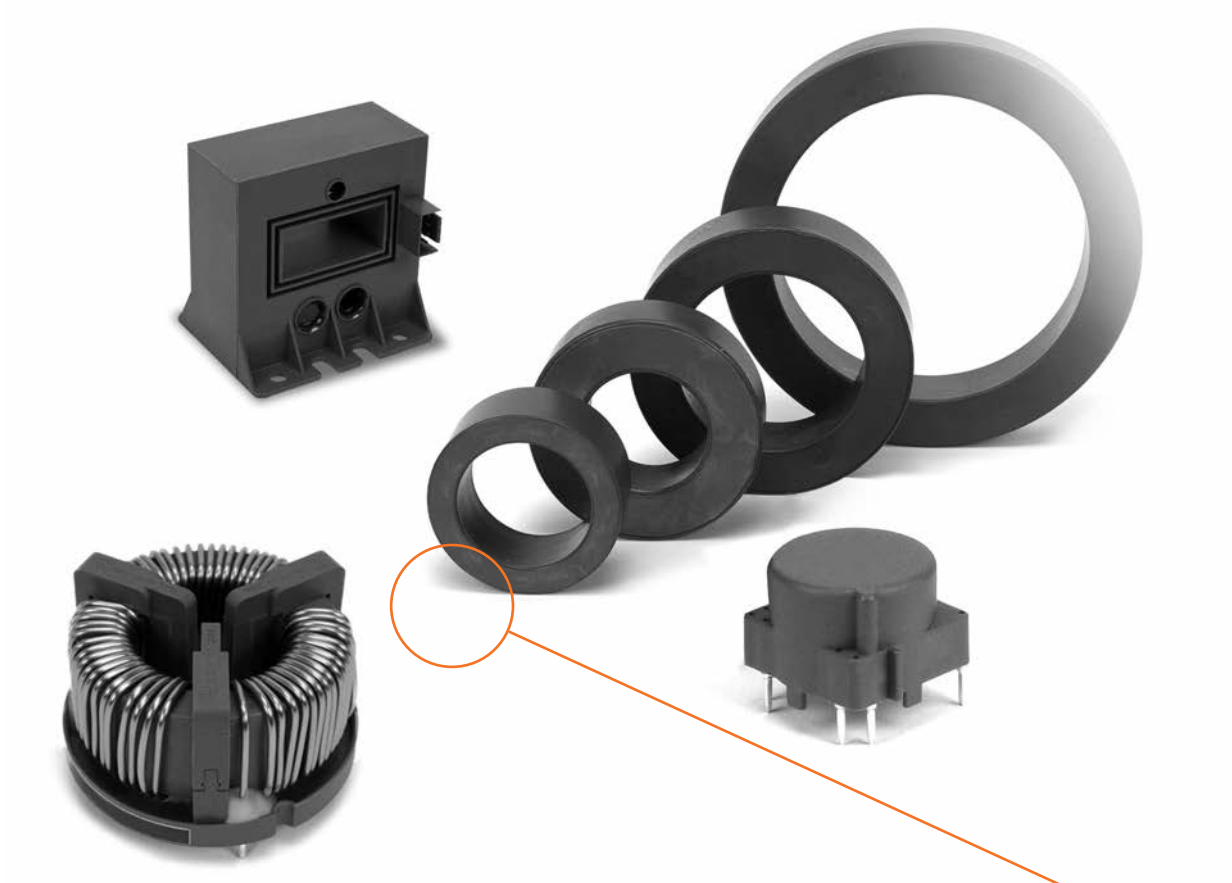
CORES AND COMPONENTS



ADVANCED MATERIALS – THE KEY TO PROGRESS

VACUUMSCHMELZE

THE COMPANY

VACUUMSCHMELZE

Der Fortschritt beginnt beim Werkstoff

Advanced Materials - The Key to Progress

进步始于先进的材料

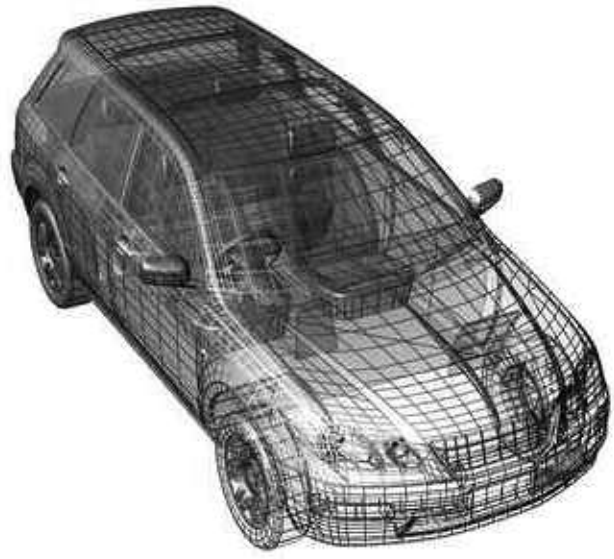
VACUUMSCHMELZE GmbH & CO. KG is one of world's leading producers of special metallic materials and related products with exceptional magnetic and physical properties. Our wide range of high quality semi-finished products, parts, components and systems are used in virtually every field of electrical and electronic engineering. This makes us one of the few global companies to offer our customers the complete range of magnetic technology products from a single source – from magnetically soft products to the most powerful permanent magnets in the world.

In all our activities, we benefit from our highly developed material expertise and our decades of experience in magnetic technology. As early as 1923, we became the first company to introduce alloy smelting in a vacuum on an industrial scale and it was from this process that the name VACUUMSCHMELZE was derived.

We are a global company with our headquarters in Hanau, Germany. We currently have over 4500 employees who are spread over production and sales locations in more than 40 countries on every continent, generating annual sales of approximately EUR 350 million.

One of our great strengths is our versatility. All of the world's key industries rely on products and expertise from VACUUMSCHMELZE, with our principal customers active in drive and installation technology, medical technology, renewable energy, automation systems, process and control engineering, measurement technology, as well as the very important automotive and aerospace industries. VAC's custom solutions are developed in close cooperation with customers and reflect a high level of material and application expertise combined with the latest production technology.

AUTOMOTIVE APPLICATIONS



The trend towards increasingly efficient electronic control devices in vehicles continues unabated. Regulations such as those established by the ACEA (European Automobile Manufacturer Association) with regard to reducing CO_2 emissions have led to the development of environmentally-friendly vehicles with new drive technologies and complex electronic systems. This leads to an even greater demand for power inductors and EMC components that satisfy the requirements of the automotive industry.

Over the years, VACUUMSCHMELZE has established itself as a competent and reliable tier 2 supplier, selling millions of inductive components to the automotive industry. VAC products can be found in the majority of vehicles currently produced. We achieve this by developing bespoke solutions for a wide range of applications using a comprehensive set of tried and tested components and techniques — all according to the individual requirements of our customers. By using standard materials as well as our own innovative alloys, VAC has gained a strong reputation as an important development partner for advanced magnetic materials and associated components. Our expertise is widely recognised and highly valued by many well-known automotive OEMs. In our laboratory, we rigorously test products and designs to ensure they are suitable for use in vehicles and undertake full validation studies on behalf of our customers. Our Quality Management system is certified in accordance with TS 16949 and follows the product life cycle from development right through to application.

Products and current developments

- **Chokes for voltage stabilisation, e.g. for gasoline and diesel direct injection systems**
- **Compact and loss-optimised transformers and storage chokes for inverters and rectifiers in hybrid and electric vehicles**
- **Mechanically robust and compact EMC chokes with superb attenuation characteristics, e.g. for electric power assisted steering**
- **Highly permeable temperature resistant VITROPERM® cores for EMC applications, even within the engine bay**
- **Precise and temperature-stable current sensors based on our magnetic probe principle, e.g. for battery energy management**
- **Flexible, low weight, high performance antennae for keyless LF entry systems**

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INDUSTRIAL APPLICATIONS

The field of industrial applications is characterised by the use of state-of-the-art power electronics with great emphasis on energy, volume and cost efficiency, together with high quality to provide long life and maintenance-free operation. The fields of application are just as diverse as our technical solutions.

Our products can be found in electric drives of every power class and in a wide range of power supply units from high accuracy, ultra stable systems to high volume computer PSU's. Renewable energy is an extremely important growth area. We are continually developing and supplying innovative products for use in wind generators and, in particular, solar inverters with emphasis on our key benefits of increased energy efficiency and reduced volume. Our inductive components are also widely used in other industries such as railway technology, automation technology or household equipment (e.g. induction hobs).

In every case, our aim is offer a low-cost, highly functional product in a volume optimised package with maximum reliability. This is made possible through interdisciplinary collaboration between experienced engineers and by use of our own innovative materials. This unique combination of application and materials knowledge enables VAC to develop optimal solutions for some of the toughest design challenges.

In choosing VAC, our customers gain the benefits of our state-of-the-art materials, worldwide production locations, experience in global markets and our work with international standardisation bodies. We work closely with our customers to integrate our standard components or develop optimised innovative products that meet specific customer needs. Our certified production locations in Germany, China, Malaysia and Slovakia, as well as our global purchasing, ensure cost effectiveness and a high quality standard.

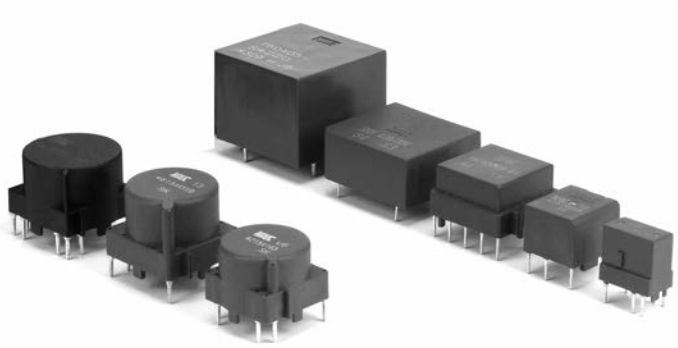
Our strength lies in our comprehensive range of standard series products, customised for diverse application profiles and individual solutions. A wide range of skills and capabilities are available from VAC, including:

- **Understanding of our customers' applications and requirements**
- **Individual dimensioning and construction**
- **Application of international standards and regulations**
- **Selection and application of optimal core materials**
- **In-house core production facility**
- **Our own crystalline, amorphous and nanocrystalline materials**
- **Continuous product maintenance and further development**
- **Logistics systems for just-in-time and ship-to-line deliveries**
- **Quality standard in accordance with DIN ISO 9001/ISO/TS 16949**

PRODUCTS

Transformers

- Compact gate drive transformers for semiconductor switches with low leakage inductance for optimal pulse transmission
- Low-loss power transformers for switched-mode power supplies and frequency converters



Cores and chokes

- Highly permeable nanocrystalline toroidal tape wound cores
- Prefabricated core modules for EMC applications
- Compact, low-loss, current-compensated radio interference suppression chokes
- Cost-effective saturable chokes (magnetic amplifiers) for precise voltage regulation

Current sensors and transformers

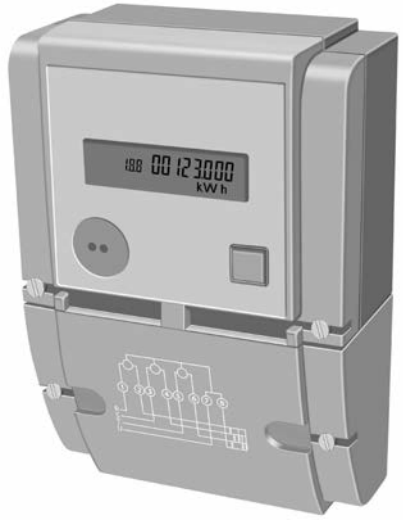
- High-precision current sensors for detecting AC and DC currents
- AC/DC-sensitive differential current sensors
- Current transformers for monitoring energy distribution networks

Toroidal tape wound and cut cores

- Low-loss nanocrystalline toroidal tape wound cores and cut cores for transformers and chokes

INSTALLATION TECHNOLOGY

Current transformers for electronic electricity meters



Electronic electricity meters are being increasingly employed worldwide. In some countries, the changeover is prescribed by law, while in others it is voluntary. We serve well-known customers in both the IEC and ANSI markets who manufacture electricity meters with VAC current transformers with great success.

Innovative and cost-effective solutions based on nanocrystalline materials from the VITROPERM alloy family have been proven to provide a robust and accurate solution in a wide range of meter designs.

Our current transformers boast many technical advantages, such as a high level of linearity, low temperature dependence and a compact design. Our current transformer product range sets new standards worldwide for precision current measurement.

In addition to our standard single current transformers for operation up to 400 A, we also offer enhanced solutions, such as triple modules for simplified assembly in polyphase meters, versions with built-in shielding for protection against external magnetic fields and designs with integrated primary current conductors and customer-specific connectors.

We offer product ranges for each of the following current transformers:

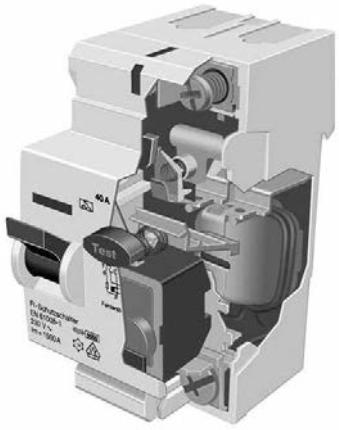
- **With or without DC tolerance according to IEC standards (based on VITROPERM)**
- **With shielding against external magnetic fields**
- **For direct or indirect connection**
- **For ANSI markets**

Cores and transformers for earth leakage circuit breakers

For several decades, we have been providing products using our high-quality materials to provide reliable function in voltage-independent residual current devices. This began with the development of high-quality NiFe materials such as VACOPERM® and PERMAX®. More recently it was possible to considerably reduce the size of the cores by using newly developed materials. At this time, ULTRAPERM® was the dominant force in the market.

Currently, the introduction of nanocrystalline materials such as VITROPERM has led to the development of innovative solutions that move far beyond the limits and possibilities of crystalline materials. VITROPERM offers optimal solutions for almost every common switch type (AC/A/B/B+).

Our unique combination of advanced materials and application expertise help to ensure that VAC remains a key innovation and development partner to our customers. The use of comprehensive simulation and dimensioning programmes allows us to optimise the accuracy of new designs, thus reducing the need for an empirical approach to development.



PLC transformers for smart metering

Several systems can be used for the data communication within the new smart meter products. Aside from wireless connections such as GSM, PLC (powerline communications) systems are becoming increasingly popular. In many systems, the combined data from several meters is sent via PLC to a concentrator for onward transmission to the data management centre using GSM technology.

VAC Powerline transformers are commonly used in the meters, concentrators and in the controller units to which electricity, gas and water meters can be connected. Our PLC products help to ensure the communications technology is galvanically isolated from the power network whilst faithfully transmitting the required signal.

Our market leading PLC transformers feature a low distortion factor, a high excitation level and low design volume.

For the most common modulation methods DCSK, FSK and OFDM, VAC offers optimised solutions in its product range for all major PLC chipsets from well-known manufacturers.

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VACUUMSCHMELZE GMBH & CO. KG

GRÜNER WEG 37
D 63450 HANAU / GERMANY
TELEFON +49 6181 38 0
FAX +49 6181 38 2645
INFO@VACUUMSCHMELZE.COM
WWW.VACUUMSCHMELZE.COM

VAC SALES USA LLC

2935 DOLPHIN DRIVE / SUITE 102
42701 ELIZABETHTOWN KY / USA
TELEFON +1 270 769-1333
FAX +1 270 765 3118
INFO-USA@VACUUMSCHMELZE.COM

VACUUMSCHMELZE SALES OFFICE SINGAPUR

61 KAKI BUKIT AVENUE 1
#04-16 SHUN LI INDUSTRIAL PARK
SINGAPORE 417943
TELEFON (+65) 63 91 26 00
FAX (+65) 63 91 26 01
VACSINGAPORE@VACUUMSCHMELZE.COM

VACUUMSCHMELZE CHINA MAGNETICS

SHANGHAI SALES OFFICE
ROOM B, 11F, QIAN JIANG TOWER NO. 971
DONGFANG ROAD, PUDONG DISTRIBUTE
SHANGHAI, PRC 200122
P.R. CHINA
TELEFON (+86) 21 / 58 31 98 37
FAX (+86) 21 / 58 31 99 37
ELTON.LU@VACUUMSCHMELZE.COM

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VACUUMSCHMELZE

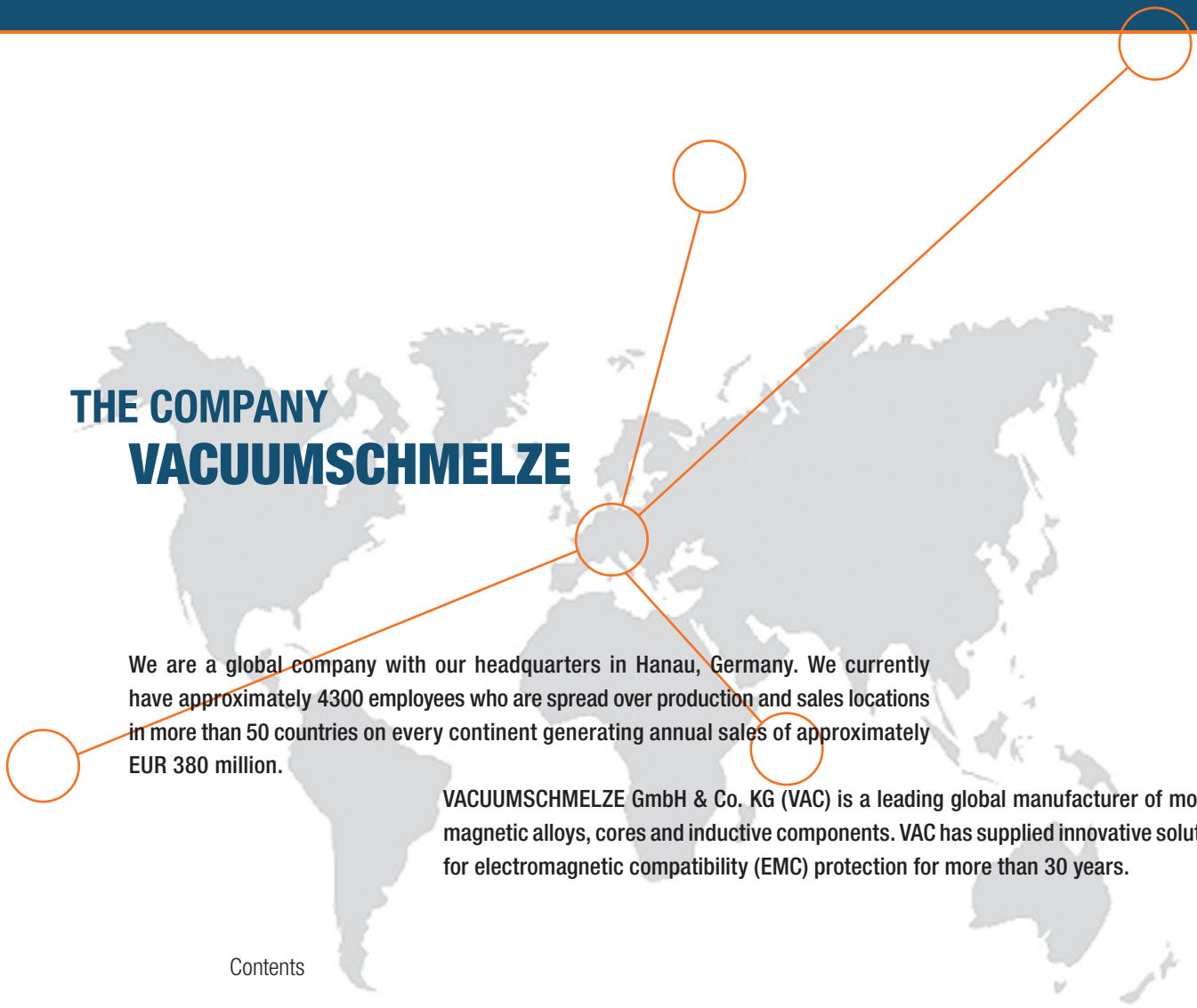
ADVANCED MATERIALS – THE KEY TO PROGRESS

EMC PRODUCTS

BASED ON NANOCRYSTALLINE VITROPERM

ADVANCED MATERIALS – THE KEY TO PROGRESS

VACUUMSCHMELZE



THE COMPANY
VACUUMSCHMELZE

We are a global company with our headquarters in Hanau, Germany. We currently have approximately 4300 employees who are spread over production and sales locations in more than 50 countries on every continent generating annual sales of approximately EUR 380 million.

VACUUMSCHMELZE GmbH & Co. KG (VAC) is a leading global manufacturer of modern magnetic alloys, cores and inductive components. VAC has supplied innovative solutions for electromagnetic compatibility (EMC) protection for more than 30 years.

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EMC PRODUCTS
BASED ON NANOCRYSTALLINE VITROPERM

Nowadays power electronics have a decisive influence on the technology of electrical energy generation, distribution and conversion. Modern semiconductors enable electrical energy to be controlled and converted rapidly and safely with low losses. However, using today's fast switching technologies results in significant network disturbances. To minimize these disturbances and stabilizing electric networks, EMI filters according to latest international standards must be used. VAC's VITROPERM® EMC products make a significant contribution in building innovative and compact filter designs with lowest losses.

Our EMC products are used in a wide range of applications:

- **Switched-mode power supplies (SMPS)**
- **Solar inverters**
- **Frequency converters**
- **EMC filters**
- **Welding equipment**
- **Wind generators**
- **Induction hobs**
- **Automotive applications**
- **Uninterruptible power supplies (UPS)**

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VITROPERM – EXTENDING THE POSSIBILITIES OF IRON

Nanocrystalline VITROPERM alloys are based on Fe with Si and B with further additions of Nb and Cu. VAC pioneered the development of rapid solidification technology resulting in the production of thin tapes or ribbons approximately 20 µm thick. Special slitting and core winding machines produce tape-wound cores with external diameters ranging from 2 mm to 600 mm. A subsequent heat treatment at around 500 - 600 °C transforms the initially amorphous microstructure of the tape into the desired nanocrystalline state, this being a two-phase structure with fine crystalline grains (average grain diameter of 10 - 40 nm) embedded in an amorphous residual phase.

VITROPERM nanocrystalline alloys are optimized to combine highest permeability and lowest coercive field strength. The combination of very thin tapes and the relatively high electrical resistance (1.1 - 1.2 µΩm) ensures minimal eddy current losses and an outstanding frequency vs. permeability behaviour. Combined with a saturation flux density of 1.2 T and wide operational temperature range, these features combine to make VITROPERM a universal solution for most common EMC problems and vastly superior in many aspects to commonly used ferrite and amorphous iron materials.

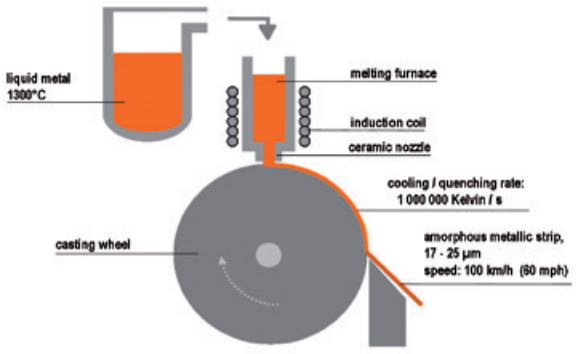


Fig. 1: Rapid solidification technology is used to produce thin metal tapes with an amorphous structure (metallic glass).

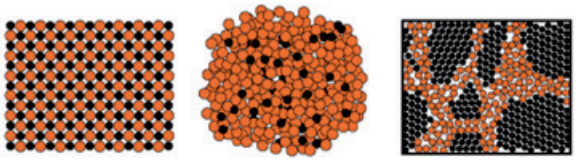


Fig 2: Crystalline structure, amorphous structure, nanocrystalline micro-structure

SUPERIOR EMC FILTER AND COMMON MODE CHOKE DESIGN

Nanocrystalline cores are widely used in common mode choke (CMC) applications due to their unique combination of properties. By utilising low-cost raw materials (Fe-based) and modern, large-scale production, VITROPERM is a very competitive solution for a wide range of applications.

Our CMCs feature high attenuation which is maintained across a wide frequency range offering extremely broad-band attenuation. In many cases, this characteristic can allow a reduction of the number of filter stages in multistage EMC filter configurations to reduce complexity, cost and filter volume. Ohmic (copper) losses are also reduced increasing the efficiency and lowering component temperature.

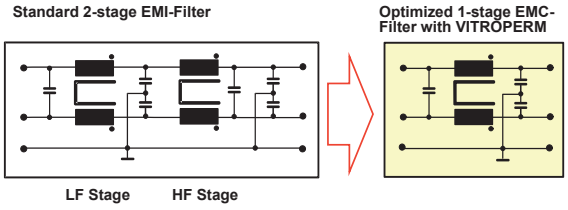


Fig. 3: Nanocrystalline chokes allow a reduction of filter stages

VACUUMSCHMELZE has extensive practical and theoretical expertise in the design of CMCs and filter configuration using nanocrystalline cores and components. At higher frequencies, the winding configuration has a major effect on the parameters of winding capacitance and leakage inductance and is therefore carefully considered in our choke designs. Figure 4 shows a comparison of insertion loss for two chokes which differ only in their winding configuration (core material, number of turns and wire thickness are identical in both cases). This illustrates how our design expertise can improve filter efficiency, maximize reliability and reduce costs.

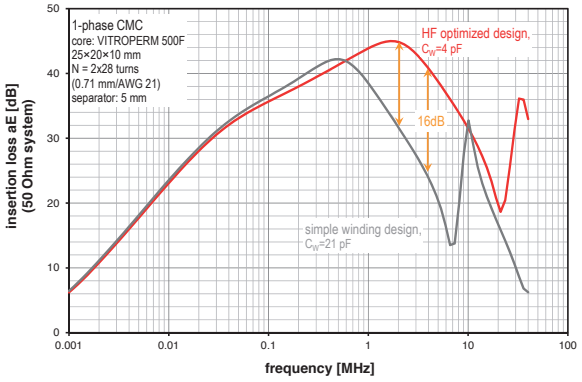


Fig. 4: Optimized choke design: improved attenuation of up to 16 dB (or more) at 4 MHz

FEATURES & BENEFITS OF VITROPERM NANOCRYSTALLINE CHOKES

ADVANTAGES	PRECONDITIONS / RELEVANT PROPERTIES
Small size	High μ, high B_S
Suitable for high currents and/or high voltages	High μ, high B_S, suitable core geometries
Single stage filter designs possible	Excellent broadband attenuation behaviour, high permeability, low-capacitance design, moderate reduction of μ up to high frequencies, low Q factor in 150 kHz range
High efficiency, low power loss	Low number of turns required for high L, reduction of filter stages
'Green', environmentally friendly	Low power loss, reduced use of material
Suitable for high and low ambient temperatures and high operating temperatures	High Curie temperature, material properties (μ, B_S, λ_s) nearly independent of temperature
'Easy filter design'	Material properties (μ, B_S, λ_s) nearly independent of temperature, linear magnetization curve delivers stable impedance across a broad range of common mode currents – VAC choke design software available
UL-compliant designs	Suitable plastic materials meet UL1446 insulation requirements
Optimized solutions for a variety of different applications	A range of μ levels and VITROPERM alloys available
No operating noise	Material is practically magnetostriction-free
Best suited for winding of thick wires	Material is practically magnetostriction-free, coatings/casings are resistant against mechanical stress

VITROPERM VS. FERRITE

Due to the optimized high-frequency properties, the insertion loss of our nanocrystalline common mode chokes is superior compared to that of a typical ferrite choke in the relevant frequency range.

