 0} \frac{\Delta B}{\Delta H} H_{\text{DC}}$$

(Permeability with superimposed DC field $H_{\text{DC}}$)

In order to measure the reversible permeability $\mu_{\text{rev}}$, a small measuring alternating field is superimposed on a DC field. In this case $\mu_{\text{rev}}$ is heavily dependent on $H_{\text{DC}}$, the core geometry and the temperature.

Important application areas for DC field-superimposed, i.e. magnetically biased coils are broadband transformer systems (feeding currents with signal superimposition) and power engineering (shifting the operating point) and the area known as “nonlinear chokes” (cf. chapter on RM cores). For the magnetic bias curves as a function of the excitation $H_{\text{DC}}$ see the chapter on “SIFERRIT materials”.

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Please read Cautions and warnings and Important notes at the end of this document.
2.6 Amplitude permeability $\mu_a$, $A_{L1}$ value

$$\mu_a = \frac{\hat{B}}{\mu_0 \hat{H}}$$  \hspace{1cm} (Permeability at high excitation)

$\hat{B}$  Peak value of flux density
$\hat{H}$  Peak value of field strength

For frequencies well below cut-off frequency, $\mu_a$ is not frequency-dependent but there is a strong dependence on temperature. The amplitude permeability is an important definition quantity for power ferrites. It is defined for specific core types by means of an $A_{L1}$ value for $f \leq 10$ kHz, $B = 320$ mT (or 200 mT), $T = 100$ °C.

$$A_{L1} = \frac{\mu_0 \cdot \mu_a}{\sum I / A}$$
3 Magnetic core shape characteristics

Permeabilities and also other magnetic parameters are generally defined as material-specific quantities. For a particular core shape, however, the magnetic data are influenced to a significant extent by the geometry. Thus, the inductance of a slim-line ring core coil is defined as:

\[ L = \mu_r \cdot \mu_0 \cdot N^2 \cdot \frac{A}{l} \]

Due to their geometry, soft magnetic ferrite cores in the field of such a coil change the flux parameters in such a way that it is necessary to specify a series of effective core shape parameters in each data sheet. The following are defined:

- \( l_e \) Effective magnetic length
- \( A_e \) Effective magnetic cross section
- \( A_{\text{min}} \) Min. magnetic cross section of the core
  (required to calculate the max. flux density)
- \( V_e = A_e \cdot l_e \) Effective magnetic volume

With the aid of these parameters, the calculation for ferrite cores with complicated shapes can be reduced to the considerably more simple problem of an imaginary ring core with the same magnetic properties. The basis for this is provided by the methods of calculation according to IEC 60205, which allow to calculate the effective core shape parameters of different core shapes.

### 3.1 Form factor

\[ \sum \frac{l}{A} = \frac{l_e}{A_e} \]

The inductance \( L \) can then be calculated as follows:

\[ L = \frac{\mu_e \cdot \mu_0 \cdot N^2}{\sum \frac{l}{A}} \]

where \( \mu_e \) denotes the effective permeability or another permeability \( \mu_{\text{rev}} \) or \( \mu_a \) (or \( \mu_l \) for cores with a closed magnetic path) adapted for the B/H range in question.

### 3.2 Inductance factor, \( A_L \) value

\[ A_L = \frac{L}{N^2} = \frac{\mu_e \cdot \mu_0}{\sum \frac{l}{A}} \]

\( A_L \) is the inductance referred to number of turns = 1. Therefore, for a defined number of turns \( N \):

\[ L = A_L \cdot N^2 \]
### 3.3 Tolerance code letters

The tolerances of the $A_L$ are coded by the letters in the third block of the ordering code in conformity with IEC 62358.

<table>
<thead>
<tr>
<th>Code letter</th>
<th>Tolerance of $A_L$ value</th>
<th>Code letter</th>
<th>Tolerance of $A_L$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$\pm 3%$</td>
<td>L</td>
<td>$\pm 15%$</td>
</tr>
<tr>
<td>B</td>
<td>$\pm 4%$</td>
<td>M</td>
<td>$\pm 20%$</td>
</tr>
<tr>
<td>C</td>
<td>$\pm 6%$</td>
<td>Q</td>
<td>$+30/-10%$</td>
</tr>
<tr>
<td>D</td>
<td>$\pm 8%$</td>
<td>R</td>
<td>$+30/-20%$</td>
</tr>
<tr>
<td>E</td>
<td>$\pm 7%$</td>
<td>U</td>
<td>$+80/-0%$</td>
</tr>
<tr>
<td>H</td>
<td>$\pm 12%$</td>
<td>X</td>
<td>filling letter</td>
</tr>
<tr>
<td>J</td>
<td>$\pm 5%$</td>
<td>Y</td>
<td>$+40/-30%$</td>
</tr>
<tr>
<td>K</td>
<td>$\pm 10%$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The tolerance values available are given in the individual data sheets.
4 Definition quantities in the small-signal range

4.1 Loss factor $\tan \delta$

Losses in the small-signal range are specified by the loss factor $\tan \delta$. Based on the impedance $\bar{Z}$ (cf. also section 2.4), the loss factor of the core in conjunction with the complex permeability $\bar{\mu}$ is defined as

$$\tan \delta_s = \frac{\mu_s''}{\mu_s'} = \frac{R_s}{\omega L_s}$$

and

$$\tan \delta_p = \frac{\mu_p''}{\mu_p'} = \frac{\omega \cdot L_p}{R_p}$$

where $R_s$ and $R_p$ denote the series and parallel resistance and $L_s$ and $L_p$ the series and parallel inductance respectively.