The properties of VITROPERM are very much different from conventional ferrites. In low-frequency ranges the permeability of VITROPERM 500 F is higher than that of ferrites. Nanocrystalline materials show a less marked reduction of permeability μ at higher frequencies. This has to be considered in the filter design for optimum solutions. The main physical and magnetic characteristics are illustrated in the following diagrams.

INSERTION LOSS

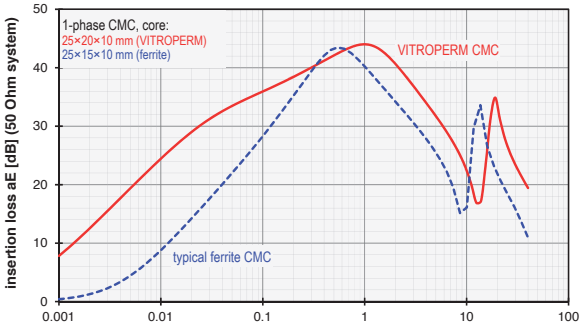


Fig. 5: Comparison of insertion loss of VITROPERM and ferrite

The permeability μ of VITROPERM 500 F is significantly higher than the μ of ferrites in the low frequency range. At higher frequencies the μ of both nanocrystalline materials remains above that of ferrites. A high choke impedance is preferred for a high attenuation. To achieve high impedance, high permeability core material rather than an increased number of turns must be used, as a low number of turns leads to low winding capacity and thus superior HF properties. VAC has focused on the favourable material properties of nanocrystalline cores to build an extensive practical and theoretical experience in the design of common-mode-chokes and filters. VAC's optimized chokes offer clearly improved HF-properties.

PERMEABILITY

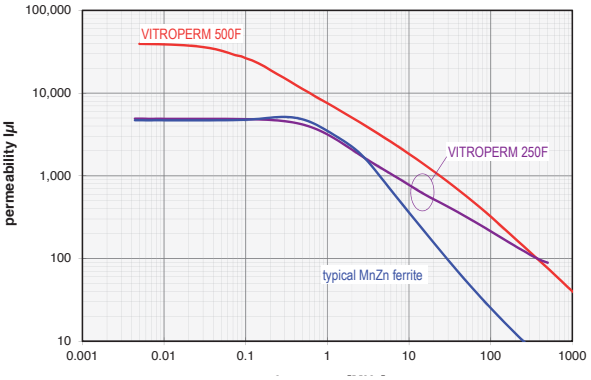


Fig. 6: Frequency response of the permeability of VITROPERM 500 F (μ = 40,000) and VITROPERM 250 F (μ = 5,000) in comparison to a typical MnZn ferrite (μ = 5,000)

PERMEABILITY AND MAGNETIZATION CURVE

As properties like the frequency dependence of permeability (fig. 7), μ(f) of VITROPERM 500 F and ferrites differ fundamentally, varied filter designs must be considered for optimization, the permeability of ferrites (μ = 5,000) shows a flat and linear characteristic up to approximately 1 MHz (ferrites with μ = 10,000 range up to approximately 200 kHz). In this flat range, the attenuation properties are determined by μ' and the impedance |Z| is dominated by the inductance L. If the self-resonance of the choke is within this frequency range, the attenuation curve is narrowband and attenuation is primarily caused by reflection of the interference signal. The attenuation of ferrites is determined by its resistive parameters at frequencies above the frequency where the flat range of the curve ends, because the real part of the impedance Re(Z) accounts for the major share of the attenuation and the imaginary part of the complex permeability μ'' becomes the dominant factor. If the self-resonance of the choke is in this frequency range the attenuation characteristic becomes increasingly broadband.

VITROPERM is basically similar in this respect. The flat sector of μ(f) of VITROPERM 500 F ranges (depending on the initial permeability level) to frequencies of several 10 kHz (20 kHz in this example), only. Consequently, attenuation (or |Z|) is already dominated by Re(Z) and is always broadband in the whole EMC-relevant range above 150 kHz. Inductance plays a minor role and describes the attenuation only partially. The determining factor is the total impedance. The approximation $|Z| = \omega L$ is valid for ferrite chokes. For VITROPERM chokes $|Z| >> \omega L$ applies. Attenuation primarily does not result from a reflection of the interference signal, but from its absorption.

Only if the different characteristics are considered, the design of optimized, compact and low-cost nanocrystalline chokes is possible. However, VITROPERM 250 F is an exception, because the flat μ(f) sector range is similar to μ = 5,000 ferrites to frequencies of up to 1 MHz and the attenuation is primarily inductive (fig. 8 a and b).

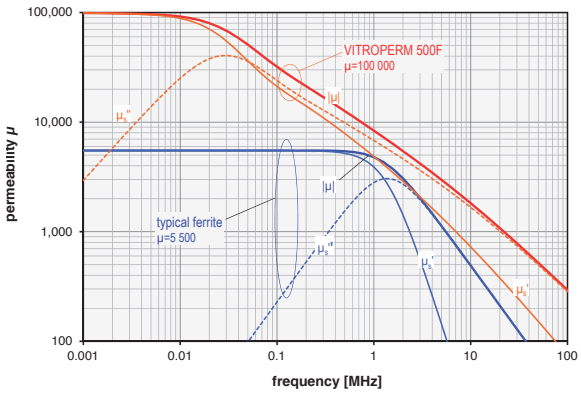


Fig. 7: Differences in the balance between μ' and μ'' for VITROPERM and ferrite lead to different attenuation mechanisms

MAGNETIZATION CURVE

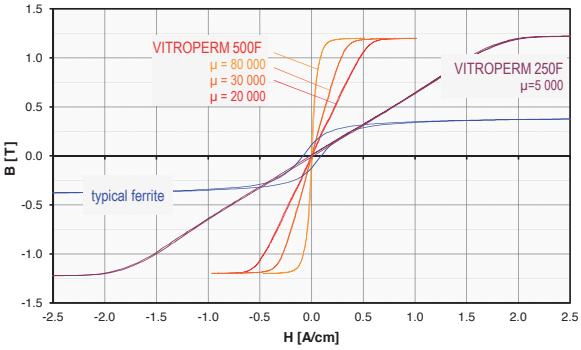


Fig. 8a: Hysteresis loops for various types of VITROPERM and typical MnZn ferrite

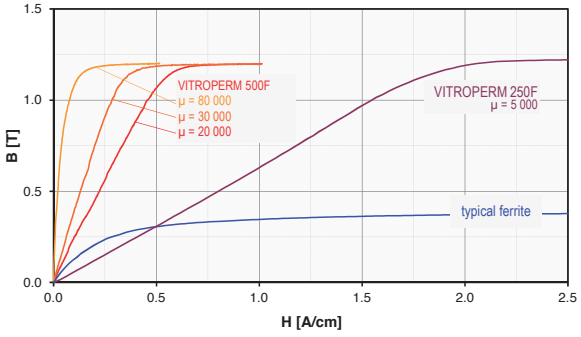


Fig. 8b: Magnetization curve of VITROPERM 500 F and VITROPERM 250 F in comparison to typical MnZn ferrite, showing noticeable differences in permeability (slope of the curve) and saturation flux density (B_S)

THERMAL PROPERTIES

The saturation flux density of VITROPERM changes by only a few percent in the operating temperature range of up to 150 °C, while MnZn ferrites decline by up to 40 % at temperatures above 100 °C (fig. 9). The high Curie temperature of VITROPERM alloys (above 600 °C), allows short term maximum operating temperatures as high as 180-200 °C[1].

The permeability of VITROPERM typically changes by less than 10 % in the temperature range from -40 °C to 120 °C, while the permeability of MnZn ferrites can drift in a range of ± 40 - 60 % around the room temperature value (fig. 10).

THERMAL BEHAVIOUR

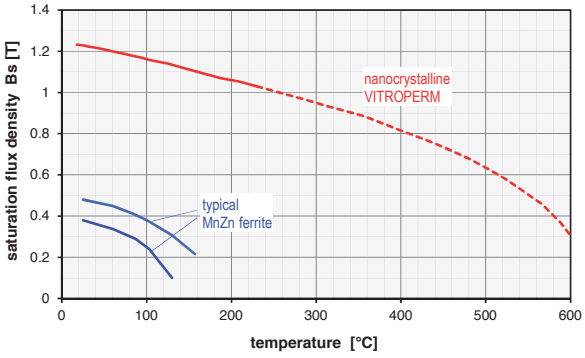


Fig. 9: Temperature dependence of saturation flux density $B_S(T)$

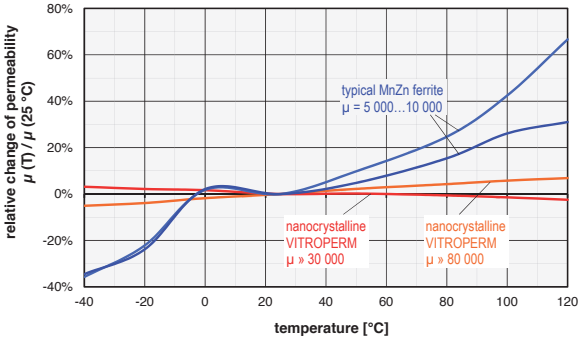


Fig. 10: Relative change of μ(T) at f = 100 kHz, normalized for room temperature

Insertion loss (and impedance) of a CMC made of VITROPERM 500 F is almost temperature-independent in the temperature range of -40 °C to above 150 °C (fig. 11a).

In contrast, ferrite chokes feature a significant drop of insertion loss with increasing temperature (fig. 11b).

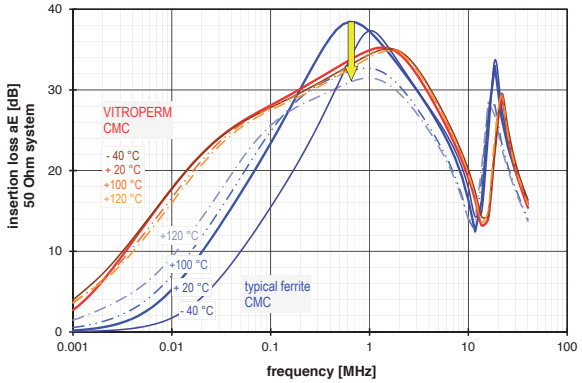


Fig. 11a: Comparison of temperature dependence of insertion loss of a VITROPERM CMC and a choke with standard MnZn ferrite core

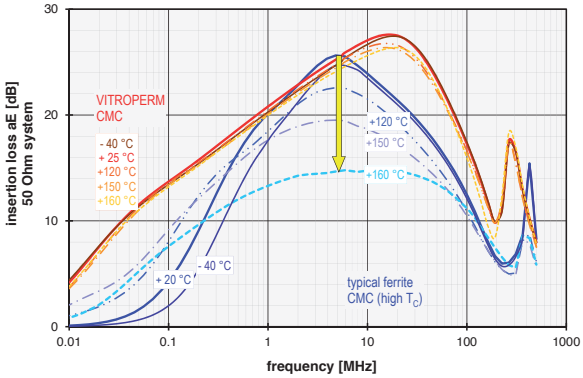


Fig. 11b: Comparison of temperature dependence of insertion loss up to 160 °C of a VITROPERM CMC and a MnZn choke using a high Curie temperature ferrite material

[1] Maximum continuous temperature depends on the casing/coating materials used. Please contact VAC for more detailed information.

SATURATION BEHAVIOUR

High permeability nanocrystalline cores enable very high inductance levels in extremely compact core or choke dimensions. However, as a consequence, an increased sensitivity to asymmetric magnetization conditions caused by common mode, unbalanced or leakage currents has to be considered. These currents may occur as low-frequency leakage currents (50/60 Hz) or as medium or high-frequency interference currents. These are caused for example by long motor cables with different capacitance of the individual conductors to earth, or by resonances which occur (commonly due to bearing currents) in such cables leading to short, extremely high and rapidly declining current peaks with amplitudes of up to several 10 A_{peak} and pulse widths in the nanosecond range (1 … several 100 ns). If these common mode currents exceed the saturation level of the choke or core, the attenuation of the choke breaks down and the choke becomes less effective.

The saturation behaviour of ferrites is less sensitive due to its lower permeability. For applications with higher imbalance currents, the advantages of VITROPERM with 1.2 T saturation flux density (approximately 3 times higher than ferrites) can still be realised since VITROPERM is available in a range of permeability levels between 4,000 and 150,000. In these cases, a lower μ level may have to be selected in order to find the optimum saturation-resistant solution. Fig. 12a shows a comparison of saturation currents for different VITROPERM designs with a typical ferrite core of similar dimensions. It can be seen that the saturation behaviour of the MnZn ferrite (μ=6,000) is comparable with that of VITROPERM 500 F (μ=17,000) up to frequencies of approximately 50 kHz. At higher frequencies, however, the VITROPERM design is becoming more advantageous. The VITROPERM solution offers a 50 % higher A_L value at 100 kHz and a significantly higher impedance (note that the impedance of

VITROPERM is determined to a small part by inductance L in this frequency range). High permeability VITROPERM 500 F cores are characterized by an extremely high attenuation or impedance at low frequencies, and they are clearly superior against ferrites at high frequencies. However, the price of this superior performance is a more sensitive saturation behaviour, which is improving with increasing frequency but still more critical than that of other core materials. It should be noted that fig. 12a shows the saturation currents of the cores without winding. Depending on the number of turns, the I_{cm} values of the chokes are some 10 mA to several 100 mA, only (see tables of standard series).

Fig. 12b shows permeability characteristics under DC bias field for a VITROPERM 500 F core (μ=20,000) and 2 typical MnZn ferrites (μ=5,000 and μ=8,000, respectively). The diagram shows the significantly higher permeability and a square $\mu(H_{DC})$ characteristic of the nanocrystalline material in comparison to the rounded properties of the two ferrite cores. This behaviour complies to the linear magnetization curve of VITROPERM (figs. 8a/8b) and leads to nearly constant inductance over a wide range of the DC bias fields.

VITROPERM 250 F is always used where highly saturation-resistant solutions are required for applications with very high common mode or unbalanced currents. However, it cannot equal the high attenuation of VITROPERM 500 F.

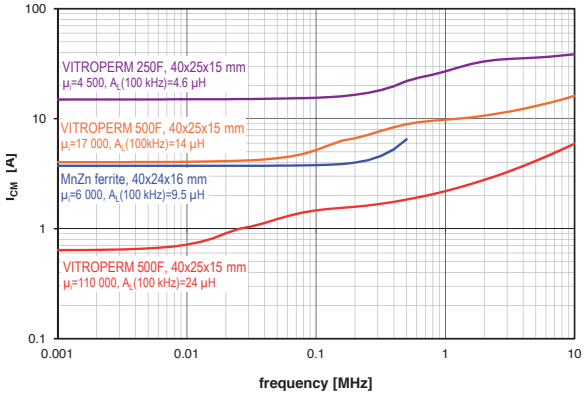


Fig. 12a: Comparison of saturation behaviour of VITROPERM 500 F, VITROPERM 250 F and MnZn ferrite

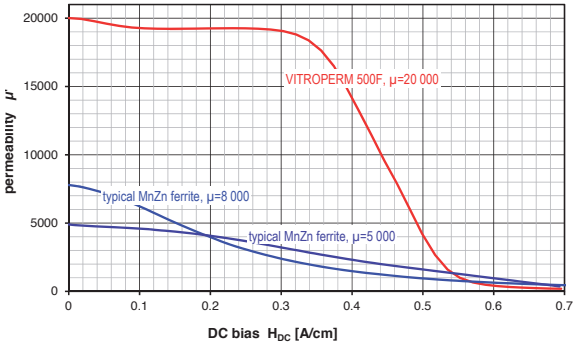


Fig. 12b: Comparison of permeability characteristics under DC bias field for VITROPERM 500 F and two typical MnZn ferrites

DESIGN ADVANTAGES WITH VITROPERM

The superior material properties of nanocrystalline VITROPERM enable common mode chokes with high inductance/ impedance with a small number of turns, resulting in reduced copper losses, low winding capacitance and excellent HF performance.

Due to the high initial permeability, low winding capacitance and a low Q-factor (above 100 kHz) VITROPERM CMCs offer a broadband insertion loss curve ranging from 10 kHz up to several MHz and improved attenuation behaviour at both low and high frequencies, in comparison to conventional ferrite chokes with similar core dimensions and identical windings (see fig. 13).

Better attenuation properties and an extended operating temperature range allow a reduction of the component volume by a factor of up to 3 or more under similar conditions. Note that the insertion loss curve of the small VITROPERM choke in fig. 14 is similar to that of ferrite materials at frequencies of about 600 kHz - 1 MHz and is superior below 500 kHz and above 1 MHz.

The excellent attenuation of VITROPERM CMCs simplifies the filter design in a wide frequency range.

For laboratory tests, VAC offers different sample kits with selected standard cores and chokes.

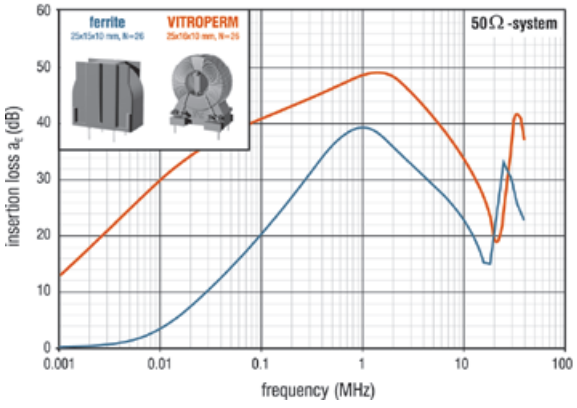


Fig. 13: Comparison of insertion loss curve of a VITROPERM 500 F CMC (red curve) and ferrite CMC (blue curve) of similar size and with the same number of turns

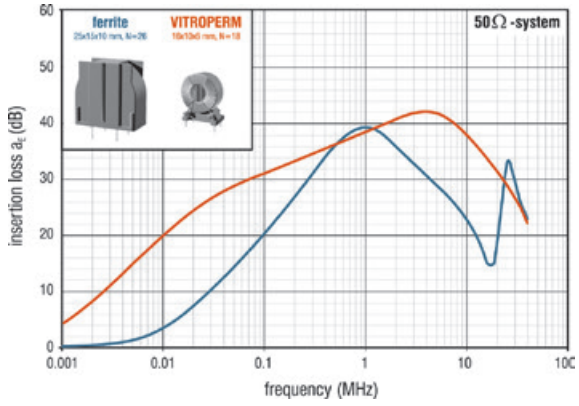
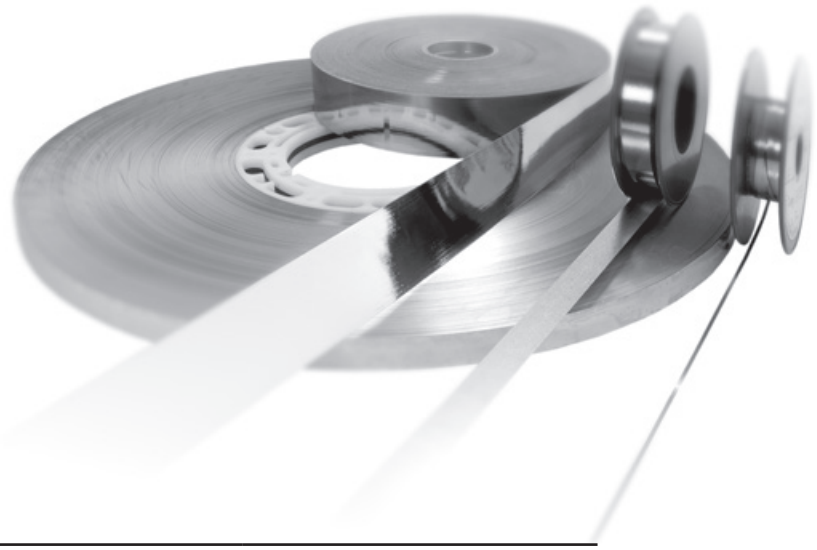


Fig. 14: Comparison of the dimensions of a VITROPERM 500 F CMC (red curve) and ferrite CMC (blue curve) with similar attenuation properties in the 1 MHz range



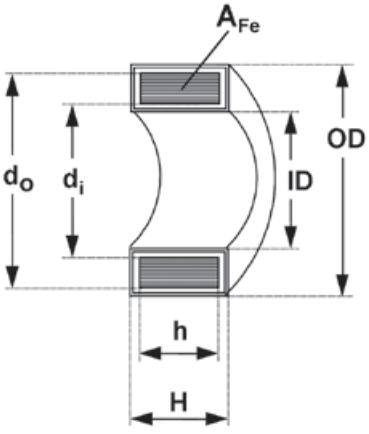
VITROPERM – TYPICAL DATA	
Saturation flux density	B_S = 1.2 T
Coercivity (static)	H_C < 3 A/m
Saturation magnetostriction (λ_S)	
VITROPERM 500 F	$\lambda_S = 10^{-8}....10^{-6}$
VITROPERM 250 F	$\lambda_S = \approx 8 \times 10^{-6}$
Specific electrical resistance	$\rho \approx 115\ \mu\Omega cm$
Curie temperature	T_C > 600 °C
Max. operational temperature (T_{max})	
Epoxy coating	T_{max} = 120 °C[2)]
Plastic casing	T_{max} = 130/155 °C[2)]
Short-term	T_{max} = 180 °C[1)]
Permeability (μ)	
VITROPERM 500 F	μ_i = 15,000…150,000
VITROPERM 250 F	μ_i = 4,000…6,000
Core losses (100 kHz, 0.3 T)	P_{Fe} = 80 W/kg (typ.)

[1)] Please contact VAC for more detailed information about the temperature limits of our casing and coating materials.

[2)] For continuous operation

STANDARD SERIES OF VITROPERM CORES

Our VITROPERM cores are available with different A_L-levels for many core sizes. Thus, saturation-resistant solutions are available for various fields of applications. Common mode currents may occur as interference currents, bias currents or, primarily, unbalanced currents. If the common mode currents exceed the saturation currents (I_{cm}) of the cores or chokes, cores with higher saturation resistance must be used. High A_L values (high µ) are more suitable for typical single-phase applications with low unbalanced current (e.g. switched-mode power supplies), while cores with lower A_L values are often used in 3-phase applications with high unbalanced currents (e.g. frequency converters with long motor cables).



A_{Fe} = iron cross section
h = nominal height
H = height (incl. coating/casing)
ID = inner diameter (incl. coating/casing)
OD = outer diameter (incl. coating/casing)
d_o = nominal outer diameter
d_i = nominal inner diameter

More detailed technical information and the data sheets are available at www.vacuumschmelze.com.
Please scan the QR-code belonging to this chapter which will lead you automatically to the respective site.

Table below

NANOCRYSTALLINE VITROPERM CORES WITH EPOXY RESIN COATING

Although the epoxy resin coating is suitable for direct winding, we recommend additional insulation between core and winding for enhanced insulation requirements. The epoxy resin is suitable for continuous operational temperatures of up to 120 °C (UL compliant 105 °C) and complies with the **UL94-V0 standard (UL File Number: E214934), class A (105 °C).**

Part number T60004-	Nominal core dimensions d_o x d_i x h mm x mm x mm	Limiting dimensions (incl. coating) OD mm	ID mm	H mm	Iron cross section A_{Fe} cm²	Mean path length l_{Fe} cm	Weight m g	A_L* 10 kHz nominal µH	A_L* 100 kHz nominal µH	Saturation current I_{cm}**, typical 10 kHz A	Saturation current I_{cm}**, typical 100 kHz A
L2016-W620 L2016-W619	16 x 12.5 x 6	17.8	10.7	8.0	0.08	4.5	2.6	15.0 6.0	4.8 3.9	0.32 1.1	0.63 1.7
L2022-W867	22 x 17 x 6	24.0	15.2	8.0	0.12	6.1	5.4	16.4	3.2	0.43	0.86
L2022-W868	22 x 17 x 10	24.0	15.2	12.0	0.20	6.1	9.0	27.4	5.3	0.43	0.86
L2025-W622 L2025-W621	25 x 20 x 10	27.3	17.5	12.3	0.19	7.1	9.9	22.5 9.0	7.2 5.9	0.5 1.8	0.99 2.8
L2030-W676	30 x 25 x 15	32.3	22.7	17.5	0.27	8.6	17.4	26.5	8.5	0.61	1.2
L2030-W911	30 x 20 x 10	32.5	17.8	12.5	0.40	7.9	23.1	56.0	13.4	0.42	0.87
L2040-W624 L2040-W623	40 x 32 x 15	42.3	29.1	17.8	0.44	11.3	36.0	32.5 13.0	10.4 8.4	0.8 2.8	1.6 4.4
L2045-W886	45 x 32 x 15	47.3	29.8	17.8	0.71	12.1	63.3	19.7	12.8	3.1	4.7
L2050-W626 L2050-W625 L2050-W583	50 x 40 x 20	52.3	37.1	22.8	0.73	14.1	76.0	43.0 17.0 11.2	13.8 11.0 10.0	1.0 3.6 5.5	2.0 5.6 7.1
L2063-W627 L2063-W721	63 x 50 x 20	65.5	46.6	22.8	0.95	17.8	124.0	18.0 13.5	11.7 12.1	4.5 6.9	6.9 8.9
L2080-W628 L2080-W722	80 x 63 x 20	83.0	59.5	22.8	1.24	22.5	205.0	18.5 12.0	12.0 10.8	5.7 8.7	8.7 11.0
L2100-W629 L2100-W723	100 x 80 x 20	104.0	75.0	23.0	1.46	28.3	303.0	17.3 11.2	11.2 10.0	7.1 11.0	11.0 14.0
L2130-W567 L2130-W630 L2130-W587	130 x 100 x 25	134.5	95.0	28.5	2.85 2.74 2.74	36.1 36.1 36.1	757.0 727.0 727.0	50.0 25.4 16.4	19.4 16.5 14.8	3.4 9.1 14.0	6.2 14.0 18.0
L2160-W631 L2160-W720	160 x 130 x 25	165.0	125.0	28.5	2.74	45.6	917.0	20.2 13.0	13.1 11.7	11.0 18.0	18.0 23.0
L2194-V105 L2194-W908	194 x 155 x 25	200.0	149.0	28.5	3.71	54.8	1,490.0	45.0 15.0	14.7 13.2	4.9 21.0	9.1 27.0

* A_L = inductance for N = 1 (tolerance +45 % / -25 %)

** I_{cm}: the listed saturation currents are guidelines only. They are calculated for nominal core dimensions at room temperature and for approx. 70 % saturation flux density. The frequency-dependent saturation behaviour is demonstrated in fig. 12.

NANOCRYSTALLINE VITROPERM 500 F AND VITROPERM 250 F CORES IN PLASTIC CASING

The plastic cases are suitable for direct winding and offer good mechanical protection of the nanocrystalline core material. This enables the best magnetic properties and highest permeability levels to be maintained. Additional winding protection is optional for heavy wire windings, where there may be a danger of core damage. The plastic materials comply with the standards **UL94-V0 / HB for small cores (UL File Number: E41871), class B (130 °C) and UL94-V0 (UL File Number E41938), Class F (155 °C).**

More detailed technical information and the data sheets are available at www.vacuumschmelze.com.
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Part number T60006-	Nominal core dimensions	Limiting dimensions (incl. case)			Iron cross section	Mean path length	Weight	A_L* 10 kHz	A_L* 100 kHz	Saturation current I_{cm}**, typical 10 kHz	Saturation current I_{cm}**, typical 100 kHz
	d_o x d_i x h	OD	ID	H	A_{Fe}	l_{Fe}	m	nominal		10 kHz	100 kHz
	mm x mm x mm	mm	mm	mm	cm²	cm	g	μH		A	A
L2009-W914	9.8 x 6.5 x 4.5	11.2	5.1	5.8	0.06	2.6	1.1	25.5	6.4	0.14	0.3
L2012-W902	12 x 8 x 4.5	14.1	6.6	6.3	0.07	3.1	1.7	28.0	6.8	0.15	0.31
L2012-W498	12.5 x 10 x 5	14.3	8.5	7.0	0.05	3.5	1.3	10.0	3.6	0.3	0.56
L2014-V098	14.4 x 11.4 x 3.2	16.5	9.6	5.0	0.04	4.1	1.1	10.5	2.6	0.21	0.44
L2015-W865	15 x 10 x 4.5	17.1	7.9	6.5	0.09	3.9	2.6	27.0	6.7	0.2	0.41
L2016-W403 L2016-W308 L2016-V165	16 x 10 x 6	17.9	8.1	8.1	0.14	4.1	4.0	43.0 10.5 2.1	9.8 6.5 2.0	0.2 1.2 5.4	0.41 1.7 5.7
L2017-W515	17.5 x 12.6 x 6	19.0	11.0	8.0	0.12	4.7	4.1	30.0	6.9	0.23	0.48
L2019-V184	19 x 15 x 5	21.2	13.0	7.3	0.08	5.3	3.1	18.0	4.1	0.26	0.54
L2019-W838	19 x 15 x 10	21.2	13.0	12.3	0.16	5.3	6.3	36.1	8.3	0.26	0.54
L2020-W409 L2020-W450	20 x 12.5 x 8	22.6	10.3	10.2	0.24	5.1	9.0	57.0 14.0	13.0 9.1	0.25 1.5	0.51 2.2
L2025-W523	25 x 20 x 10	27.6	17.4	12.8	0.20	7.1	10.0	28.4	6.5	0.41	0.84
L2025-W380 L2025-W451 L2025-W980	25 x 16 x 10	27.9	13.6	12.5	0.36	6.4	17.0	67.0 17.1 3.2	15.5 11.5 3.1	0.32 1.8 9.3	0.65 2.7 9.6
L2030-W423 L2030-W358 L2030-W981	30 x 20 x 10	32.8	17.6	12.5	0.40	7.9	23.0	66.0 15.5 2.9	15.8 10.5 2.8	0.36 2.1 12.0	0.73 3.2 12.0
L2030-W514 L2030-V188 L2030-V129	30 x 20 x 15	32.8	17.5	17.8	0.57	7.9	33.0	88.0 26.9 15.7	20.4 16.2 14.1	0.38 1.8 3.1	0.79 2.8 3.9
L2040-W422 L2040-V113 L2040-W452 L2040-W964	40 x 32 x 15	43.1	28.7	18.5	0.46	11.3	38.0	48.0 13.0 10.2 2.3	11.2 8.4 7.9 2.2	0.55 3.0 3.8 17.0	1.1 4.6 5.2 17.0
L2040-W424 L2040-W453	40 x 25 x 15	43.1	22.5	18.5	0.86	10.2	64.0	99.0 25.0	23.1 17.2	0.5 2.9	1.0 4.4

Table below

Part number T60006-	Nominal core dimensions	Limiting dimensions (incl. case)			Iron cross section	Mean path length	Weight	A_L*		Saturation current I_{cm}**, typical	
								10 kHz	100 kHz	10 kHz	100 kHz
	d_o x d_i x h	OD	ID	H	A_{Fe}	l_{Fe}	m	nominal			
	mm x mm x mm	mm	mm	mm	cm^2	cm	g	μH		A	A
L2045-V102	45 x 30 x 15	48.3	26.4	18.2	0.86	11.8	74.0	87.6	20.0	0.59	1.2
L2045-V118								24.3	15.8	3.0	4.6
L2045-V101								15.7	14.1	4.6	5.9
L2050-W516	50 x 40 x 20	53.5	36.3	23.4	0.76	14.1	79.0	45.0	13.5	1.0	2.0
L2050-W565			36.3					18.0	10.0	3.6	5.5
L2050-V146			36.6					11.7	10.0	5.5	7.1
L2050-V166			36.6					3.1	3.0	20.0	21.0
L2054-V172	54 x 40 x 20	57.5	37.7	24.1	1.06	14.8	115.0	87.0	19.9	0.72	1.5
L2054-V178								24.0	15.7	3.7	5.8
L2063-W517	63 x 50 x 25	67.3	46.5	28.6	1.24	17.8	161.0	59.0	17.5	1.2	2.5
L2063-V110							161.0	23.3	13.8	4.5	6.9
L2063-V144							161.0	15.1	13.5	6.9	8.9
L2063-W985							163.0	3.3	3.3	30.0	31.0
L2080-V140	80 x 50 x 20	85.8	44.6	25.5	2.28	20.4	342.0	94.0	28.0	1.4	2.8
L2080-W531		86.0	44.7	25.7			342.0	35.0	24.0	5.5	8.4
L2080-V091		86.0	44.7	25.7			347.0	9.6	6.9	26.0	28.0
L2090-W518	90 x 60 x 20	95.4	54.7	24.7	2.28	23.6	395.0	81.0	25.1	1.7	3.3
L2090-V173							400.0	32.5	21.1	5.9	9.1
L2090-W984							400.0	4.6	4.5	41.0	42.0
L2100-V082	100 x 80 x 25	105.5	75.0	29.6	1.90	28.3	379.0	56.3	16.9	2.0	3.9
L2100-V081							379.0	14.6	13.1	11.0	14.0
L2102-W468	102 x 76 x 25	108.1	70.0	30.3	2.47	28.0	508.0	55.0	21.6	2.7	4.9
L2102-V080							508.0	19.1	17.2	11.0	14.0
L2102-W947							515.0	4.3	4.2	48.0	49.0
L2160-V074	160 x 130 x 25	166.9	123.9	30.5	2.74	45.6	917	28.0	14.0	8.5	14.0
L2160-V088					2.74		917	20.0	13.1	11.0	18.0
L2160-V066					2.74		917	13.0	11.7	18.0	23.0
L2160-W982					2.85		967	3.0	2.9	80.0	82.0

* A_L = inductance for N = 1 (tolerance +45 % / -25 %)

** I_{cm}: the listed saturation currents are guidelines only. They are calculated for nominal core dimensions at room temperature and for approx. 70 % saturation flux density. The frequency-dependent saturation behaviour is demonstrated in fig. 12.

CORE STACK ASSEMBLIES WITH NANOCRYSTALLINE CORES

Single-turn chokes employing a number of nanocrystalline cores assembled in a stack are an effective solution for bearing current problems or extremely high common mode noise from other causes in large-scale variable speed drives, wind generators and other applications.

In these applications resonance phenomena cause high-amplitude interference currents with peak values ranging from several 10 A to over 100 A. These generally take the form of short and thus high-frequency current peaks. For these applications, VAC offers assembled core stacks which can be easily and securely integrated into existing applications with the minimum of effort.

The core stacks are available in two sizes with two different through-hole diameters. They are custom-designed, allowing an individual selection of core type and the number of stacked cores (up to 7 pieces) depending on the required saturation level and the required inductance.

More detailed technical information and the data sheets are available at www.vacuumschmelze.com.
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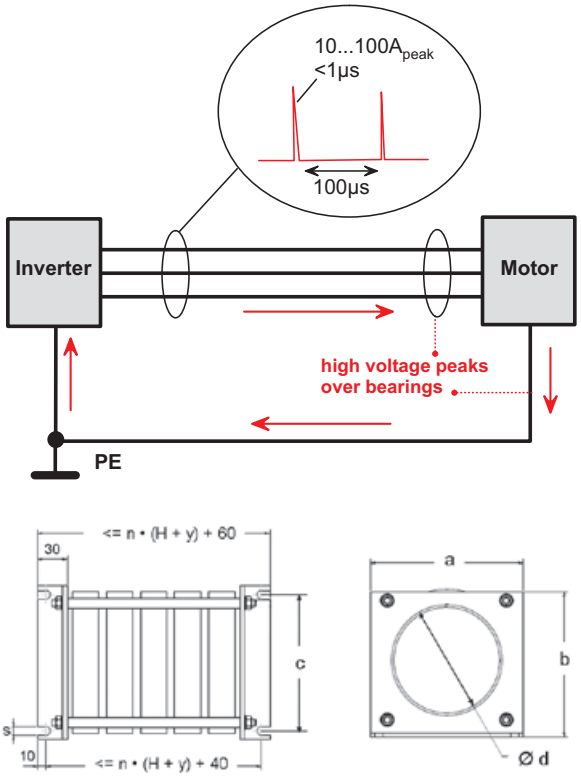


Dimensions of the core stack assemblies

	a	b	c	d	s
	(mm)	(mm)	(mm)	(mm)	(mm)
Size 1	120	130	70	~ 70	7
Size 2	180	190	130	>118	10

n = number of stacked cores

H = maximum core height

y = 9.5 for epoxy coated cores, T60004…

y = 10.2 for cased cores, T60006…

L = n*(H+y)+60

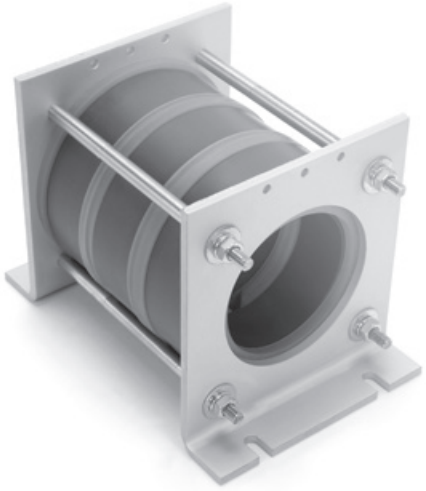
The inductance L of a core stack can be calculated by multiplying the number of stacked cores with the A_L-value of the single core.

A_L: inductance of single core

I_{cm}: maximum permissible leakage or common mode current

Calculated guideline for nominal core dimensions at room temperature and for approximately 70 % saturation flux density.

Table below



CORE DATA							DATA OF CORE STACK EXAMPLE FOR 5 STACKED CORES				
Core part number	Nominal core dimensions d_o x d_i x h	Limit core dimensions (incl. case/coating)			A_L 10 kHz 100 kHz nominal		Size	I_{cm} 10 kHz 100 kHz typical		L 10 kHz 100 kHz nominal	
	mm x mm x mm	OD mm	ID mm	H mm	µH			A		µH	
T60004-L2100-W629	100 x 80 x 20	104.0	75.0	23.0	17.3	11.2	1	7.1	11.0	86.5	56.0
T60004-L2100-W723	100 x 80 x 20	104.0	75.0	23.0	11.2	10.0	1	11.0	14.0	56.0	50.0
T60006-L2100-V082	100 x 80 x 25	105.5	75.0	29.6	56.3	16.9	1	2.0	3.9	281.5	84.5
T60006-L2100-V081	100 x 80 x 25	105.5	75.0	29.6	14.6	13.1	1	11.0	14.0	73.0	65.5
T60006-L2102-W468	102 x 76 x 25	108.1	70.0	30.3	69.4	21.5	1	2.1	4.1	347.0	108.0
T60006-L2102-V080	102 x 76 x 25	108.1	70.0	30.3	19.1	17.2	1	11.0	14.0	95.5	86.0
T60006-L2102-W947	102 x 76 x 25	108.1	70.0	30.3	4.3	4.2	1	48.0	49.0	21.5	21.0
T60006-L2160-V074	160 x 130 x 25	166.9	123.9	30.5	28.0	14.0	2	8.5	14.0	140.0	70.0
T60006-L2160-V088	160 x 130 x 25	166.9	123.9	30.5	20.0	13.1	2	11.0	18.0	100.0	65.5
T60006-L2160-V066	160 x 130 x 25	166.9	123.9	30.5	13.0	11.7	2	18.0	23.0	65.0	58.5
T60006-L2160-W982	160 x 130 x 25	166.9	123.9	30.5	3.0	2.9	2	80.0	82.0	15.0	14.5

In case of interest for a specific core stack with 2-7 cores chosen from above list please contact VAC.

Existing Core Stacks

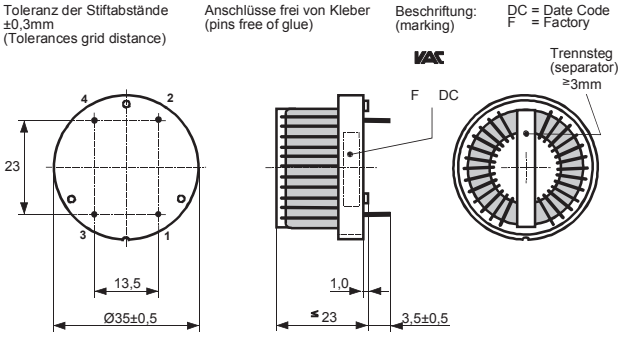
Core stack part number	Nominal core dimensions (part number) x number of cores	Nominal core stack dimensions		A_L 10 kHz 100 kHz		Size	I_{cm} 10 kHz 100 kHz	
	d_o x d_i x h	base dimension (L x a)	height (b)	nominal			typical	
	mm x mm x mm	mm	mm	µH			A	
T60016-L2102-W075	102 x 76 x 25 (W947) x 2	140 x 120	130	9.1	8.4	1	48	49
T60016-L2102-W078	102 x 76 x 25 (W468) x 6	300 x 120	130	416	130	1	2.1	4.1
T60016-L2160-W076	160 x 130 x 25 (W982) x 5	261 x 180	190	16	14.5	2	80	82
T60016-L2160-W079	160 x 130 x 25 (V066) x 4	210 x 180	190	52	46.8	2	18	23
T60016-L2160-W080	160 x 130 x 25 (V066) x 7	310 x 180	190	91	81.9	2	18	23
T60016-L2160-W081	160 x 130 x 25 (V066) x 5	240 x 180	190	65	58.5	2	18	23

COMMON MODE CHOKES
UL1446 STANDARD SERIES

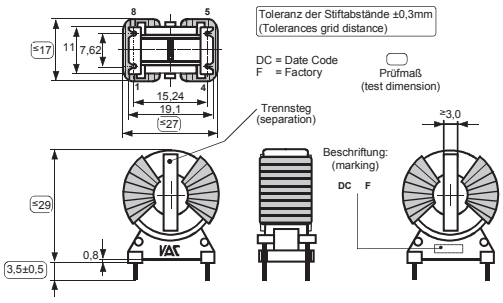
Common Mode Chokes using VITROPERM cores offer universal solutions for various EMI problems due to highest inductance at a low number of turns in compact designs, excellent high frequency properties and stable performance over a wide temperature range.

All standard types in low profile or upright constructions are designed for operation in grid connected RFI filters or for applications with higher operating voltages. Construction, production and testing of the chokes are in accordance with **EN50178, resp. IEC 62109**. The plastic materials comply with the following UL standards **UL94-V0/HB for small chokes (file number E41871) and UL1446 (file number OBJY2.E329745) for temperature class B (130 °C)**.

Example: low profile



upright profile



GENERAL INFORMATION

I_N = nominal current in each winding

$U_{N\ OVCat\ III/II}$ = operating voltage for overvoltage category III/II

L_N = nominal inductance, tolerance +50 %/-30 %

Ambient temperature T_a = -40 °C ... +70 °C (short-term +90 °C)

Operating temperature T_{op} = -40 °C ... +130 °C (short-term +150 °C)

R_{Cu}: winding resistance per winding

IZI: choke impedance

f_R: choke resonance frequency

The standard chokes are designed for a temperature rise of ΔT = 45....60 K at T_a = 70 °C and I = I_N in each winding. Data derating is necessary for deviating ambient temperature or deviating nominal current. Please contact VAC for further detailed information.

More detailed technical information and the data sheets are available at www.vacuumschmelze.com.
Please scan the QR-code belonging to this chapter which will lead you automatically to the respective site.

1-PHASE CMCs

For comfortable CMC selections please download our software tool (requires Microsoft EXCEL): **VAC CMC Quick-Selector**. If suitable standard CMCs are not available in the table below, please contact us using our **design check list (printed on page 26/27, QR-Code: page 24)**. For testing purposes, VAC offers special sample kits consisting of standard CMCs **CMC Sample Kit (QR-Code page 24)**.

Further types

Table below

STANDARD SERIES CMCs FOR 1-PHASE APPLICATIONS

Part number T60405-	I_N	Design	U_N	L_N		R_{Cu}	|Z|	f_R	I_{cm}	Dimensions		
			OVCat III / II	10 kHz	100 kHz		100 kHz		10 kHz	l	w	h
	A		V	mH	mH	mΩ	Ω	MHz	mA	mm	mm	mm
R6131-X402	2	upright	300/600	2 x 12.1	2 x 2.8	101.7	3000	3.6	12	22	12	25
R6131-X204	4.5	upright	300/600	2 x 10.8	2 x 2.5	27.5	2320	1	12	22	12	25
R6161-X504	5	upright	300/600	2 x 28.3	2 x 6.6	35.6	6500	0.4	10	27	17	29
R6166-X206	6	upright	300/600	2 x 29.1	2 x 6.7	37.6	8500	0.25	14	35	21	37
R6166-X208	8.5	upright	300/600	2 x 16.4	2 x 3.7	19.1	4200	0.5	17	35	21	36.5
R6123-X210	10	low profile	300/600	2 x 11.4	2 x 2.6	12	3200	0.7	16	35	35	23
R6166-X210	10	upright	300/600	2 x 11.4	2 x 2.6	12.7	3150	0.7	16	35	21	37
R6126-X212	12	upright	300/600	2 x 11.4	2 x 2.6	9	2950	0.7	22	38	22	35
R6123-X213	12.4	low profile	300/600	2 x 11.4	2 x 2.6	8.8	2950	0.7	22	35	35	25
R6122-X095	13.5	upright	600/1000	2 x 16.9	2 x 3.6	7.6	4000	0.7	22	41	21	37
R6102-X016	13	low profile	300/600	2 x 8.6	2 x 2.2	6.3	2250	1.1	28	35	35	22.5
R6123-X616	16	low profile	300/600	2 x 12.9	2 x 3.1	5.7	3000	3	26	40	40	24
R6126-X216	16	upright	600/1000	2 x 5.3	2 x 1.3	2.8	1300	3.5	40	41.5	23.5	40
R6166-X033	18	upright	300/600	2 x 6	2 x 1.5	4.6	1600	1	35	38	21	38
R6166-X039	18	upright	300/600	2 x 2.9	2 x 0.7	3.9	830	3.3	50	36	21	38
R6123-X220	20.5	low profile	300/600	2 x 1.8	2 x 0.4	3.2	500	11.5	40	35	35	23.5
R6123-X221	20	low profile	300/600	2 x 6.6	2 x 1.6	2.9	1470	4.5	35	43	43	24
R6128-X220	20	upright	600/1000	2 x 5.6	2 x 1.3	2.8	1300	3.6	40	42	27	38
R6123-X226	25	low profile	300/600	2 x 4.2	2 x 1	1.9	970	7.1	45	43	39.5	25
R6123-X227	25	low profile	600 / 1000	2 x 12	2 x 2.8	3.5	2900	2.2	45	52	52	32
R6128-X225	25	upright	300/600	2 x 4.2	2 x 1	1.9	970	4.9	45	42	27	40
R6128-X226	25	upright	600/1000	2 x 12	2 x 2.8	3.3	3000	1.5	40	52	28.5	48.5
R6123-X232	30	low profile	600 / 1000	2 x 3.9	2 x 0.9	2.4	920	7	50	52	52	29
R6128-X031	30	upright	600 / 1000	2 x 3.9	2 x 0.9	2.3	900	4	65	51	27	50
R6128-X230	30	upright	600 / 1000	2 x 6.3	2 x 1.5	2.3	1620	2.7	55	52	27	47
R6123-X241	40	low profile	600 / 1000	2 x 3.6	2 x 0.8	1.4	870	6	90	52	52	32
R6123-X248	46	low profile	600 / 1000	2 x 2.5	2 x 0.6	1	660	5.7	100	57	51	33
R6123-X263	63	low profile	600 / 1000	2 x 1.6	2 x 0.4	0.5	390	9.3	120	56	56	32
R6123-X285	85	low profile	600 / 1000	2 x 1.6	2 x 0.5	0.6	510	1.6	200	73	73	40

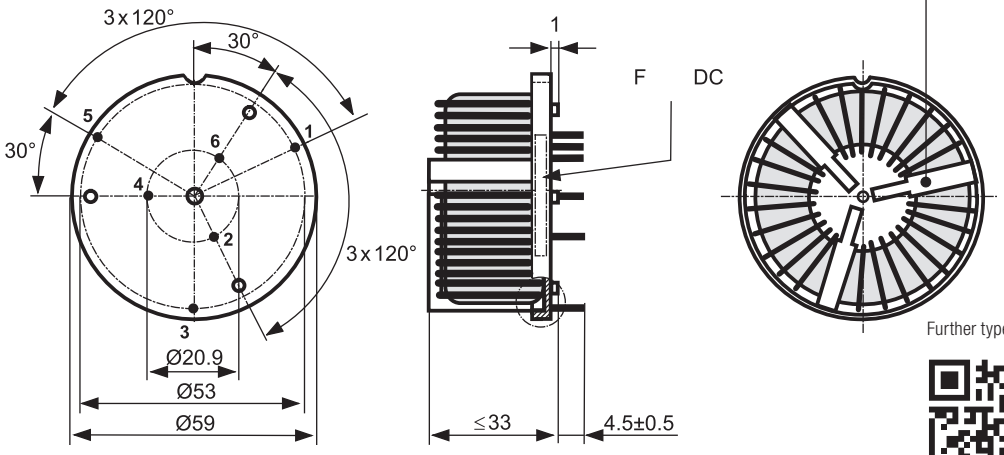
3-PHASE CMCs

Tolerances grid distance
±0.3 mm

DC = Date Code
F = Factory

Marking

Separation
≥5.5 mm



Further types

Table below

Example outline of the 3-phase CMC T60405-S6123-X332.

STANDARD SERIES 3-PHASE CHOKES FOR 3-PHASE APPLICATIONS

Part number T60405-	I_N	Design	U_N	L_N		R_{Cu}	|Z|	f_R	I_{cm}	Dimensions		
			0VCat III / II	10 kHz	100 kHz	typ.	100 kHz	typ.	10 kHz	l	w	h
	A		V	mH	mH	mΩ	Ω	MHz	mA	mm	mm	mm
S6123-X306	7	low profile	600/1000	3 x 31.8	3 x 7.4	24.6	8650	0.23	22	40.5	40.5	32.5
S6123-X310	10	low profile	600/1000	3 x 13.9	3 x 3.2	14	3500	1.6	30	51	51	32
S6123-X308	11	low profile	600/1000	3 x 10.6	3 x 2.5	8.5	2600	0.8	35	42	42	32
S6123-X312	12	low profile	600/1000	3 x 5.7	3 x 3.7	11.8	2650	0.48	150	51	51	32
S6123-X315	16	low profile	600/1000	3 x 4.3	3 x 1	2.9	1050	2.5	50	42	42	32
S6123-X316	16	low profile	600/1000	3 x 4.8	3 x 3.1	6.5	2500	0.65	200	59	59	32
S6123-X317	16	low profile	600/1000	3 x 9.4	3 x 2.2	5.9	2400	1.5	35	51.5	51.5	34
S6123-X320	20	low profile	600/1000	3 x 10.6	3 x 2.4	4.1	2650	0.9	60	59	59	33
S6123-X321	20	low profile	600/1000	3 x 4.8	3 x 1.1	2.8	1200	2.4	55	52	52	34
S6123-X325	25	low profile	600/1000	3 x 2	3 x 1.3	2.27	1000	2.8	380	60	60	33
S6123-X326	25	low profile	600/1000	3 x 4.9	3 x 1.1	2.1	1150	2	60	51.5	51.5	32
S6122-X326	26	upright	600/1000	3 x 10.6	3 x 2.4	3.5	2500	0.9	55	64	35	65
S6122-X329	29	upright	300/600	3 x 3.6	3 x 0.8	1.7	850	3.3	80	64	32	58
S6123-X332	32	low profile	600/1000	3 x 1.2	3 x 0.8	1.4	600	4.9	480	59	59	33
S6122-X333	32	upright	600/1000	3 x 1.2	3 x 0.8	1.6	660	3.5	420	64	32	60
S6123-X140	40*	low profile	600/1000	3 x 2.5	3 x 0.6	1.2	600	4.7	100	52	52	33
S6123-X240	40*	low profile	600/1000	3 x 1.5	3 x 0.8	1.72	680	4	380	70	70	37
S6123-X363	63	low profile	600/1000	3 x 1.6	3 x 0.5	0.72	500	1	170	70	70	42
S6123-X370	70	low profile	600/1000	3 x 0.8	3 x 0.5	0.86	415	1.7	900	82	82	50
S6123-X311	110	low profile	600/1000	3 x 0.7	3 x 0.6	0.63	430	1.3	1750	135	135	57

4-FOLD CMCs

Table below

More detailed technical information and the data sheets are available at www.vacuumschmelze.com.
Please scan the QR-code belonging to this chapter which will lead you automatically to the respective site.

STANDARD SERIES 4-FOLD CHOKES

Part number T60405-	I_N A	Design	U_N OVCat III / II V	L_N 10 kHz mH	L_N 100 kHz mH	R_{Cu} typ. mΩ	|Z| 100 kHz Ω	f_R typ. MHz	I_{cm} 10 kHz mA	Dimensions l mm	w mm	h mm
S6123-X400	10** 12*	low profile	600 / 1000	4 x 6.9	4 x 1.6	7.66	1500	1.4	40	51	51	33
S6123-X401	16** 20*	low profile	600 / 1000	4 x 3.6	4 x 0.8	2.75	860	3.4	90	51.5	51.5	33
S6123-X402	24** 30*	low profile	600 / 1000	4 x 3.2	4 x 0.7	1.5	750	3.5	100	60	60	33.5
S6123-X403	32** 40*	low profile	600 / 1000	4 x 1.4	4 x 0.3	0.82	360	7	160	60	60	33

* for $T_a \leq 60\,°C$ ** for $T_a \leq 85\,°C$

CMCs FOR HIGH POWER CENTRAL AND UTILITY GRADE PHOTOVOLTAIC-INVERTERS UP TO THE MW-RANGE

[1] Design example: $I_{rms} = 2 \times 400$ A, $L = 2 \times 1.5$ mH, $U_{is} = 1000\ V_{rms}$, mechanical dimension 276 mm x 287 mm (without cable and cable lugs)

FURTHER DESIGN SUPPORT

For CMC selections (even at deviating operational data) please download our software tool (requires Microsoft EXCEL) VAC CMC Quick Selector which can be accessed using the QR-codes in this brochure that link to the product pages.