From the relationships between series and parallel circuits we obtain:

$$\mu_p' = \mu_s' \cdot (1 + (\tan \delta)^2)$$

$$\mu_p'' = \mu_s'' \cdot \left(1 + \left(\frac{1}{\tan \delta}\right)^2\right)$$

4.2 Relative loss factor $\tan \delta/\mu_i$

In gapped cores the material loss factor $\tan \delta$ is reduced by the factor $\mu_e/\mu_i$. This results in the relative loss factor $\tan \delta_e$ (cf. also section 2.2):

$$\tan \delta_e = \frac{\tan \delta}{\mu_i} \cdot \mu_e$$

The table of material properties lists the relative loss factor $\tan \delta/\mu_i$. This is determined to IEC 60401-3 at $B = 0.25$ mT, $T = 25$ °C.
4.3 Quality factor Q

The ratio of reactance to total resistance of an induction coil is known as the quality factor Q.

\[ Q = \frac{\omega L}{R_L} = \frac{\text{reactance}}{\text{total resistance}} \]

The total quality factor Q is the reciprocal of the total loss factor \( \tan \delta \) of the coil; it is dependent on the frequency, inductance, temperature, winding wire and permeability of the core.

4.4 Hysteresis loss resistance \( R_h \) and hysteresis material constant \( \eta_B \)

In transformers, in particular, the user cannot always be content with very low saturation. The user requires details of the losses which occur at higher saturation, e.g. where the hysteresis loop begins to open.

Since this hysteresis loss resistance \( R_h \) can rise sharply in different flux density ranges and at different frequencies, it is measured to IEC 60401-3 for \( \mu_i \) values greater than 500 at \( B_1 = 1.5 \) and \( B_2 = 3 \) mT (\( \Delta B = 1.5 \) mT), a frequency of 10 kHz and a temperature of 25 °C (for \( \mu_i < 500: f = 100 \) kHz, \( B_1 = 0.3 \) mT, \( B_2 = 1.2 \) mT). The hysteresis loss factor \( \tan \delta_h \) can then be calculated from this.

\[ \tan \delta_h = \frac{R_h}{\omega L} = \tan \delta(B_2) - \tan \delta(B_1) \]

For the hysteresis material constant \( \eta_B \) we obtain:

\[ \eta_B = \frac{\tan \delta_h}{\mu_e \cdot \Delta \hat{B}} \]

The hysteresis material constant, \( \eta_B \), characterizes the material-specific hysteresis losses and is a quantity independent of the air gap in a magnetic circuit.

The hysteresis loss factor of an inductor can be reduced, at a constant flux density, by means of an (additional) air gap

\[ \tan \delta_h = \eta_B \cdot \Delta \hat{B} \cdot \mu_e \]

For further details on the measurement techniques see IEC 62044-2.
5 Definition quantities in the high-excitation range

While in the small-signal range \( H \leq H_c \), i.e. in filter and broadband applications, the hysteresis loop is generally traversed only in lancet form (figure 2), for power applications the hysteresis loop is driven partly into saturation. The defining quantities are then

\[ \mu_{\text{rev}} = \text{reversible permeability in the case of superimposition with a DC signal} \]

\( \mu_a = \text{amplitude permeability and} \)

\[ P_V = \text{core losses}. \]

5.1 Core losses \( P_V \)

The losses of a ferrite core or core set \( P_V \) is proportional to the area of the hysteresis loop in question. It can be divided into three components:

\[ P_V = P_V, \text{hysteresis} + P_V, \text{eddycurrent} + P_V, \text{residual} \]

Owing to the high specific resistance of ferrite materials, the eddy current losses in the frequency range common today (1 kHz to 2 MHz) may be practically disregarded except in the case of core shapes having a large cross-sectional area.

The power loss \( P_V \) is a function of the temperature \( T \), the frequency \( f \), the flux density \( B \) and is of course dependent on ferrite material and core shape.

The temperature dependence can generally be approximated by means of a third-order polynomial, while

\[ P_V(f) \sim f^{1+x} \quad 0 \leq x \leq 1 \]

applies for the frequency dependence and

\[ P_V(B) \sim B^{2+y} \quad 0 \leq y \leq 1 \]

for the flux density dependence. The coefficients \( x \) and \( y \) are dependent on core shape and material, and there is a mutual dependence between the coefficients of the definition quantity (e.g. \( T \)) and the relevant parameter set (e.g. \( f, B \)).

In the case of cores which are suitable for power applications, the total core losses \( P_V \) are given explicitly for a specific frequency \( f \), flux density \( B \) and temperature \( T \) in the relevant data sheets.

When determining the total power loss for an inductive component, the winding losses must also be taken into consideration in addition to the core-specific losses.

\[ P_{V, \text{tot}} = P_{V, \text{core}} + P_{V, \text{winding}} \]

where, in addition to insulation conditions in the given frequency range, skin effect and proximity effect must also be taken into consideration for the winding.
5.2 Performance factor \( (PF = f \cdot B_{\text{max}}) \)

The performance factor is a measure of the maximum power which a ferrite can transmit, whereby it is generally assumed that the loss does not exceed 300 kW/m\(^3\). Heat dissipation values of this order are usually assumed when designing small and medium-sized transformers. Increasing the performance factor will either enable an increase of the power that can be transformed by a core of identical design, or a reduction in component size if the transformed power is not increased.

If the performance factors of different power transformer materials are plotted as a function of frequency, only slight differences are observed at low frequencies (<300 kHz), but these differences become more pronounced with increasing frequency. This diagram can be used to determine the optimum material for a given frequency range.
6 Influence of temperature

6.1 $\mu(T)$ curve, Curie temperature $T_C$

The initial permeability $\mu_i$ as a function of $T$ is given for all materials (see chapter on SIFERRIT materials). Important parameters for a $\mu(T)$ curve are the position of the secondary permeability maximum (SPM) and the Curie temperature. Minimum losses occur at the SPM temperature.

Above the Curie temperature $T_C$ ferrite materials lose their ferrimagnetic properties, i.e. $\mu_i$ drops to $\mu_i = 1$. This means that the parallel alignment of the elementary magnets (spontaneous magnetization) is destroyed by increasing thermal activation. This phenomenon is reversible, i.e. when the temperature is reduced below $T_C$ again, the ferrimagnetic properties are restored.

The Curie temperature $T_C$ is defined as the cross of the straight line between 80% and 20% of $L_{max}$ with the temperature axes (figure 7).

![Figure 7](image)

**Figure 7**
Definition of Curie temperature

6.2 Temperature coefficient of permeability $\alpha$

By definition the temperature coefficient $\alpha$ represents a straight line of average gradient between the reference temperatures $T_1$ and $T_2$. If the $\mu(T)$ curve is approximately linear in this temperature range, this is a good approximation; in the case of heavily pronounced maxima, however, this is less true. The following applies:

$$\alpha = \frac{\mu_{i2} - \mu_{i1}}{\mu_{i1}} \cdot \frac{1}{T_2 - T_1}$$

$\mu_{i1}$ Initial permeability $\mu_i$ at $T_1 = 25 \degree C$

$\mu_{i2}$ The initial permeability $\mu_i$ associated with the temperature $T_2$

6.3 Relative temperature coefficient $\alpha_F$

$$\alpha_F = \frac{\alpha}{\mu_i} = \frac{\mu_{i2} - \mu_{i1}}{\mu_{i2} \cdot \mu_{i1}} \cdot \frac{1}{T_2 - T_1}$$

In a magnetic circuit with an air gap and the effective permeability $\mu_e$ the temperature coefficient is reduced by the factor $\mu_e/\mu_i$ (cf. also section 2.2).
6.4 Permeability factor
The first factor in the equation for determining the relative temperature coefficient \( \frac{\mu_2 - \mu_1}{\mu_2 \cdot \mu_1} \) is known as the permeability factor.
In the case of SIFERRIT materials for resonant circuits, the temperature dependence of the permeability factor can be seen from the relevant diagram.

6.5 Effective temperature coefficient \( \alpha_e \)
\[
\alpha_e = \frac{\mu_e}{\mu_i} \cdot \alpha
\]
In the case of the ferrite materials for filter applications, the \( \alpha/\mu_i \) values for the ranges 25 to 55 °C and 5 to 25 °C are given in the table of material properties.
The effective permeability \( \mu_e \) is required in order to calculate \( \alpha_e \); therefore this is given for each core in the individual data sheets.

6.6 Relationship between the change in inductance and the permeability factor
The relative change in inductance between two temperature points can be calculated as follows:
\[
\frac{L_2 - L_1}{L_1} = \frac{\alpha}{\mu_i} \cdot (T_2 - T_1) \cdot \mu_e
\]
\[
\frac{L_2 - L_1}{L_1} = \frac{\mu_{i2} - \mu_{i1}}{\mu_{i2} \cdot \mu_{i1}} \mu_e
\]

6.7 Temperature dependence of saturation magnetization
The saturation magnetization \( B_S \) drops monotonically with temperature and at \( T_C \) has fallen to \( B_S = 0 \) mT. The drop for \( B_S(25 \, ^\circ\text{C}) \) and \( B_S(100 \, ^\circ\text{C}) \), i.e. the main area of application for the ferrites, can be taken from the table of material properties.

6.8 Temperature dependence of saturation-dependent permeability (amplitude permeability)
It can be seen from the \( \mu_a(B) \) curves for the different materials that \( \mu_a \) exhibits a more pronounced maximum with increasing temperature and drops off sooner on account of decreasing saturation.
7 Disaccommodation

Ferrimagnetic states of equilibrium can be influenced by mechanical, thermal or magnetic changes (shocks). Generally, an increase in permeability occurs when a greater mobility of individual magnetic domains is attained through the external application of energy. This state is not temporally stable and returns logarithmically with time to the original state.