If you cannot find a suitable CMC from the listed standard range, please contact us using our design checklist.

VAC Design Checklist

For testing purposes, VAC offers special sample kits consisting of tape-wound cores Core Sample Kit VITROPERM and Common Mode Chokes CMC Sample Kit.

Core Sample Kit (Content)

CMC Sample Kit (Content)

CMC DESIGN CHECKLIST (EN50178) - 1/2

For IEC 62109/IEC61800 please use the separate checklist from our website.

Company name:		**Contact person:**	
Address:		**Tel.:**	
	☐ New project ☐ Replacement for:	**E-Mail:**	
Application (please specify in more detail):	☐ SMPS/UPS: ☐ Drives/Inverter: ☐ Solar/Photovoltaic: ☐ Welding: ☐ Other: Power: kW	**Date:**	
		Project name(s), description:	

Expected annual usage [pcs.]:	Year 1	Year 2	Year 3	Year 4	**Target price [€]:**	
					Product life cycle [years]:	
Sample quantity:	pcs.	**Sample date:**			**SOP:**	

Operational Characteristics

Number of windings:		**Rated voltage** [1]**:**	
Nominal load current:	A (RMS or DC)	OVCat 3:	V ☐ RMS ☐ DC
Overload current:	A for **s**	OVCat 2:	V ☐RMS ☐ DC
Nominal impedance:	Ω @ kHz	**Pollution degree (typ. 2):**	
Nominal inductance:	**mH** @ 10 kHz	**Max. ambient temperat.:**	°C
	mH @ 100 kHz	**Max. operational temp.:**	°C
Switching frequency:	kHz	**Cooling mechanism:**	☐ Convection
Max. Common Mode Current:	mA @ LF (<20kHz)	Forced cooling Fan:	☐ m/s
(leak. curr. / unbalanced current / noise)	mA @ kHz	Heat sink:	☐ K/W
Leakage inductance:	µH	**Copper resistance R_{Cu}:**	Ω
Results from own tests: Core:		**Casing construction:**	
No of turns:		**Design:** upright ☐	low profile ☐
(Number of strands) × $Ø_{Cu}$:	× mm	PTH ☐ SMD ☐	Cable Lugs ☐
Max. dimensions: W × D × H:	× × mm	**Pinning already fixed:**	☐ yes ☐ no

[1] typically: Overvoltage Category 3 = connected to mains, Overvoltage Category 2 = not connected to mains

Additional Specifications

Electrical standards:	☐ **EN50178**	☐ UL	☐ other:	☐ none	For IEC62109 and IEC61800 please use separate checklist
Environmental demands:	Vibration:		Humidity:		Dust:
QM-Requirement:	☐ **ISO 9001**		☐ **TS16949**	☐ **Others:**	

Filter Design:

Filter:	1-stage ☐	2-stage ☐	multi-stage ☐ (No. of stages:)
Schematic:	draft on page 2 ☐	separate attachment ☐	

CMC DESIGN CHECKLIST (EN50178) - 2/2

Further comments:

Draft of filter schematic:

VACUUMSCHMELZE GMBH & CO. KG
GRÜNER WEG 37
D 63450 HANAU / GERMANY
PHONE +49 6181 38 0
FAX +49 6181 38 2645
INFO@VACUUMSCHMELZE.COM
WWW.VACUUMSCHMELZE.COM

VAC MAGNETICS LLC
2935 DOLPHIN DRIVE
SUITE 102
ELIZABETHTOWN, KY 42701
PHONE +1 270 769 1333
FAX +1 270 769 3118
INFO-USA@VACMAGNETICS.COM

VACUUMSCHMELZE SINGAPORE PTE LTD
1 TAMPINES CENTRAL 5, #06-09
CPF TAMPINES BUILDING
SINGAPORE 529508
PHONE +65 6391 2600
FAX +65 6391 2601
VACSINGAPORE@VACUUMSCHMELZE.COM

VACUUMSCHMELZE CHINA MAGNETICS
SHANGHAI SALES OFFICE
ROOM 06, 19F
ZHONGRONG HENGRUI INTERNATIONAL PLAZA
620 ZHANGYANG ROAD, PUDONG DISTRICT
SHANGHAI, PRC 200122
PHONE +86 21 58 31 98 37
FAX +86 21 58 31 99 37
VAC_CHINA@VACUUMSCHMELZE.COM

PB-EMC EMC PRODUCTS BASED ON NANOCRYSTALLINE VITROPERM • EDITION 2016

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VACUUMSCHMELZE

ADVANCED MATERIALS – THE KEY TO PROGRESS

VITROPERM 712 F

NEW NANOCRYSTALLINE CORES TO COVER FULL RANGE OF COMMON MODE CURRENTS

Tape wound cores made of our new alloy VITROPERM® 712 F with a permeability (μ) of 12,000 close the gap between VITROPERM 500 F (μ = 17,000 - 100,000) and VITROPERM 250 F (μ = 3,000 - 5,000).

VITROPERM 712 F offers medium bias current capability (LF and HF) and superior broadband RFI-attenuation in comparison to typical EMI ferrites.

TARGET APPLICATIONS

Wind Generators, High Power Solar Inverters, Variable Frequency Drives, Automotive, Naval.

VITROPERM 712 F offers significant advantages in volume and performance for RFI-noise suppression and is the ultimate choice for reducing bearing currents of inverter driven motors.

Due to high saturation flux density of VITROPERM suitable impedance values in optimized space can be achieved for common mode noise reduction.

In summary, common mode chokes using cores made of VITROPERM 712 F offer the following impressive features:

- saturation current 2.5…4 times higher compared to ferrites with μ ≈ 10,000 for same core size and same number of turns
- broadband insertion loss characteristic
- small choke size for volume and weight optimized solutions especially for One-Turn-CMC

MATERIAL DATA OF VITROPERM 712 F (TYPICAL VALUES)

Saturation flux density	1.23 T (room temperature)
Coercivity (static)	< 3 A/m
Saturation magnetostriction	~ 0.5 x 10^{-6}
Specific electrical resistivity	1.15 Ω mm^2/m
Curie temperature	> 600 °C
Upper operational temperature	plastic case: 130 °C*
	core mat.: 155 °C
	180 °C (lim. time)
Typical permeability μ_3	~ 12,000 (10 kHz)

* Plastic cases suitable for upper continuous application temperatures of 155 °C are available on request.

EXAMPLES FOR DIFFERENT VITROPERM CORES

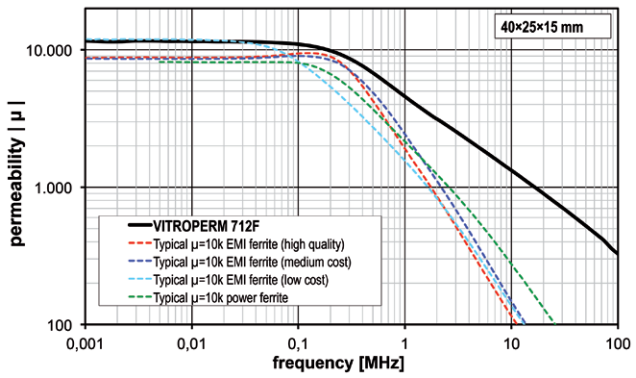
Size: 40 × 25 × 15 mm (finished: 43.1 × 22.5 × 18.5 mm)

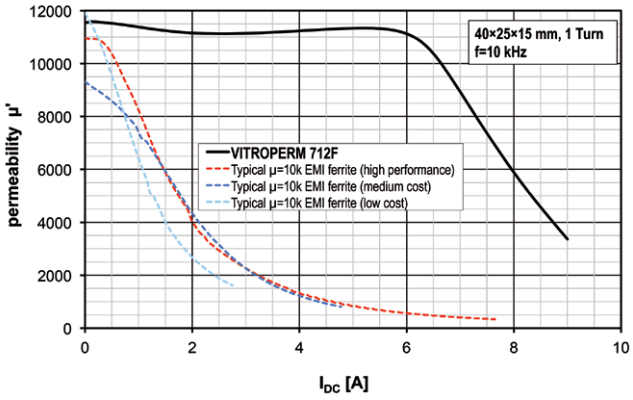
A_{Fe} = 0.86 cm^2, l_{Fe} = 10.2 cm, typical values

VAC alloy brand	Intrinsic permeability μ_i	A_L 100 kHz	Saturation current I_{cm} at 20 °C, ~70 % B_s, 10 / 100 kHz, 1 turn
VP 500 F	≈ 100,000	23.1 μH	0.45 / 1.0 A
VP 500 F	≈ 24,000	17.2 μH	2.9 / 4.4 A
VP 712 F	**≈ 12,000**	**11.1 μH**	**5.7 / 6.5 A**
VP 250 F	≈ 4,500	4.1 μH	16.9 / 17.4 A

All listed cores are in plastic cases to achieve good mechanical protection.

TYPICAL CHARACTERISTICS: VITROPERM – FERRITE MATERIALS





VACUUMSCHMELZE GMBH & CO. KG
GRÜNER WEG 37
D 63450 HANAU / GERMANY
PHONE +49 6181 38 0
FAX +49 6181 38 2645
INFO@VACUUMSCHMELZE.COM
WWW.VACUUMSCHMELZE.COM

VAC MAGNETICS LLC
2935 DOLPHIN DRIVE
SUITE 102
ELIZABETHTOWN, KY 42701
PHONE +1 270 769 1333
FAX +1 270 769 3118
INFO-USA@VACMAGNETICS.COM

VACUUMSCHMELZE SINGAPORE PTE LTD
1 TAMPINES CENTRAL 5, #06-09
CPF TAMPINES BUILDING
SINGAPORE 529508
PHONE +65 6391 2600
FAX +65 6391 2601
VACSINGAPORE@VACUUMSCHMELZE.COM

VACUUMSCHMELZE CHINA MAGNETICS
SHANGHAI SALES OFFICE
ROOM 06, 19F
ZHONGRONG HENGRUI INTERNATIONAL PLAZA
620 ZHANGYANG ROAD, PUDONG DISTRICT
SHANGHAI, PRC 200122
PHONE +86 21 58 31 98 37
FAX +86 21 58 31 99 37
VAC_CHINA@VACUUMSCHMELZE.COM

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ACTIVE
CURRENT SENSORS
FOR PCB MOUNTING

ADVANCED MATERIALS – THE KEY TO PROGRESS

VACUUMSCHMELZE

THE COMPANY
VACUUMSCHMELZE

VACUUMSCHMELZE GmbH & Co. KG (VAC) is one of the world's leading producers of special metallic materials with particular physical properties and products produced from them. With approximately 4,300 employees worldwide, the company is represented in 50 countries and currently achieves a turnover of approximately EUR 380 million.

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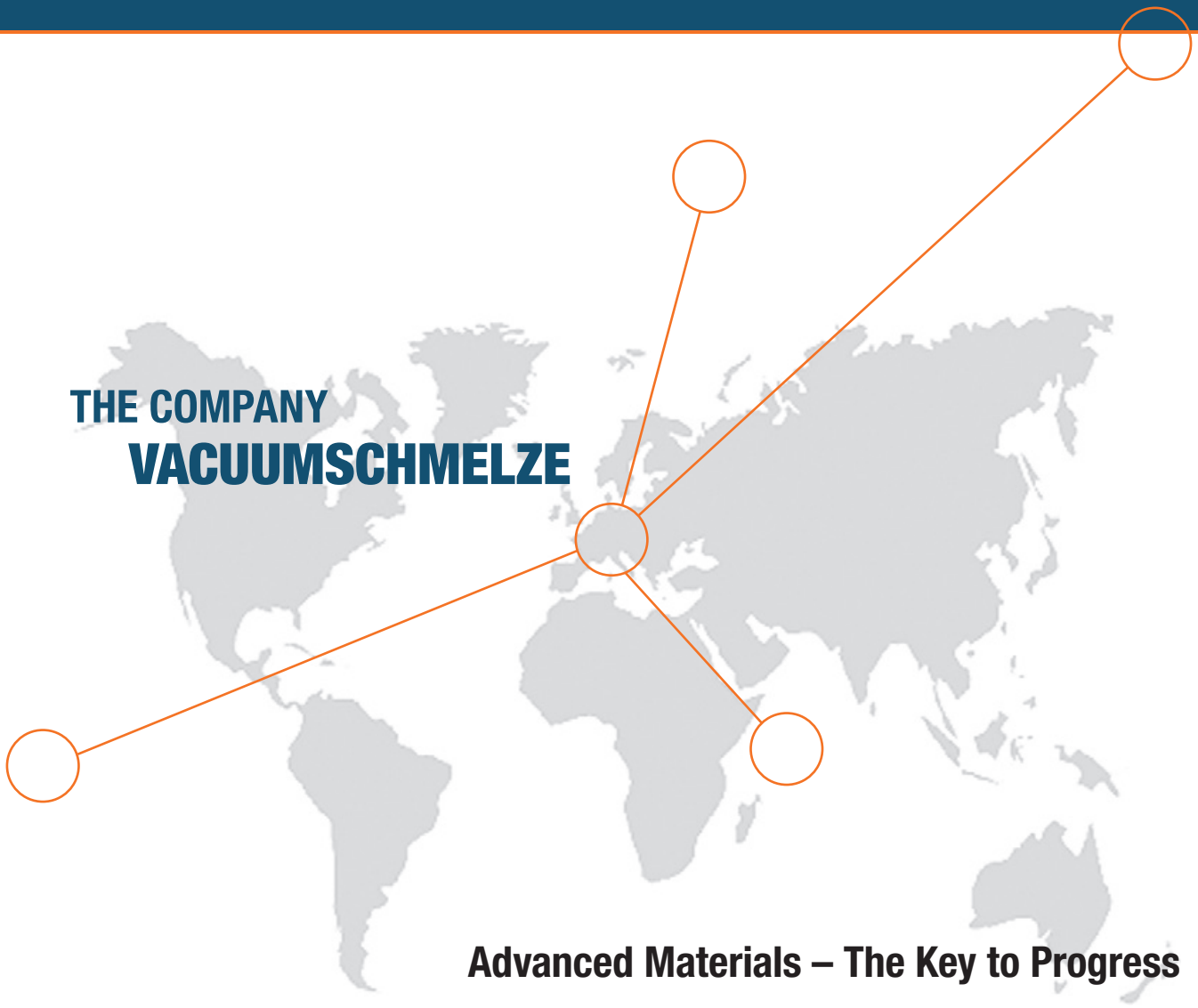


THE COMPANY VACUUMSCHMELZE

Advanced Materials – The Key to Progress

VACUUMSCHMELZE GmbH & Co. KG is one of world's leading producers of special metallic materials and related products. Our wide range of high quality semi-finished products, parts, components and systems are used in virtually every field of electrical and electronic engineering. This makes us one of the few global companies to offer its customers the complete range of magnetic technology products from a single source – from magnetically soft products to the most powerful permanent magnets in the world.

In all our activities, we benefit from our highly developed material expertise and our decades of experience in magnetic technology. As early as 1923, we became the first company to introduce alloy smelting in a vacuum on an industrial scale and it was from this process that the name VACUUMSCHMELZE was derived.

One of our great strengths is our versatility. All of the world's key industries rely on products and expertise from VACUUMSCHMELZE, with our principal customers active in drive and installation technology, medical technology, renewable energy, automation systems, process and control engineering, measurement technology, as well as the very important automotive and aerospace industries. VAC's dedicated solutions are developed in close cooperation with customers and reflect the highest levels of material and application expertise combined with the latest production technology.

ACTIVE CURRENT SENSORS FOR PCB MOUNTING

VAC CURRENT SENSOR SERIES

VAC offers several series of active current sensors for print mounting in which the primary conductor is integrated. The electronics of the new VAC current sensors are almost completely concentrated in a novel ASIC developed jointly with a leading semiconductor manufacturer. Despite the compact design, all types offer the detection of high maximum and continuous currents.

TYPICAL APPLICATIONS

- Frequency converters for drives
- Photovoltaic inverters
- Wind power converters
- Charging stations for e-mobility
- Welding inverters
- Switched mode power supplies

TYPICAL PROPERTIES

- Closed-loop current sensors with the VAC-invented magnetic probe as zero field detector
- Standard series for nominal currents from 6 to 100 A and peak currents up to ± 200 A in compact designs
- types for + 5 Volt power supply with voltage output
- types for ± 12 ... 15 Volt power supply with current output
- very good measuring accuracy, minimum DC offset with very low hysteresis
- negligible output noise
- very low temperature dependence and long-term drift of the output variable
- low rise time, wide frequency range
- cost-effective construction
- dimensions and pinning compatible

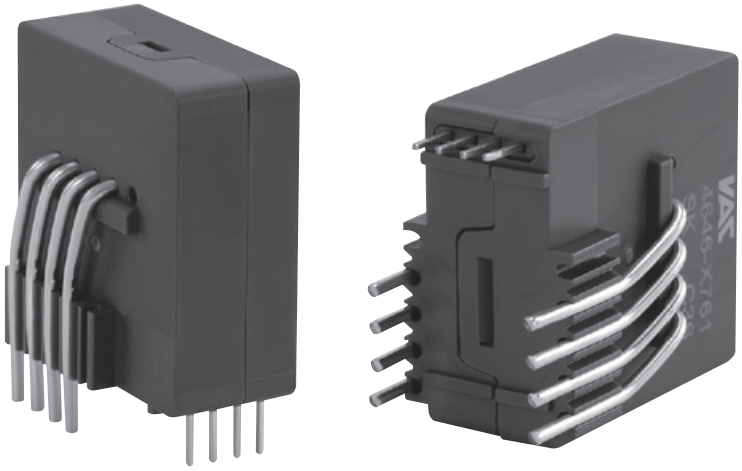
NEW ASIC

A newly developed ASIC contains most of the electronics for the ±12, ±15 or ±24 Volt-powered sensors with current output. The new sensors are available under the family designation T60404-N4648 - X .... They are fully compatible with previous models.

TESTED ESD STRENGTH AND EMC-IMPROVED SENSOR TYPES

Our current sensors offer a high ESD strength, which we document gradually in the data sheets. We also offer new series with increased electromagnetic compatibility under the family designation T60404-N4647-Xxxx.

You can find more information about our innovations in the technical appendix at the end of this brochure.



TYPE SERIES OF VAC CURRENT SENSORS

Item no. Type T60404-N…		**Rated current** $I_{PN, rms}$@K_N = 1 : N [A]	**Max. measuring range** $I_{Pmax.}$ @ V_C = + 5 V or V_C = ± 15 V [A]	**Turns ratio** K_N	**Output variable**	**V_{ref}-input/output²**	**Ambient temperature range** T_{amb} [° C] -40 to	**Supply voltage** V_C [V]	**Creepage/clearance** [mm]	**System/working voltage acc. to EN 61800-5-1** (reinforced insul.; insul. mat. group 1; PD 2; OV 3) [V]	**Frequency range** f [kHz] DC to	**Accuracy** X @ I_{PN}; T_{amb} = 25 °C [%]	**Mechanical outline**
	4646-X653[3,4,5]	6 3 2	±20 ±10 ±7	1:2000 2:2000 3:2000	U		+ 85	+ 5	7/7	300/650	200	0.7	1
	4646-X652[3,4,5]	15 7.5 5	±51 ±25 ±17	1:2000 2:2000 3:2000	U		+ 85	+ 5	7/7	300/650	200	0.7	1
	4646-X651[3,4,5]	25 12 8	±85 ±42 ±28	1:2000 2:2000 3:2000	U		+ 85	+ 5	7/7	300/650	200	0.7	1
	4646-X654[3,4,5]	50 12 8	±150 ±75 ±50	1:1400 2:1400 3:1400	U		+ 85	+ 5	7/7	300/650	200	0.7	1
	4646-X663[2,4,5] 4647-X663[1,2,4,5]	6 3 2	±20 ±10 ±7	1:2000 2:2000 3:2000	U	yes	+ 85	+ 5	7/7	300/650	200	0.7	2
	4646-X662[2,4,5] 4647-X662[1,2,4,5]	15 7.5 5	±51 ±25 ±17	1:2000 2:2000 3:2000	U	yes	+ 85	+ 5	7/7	300/650	200	0.7	2
	4646-X661[2,4,5] 4647-X661[1,2,4,5]	25 12 8	±85 ±42 ±28	1:2000 2:2000 3:2000	U	yes	+ 85	+ 5	7/7	300/650	200	0.7	2
	4646-X664[2,4,5] 4647-X664[1,2,4,5]	50 12 8	±150 ±75 ±50	1:1400 2:1400 3:1400	U	yes	+ 85	+ 5	7/7	300/650	200	0.7	2

Item no. Type T60404-N…		Rated current $I_{PN, rms}$@K_N = 1 : N [A]	Max. measuring range $I_{Pmax.}$ @ V_C = + 5 V or V_C = ± 15 V [A]	Turns ratio K_N	Output variable	V_{ref}-input/output[2]	Ambient temperature range T_{amb} [° C] -40 to	Supply voltage V_C [V]	Creepage/clearance [mm]	System/working voltage acc. to EN 61800-5-1 (reinforced insul.; insul. mat. group 1; PD 2; OV 3) [V]	Frequency range f [kHz] DC to	Accuracy X @ I_{PN}; T_{amb} = 25 °C [%]	Mechanical outline
	4646-X763[2,4,5] 4647-X763[1,2,4,5]	6 3 1.5	±20 ±10 ±5	1:2000 2:2000 4:2000	U	yes	+ 85	+ 5	9.6/10.6	600/1060	200	0.7	3
	4646-X762[2,4,5] 4647-X762[1,2,4,5]	15 7.5 3.75	±51 ±25.5 ±12.5	1:2000 2:2000 4:2000	U	yes	+ 85	+ 5	9.6/10.6	600/1060	200	0.7	3
	4646-X761[2,4,5] 4647-X761[1,2,4,5]	25 12 6	±85 ±42 ±21	1:2000 2:2000 4:2000	U	yes	+ 85	+ 5	9.6/10.6	600/1060	200	0.7	3
	4646-X764[2,4,5] 4647-X764[1,2,4,5]	50 12 6	±150 ±75 ±37.5	1:1400 2:1400 4:1400	U	yes	+ 85	+ 5	9.6/10.6	600/1060	200	0.7	3
	4646-X460[2,5] 4647-X460[1,2,5]	50 25 17	±150 ±75 ±50	1:1400 2:1400 3:1400	U	yes	+ 85	+ 5	10.2/10.2	600/1020	100	0.7	4
	4646-X461[2,5] 4647-X461[1,2,5]	100 50 33	±200 ±100 ±66	1:1100 2:1100 3:1100	U	yes	+ 85	+ 5	10.2/10.2	600/1020	100	0.7	4
	4646-X300 4648-X300[6]	25 12 8 6 5	±85 ±43 ±28 ±21 ±17	1:1000 2:1000 3:1000 4:1000 5:1000	I		+ 85	± 12 ... 15	10.2/10.2	600/1020	200	0.5	5

Item no. Type T60404-N…		Rated current $I_{PN, rms}$@K_N = 1 : N [A]	Max. measuring range $I_{pmax.}$ @ V_C = + 5 V or V_C = ± 15 V [A]	Turns ratio K_N	Output variable	V_{ref}-input/output[2]	Ambient temperature range T_{amb} [° C] -40 to	Supply voltage V_C [V]	Creepage/clearance [mm]	System/working voltage acc. to EN 61800-5-1 (reinforced insul.; insul. mat. group 1; PD 2; OV 3) [V]	Frequency range f [kHz] DC to	Accuracy X @ I_{PN}; T_{amb} = 25 °C [%]	Mechanical outline
	4646-X400 4648-X400[6]	25 10 8	±130 ±65 ±43	1:1000 2:1000 3:1000	I		+ 85	± 12 ... 15	10.2/10.2	600/1020	200	0.5	6
	4646-X410 4648-X410[6]	50 20 15	±128 ±64 ±43	1:1000 2:1000 3:1000	I		+ 85	± 12 ... 15	10.2/10.2	600/1020	200	0.5	7
	4646-X412 4648-X412[6]	100 35 25	±175 ±82 ±58	1:2000 2:2000 3:2000	I		+ 85	± 12 ... 15	10.2/10.2	600/1020	200	0.5	7
	4646-X413 4648-X413[6]	100 35 25	±208 ±104 ±69	1:1500 2:1500 3:1500	I		+ 85	± 12 ... 15	10.2/10.2	600/1020	200	0.5	7

[1] Types 4647 have additional measures to improve EMC. They are fully compatible with the corresponding types 4646. See also the technical appendix.

[2] Reference voltage output 2.5 ± 0.005 V. Ri = 670 Ohm. Can be overwritten and therefore used as an input for an external reference. Voltage range 0 ... 4 V.

[3] Types without reference voltage input/output (V_{ref} – pin): For new developments we recommend the use of the types of 4646-X66x or 4646-X76x with reference voltage input/output to achieve higher measuring accuracy.

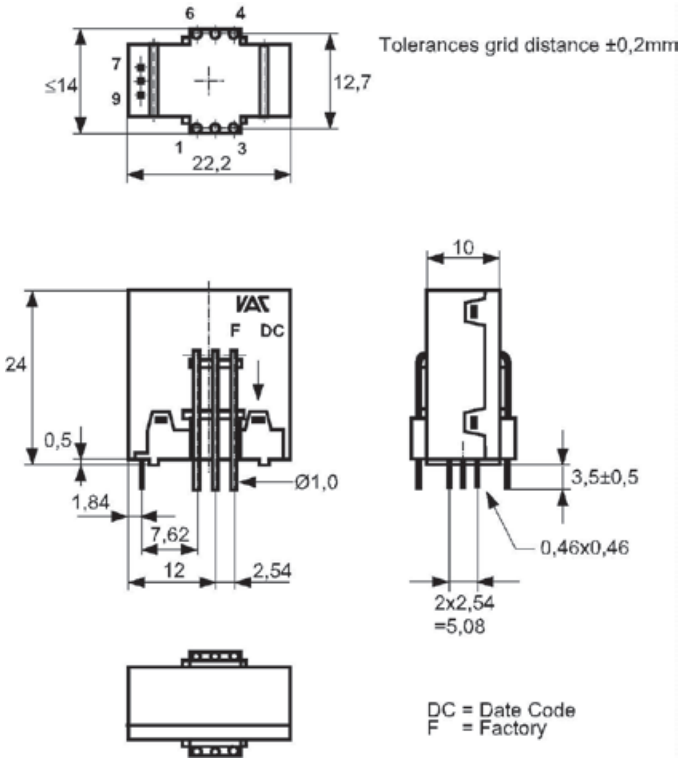
[4] The rated current for these types is only a reference value. They all can be used up to the maximum ambient temperature, loaded with the following rms values per primary turn: 17 A in parallel connection, 12 A in series connection. Within these limits, the sensor type can be selected according to the measuring range.