7.1 Disaccommodation coefficient \( d \)

\[
d = \frac{\mu_{i1} - \mu_{i2}}{\mu_{i1} \cdot (lg t_2 - lg t_1)}
\]

\( \mu_{i1} \) Permeability at time \( t_1 \)
\( \mu_{i2} \) Permeability at time \( t_2 \) and \( t_2 > t_1 \)

7.2 Disaccommodation factor \( DF \)

\[
DF = \frac{d}{\mu_{i1}}
\]

Accordingly, a change in inductance can be calculated with the aid of \( DF \):

\[
\frac{L_1 - L_2}{L_1} = DF \cdot \mu_0 \cdot \log \frac{t_2}{t_1}
\]
8 General mechanical, thermal, electrical and magnetic properties of ferrites

Typical figures for the mechanical and thermal properties of ferrites

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>approx. 30 N/mm²</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>approx. 800 N/mm²</td>
</tr>
<tr>
<td>Vickers hardness HV₁₅</td>
<td>approx. 600 N/mm²</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>approx. 150000 N/mm²</td>
</tr>
<tr>
<td>Fracture toughness K₁c</td>
<td>approx. 0.8 … 1.1 MPa·m¹/²</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>approx. 4 … 7·10⁻³ J/mm·s·K</td>
</tr>
<tr>
<td>Coefficient of linear expansion</td>
<td>approx. 7 … 10⁻⁶ 1/K</td>
</tr>
<tr>
<td>Specific heat</td>
<td>approx. 0.7 J/g·K</td>
</tr>
</tbody>
</table>

8.1 Mechanical properties

Ferrite cores have to meet mechanical requirements during assembling and for a growing number of applications. Since ferrites are ceramic materials one has to be aware of the special behavior under mechanical load.

As valid for any ceramic material, ferrite cores are brittle and sensitive to any shock, fast changing or tensile load. Especially high cooling rates under ultrasonic cleaning and high static or cyclic loads can cause cracks or failure of the ferrite cores.

![Figure 8](image)

**Figure 8**

Weibull plot of fracture strength values of the materials T38 and N87
There are two modes of crack growth: fast (critical) or slow (subcritical) crack propagation. In the first case spontaneous breakdown occurs. In the second case the crack propagates slowly during static or cycling loading, and then the sample can only fail if a critical crack length is achieved. According to the linear elastic fracture mechanics these two mechanisms could be described in terms of stress intensity factors. For life time predictions the knowledge of subcritical crack growth and R- (respectively KR–) curve behavior of the material is essential.

The reduction of the material strength by temperature induced propagating microstructural cracks can be described as follows:

$$
\sigma = \alpha \cdot \Delta T \frac{E_0}{1 + 2\pi N l^2}
$$

\( \sigma \) Effective strength

\( \alpha \) Coefficient of thermal expansion (7 to 12 \( \cdot \) 10\(^{-6} \) 1/K)

\( E_0 \) Modulus of elasticity

\( N \) Number of temperature changes

\( l \) Crack length

The brittleness of ferrite materials can be quantified by means of the fracture toughness. High fracture toughness values indicate decreased material brittleness. The quantity of the fracture toughness is a measure for the stress in the core necessary for a propagating crack. For the crack propagation it is required that the stress intensity factor exceeds the fracture toughness.

$$
K_1 \geq K_{1C} \text{ with } K_1 = \sigma_{\text{appl}} \sqrt{Y} \text{ and } K_{1C} = \sqrt{G_C E}
$$

\( K_1 \) Stress intensity factor

\( K_{1C} \) Fracture toughness

\( \sigma_{\text{appl}} \) Applied stress

\( Y \) Factor for fracture/sample geometry

\( G_C \) Critical fracture area energy

\( E \) Modulus of elasticity

Typical fracture toughness values are approx. 0.8 to 1.1 MPa\( \cdot \)m\(^{1/2} \).

Ferrite materials have a pronounced R curve behavior, i.e. the fracture toughness increases with propagating crack length. In practice there is a rather tolerant behavior towards moderate single stress events.
8.2  Stress sensitivity of magnetic properties

Stresses in the core affect not only the mechanical but also the magnetic properties. It is apparent that the initial permeability is dependent on the stress state of the core. With

\[ \mu_i \equiv \frac{1}{1 + k \cdot \sigma_T}; \quad k = 30 \cdot 10^{-6} \cdot \frac{1}{\text{MPa}} \]

where \( \mu_{io} \) is the initial permeability of the unstressed material, it can be shown that the higher the stresses are in the core, the lower is the value for the initial permeability. Embedding the ferrite cores (e.g. in plastic) can induce these stresses. A permeability reduction of up to 50% and more can be observed, depending on the material. In this case, the embedding medium should have the greatest possible elasticity.

8.3  Magnetostriction

Linear magnetostriction is defined as the relative change in length of a magnetic core under the influence of a magnetic field. The greatest relative variation in length \( \lambda = \Delta l/l \) occurs at saturation magnetization. The values of the saturation magnetostriction (\( \lambda_s \)) of our ferrite materials are given in the following table (negative values denote contraction).

<table>
<thead>
<tr>
<th>SIFFERIT material</th>
<th>K1</th>
<th>N48</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_s ) in ( 10^{-6} )</td>
<td>−18</td>
<td>−1.5</td>
</tr>
</tbody>
</table>

Magnetostrictive effects are of significance principally when a coil is operated in the frequency range <20 kHz and then undesired audible frequency effects (distortion etc.) occur.

8.4  Resistance to radiation

SIFERRIT materials can be exposed to the following radiation without significant variation (\( \Delta L/L \leq 1\% \) for ungapped cores):

- gamma quanta: \( 10^9 \) rad
- quick neutrons: \( 2 \cdot 10^{20} \) neutrons/m²
- thermal neutrons: \( 2 \cdot 10^{22} \) neutrons/m²
8.5 Resistivity $\rho$, dielectric constant $\varepsilon$

At room temperature, ferrites have a resistivity in the range $1 \, \Omega \cdot \text{m}$ to $10^5 \, \Omega \cdot \text{m}$; this value is usually higher at the grain boundaries than in the grain interior. The temperature dependence of the core resistivity corresponds to that of a semiconductor:

$$\rho \sim e^{\frac{E_a}{kT}}$$

$E_a$ Activation energy (0.1 to 0.5 eV)  
$k$ Boltzmann constant  
$T$ Absolute temperature (K)

Thus the resistivity at 100 °C is one order of magnitude less than at 25 °C, which is significant, particularly in power applications, for the magnitude of the eddy-current losses.

Similarly, the resistivity decreases with increasing frequency.

Example: Material N48

![Figure 9](Image)

Resistivity and dielectric constant versus frequency

The different resistivity values for grain interior and grain boundary result in high (apparent) dielectric constants $\varepsilon$ at low frequencies. The dielectric constant $\varepsilon$ for all ferrites falls to values around 10 to 20 at very high frequencies. NiZn ferrites already reach this value range at frequencies around 100 kHz.
Magnetostrictive effects are of significance principally when a coil is operated in the frequency range <20 kHz and then undesired audible frequency effects occur.

### General

#### Definitions

<table>
<thead>
<tr>
<th>SIFFERIT material</th>
<th>Resistivity (approx.) ( \Omega \text{m} )</th>
<th>Dielectric constant ( \varepsilon ) at (approximate values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1 (NiZn)</td>
<td>10⁵</td>
<td>10 kHz 100 kHz 1 MHz 100 MHz 300 MHz</td>
</tr>
<tr>
<td>N48 (MnZn)</td>
<td>1</td>
<td>30 140 ( \cdot 10^3 ) 15 115 ( \cdot 10^3 ) 12 80 ( \cdot 10^3 ) 11 11</td>
</tr>
</tbody>
</table>
9 Coil characteristics

Resistance factor $A_R$

The resistance factor $A_R$, or $A_R$ value, is the DC resistance $R_{Cu}$ per unit turn, analogous to the $A_L$ value.

$$A_R = \frac{R_{Cu}}{N^2}$$

When the $A_R$ value and number of turns $N$ are given, the DC resistance can be calculated from $R_{Cu} = A_R N^2$.

From the winding data etc. the $A_R$ value can be calculated as follows:

$$A_R = \frac{\rho \cdot l_N}{f_{Cu} \cdot A_N}$$

where $\rho$ = resistivity (for copper: $17.2 \ \mu\Omega \ mm$), $l_N$ = average length of turn in mm, $A_N$ = cross section of winding in mm$^2$, $f_{Cu}$ = copper space factor. If these units are used in the equation, the $A_R$ value is obtained in $\mu\Omega = 10^{-6} \ \Omega$. For calculation of $l_N$ and $A_N$ the middle dimensions are used.

For coil formers, $A_R$ values are given in addition to $A_N$ and $l_N$. They are based on a copper filling factor of $f_{Cu} = 0.5$. This permits the $A_R$ value to be calculated for any filling factor $f_{Cu}$:

$$A_{R(f_{Cu})} = A_{R(0.5)} \cdot \frac{0.5}{f_{Cu}}$$

For rough estimation a copper filling factor of $f_{Cu} = 0.5$ is sufficient.
Mechanical stress and mounting
Ferrite cores have to meet mechanical requirements during assembling and for a growing number of applications. Since ferrites are ceramic materials one has to be aware of the special behavior under mechanical load.

As valid for any ceramic material, ferrite cores are brittle and sensitive to any shock, fast temperature changing or tensile load. Especially high cooling rates under ultrasonic cleaning and high static or cyclic loads can cause cracks or failure of the ferrite cores.

For detailed information see data book, chapter “General - Definitions, 8.1”.

Effects of core combination on $A_L$ value
Stresses in the core affect not only the mechanical but also the magnetic properties. It is apparent that the initial permeability is dependent on the stress state of the core. The higher the stresses are in the core, the lower is the value for the initial permeability. Thus the embedding medium should have the greatest possible elasticity.

For detailed information see data book, chapter “General - Definitions, 8.1”.

Heating up
Ferrites can run hot during operation at higher flux densities and higher frequencies.

NiZn-materials
The magnetic properties of NiZn-materials can change irreversible in high magnetic fields.

Ferrite Accessories
Our ferrite accessories have been designed and evaluated only in combination with our ferrite cores. We explicitly point out that our ferrite accessories or our ferrite cores may not be compatible with those of other manufacturers. Any such combination requires prior testing by the customer and will be at the customer’s own risk.

We assume no warranty or reliability for the combination of our ferrite accessories with cores and other accessories from any other manufacturer.

Processing remarks
The start of the winding process should be soft. Else the flanges may be destroyed.