[5] $V_A = V_{ref} \pm (0.625 * I_P/I_{PN})$, resp. $V_A = 2.5\,V \pm (0.625 * I_P/I_{PN})$.
Examples, type 4646-X761: Primary current (peak) = 85 A. Output voltage range (peak) = 2.5 V ± (0.625 * 85 A/25 A) = 0.375 V ... 4.625 V
Primary current (RMS) = 20 A. Output voltage range (RMS) = 0.625 * 20 A/25 A = 0.5 V_{rms}

[6] Types 4648 are equipped with a new ASIC. They are fully compatible with the corresponding types 4646. See also the technical appendix.

MECHANICAL OUTLINES

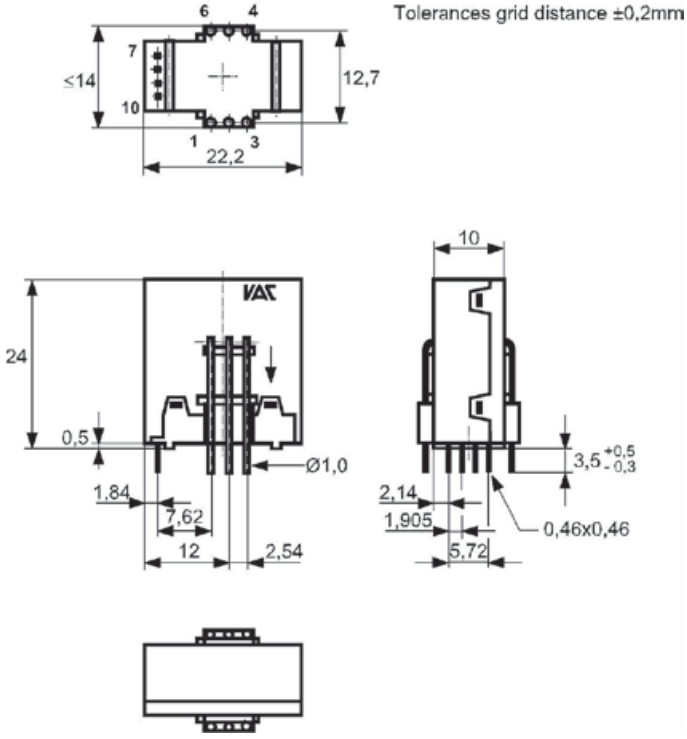
Drawing no. 1



Type

T60404-N4646-X651
T60404-N4646-X652
T60404-N4646-X653
T60404-N4646-X654

Drawing no. 2

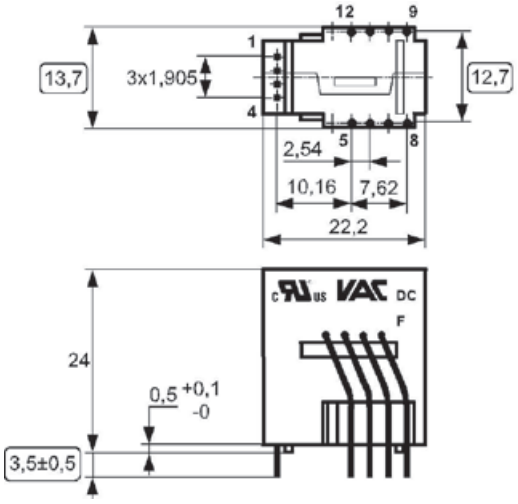


Type

T60404-N4646-X661 / 7-X661
T60404-N4646-X662 / 7-X662
T60404-N4646-X663 / 7-X663
T60404-N4646-X664 / 7-X664

Photos for illustration purposes only

Drawing no. 3



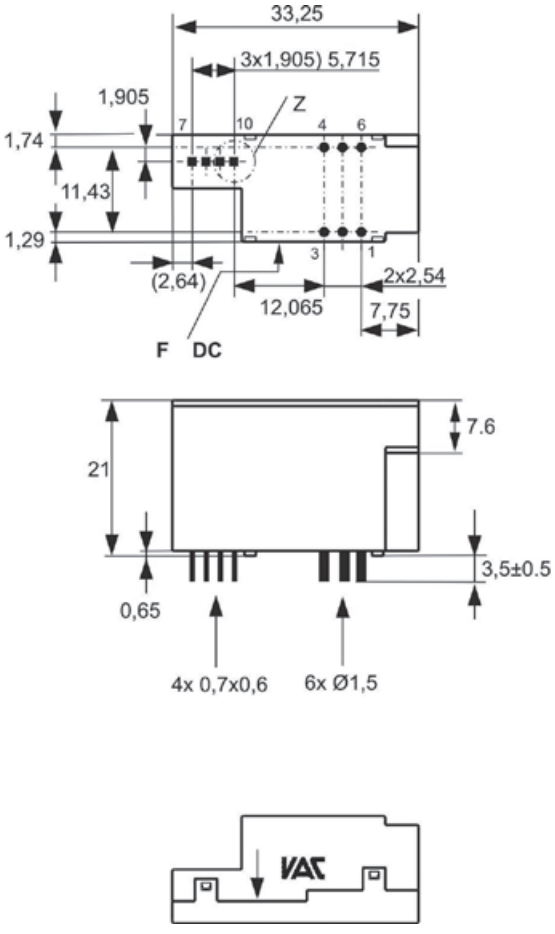
test dimension

Tolerances grid distance ±0,25mm

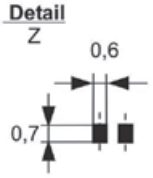
Type

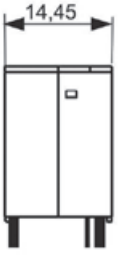
T60404-N4646-X761 / 7-X761
T60404-N4646-X762 / 7-X762
T60404-N4646-X763 / 7-X763
T60404-N4646-X764 / 7-X764

Drawing no. 4



Tolerances grid distance ±0,2mm

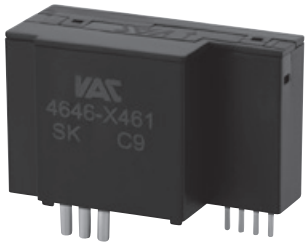




DC = Date Code
F= Factory

Type

T60404-N4646-X460 / 7-X460
T60404-N4646-X461 / 7-X461



Photos for illustration purposes only

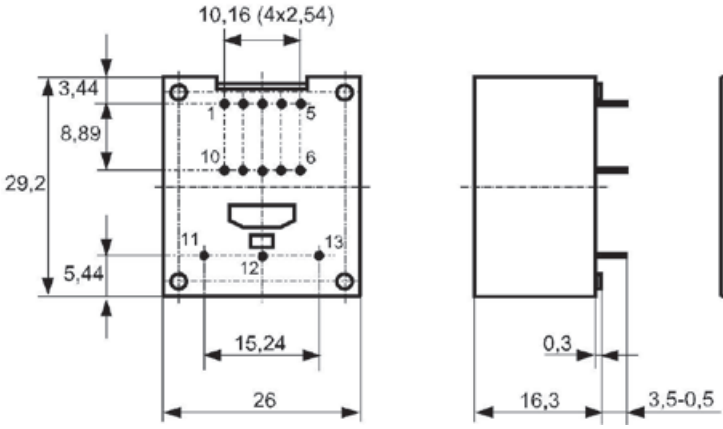
Drawing no. 5

Type
T60404-N4646-X300 / 8-X300

Tolerances grid distance ±0,3

Numbers 1 - 13 not imprinted

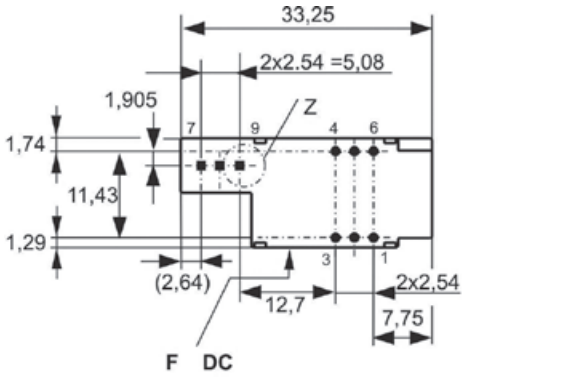
DC = Date Code
F = Factory

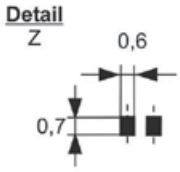


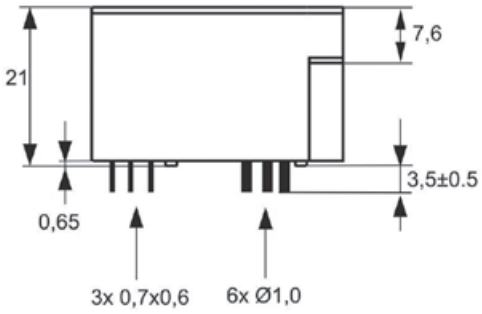
Drawing no. 6

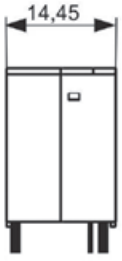
Type
T60404-N4646-X400 / 8-X400

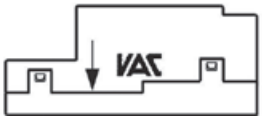
Tolerances grid distance ±0,2mm







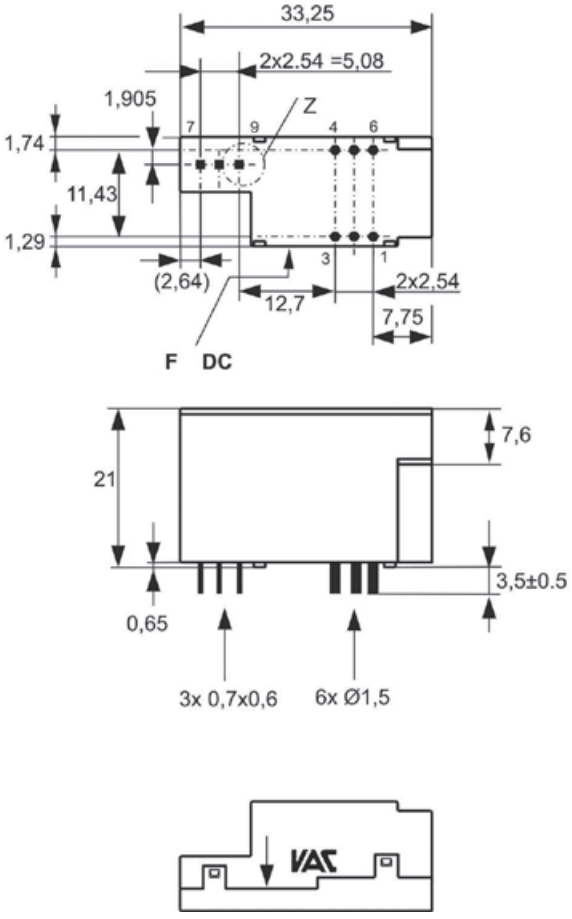




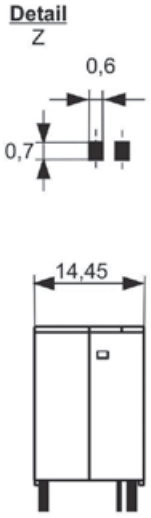
DC = Date Code
F= Factory

Photos for illustration purposes only

Drawing no. 7



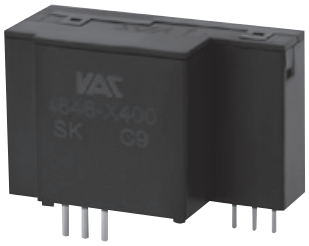
Tolerances grid distance
±0,2mm



DC = Date Code
F= Factory

Type

T60404-N4646-X410 / 8-X410
T60404-N4646-X412 / 8-X412
T60404-N4646-X413 / 8-X413



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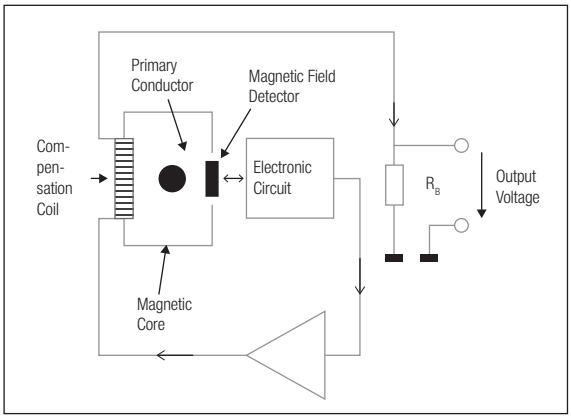
FUNCTIONAL PRINCIPLE OF THE VAC COMPENSATION SENSORS

The current I_P to be measured generates a flux in the soft magnetic core. The sensor electronics generates a flux in the opposite direction via the compensation current I_S and controls the sum of the fluxes to zero. This is done by means of a magnetic field probe, which is located in the air gap of the core. At frequencies above a few kHz, the magnetic system consisting of the primary winding, the magnetic core and the secondary winding functions independently of the electronics as a current transformer.

The compensating current corresponds in amount and shape to the primary current divided by the number of turns of the secondary winding. A voltage can be derived from the measuring resistor.

The main advantages of the closed loop current sensors are their high measuring accuracy, as well as their low rise time and wide bandwidth. VAC closed loop sensors with magnetic probe achieve an even higher accuracy over the entire application temperature range than their counterparts with Hall element and have a minimal noise component in the output signal.



CURRENT SHAPES

The operating currents to be measured in the power electronics are, as a rule, direct currents or alternating currents up to a maximum of a few 100 Hz with a high amplitude. They are superimposed by the switching currents of the power semiconductors, which reach into the single to medium double-digit kHz range and have harmonics up to the three-digit range. Their amplitude is lower by one order of magnitude. Our current sensors are designed for this type of current. If the amplitude of high frequency components is permanently much greater, an excessive heating of the sensor core may occur. So, apart from the level of the current to be measured, its shape also has an influence on the losses and thus the heating of the sensor.

NEW ASIC LEADS TO IMPROVED SENSOR FAMILIES

A new IC, developed jointly with a leading semiconductor manufacturer, contains most of the electronics for the ±12, ±15 or ±24 V-supplied sensors with current output.

Only a few discrete components are required. This improves statistical reliability, e.g. the MTBF and FIT rates. In addition, the new IC includes a further improved operational reliability after undefined operating conditions, e.g. temporary supply voltage dips or switching on the supply voltage with the primary current already present.

The new sensors will have item number range T60404-N4648-X ... They are electrically and mechanically fully compatible with corresponding types of families T60404-N4646-X .... For new designs, we recommend the new series.

EMC-IMPROVED SENSOR TYPES

Under very unfavorable circumstances, the current sensor can be influenced by irradiation of high-frequency interference. As a rule, such disturbances are kept away by the shielding effect of the housing of the user device. This device is tested according to the relevant standards, without a single component contained therein, e.g. the current sensor, being exposed to the test radiation in full intensity at all.

In some cases, however, the corresponding electromagnetic compliance is already required by the sensor itself. For this purpose, VAC offers EMC-improved versions of our 5 Volt-powered sensors with voltage output.

They have been tested according to EN 61000-4-3: 2010 with a field strength of 20 V/m and 80 % AM with 1 kHz over a frequency range from 80 MHz to 1000 MHz. The detected measurement deviations were always below 2 % under these conditions. In our data sheets we state a maximum permissible deviation of 5 %.

The new sensors are introduced gradually. They are given the item number range T60404-N4647-Xxxx and are fully compatible with corresponding types of the T60404-N4646-Xxxx families.

ESD-STRENGTH

Our current sensors generally fulfill the following ESD strength according to DIN EN 6100-4-2: 2009:
Contact discharge at all connection pins: ± 8 kV
Surface discharge at the sensor housing: ± 15 kV

THE OFFSET RIPPLE

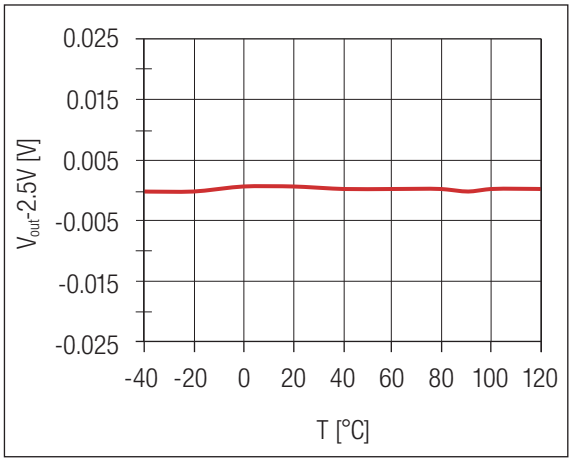
The quiescent signal of the VAC sensors has practically no noise component. The so-called “Offsetripple” i_{OSS}, which is shown in our data sheets, is actually not an offset. Instead, it is the not completely suppressed residual of the internal clock signal of the magnetic probe. The frequency of this signal is approx. 400 kHz. It is zero-symmetrical and does not affect the measuring accuracy if it is integrated over at least one period. Also it can be further reduced with a simple low-pass filter (capacitor parallel to the measuring resistor). Information on this can be found in the data sheets.

TYPICAL PERFORMANCE

Measured at VAC sensor with unipolar + 5 V supply and voltage output.
T60404-N4646-X661, $I_{P,N}$ = 25 A, $I_{Pmax.}$ = ± 85 A.

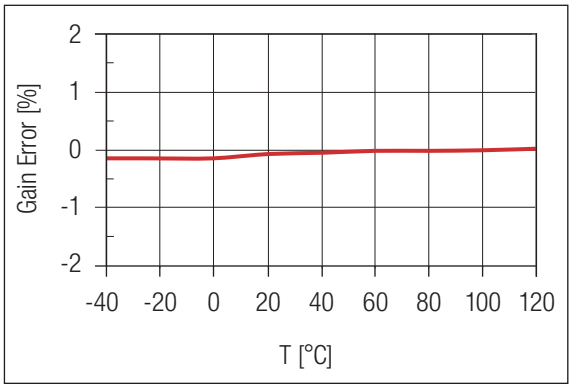
TEMPERATURE RESPONSE OFFSET

Low offset, almost temperature-independent, easily compensatable ($I_P = I_0$)



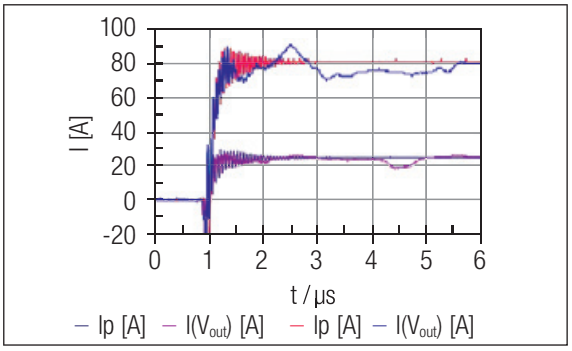
TEMPERATURE RESPONSE GAIN

Low gain-error, almost temperature-independent ($I_P = I_{P,N}$)



PULSE RESPONSE

The output signal V_{out} (here expressed as the equivalent of the input current) follows the input signal I_P with negligible delay and adapts quickly to the static value. Shown here for I_P = 25 A and I_P = 80 A.



VACUUMSCHMELZE GMBH & CO. KG
GRÜNER WEG 37
D 63450 HANAU / GERMANY
PHONE +49 6181 38 0
FAX +49 6181 38 2645
INFO@VACUUMSCHMELZE.COM
WWW.VACUUMSCHMELZE.COM

VAC MAGNETICS LLC
2935 DOLPHIN DRIVE
SUITE 102
ELIZABETHTOWN, KY 42701
PHONE +1 270 769 1333
FAX +1 270 769 3118
INFO-USA@VACMAGNETICS.COM

VACUUMSCHMELZE SINGAPORE PTE LTD
1 TAMPINES CENTRAL 5, #06-09
CPF TAMPINES BUILDING
SINGAPORE 529508
PHONE +65 6391 2600
FAX +65 6391 2601
VACSINGAPORE@VACUUMSCHMELZE.COM

VACUUMSCHMELZE CHINA MAGNETICS
SHANGHAI SALES OFFICE
ROOM 06, 19F
ZHONGRONG HENGRUI INTERNATIONAL PLAZA
620 ZHANGYANG ROAD, PUDONG DISTRICT
SHANGHAI, PRC 200122
PHONE +86 21 58 31 98 37
FAX +86 21 58 31 99 37
VAC_CHINA@VACUUMSCHMELZE.COM

KB – CURRENT SENSORS FOR PCB MOUNTING • EDITION 2017

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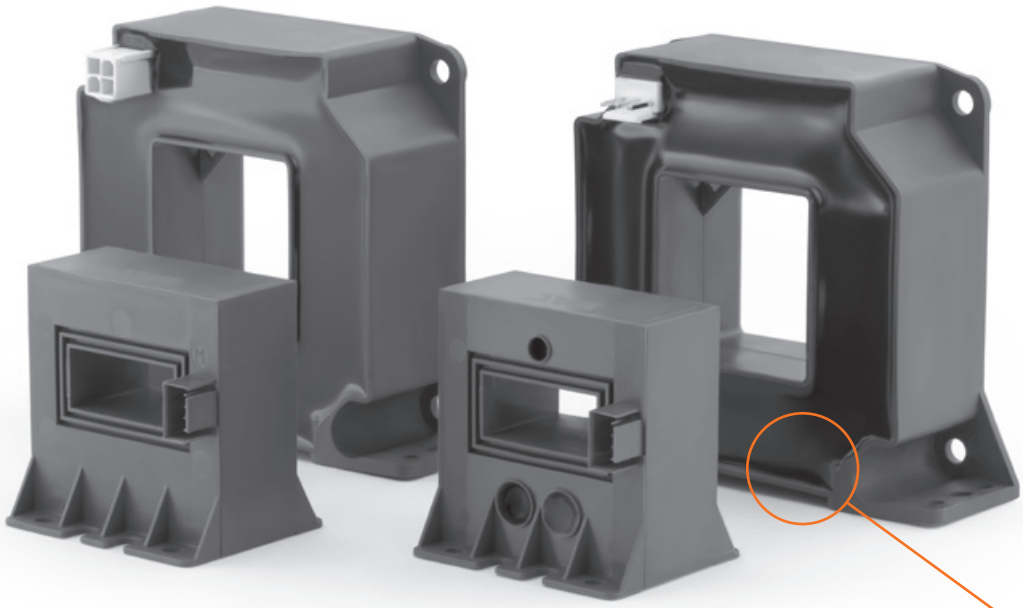
® ADVANCED MATERIALS – THE KEY TO PROGRESS

MAXIMUM ACCURACY

CURRENT SENSORS

FOR PANEL MOUNTING



ADVANCED MATERIALS – THE KEY TO PROGRESS

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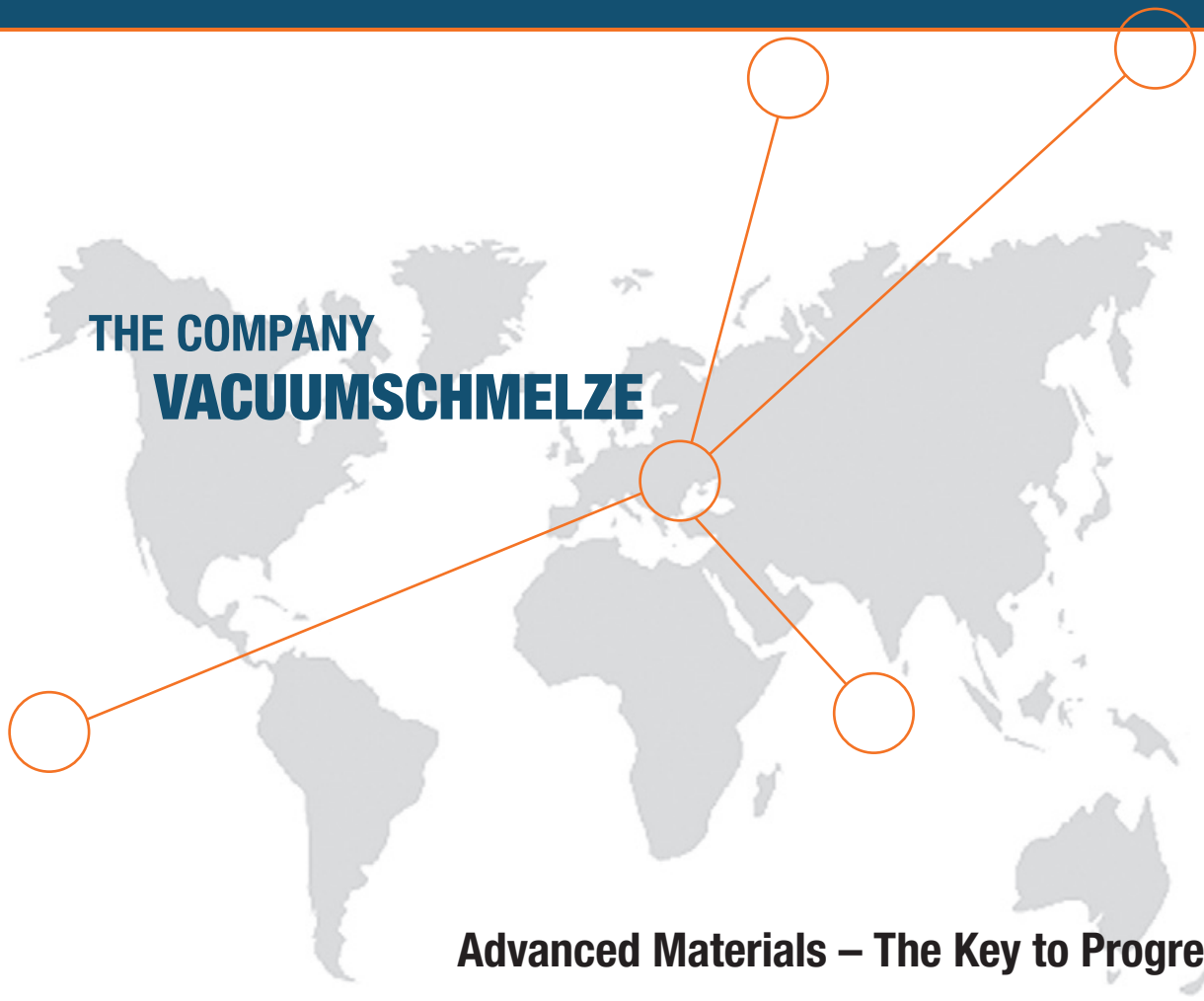

THE COMPANY
VACUUMSCHMELZE

Advanced Materials – The Key to Progress

VACUUMSCHMELZE GmbH & Co. KG is one of world's leading producers of special metallic materials and related products. Our wide range of high quality semi-finished products, parts, components and systems are used in virtually every field of electrical and electronic engineering. This makes us one of the few global companies to offer its customers the complete range of magnetic technology products from a single source – from magnetically soft products to the most powerful permanent magnets in the world.