– Too strong winding forces may blast the flanges or squeeze the tube that the cores can not be mounted any more.
– Too long soldering time at high temperature (>300 °C) may effect coplanarity or pin arrangement.
– Not following the processing notes for soldering of the J-leg terminals may cause solderability problems at the transformer because of pollution with Sn oxyde of the tin bath or burned insulation of the wire. For detailed information see chapter “Processing notes”, section 2.2.
– The dimensions of the hole arrangement have fixed values and should be understood as a recommendation for drilling the printed circuit board. For dimensioning the pins, the group of holes can only be seen under certain conditions, as they fit into the given hole arrangement.
To avoid problems when mounting the transformer, the manufacturing tolerances for positioning the customers’ drilling process must be considered by increasing the hole diameter.
Display of ordering codes for TDK Electronics products

The ordering code for one and the same product can be represented differently in data sheets, data books, other publications, on the company website or in order-related documents such as shipping notes, order confirmations and product labels. The varying representations of the ordering codes are due to different processes employed and do not affect the specifications of the respective products. Detailed information can be found on the Internet under www.tdk-electronics.tdk.com/orderingcodes.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Cross section of coil</td>
<td>mm²</td>
</tr>
<tr>
<td>Aᵅ</td>
<td>Effective magnetic cross section</td>
<td>mm²</td>
</tr>
<tr>
<td>A_L</td>
<td>Inductance factor; ( A_L = L/N^2 )</td>
<td>nH</td>
</tr>
<tr>
<td>A_L1</td>
<td>Minimum inductance at defined high saturation (≥ ( \mu_a ))</td>
<td>nH</td>
</tr>
<tr>
<td>A_min</td>
<td>Minimum core cross section</td>
<td>mm²</td>
</tr>
<tr>
<td>A_N</td>
<td>Winding cross section</td>
<td>mm²</td>
</tr>
<tr>
<td>A_R</td>
<td>Resistance factor; ( A_R = R_{Cu}/N^2 )</td>
<td>( \mu \Omega = 10^{-6} \Omega )</td>
</tr>
<tr>
<td>B</td>
<td>RMS value of magnetic flux density</td>
<td>Vs/m², mT</td>
</tr>
<tr>
<td>( \Delta B )</td>
<td>Flux density deviation</td>
<td>Vs/m², mT</td>
</tr>
<tr>
<td>( \hat{B} )</td>
<td>Peak value of magnetic flux density</td>
<td>Vs/m², mT</td>
</tr>
<tr>
<td>( \Delta \hat{B} )</td>
<td>Peak value of flux density deviation</td>
<td>Vs/m², mT</td>
</tr>
<tr>
<td>B_{DC}</td>
<td>DC magnetic flux density</td>
<td>Vs/m², mT</td>
</tr>
<tr>
<td>B_R</td>
<td>Remanent flux density</td>
<td>Vs/m², mT</td>
</tr>
<tr>
<td>B_S</td>
<td>Saturation magnetization</td>
<td>Vs/m², mT</td>
</tr>
<tr>
<td>C₀</td>
<td>Winding capacitance</td>
<td>F = As/V</td>
</tr>
<tr>
<td>CDF</td>
<td>Core distortion factor</td>
<td>mm⁻⁴.⁵</td>
</tr>
<tr>
<td>DF</td>
<td>Relative disaccommodation coefficient ( DF = d/\mu_i )</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>Disaccommodation coefficient</td>
<td></td>
</tr>
<tr>
<td>E_a</td>
<td>Activation energy</td>
<td>J</td>
</tr>
<tr>
<td>f</td>
<td>Frequency</td>
<td>s⁻¹, Hz</td>
</tr>
<tr>
<td>( f_{cutoff} )</td>
<td>Cut-off frequency</td>
<td>s⁻¹, Hz</td>
</tr>
<tr>
<td>( f_{max} )</td>
<td>Upper frequency limit</td>
<td>s⁻¹, Hz</td>
</tr>
<tr>
<td>( f_{min} )</td>
<td>Lower frequency limit</td>
<td>s⁻¹, Hz</td>
</tr>
<tr>
<td>( f_r )</td>
<td>Resonance frequency</td>
<td>s⁻¹, Hz</td>
</tr>
<tr>
<td>( f_{Cu} )</td>
<td>Copper filling factor</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>Air gap</td>
<td>mm</td>
</tr>
<tr>
<td>H</td>
<td>RMS value of magnetic field strength</td>
<td>A/m</td>
</tr>
<tr>
<td>( \hat{H} )</td>
<td>Peak value of magnetic field strength</td>
<td>A/m</td>
</tr>
<tr>
<td>H_{DC}</td>
<td>DC field strength</td>
<td>A/m</td>
</tr>
<tr>
<td>H_c</td>
<td>Coercive field strength</td>
<td>A/m</td>
</tr>
<tr>
<td>h</td>
<td>Hysteresis coefficient of material</td>
<td>10⁻⁶ cm/A</td>
</tr>
<tr>
<td>( h/\mu_i^2 )</td>
<td>Relative hysteresis coefficient</td>
<td>10⁻⁶ cm/A</td>
</tr>
<tr>
<td>I</td>
<td>RMS value of current</td>
<td>A</td>
</tr>
<tr>
<td>I_{DC}</td>
<td>Direct current</td>
<td>A</td>
</tr>
<tr>
<td>( \hat{I} )</td>
<td>Peak value of current</td>
<td>A</td>
</tr>
<tr>
<td>J</td>
<td>Polarization</td>
<td>Vs/m²</td>
</tr>
<tr>
<td>k</td>
<td>Boltzmann constant</td>
<td>J/K</td>
</tr>
<tr>
<td>k₃</td>
<td>Third harmonic distortion</td>
<td></td>
</tr>
<tr>
<td>k₃c</td>
<td>Circuit third harmonic distortion</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Inductance</td>
<td>H = Vs/A</td>
</tr>
</tbody>
</table>
### Symbols and terms

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔL/L</td>
<td>Relative inductance change</td>
<td>H</td>
</tr>
<tr>
<td>L₀</td>
<td>Inductance of coil without core</td>
<td>H</td>
</tr>
<tr>
<td>L_H</td>
<td>Main inductance</td>
<td>H</td>
</tr>
<tr>
<td>L_p</td>
<td>Parallel inductance</td>
<td>H</td>
</tr>
<tr>
<td>L_rev</td>
<td>Reversible inductance</td>
<td>H</td>
</tr>
<tr>
<td>L_s</td>
<td>Series inductance</td>
<td>H</td>
</tr>
<tr>
<td>I_e</td>
<td>Effective magnetic path length</td>
<td>mm</td>
</tr>
<tr>
<td>I_N</td>
<td>Average length of turn</td>
<td>mm</td>
</tr>
<tr>
<td>N</td>
<td>Number of turns</td>
<td></td>
</tr>
<tr>
<td>P_Cu</td>
<td>Copper (winding) losses</td>
<td>W</td>
</tr>
<tr>
<td>P_trans</td>
<td>Transferrable power</td>
<td>W</td>
</tr>
<tr>
<td>P_V</td>
<td>Relative core losses</td>
<td>mW/g</td>
</tr>
<tr>
<td>PF</td>
<td>Performance factor</td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>Quality factor (Q = \omega L / R_s = 1 / \tan \delta_L)</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Resistance</td>
<td>Ω</td>
</tr>
<tr>
<td>R_Cu</td>
<td>Copper (winding) resistance (f = 0)</td>
<td>Ω</td>
</tr>
<tr>
<td>R_h</td>
<td>Hysteresis loss resistance of a core</td>
<td>Ω</td>
</tr>
<tr>
<td>ΔR_h</td>
<td>(R_h) change</td>
<td>Ω</td>
</tr>
<tr>
<td>R_i</td>
<td>Internal resistance</td>
<td>Ω</td>
</tr>
<tr>
<td>R_p</td>
<td>Parallel loss resistance of a core</td>
<td>Ω</td>
</tr>
<tr>
<td>R_s</td>
<td>Series loss resistance of a core</td>
<td>Ω</td>
</tr>
<tr>
<td>R_th</td>
<td>Thermal resistance</td>
<td>K/W</td>
</tr>
<tr>
<td>R_V</td>
<td>Effective loss resistance of a core</td>
<td>Ω</td>
</tr>
<tr>
<td>s</td>
<td>Total air gap</td>
<td>mm</td>
</tr>
<tr>
<td>T</td>
<td>Temperature</td>
<td>°C</td>
</tr>
<tr>
<td>ΔT</td>
<td>Temperature difference</td>
<td>K</td>
</tr>
<tr>
<td>T_C</td>
<td>Curie temperature</td>
<td>°C</td>
</tr>
<tr>
<td>t</td>
<td>Time</td>
<td>s</td>
</tr>
<tr>
<td>t_v</td>
<td>Pulse duty factor</td>
<td></td>
</tr>
<tr>
<td>tan δ</td>
<td>Loss factor</td>
<td></td>
</tr>
<tr>
<td>tan δ_L</td>
<td>Loss factor of coil</td>
<td></td>
</tr>
<tr>
<td>tan δ_r</td>
<td>(Residual) loss factor at (H \rightarrow 0)</td>
<td></td>
</tr>
<tr>
<td>tan δ_e</td>
<td>Relative loss factor</td>
<td></td>
</tr>
<tr>
<td>tan δ_h</td>
<td>Hysteresis loss factor</td>
<td></td>
</tr>
<tr>
<td>tan δ/μ_i</td>
<td>Relative loss factor of material at (H \rightarrow 0)</td>
<td></td>
</tr>
<tr>
<td>U</td>
<td>RMS value of voltage</td>
<td>V</td>
</tr>
<tr>
<td>Ü</td>
<td>Peak value of voltage</td>
<td>V</td>
</tr>
<tr>
<td>V_e</td>
<td>Effective magnetic volume</td>
<td>mm³</td>
</tr>
<tr>
<td>Z</td>
<td>Complex impedance</td>
<td>Ω</td>
</tr>
<tr>
<td>Z_n</td>
<td>Normalized impedance (</td>
<td>Z_n</td>
</tr>
</tbody>
</table>
## Symbols and terms