In all our activities, we benefit from our highly developed material expertise and our decades of experience in magnetic technology. As early as 1923, we became the first company to introduce alloy smelting in a vacuum on an industrial scale and it was from this process that the name VACUUMSCHMELZE was derived.

One of our great strengths is our versatility. All of the world's key industries rely on products and expertise from VACUUMSCHMELZE, with our principal customers active in drive and installation technology, medical technology, renewable energy, automation systems, process and control engineering, measurement technology, as well as the very important automotive and aerospace industries. VAC's dedicated solutions are developed in close cooperation with customers and reflect the highest levels of material and application expertise combined with the latest production technology.

THE COMPANY
VACUUMSCHMELZE

We are a global company with our headquarters in Hanau, Germany. We currently have approximately 4300 employees who are spread over production and sales locations in more than 50 countries on every continent generating annual sales of approximately EUR 380 million.

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MAXIMUM ACCURACY
CURRENT SENSORS
FOR PANEL MOUNTING

VAC is the technology leader in DC and AC current sensing, providing a wide range of products to the industry. VAC owns state of the art R&D facilities and worldwide manufacturing sites, offering outstanding product quality at low cost.

Major applications for the VAC current sensors are variable speed drives, photovoltaic inverters, welding inverters, switched mode power supplies. The detectable currents range from a few amperes to more than 2000 amperes. Our differential current sensors measure even in the range of several ten milliamperes.

If the current of the application is more than 100 A or even in the four digit range, the current sensor is mounted on the equipment chassis and the supply and signal connections are contacted via plug.

The VAC model series in this segment are designed for maximum rated currents from 500 to 1000 A with measuring ranges up to 2500 A. They operate from a symmetrical voltage supply with usually ±15 volts or ±24 volts. The output signal is a current.

The VAC-invented measuring principle of the closed-loop sensor with magnetic probe as a zero field detector is distinguished by maximum precision of the current detection. It is at least twice as accurate compared with even the latest closed loop Hall-effect sensors and by far better than any open loop sensor.

BENEFITS

- very good accuracy (gain error typ. 0.1 %). Minimum DC-offset and hysteresis
- negligible temperature drift, excellent long-term stability of the output (typ. 0.1 % over the temperature range -40 ... +85 ° C)
- insignificant output noise
- low rise time (typ. < 0.5 microseconds), wide frequency range (e.g., DC to 100 kHz or 200 kHz)
- high operational safety, i.e. recovery after clipping, or power supply failure
- great robustness against HV transients, pulse currents, ESD, external DC or AC fields
- high reliability by electronics largely realized in application specific integrated circuits
- cost-effective design, mass production on highest qualitative level
- dimensions and pinning compatible to common industry standards
- relevant international standards are met, UL approved

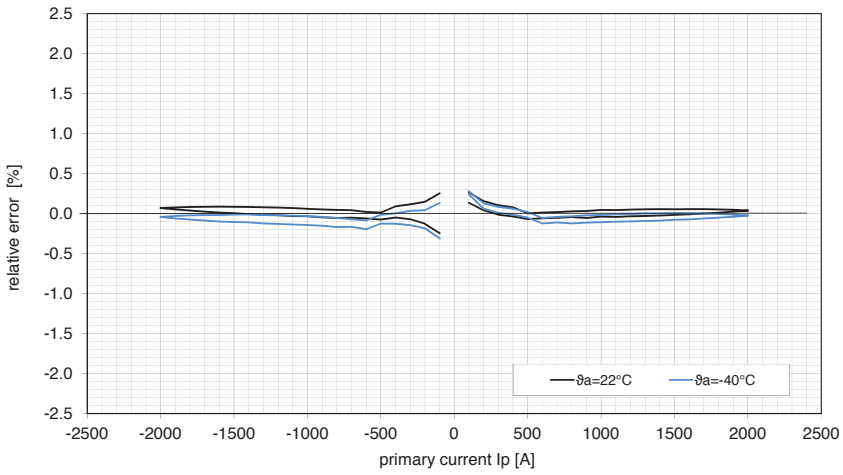


Fig. 1: Accuracy (relative) at room temperature and at the most critical temperature -40 °C 1000 A sensor T60404-P4640-X150

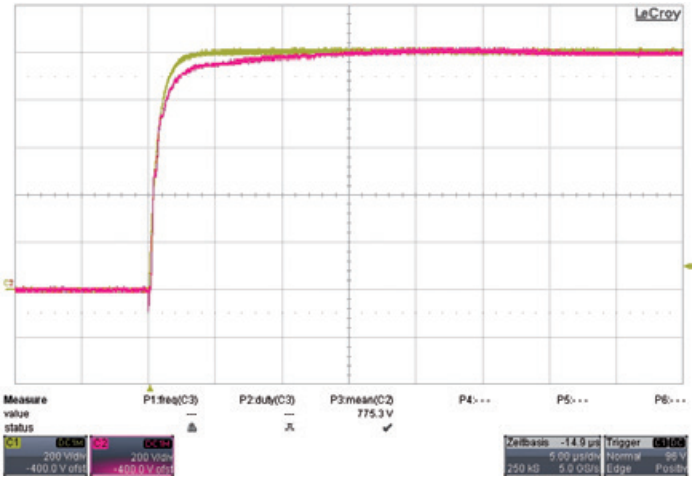


Fig. 2: Step response 1000 A sensor T60404-P4640-X150 (screenshot). Horizontal 2.00 ms / div, vertical 200 A / div

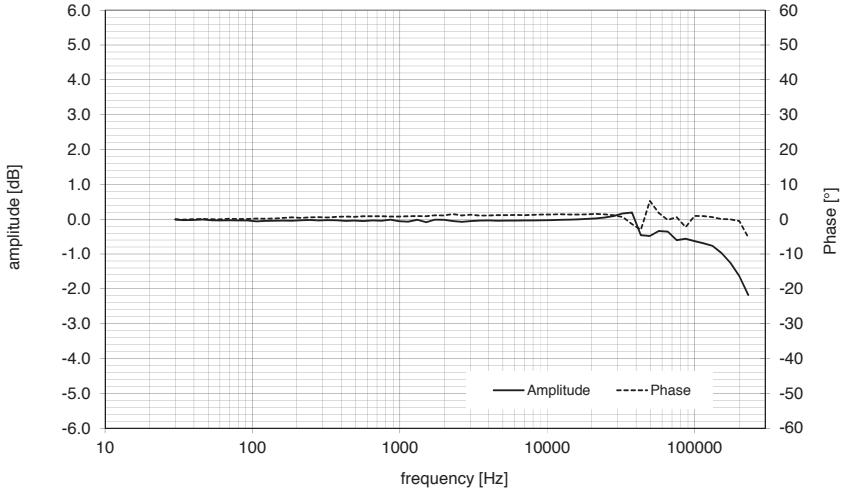


Fig. 3: Frequency response 1000 A sensor T60404-P4640-X150

TYPE SERIES OF VAC CURRENT SENSORS

VAC Item no. Type T60404-…	Rated current $I_{PN,\ rms}$@K_N = 1 : N [A]	Max. measuring range $I_{Pmax.}$(@V_C = ± 15 V or ± 24 V; $T_{A,max.}$)@ R_{meas} [A]@ [Ω]	Ambient temperature range T_A [° C] +40 to	Turns ratio K_N	Supply voltage V_C [V]	Frequency range f [kHz] DC to
N4648-X052[2]	500 400 250	± 700 @ 10	+70 +85 +105	1 : 2000	± 15	50
N4648-X053[2]	500 400 250	± 700 @ 10	+70 +85 +105	1 : 2000	± 15	50
N4648-X054[1,2]	700 400 250	± 1250 @ 10	+70 +85 +105	1 : 3000	± 15	50
N4648-X056[2]	500	± 1000 @ 10	+75	1 : 3000	± 24	50
P4640-X100	1000	± 1340 @ 10	+85	1 : 5000	± 15	100
P4640-X101	1000	± 1340 @ 10	+85	1 : 5000	± 15	100
P4640-X102	1000	± 1340 @ 10	+85	1 : 5000	± 15	100
P4640-X150	1000	± 2150 @ 10	+85	1 : 5000	± 24	100
P4640-X151	1000	± 2150 @ 10	+85	1 : 5000	± 24	100
P4640-X152	1000	± 2150 @ 10	+85	1 : 5000	± 24	100
P4640-X153[6]	1000	± 2150 @ 10	+85	1 : 5000	± 24	100
P4640-X154	1000	± 2150 @ 10	+85	1 : 5000	± 24	100
P4640-X156	1000	± 2150 @ 10	+85	1 : 5000	± 24	100
P4640-X157[6]	1000	± 2150 @ 10	+85	1 : 5000	± 24	100
P4640-X159[6]	1000	± 2150 @ 2	+85	1 : 4000	± 18	100

Remarks

The output variable of these types is always a current.

(1) This type has a differential output whose potential changes depending on the signal polarity. To establish a ground reference, it is imperative to put an external differential amplifier behind it.

(2) For new applications, these types replace the suitable types of the series N4644-X ...

(4) EN 61800-5-1, reinforced insulation, insulation material group 1, pollution degree 2, overvoltage category 3

	Creepage/ clearance [mm]	System/working voltage acc. to EN 61800-5-1[4] Voltage Potential Difference acc. to UL 508[5] [V]	Primary connection [mm]	Secondary connection	Moulded	Dimensions approx. l x w x h [mm]	Mecha-nical outline
	14 / 20	600[4] / 1000[4] / 600[5]	opening 30 x 13	Molex 5045	no	56 x 46 (26) x 56	1
	14 / 20	600[4] / 1000[4] / 600[5]	opening 30 x 13	Molex 5045	yes	56 x 46 (26) x 56	1
	14 / 20	600[4] / 1000[4] / 600[5]	opening 30 x 13	Molex 5045	yes	56 x 46 (26) x 56	2
	14 / 20	600[4] / 1000[4] / 600[5]	opening 30 x 13	Molex 5045	yes	56 x 46 (26) x 56	1
	20 / 20	1000[4] / 1000[4] / 1000[5]	opening 40 x 20 (40)	Molex 7478	yes	90 (110) x 34 x 95	3
	20 / 20	1000[4] / 1000[4] / 1000[5]	opening 40 x 20 (40)	JST B3PS-VH	yes	90 (110) x 34 x 95	3
	20 / 20	1000[4] / 1000[4] / 1000[5]	opening 40 x 20 (40)	Molex Minifit jr	yes	90 (110) x 34 x 95	4
	20 / 20	1000[4] / 1000[4] / 1000[5]	opening 40 x 20 (40)	Molex 7478	yes	90 (110) x 34 x 95	3
	20 / 20	1000[4] / 1000[4] / 1000[5]	opening 40 x 20 (40)	JST B3PS-VH	yes	90 (110) x 34 x 95	3
	20 / 20	1000[4] / 1000[4] / 1000[5]	opening 40 x 20 (40)	Molex Minifit jr	yes	90 (110) x 34 x 95	4
	20 / 20	1000[4] / 1000[4] / 1000[5]	opening 40 x 20 (40)	JST B3PS-VH bottom left	yes	90 (110) x 34 x 95	5
	20 / 20	1000[4] / 1000[4] / 1000[5]	opening 40 x 20 (40)	JST B3PS-VH JST B3PS-VH 90° angled	yes	90 (110) x 34 x 95	6
	20 / 20	1000[4] / 1000[4] / 1000[5]	opening 40 x 20 (40)	JST BH03B-XASK-BN	yes	90 (110) x 34 x 95	7
	20 / 20	1000[4] / 1441[4] / 600[5]	opening 40 x 20 (40)	JST B3PS-VH top central	yes	90 (110) x 34 x 95	8
	20 / 20	1000[4] / 1000[4] / 1000[5]	opening 40 x 20 (40)	Molex Minifit jr	yes	90 (110) x 34 x 95	9

(5) clearance and creepage distances, voltage potential difference according to UL508, Table 36.1.

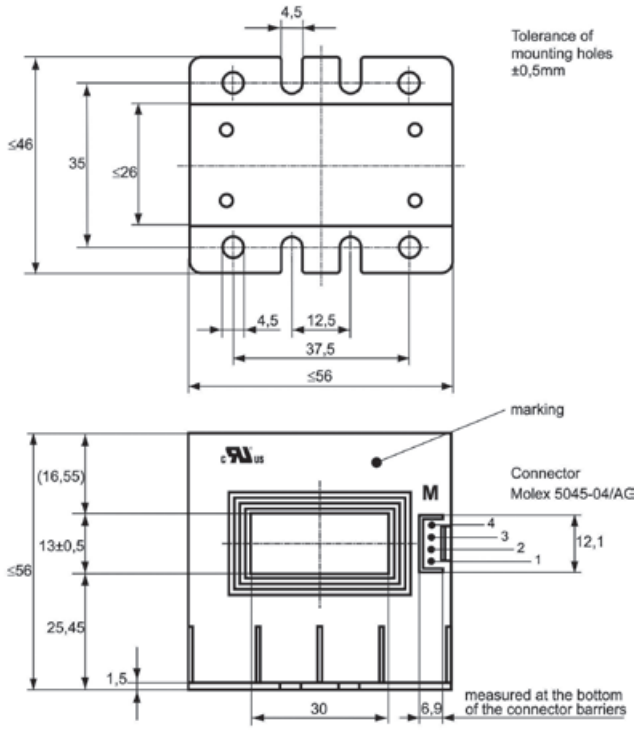
(6) Models under preparation

Other types (for example, with other connectors) are available. Thank you for your inquiry.

For the most recent information and additional information, see our data sheets under www.vacuumschmelze.com > Products > Cores & Inductive Components > Applications > Current Sensors / Transducers

MECHANICAL OUTLINES

Drawing no. 1



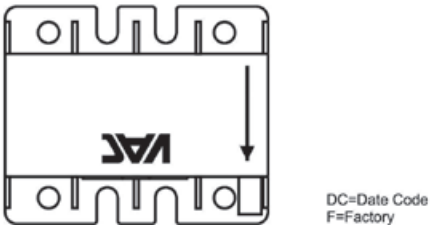
Type

T60404-N4648-X052
T60404-N4648-X053
T60404-N4648-X056

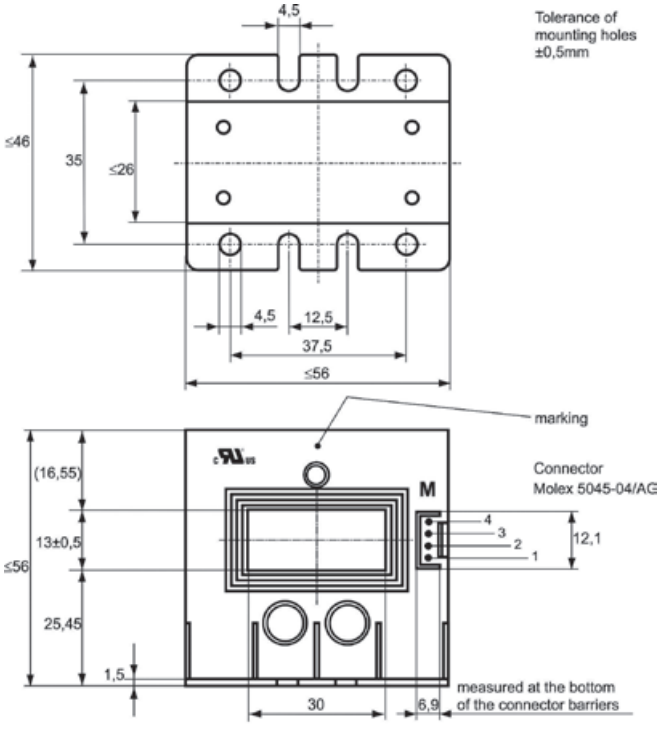
General tolerances DIN ISO 2768-c

Pin Assignment

1 $+U_b$
2 $-U_b$
3 I_s (output current)
4 Internal GND (can be omitted)



Drawing no. 2



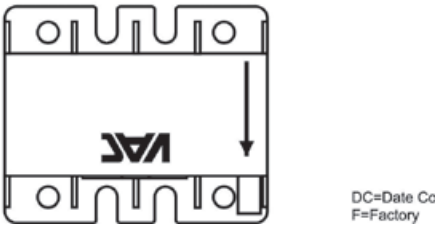
Type

T60404-N4648-X054

General tolerances DIN ISO 2768-c

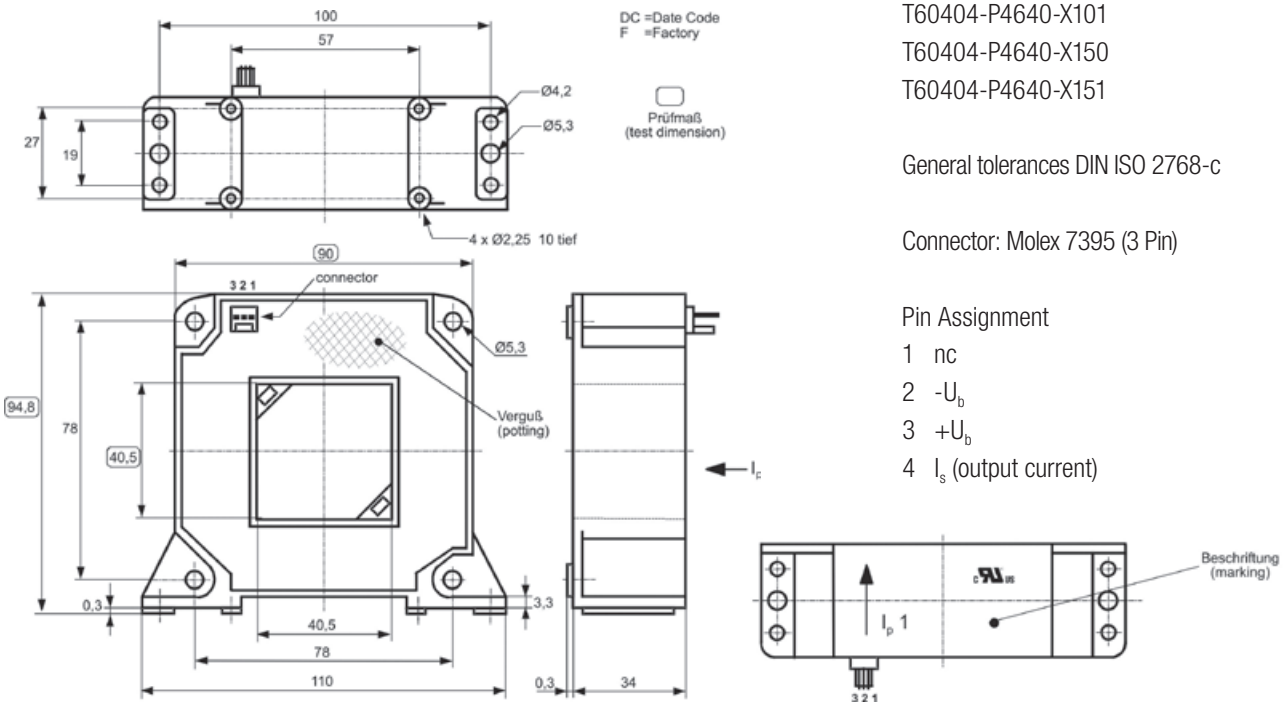
Pin Assignment

1 $+U_b$
2 $-U_b$
3 I_s (output current)
4 U_{ref} (never connect to GND)



Photos for illustration purposes only

Drawing no. 3



Type

T60404-P4640-X100
T60404-P4640-X101
T60404-P4640-X150
T60404-P4640-X151

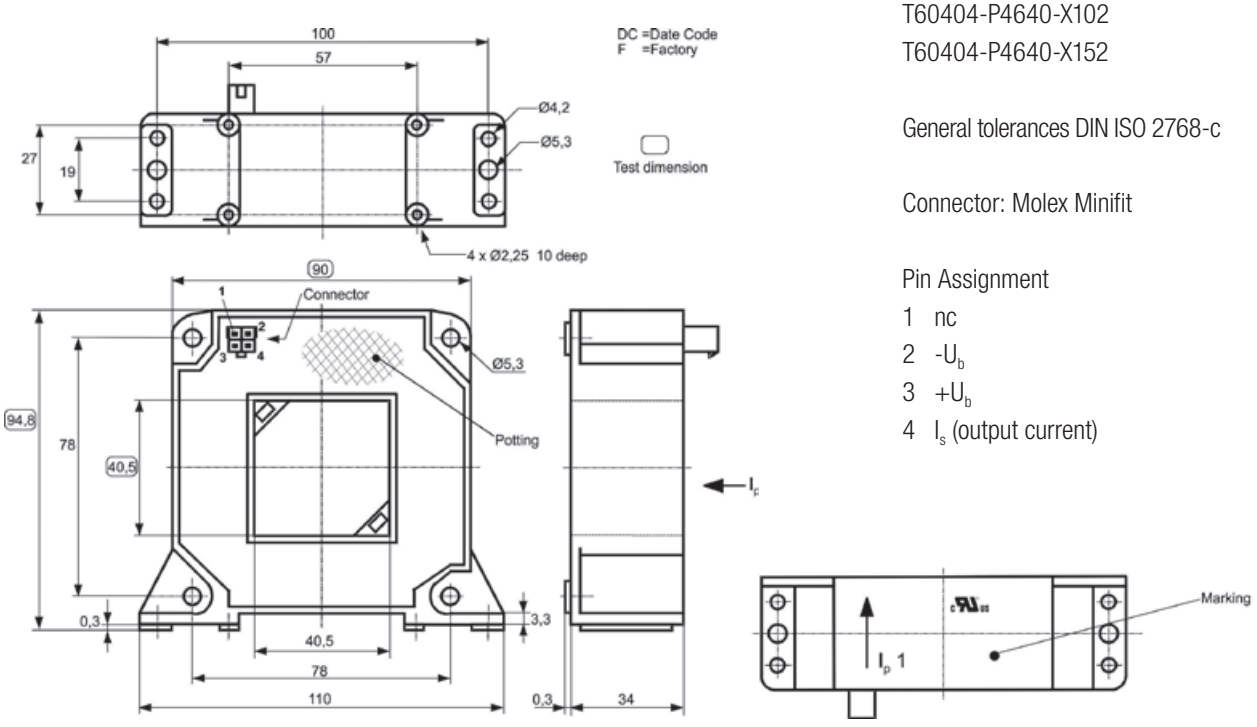
General tolerances DIN ISO 2768-c

Connector: Molex 7395 (3 Pin)

Pin Assignment

1 nc
2 $-U_b$
3 $+U_b$
4 I_s (output current)

Drawing no. 4



Type

T60404-P4640-X102
T60404-P4640-X152

General tolerances DIN ISO 2768-c

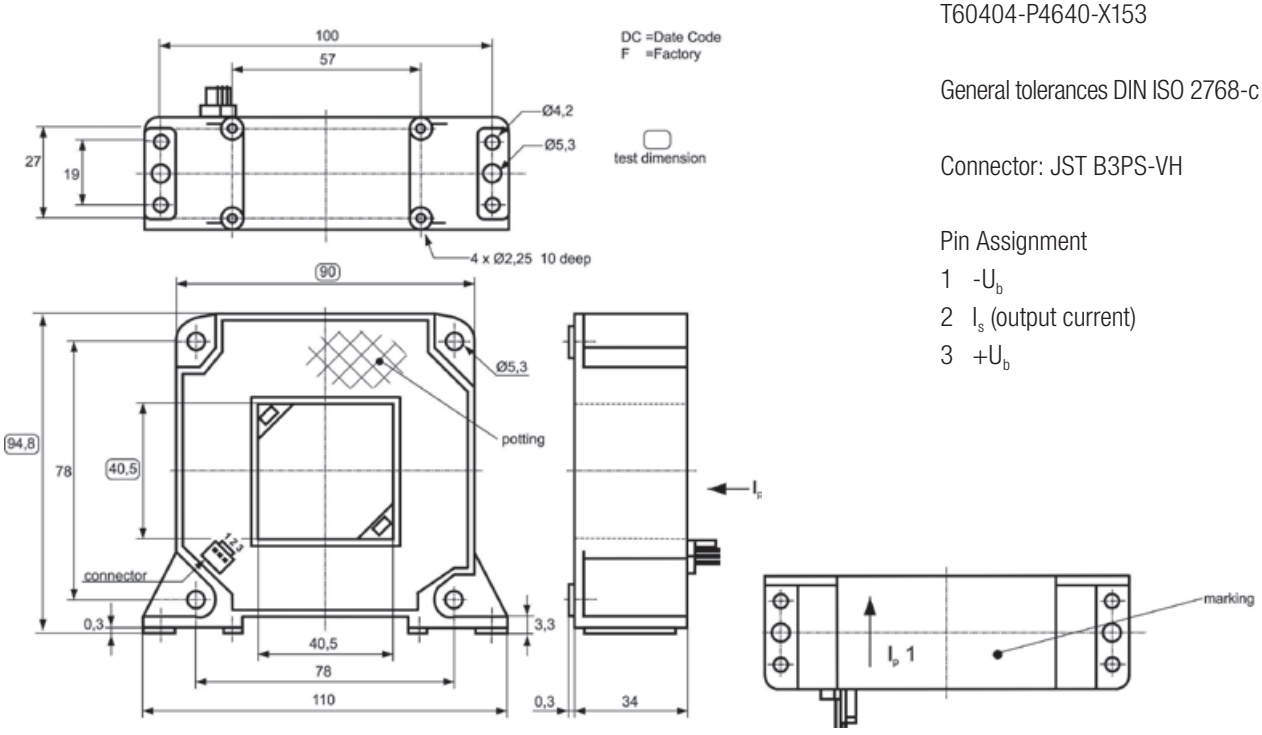
Connector: Molex Minifit

Pin Assignment

1 nc
2 $-U_b$
3 $+U_b$
4 I_s (output current)