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>Temperature coefficient (TK)</td>
<td>1/K</td>
</tr>
<tr>
<td>$\alpha_F$</td>
<td>Relative temperature coefficient of material</td>
<td>1/K</td>
</tr>
<tr>
<td>$\alpha_e$</td>
<td>Temperature coefficient of effective permeability</td>
<td>1/K</td>
</tr>
<tr>
<td>$\varepsilon_r$</td>
<td>Relative permittivity</td>
<td></td>
</tr>
<tr>
<td>$\Phi$</td>
<td>Magnetic flux</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>Efficiency of a transformer</td>
<td>Vs</td>
</tr>
<tr>
<td>$\eta_B$</td>
<td>Hysteresis material constant</td>
<td>mT$^{-1}$</td>
</tr>
<tr>
<td>$\eta_i$</td>
<td>Hysteresis core constant</td>
<td>A$^{-1}$H$^{-1/2}$</td>
</tr>
<tr>
<td>$\lambda_S$</td>
<td>Magnetostriction at saturation magnetization</td>
<td></td>
</tr>
<tr>
<td>$\mu$</td>
<td>Relative complex permeability</td>
<td></td>
</tr>
<tr>
<td>$\mu_0$</td>
<td>Magnetic field constant</td>
<td>Vs/Am</td>
</tr>
<tr>
<td>$\mu_a$</td>
<td>Relative amplitude permeability</td>
<td></td>
</tr>
<tr>
<td>$\mu_{app}$</td>
<td>Relative apparent permeability</td>
<td></td>
</tr>
<tr>
<td>$\mu_e$</td>
<td>Relative effective permeability</td>
<td></td>
</tr>
<tr>
<td>$\mu_i$</td>
<td>Relative initial permeability</td>
<td></td>
</tr>
<tr>
<td>$\mu_p'$</td>
<td>Relative real (inductive) component of $\mu$ (for parallel components)</td>
<td></td>
</tr>
<tr>
<td>$\mu_p''$</td>
<td>Relative imaginary (loss) component of $\mu$ (for parallel components)</td>
<td></td>
</tr>
<tr>
<td>$\mu_r$</td>
<td>Relative permeability</td>
<td></td>
</tr>
<tr>
<td>$\mu_{rev}$</td>
<td>Relative reversible permeability</td>
<td></td>
</tr>
<tr>
<td>$\mu_s'$</td>
<td>Relative real (inductive) component of $\mu$ (for series components)</td>
<td></td>
</tr>
<tr>
<td>$\mu_s''$</td>
<td>Relative imaginary (loss) component of $\mu$ (for series components)</td>
<td></td>
</tr>
<tr>
<td>$\mu_{tot}$</td>
<td>Relative total permeability derived from the static magnetization curve</td>
<td></td>
</tr>
<tr>
<td>$\rho$</td>
<td>Resistivity</td>
<td>$\Omega$m$^{-1}$</td>
</tr>
<tr>
<td>$\Sigma/A$</td>
<td>Magnetic form factor</td>
<td>mm$^{-1}$</td>
</tr>
<tr>
<td>$\tau_{Cu}$</td>
<td>DC time constant $\tau_{Cu} = L/R_{Cu} = A_L/A_R$</td>
<td>s</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Angular frequency; $\omega = 2\pi f$</td>
<td>s$^{-1}$</td>
</tr>
</tbody>
</table>

All dimensions are given in mm.

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Surface-mount device

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Please read *Caution and warnings* and *Important notes* at the end of this document.
The following applies to all products named in this publication:

1. Some parts of this publication contain statements about the suitability of our products for certain areas of application. These statements are based on our knowledge of typical requirements that are often placed on our products in the areas of application concerned. We nevertheless expressly point out that such statements cannot be regarded as binding statements about the suitability of our products for a particular customer application. As a rule, we are either unfamiliar with individual customer applications or less familiar with them than the customers themselves. For these reasons, it is always ultimately incumbent on the customer to check and decide whether a product with the properties described in the product specification is suitable for use in a particular customer application.

2. We also point out that in individual cases, a malfunction of electronic components or failure before the end of their usual service life cannot be completely ruled out in the current state of the art, even if they are operated as specified. In customer applications requiring a very high level of operational safety and especially in customer applications in which the malfunction or failure of an electronic component could endanger human life or health (e.g. in accident prevention or life-saving systems), it must therefore be ensured by means of suitable design of the customer application or other action taken by the customer (e.g. installation of protective circuitry or redundancy) that no injury or damage is sustained by third parties in the event of malfunction or failure of an electronic component.

3. The warnings, cautions and product-specific notes must be observed.

4. In order to satisfy certain technical requirements, some of the products described in this publication may contain substances subject to restrictions in certain jurisdictions (e.g. because they are classed as hazardous). Useful information on this will be found in our Material Data Sheets on the Internet (www.tdk-electronics.tdk.com/material). Should you have any more detailed questions, please contact our sales offices.

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6. Unless otherwise agreed in individual contracts, all orders are subject to our General Terms and Conditions of Supply.
7. **Our manufacturing sites serving the automotive business apply the IATF 16949 standard.**

   The IATF certifications confirm our compliance with requirements regarding the quality management system in the automotive industry. Referring to customer requirements and customer specific requirements (“CSR”) TDK always has and will continue to have the policy of respecting individual agreements. Even if IATF 16949 may appear to support the acceptance of unilateral requirements, we hereby like to emphasize that **only requirements mutually agreed upon can and will be implemented in our Quality Management System.** For clarification purposes we like to point out that obligations from IATF 16949 shall only become legally binding if individually agreed upon.

8. The trade names EPCOS, CarXield, CeraCharge, CeraDiode, CeraLink, CeraPad, CeraPlas, CSMP, CTVS, DeltaCap, DigiSiMic, ExoCore, FilterCap, FormFit, InsuGate, LeaXield, MiniBlue, MiniCell, MKD, MKK, ModCap, MotorCap, PCC, PhaseCap, PhaseCube, PhaseMod, PhiCap, PowerHap, PQSine, PQvar, SIFERRIT, SIFI, SIKOREL, SilverCap, SIMDAD, SiMic, SIMID, SineFormer, SIOV, ThermoFuse, WindCap, XieldCap are **trademarks registered or pending** in Europe and in other countries. Further information will be found on the Internet at [www.tdk-electronics.tdk.com/trademarks](http://www.tdk-electronics.tdk.com/trademarks).

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