Photos for illustration purposes only

Drawing no. 5



Type

T60404-P4640-X153

General tolerances DIN ISO 2768-c

Connector: JST B3PS-VH

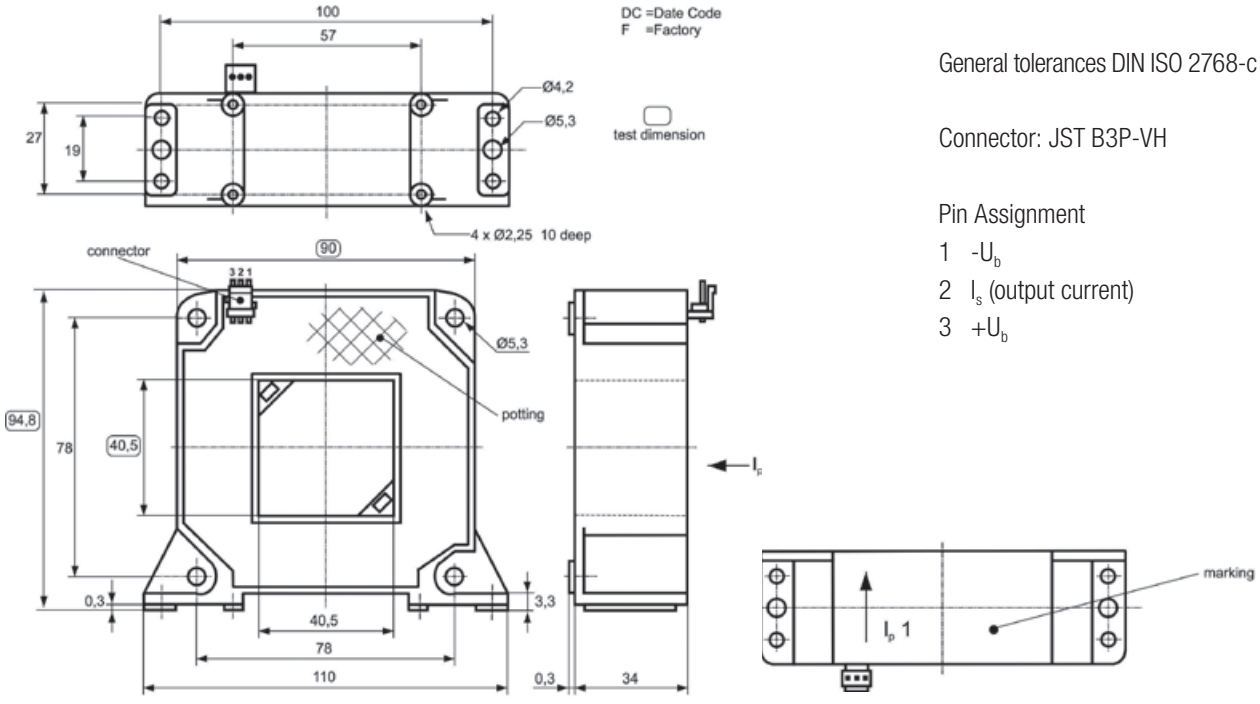
Pin Assignment

1 $-U_b$

2 I_s (output current)

3 $+U_b$

Drawing no. 6



Type

T60404-P4640-X154

General tolerances DIN ISO 2768-c

Connector: JST B3P-VH

Pin Assignment

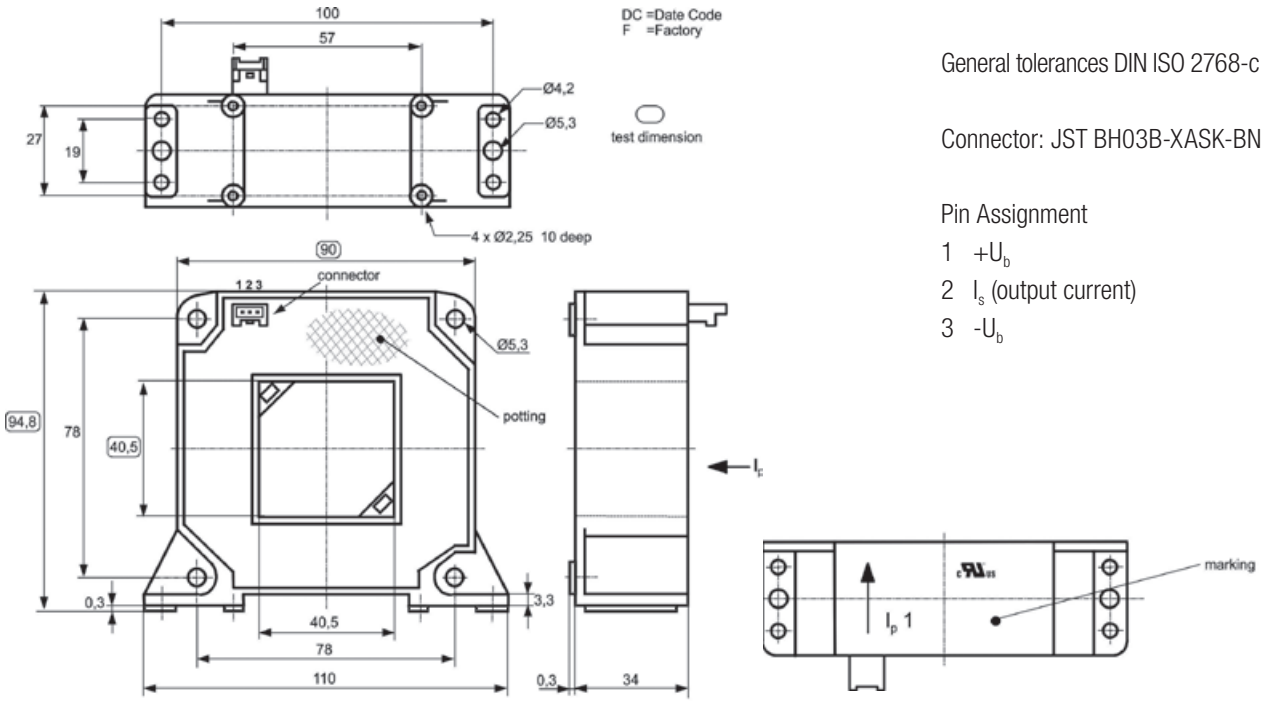
1 $-U_b$

2 I_s (output current)

3 $+U_b$

Photos for illustration purposes only

Drawing no. 7



Type

T60404-P4640-X156

General tolerances DIN ISO 2768-c

Connector: JST BH03B-XASK-BN

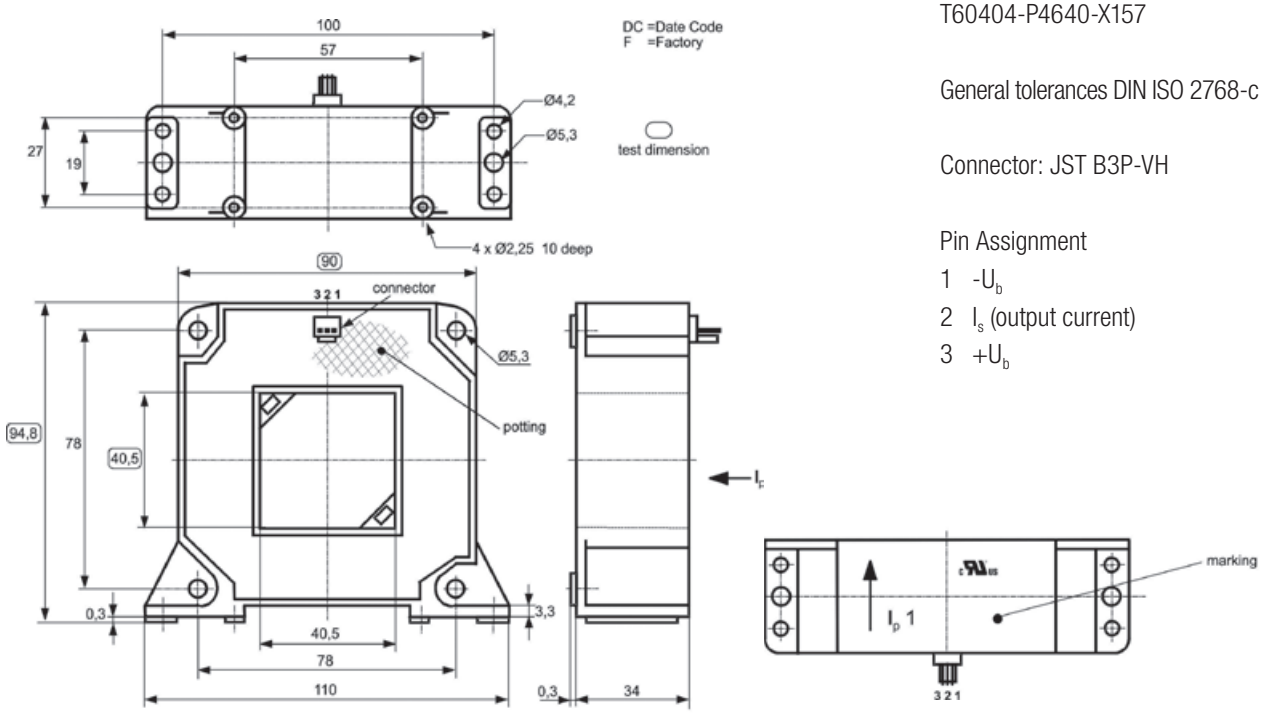
Pin Assignment

1 $+U_b$

2 I_s (output current)

3 $-U_b$

Drawing no. 8



Type

T60404-P4640-X157

General tolerances DIN ISO 2768-c

Connector: JST B3P-VH

Pin Assignment

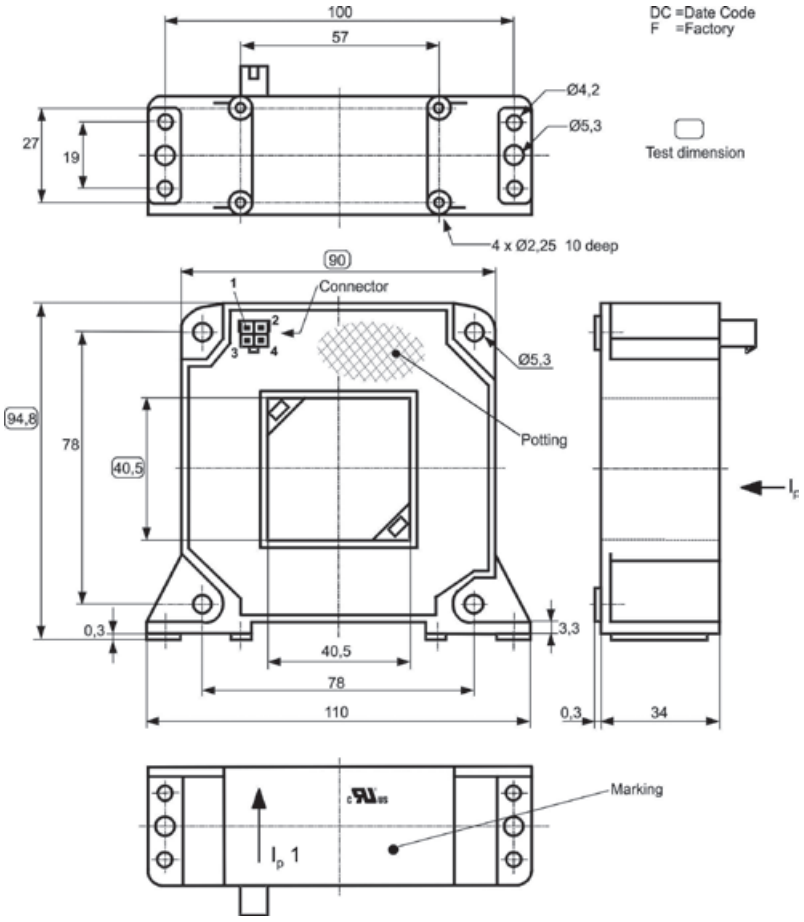
1 $-U_b$

2 I_s (output current)

3 $+U_b$

Photos for illustration purposes only

Drawing no. 9



Type

T60404-P4640-X159

General tolerances DIN ISO 2768-c

Connector: Molex Minifit Jr.

Pin Assignment

1 nc

2 $-U_b$

3 Is (output current)

4 $+U_b$

RECOMMENDED CONNECTORS

Type	Connector on the VAC sensor	Counterpart connector housing	Counterpart connector contact
N4648-X052	Molex 5045 p/n 22-04-1041 (4 ctk.) or compatible	Molex 51191	Molex 50802
N4648-X053			
N4648-X054		Molex 5051	Molex 2759 or 5159
N4648-X056			
P4640-X100	Molex 7478, 6410, 7395 (3 ctk.) or compatible	Molex 2695 or 6471 (3 ctk.)	Molex 2759 or 4809
P4640-X150			
P4640-X101	JST B3PS-VH(LF)(SN) (3 ctk.) or compatible	JST VHR-3N	JST BVH-21T-P1.1
P4640-X151			
P4640-X153			
P4640-X154			
P4640-X156	JST BH03B-XASK-BN	XAP-03V-1	JST SXA-001T-P0.6
P4640-X102	Molex Minifit jr. 5569 (2 x 2 ctk.)	Molex Minifit jr. 5557	Molex 5556 or 45750
P4640-X152			
P4640-X159			

CURRENT WAVEFORMS

As well as the amplitude, the waveform of the current to be measured has an influence on the losses and thus the heating of the sensor. The operating currents to be measured in power electronics are usually direct currents, or alternating currents up to a maximum frequency of several 100 Hz, with a high amplitude. They are superimposed by the switching currents of the power semiconductors, which are in the single digit to mid double digit kHz range and have harmonics up into the triple digits. Their amplitude is lower by an order of magnitude.

Our current sensors are designed to operate with such primary currents. However, when the amplitude of the high frequency components is continuously much higher, it can lead to excessive heating of the sensor core. The heating also depends on the location of the primary conductor in the sensor opening and the position of the return conductor relative to the sensor.

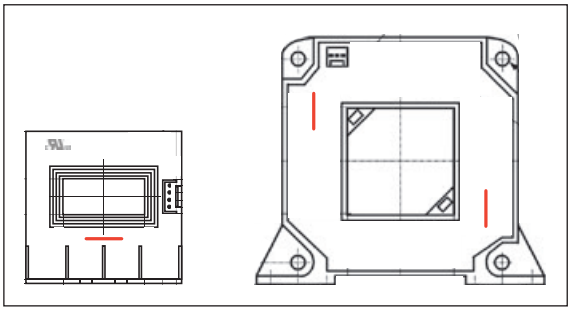
POSITIONING OF THE PRIMARY CONDUCTOR IN CURRENT SENSORS WITH A PRIMARY OPENING

In compensation sensors, a magnetic flux generated by the primary current is detected in the sensor core and compensated for by an equally large flux of reversed polarity.

Although our sensors are magnetically very robust in design, the optimal function of this measuring principle is not completely independent of the position of the conductor in the magnetic circuit, or of the position of external current-carrying conductors relative to the magnetic circuit and the zero-field probe sensor. Also of importance are the amplitude and frequency of the current. The resultant influence can affect the dynamic characteristics of the sensor, the measuring accuracy at high levels and possibly heating.

Generally, the best results are achieved if the conductor is put centrally through the sensor opening and the immediate area around the current sensor is kept free of conductors carrying high currents.

More information is available on request.



Location of the magnetic probes in the sensor families N4648-X0xx und P4640-X1xx

CONDUCTED AND RADIATED EMISSIONS

Under very unfavourable conditions, there may be an influence on the sensor by irradiation from interference signals. Low or medium-frequency interference is due to magnetic fields, for example from power chokes or transformers. High-frequency interference, usually in the range of several hundred MHz, can be injected directly into the sensor or via the connecting leads.

Whether a possible high-frequency effect on the current sensor has practical consequences for the application depends on the design of, for example, the shielding of the housing.

The VAC current sensors from the various series are successively tested for electromagnetic compatibility according to EN 61000-4-3: 2010 with a field strength of 20 V/m and 80 % AM 1 kHz over the frequency range 80 MHz to 1000 MHz. Please contact us to inquire on the current status of the tests.

THE ”OFFSET RIPPLE”

The so-called ”offset ripple” stated in our data sheets is actually no offset. Instead, it is the not completely suppressed remnant of the internal probe signal. The frequency of this signal is 400 kHz or more. It is zero symmetrical and does not affect the measurement accuracy when integrated over at least one period. In addition, it can be further reduced with a simple low pass filter (capacitor parallel to the measuring resistor). Details are given in the data sheets.

STANDARDS AND REGULATIONS

Our sensors are designed according to EN 61800-5-1 “Adjustable speed electrical power drive systems”. However, the sensors also meet many claims of other standards, such as EN 50178 “Electronic equipment for use in power installations” or EN 62109 “Safety of power converters for use in photovoltaic power systems”.

Furthermore, our standard types are certified by Underwriters Laboratories according to UL508, “Industrial Control Equipment” and CNR C22.2. The category is NMTR2 (Component – Power Circuit and Motor – mounted Apparatus). VAC sensors can be found in the Files E317483 and E169721.

VALIDATION AND TYPE TESTING

All newly created series are subjected to extensive type testing and validation. The criteria of the type tests are described in our data sheets under the headings “Electrical data: (investigated by type testing)” and “Routine tests”. The validation includes placement in damp climate, alternating temperatures in damp climate, rapid temperature changes, repeated on/off cycles, sinusoidal vibration, continuous shock, solderability and resistance to solder heat tests.

ROHS AND REACH

The products described in this brochure contain no hazardous substances pursuant to the relevant ban lists, such as RoHS, REACH, WEE, ECHA, JIG, GADSL and others.

VACUUMSCHMELZE GMBH & CO. KG
GRÜNER WEG 37
D 63450 HANAU / GERMANY
PHONE +49 6181 38 0
FAX +49 6181 38 2645
INFO@VACUUMSCHMELZE.COM
WWW.VACUUMSCHMELZE.COM

VAC MAGNETICS LLC
2935 DOLPHIN DRIVE
SUITE 102
ELIZABETHTOWN, KY 42701
PHONE +1 270 769 1333
FAX +1 270 769 3118
INFO-USA@VACMAGNETICS.COM

VACUUMSCHMELZE SINGAPORE PTE LTD
1 TAMPINES CENTRAL 5, #06-09
CPF TAMPINES BUILDING
SINGAPORE 529508
PHONE +65 6391 2600
FAX +65 6391 2601
VACSINGAPORE@VACUUMSCHMELZE.COM

VACUUMSCHMELZE CHINA MAGNETICS
SHANGHAI SALES OFFICE
ROOM 06, 19F
ZHONGRONG HENGRUI INTERNATIONAL PLAZA
620 ZHANGYANG ROAD, PUDONG DISTRICT
SHANGHAI, PRC 200122
PHONE +86 21 58 31 98 37
FAX +86 21 58 31 99 37
VAC_CHINA@VACUUMSCHMELZE.COM

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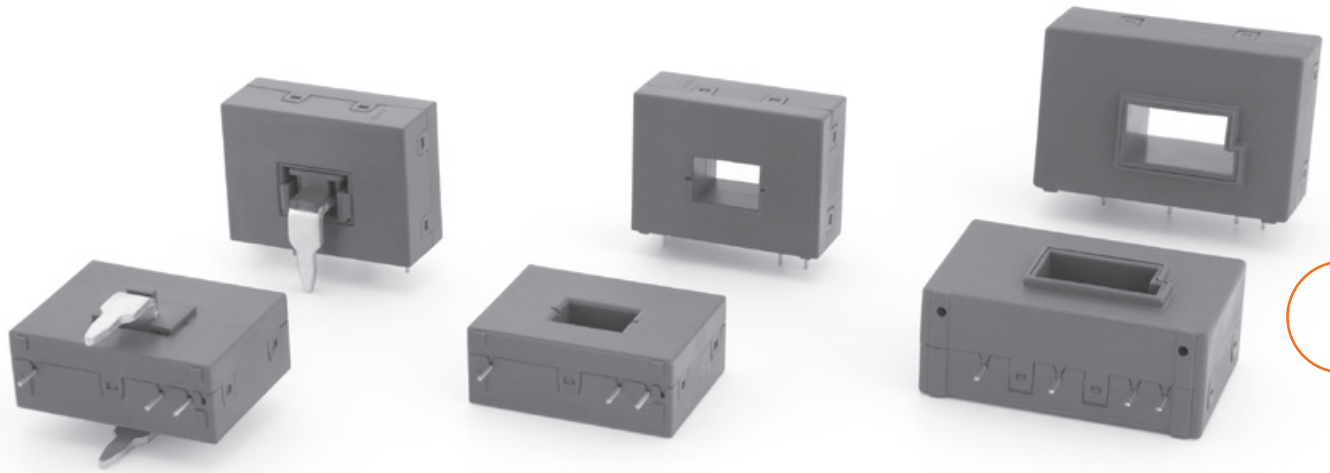
ADVANCED MATERIALS – THE KEY TO PROGRESS

NEW ACTIVE

CURRENT SENSORS

WITH PRIMARY CONDUCTOR OPENING



ADVANCED MATERIALS – THE KEY TO PROGRESS

VACUUMSCHMELZE

THE COMPANY
VACUUMSCHMELZE

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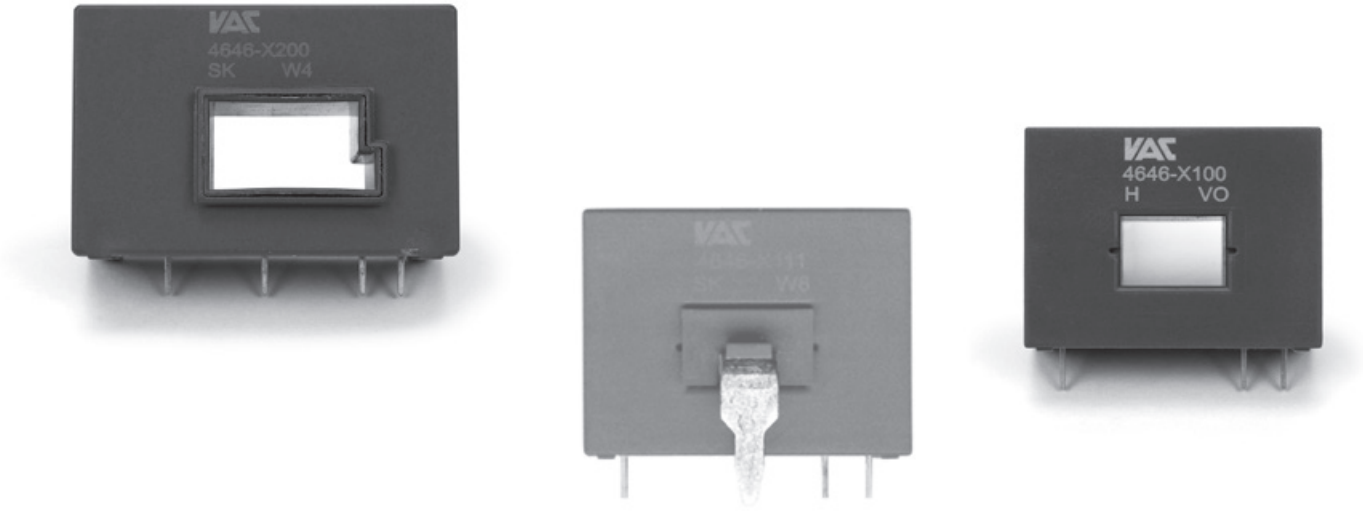


- closed loop sensor with magnetic probe developed by VAC as a zero field detector
- two new type series for rated currents of 50 A to 200 A and peak currents up to ± 390 A in compact designs
- types for + 5 Volt power supply with voltage output
- types for ± 12 . . . 15 Volt power supply with current output
- very good measuring accuracy, minimum DC – offset with very low hysteresis
- negligible output noise or periodic signal at zero input
- very low temperature dependence and long-term drift of the output variable
- low rise time, wide frequency range
- low-cost constructions
- compatible dimensions and pinning

TWO NEW VAC CURRENT SENSOR SERIES

VAC offers two new current sensor series for PCB mounting with integrated electronics and with an opening for the primary conductor. Thus they supplement the already introduced new active current sensor series for maximum accuracy with integrated primary conductor.

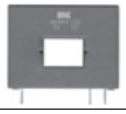
The new types apply the principle, developed by VAC, of the closed-loop sensor with magnetic probe as a zero field detector, and use the IC developed together with a leading semiconductor manufacturer.

All new types offer the detection of high maximum and continuous currents. The new VAC sensors can be used in many customer applications without adaptations.

DETECTING HIGHEST CURRENTS WITH A UNIPOLAR + 5 V-SUPPLY

The types T60404-N4646-X160 and -X161 detect maximum rms continuous currents up to 100 A and peak currents up to ± 230 A and require nevertheless only a unipolar 5 V-supply.

TYPE SERIES OF NEW CURRENT SENSORS WITH PRIMARY CONDUCTOR OPENING

Item no. Type T60404-N…		Rated current $I_{PN, rms}$ @ K_N = 1 : N [A]	Max. measuring range $I_{P,max.}$ @ V_C = +5 V or V_C = ± 12…15 V [A]	Ambient temperature range T_{amb} [° C] -40 to	Supply voltage V_C [V]	Turns ratio $K_{N=1:}$	Output variable	Frequency range f [kHz] DC to	Max. error X @ I_{PN}; T_{amb} = 25 °C [%]	Primary Connection: Conductor	Primary Connection: Opening	Secondary Connection: Pins	Integrated Electronics	Encapsulated	Dimensional diagrams
	4646-X100	100	± 235[1] ± 180[2]	+85	± 12 ... 15	1000	I	200	0.5		•	•	•	•	1
	4646-X111	100	± 188[1] ± 236[2]	+85	± 12 ... 15	2000	I	200	0.5	•		•	•	•	2
	4646-X101	100	± 188[1] ± 236[2]	+85	± 12 ... 15	2000	I	200	0.5		•	•	•	•	1
	4646-X112	100	± 235[1] ± 180[2]	+85	± 12 ... 15	1000	I	200	0.5	•		•	•	•	2
	4646-X160[3]	100	±230	+85	+5	1000	U[4]	100	1.0		•	•	•	•	3
	4646-X161[3]	50	±172	+85	+5	1000	U[4]	100	1.0		•	•	•	•	3
	4646-X200	125	±201[1] ±214[2]	+85	± 12 ... 15	1000	I	100	0.5		•	•	•	•	4
	4646-X201	200	±305[1] ±390[2]	+85	± 12 ... 15	2000	I	100	0.5		•	•	•	•	4

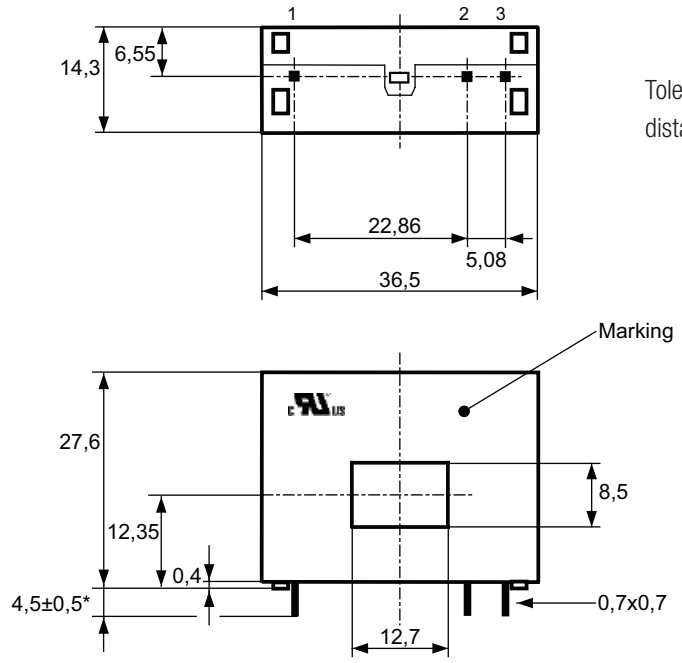
Abbreviations and terms

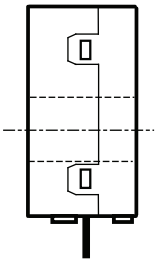
[1] for supply voltage ±12 V*
[2] for supply voltage ±15 V*
[3] reference voltage input 0 ... 4 V, which also can be used as reference voltage output 2.5 ±0.005 V. Source resistance R_S = 670 Ohm
[4] V_{out} = V_{ref} ±(0.625 x IP/IPN)
* value depends on chosen measuring resistance

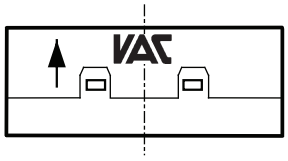
$I_{PN,rms}$	[A]	primary rated current
$I_{P,max.}$	[A]	maximum measuring range
T_A	[°C]	ambient temperature
V_c	[V]	supply voltage
K_N		turns ratio
f	[kHz]	frequency range
X	[%]	accuracy

DIMENSIONAL DIAGRAMS

Drawing no. 1







Type
T60404-N4646-X100 and ...X101

Tolerances grid distance ± 0.2 mm

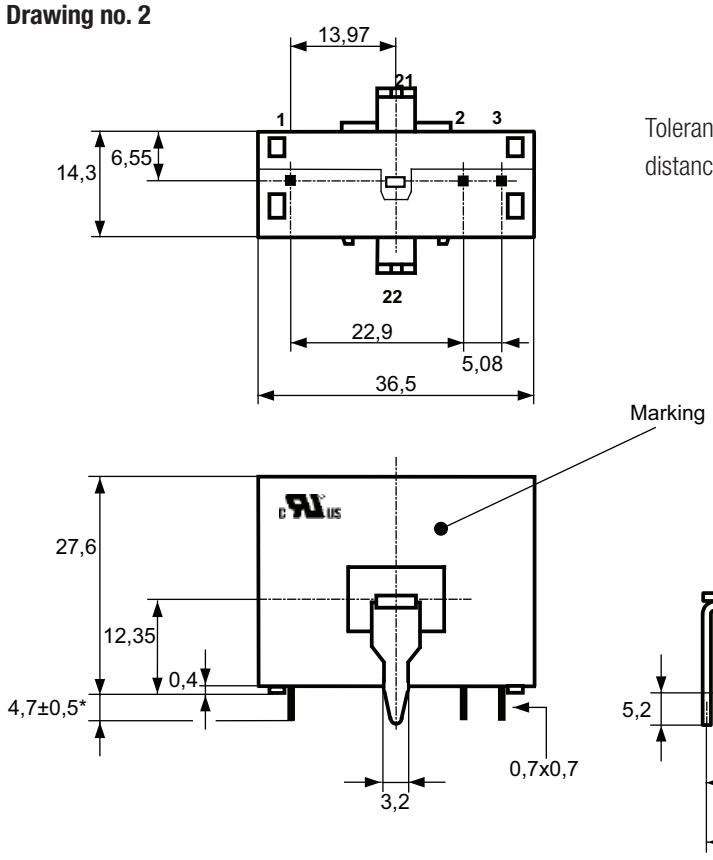
Marking:
Excerpt from item no. F DC

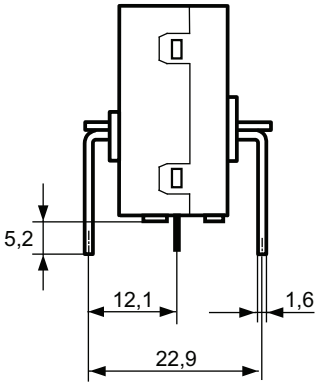
F = Factory
DC = Date Code

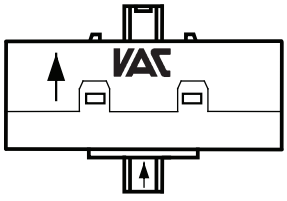
Connections:
1 . . . 3: 0.7 x 0.7 mm

Pin Assignments:
1: $+V_C$
2: $-V_C$
3: I_S

Drawing no. 2







Type
T60404-N4646-X111 and ...X112

Tolerances grid distance ± 0.2 mm

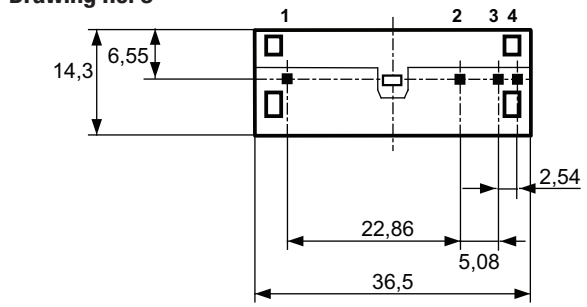
Marking:
Excerpt from item no. F DC

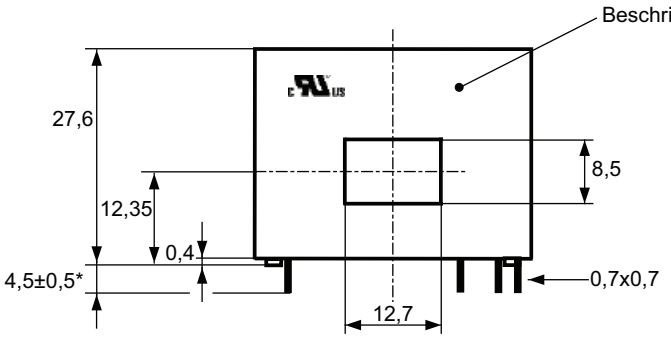
F = Factory
DC = Date Code

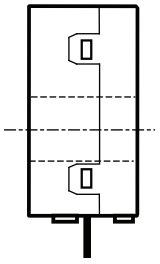
Connections:
1 . . . 3: 0.7 x 0.7 mm
21, 22: 3.2 x 1.6 mm

Pin Assignments:
1: $+V_C$
2: $-V_C$
3: I_S
21, 22: I_P

Drawing no. 3







Tolerances grid distance ± 0.2 mm

Type

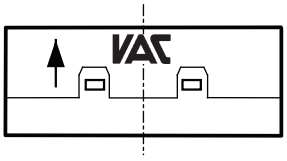
T60404-N4646-X160 and ...X161

Marking:
Excerpt from item no. F DC

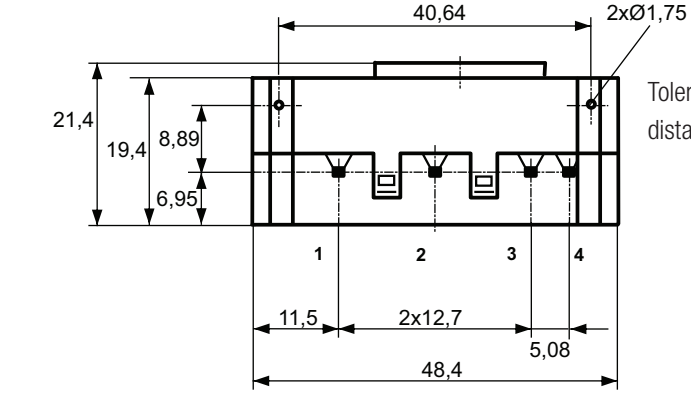
F = Factory
DC = Date Code

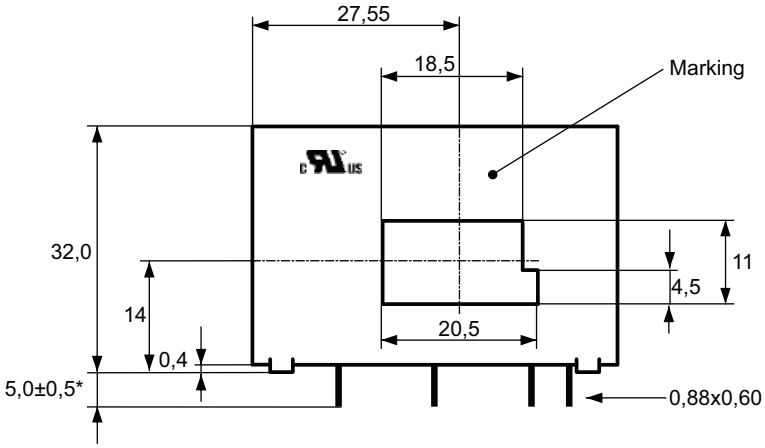
Connections:
1 . . . 4: 0.7 x 0.7 mm

Pin Assignments:
1: $+V_C$
2: earth
3: V_{OUT}
4: V_{REF} in/out



Drawing no. 4





Tolerances grid distance ± 0.2 mm

Type

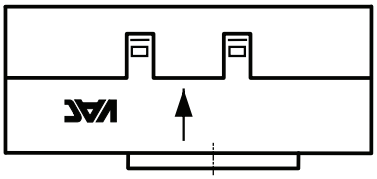
T60404-N4646-X200 and ...X201

Marking:
Excerpt from item no. F DC

F = Factory
DC = Date Code

Connections:
1 . . . 3: 0.6 x 0.88 mm

Pin Assignments:
1: $-V_C$
2: I_S
3: $+V_C$
4: n/c



CURRENT WAVEFORMS

As well as the amplitude, the waveform of the current to be measured has an influence on the losses and thus the heating of the sensor. The operating currents to be measured in power electronics are usually direct currents, or alternating currents up to a maximum frequency of several 100 Hz, with a high amplitude. They are superimposed by the switching currents of the power semiconductors, which are in the single digit to mid double digit kHz range and have harmonics up into the triple digits. Their amplitude is lower by an order of magnitude.

Our current sensors are designed to operate with such primary currents. However, when the amplitude of the high frequency components is continuously much higher, it can lead to excessive heating of the sensor core. The heating also depends on the location of the primary conductor in the sensor opening and the position of the return conductor relative to the sensor.

POSITIONING OF THE PRIMARY CONDUCTOR IN CURRENT SENSORS WITH A PRIMARY OPENING

In compensation sensors, a magnetic flux generated by the primary current is detected in the sensor core and compensated for by an equally large flux of reversed polarity.

Although our sensors are magnetically very robust in design, the optimal function of this measuring principle is not completely independent of the position of the conductor in the magnetic circuit, or of the position of external current-carrying conductors relative to the magnetic circuit and the zero-field probe sensor. Also of importance are the amplitude and frequency of the current. The resultant influence can affect the dynamic characteristics of the sensor, the measuring accuracy at high levels and possibly heating.

Generally, the best results are achieved if the conductor is put centrally through the sensor opening and the immediate area around the current sensor is kept free of conductors carrying high currents.

More information is available on request.

CONDUCTED AND RADIATED EMISSIONS

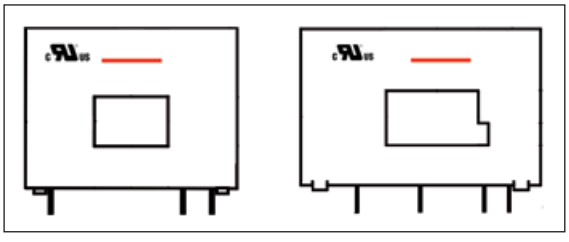
Under very unfavourable conditions, there may be an influence on the sensor by irradiation from interference signals. Low or medium-frequency interference is due to magnetic fields, for example from power chokes or transformers. High-frequency interference, usually in the range of several hundred MHz, can be injected directly into the sensor or via the connecting leads.

Whether a possible high-frequency effect on the current sensor has practical consequences for the application depends on the design of, for example, the shielding of the housing.

The VAC current sensors from the various series are successively tested for electromagnetic compatibility according to EN 61000-4-3: 2010 with a field strength of 20 V/m and 80 % AM 1 kHz over the frequency range 80 MHz to 1000 MHz. Please contact us to inquire on the current status of the tests.

THE ”OFFSET RIPPLE”

The so-called ”offset ripple” stated in our data sheets is actually no offset. Instead, it is the not completely suppressed remnant of the internal probe signal. The frequency of this signal is 400 kHz or more. It is zero symmetrical and does not affect the measurement accuracy when integrated over at least one period. In addition, it can be further reduced with a simple low pass filter (capacitor parallel to the measuring resistor). Details are given in the data sheets.



Location of the magnetic probes in the sensor families N464 and -X1xx and N4646-x2xx

VACUUMSCHMELZE GMBH & CO. KG
GRÜNER WEG 37
D 63450 HANAU / GERMANY
PHONE +49 6181 38 0
FAX +49 6181 38 2645
INFO@VACUUMSCHMELZE.COM
WWW.VACUUMSCHMELZE.COM

VAC MAGNETICS LLC
2935 DOLPHIN DRIVE
SUITE 102
ELIZABETHTOWN, KY 42701
PHONE +1 270 769 1333
FAX +1 270 769 3118
INFO-USA@VACMAGNETICS.COM

VACUUMSCHMELZE SINGAPORE PTE LTD
1 TAMPINES CENTRAL 5, #06-09
CPF TAMPINES BUILDING
SINGAPORE 529508
PHONE +65 6391 2600
FAX +65 6391 2601
VACSINGAPORE@VACUUMSCHMELZE.COM

VACUUMSCHMELZE CHINA MAGNETICS
SHANGHAI SALES OFFICE
ROOM 06, 19F
ZHONGRONG HENGRUI INTERNATIONAL PLAZA
620 ZHANGYANG ROAD, PUDONG DISTRICT
SHANGHAI, PRC 200122
PHONE +86 21 58 31 98 37
FAX +86 21 58 31 99 37
VAC_CHINA@VACUUMSCHMELZE.COM

KB – ACTIVE CURRENT SENSORS • EDITION 2016

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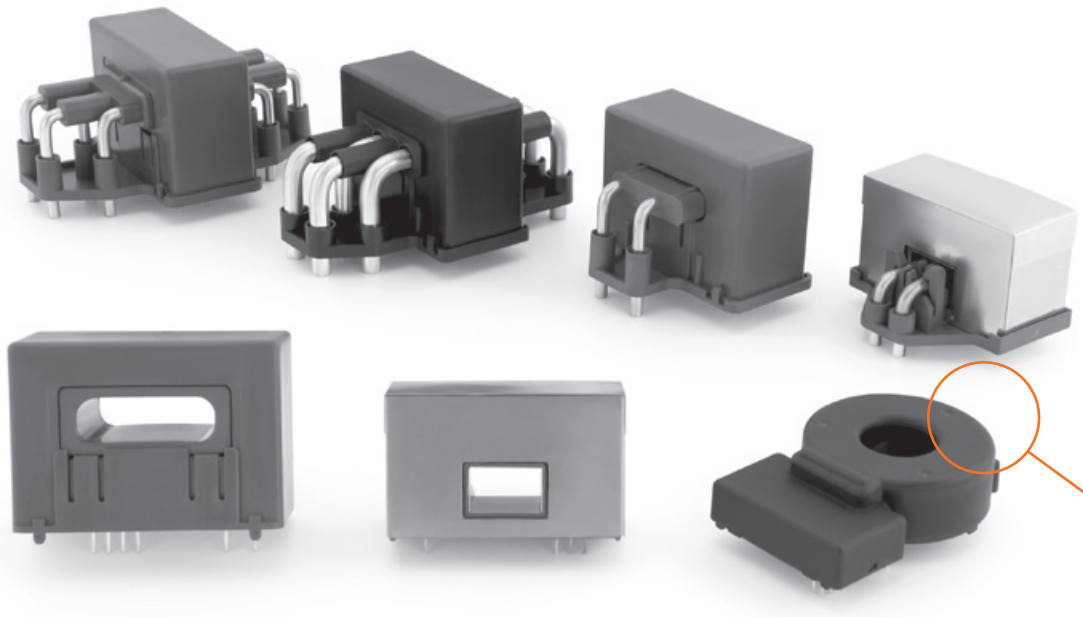
VACUUMSCHMELZE

ADVANCED MATERIALS – THE KEY TO PROGRESS

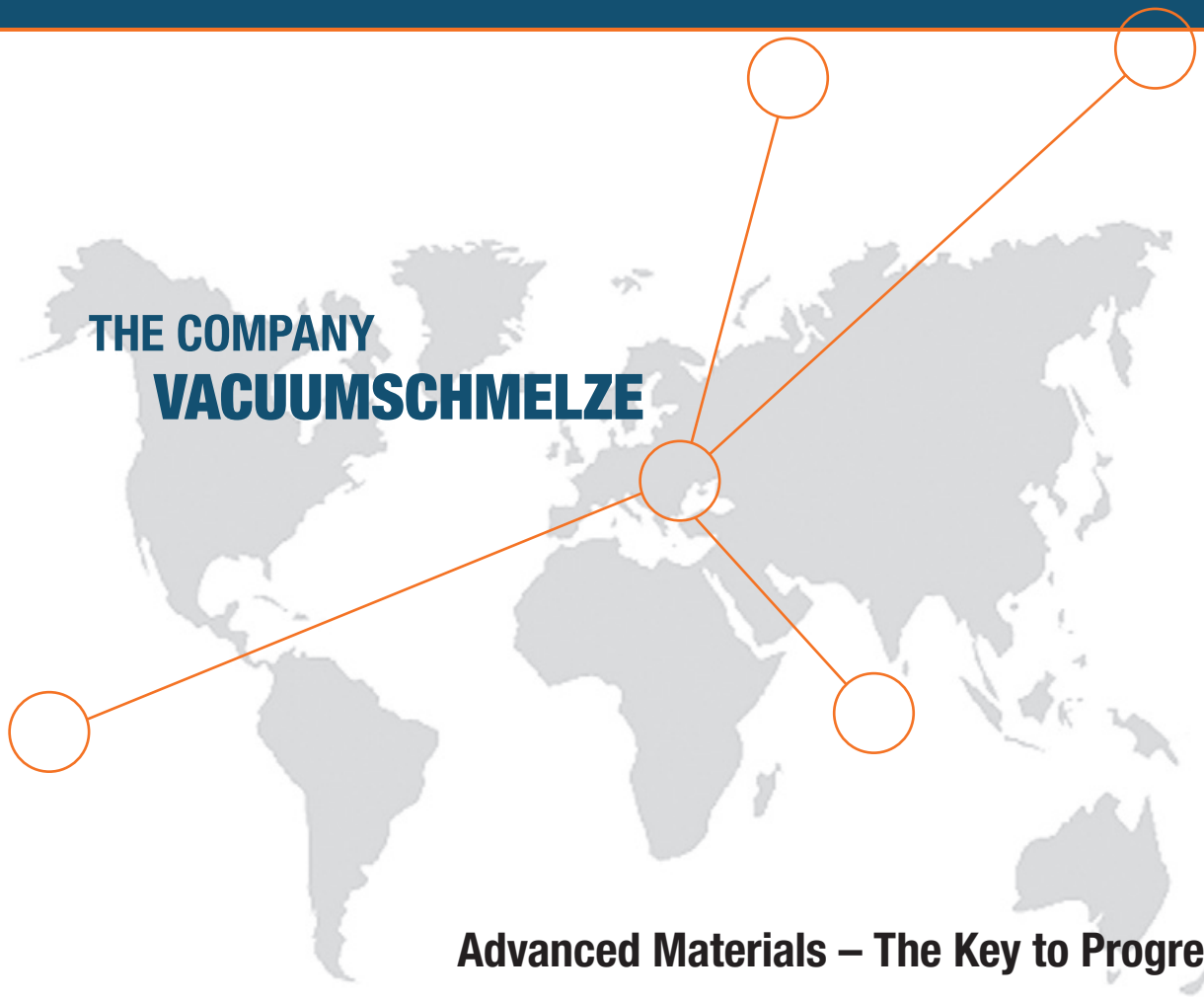
ALL-CURRENT SENSITIVE DIFFERENTIAL CURRENT SENSORS

(AC/DC DI-SENSORS FOR PV INVERTER AND EV CHARGING)



ADVANCED MATERIALS – THE KEY TO PROGRESS

VACUUMSCHMELZE



THE COMPANY
VACUUMSCHMELZE

Advanced Materials – The Key to Progress

VACUUMSCHMELZE GmbH & Co. KG is one of world's leading producers of special metallic materials and related products. Our wide range of high quality semi-finished products, parts, components and systems are used in virtually every field of electrical and electronic engineering. This makes us one of the few global companies to offer its customers the complete range of magnetic technology products from a single source – from magnetically soft products to the most powerful permanent magnets in the world.

In all our activities, we benefit from our highly developed material expertise and our decades of experience in magnetic technology. As early as 1923, we became the first company to introduce alloy smelting in a vacuum on an industrial scale and it was from this process that the name VACUUMSCHMELZE was derived.

One of our great strengths is our versatility. All of the world's key industries rely on products and expertise from VACUUMSCHMELZE, with our principal customers active in drive and installation technology, medical technology, renewable energy, automation systems, process and control engineering, measurement technology, as well as the very important automotive and aerospace industries. VAC's dedicated solutions are developed in close cooperation with customers and reflect the highest levels of material and application expertise combined with the latest production technology.

THE COMPANY
VACUUMSCHMELZE

We are a global company with our headquarter in Hanau, Germany. We currently have approximately 4300 employees who are spread over production and sales locations in more than 50 countries on every continent generating annual sales of approximately EUR 380 million.

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2. Sensor variants	Page 4
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4. Type series of VAC differential current sensors	Page 6
5. Mechanical outlines	Page 8
6. DI-Sensors for IC-CPD (In-Cable Control and Protection Device) applications	Page 15

ALL-CURRENT SENSITIVE DIFFERENTIAL CURRENT SENSORS

(AC/DC DI-SENSORS)

- closed loop sensors with magnetic probe for highest accuracy and reliability
- differential current range of typically 30 mA up to 1000 mA
- full load current to 85 A
- single +5 V voltage supply
- voltage output for direct connection at A/D-converters
- automatic demagnetization of the sensor core for offset decrease
- self-monitoring and test functions
- measuring accuracy 1.5 %
- smallest temperature drift and highest long-term stability
- magnetic shielding against external fields
- frequency range DC to 10 kHz
- variants with pass-through opening or integrated primary conductors
- variants with or without test winding
- cost effective design

DESCRIPTION AND APPLICATIONS

Control devices with all-current sensitive differential current sensors are used primarily in transformerless solar or traction inverters. Also in EV charging infrastructure and charging devices in general, DI sensors can be used.

An important safety function of these devices is the monitoring of leakage currents against earth of the entire system. These systems consist of either a photovoltaic module or motor in combination with the inverter, or the grid in combination with a battery. A defective system can become dangerous for humans or cause fire, therefore corresponding standards require that the inverter or charger disconnects from the grid, before it might become dangerous for the system or humans.

Leakage currents are unintended hence uncontrollable fault currents against earth and can contain direct as well as alternating portions, therefore AC/DC-sensitive monitoring is necessary. The key component is the VAC differential current sensor, whose measurement value is transmitted as an output voltage and evaluated by the control system.

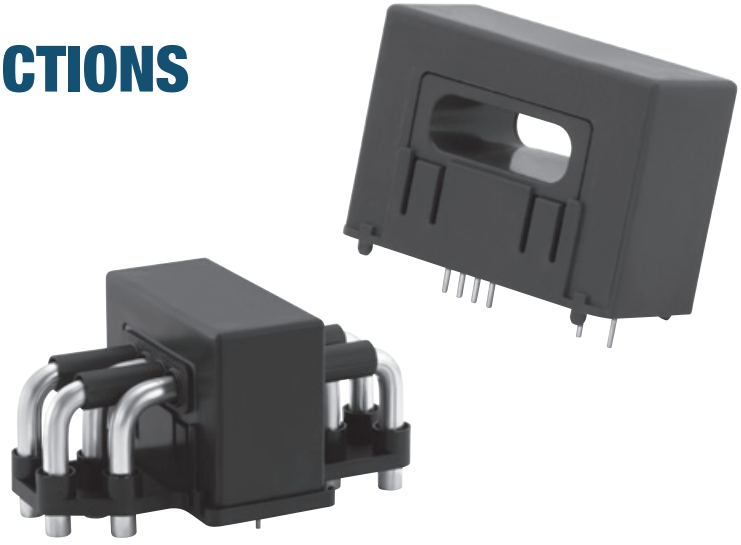
Generally, protection devices with AC/DC-sensitive differential current sensors shall be used, where flat or pulsating direct currents can occur, whose amount is permanently greater than zero. Further examples are power supplies or uninterruptible power supplies.

SENSOR VARIANTS

Available types are with pass trough opening as well as with integrated primary conductors for PCB mounting. Those sensors are designed with two or four conductors for single and three phase systems.

The additional functions demagnetization, error signaling and internal test are accessible through defined levels at the in/outputs V_{out} and V_{ref}.

APPLICATION INSTRUCTIONS



REFERENCE VOLTAGE V_{REF} IN/OUT

Optionally the reference pin V_{ref} can be used as input or output. Thereby the internally generated reference REF_{OUT} can be routed as output or an external reference REF_{IN} can be connected as input to the sensor.

It is recommended to evaluate the output voltage V_{OUT} differentially against the precise reference connected at the REF_{OUT} output and not against ground. Doing so, lowest offset values of the current sensor can be achieved.

ADDITIONAL FUNCTION DEMAGNETIZATION

The sensor will automatically perform a demagnetization cycle at every power up and is ready for use after approximately 150 ms. It is recommended to perform a demagnetization periodically during the operation of the sensor. This will ensure that any potentially remaining magnetization of the compensation core will be eliminated and the measuring accuracy and offset are in the optimum range.

To perform a demagnetization cycle, please proceed as follows:

- V_{REF} must be set to 0 V for > 100 µs; start of internal test-current generation
- once V_{REF} is reset to its reference values, demagnetization will begin
- sensor runs a 110 ms demagnetization cycle
- during this period the output is set to $V_{OUT} < 0{,}5$ V
- afterwards the sensor is ready for use

INTERNAL TEST-CURRENT GENERATION

As soon as V_{REF} is set to 0 V, the current sensor will generate a test-current whereby a constant output voltage $V_{OUT} = 250$ mV will be set. This function can be used, to verify correct functionality of the sensor.

EXTERNAL TEST-CURRENT GENERATION

Most of the shown sensors of the N4646 series offer additional connections for external test-current generation. Inside the sensor a separate winding is placed on the magnetic module and fed to the outside. It is recommended to apply a sufficiently high external current to verify correct functionality and, if necessary, the intended switch-off threshold.

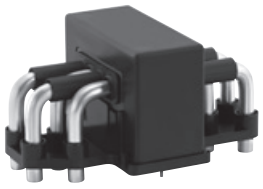
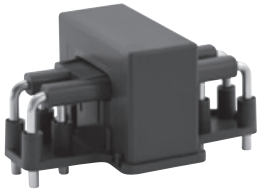
VALIDATION AND TYPE TESTING OF VAC SENSORS

All newly created series are subjected to extensive type testing and validation. The criteria of the type tests can be found in our data sheets under the headings “Electrical data: (investigated by type testing)” and “Routine tests”. The validation includes placement in damp climate, alternating temperatures in damp climate, rapid temperature changes, repeated on/off cycles, sinusoidal vibration, continuous shock, solderability and resistance to solder heat tests.

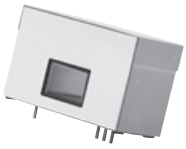
ROHS AND REACH

The products described in this brochure contain no hazardous substances pursuant to the relevant ban lists, such as RoHS, REACH, WEE, ECHA, JIG, GADSL and others.

TYPE SERIES OF VAC DIFFERENTIAL CURRENT SENSORS

VAC Item no.	T60404-N4646-		
	… X921	… X931	… X932
Mechanical outline no.	1	2	3
Primary conductor style	via PCB two conductors Ø 2.8 mm each	via PCB four conductors Ø 4.5 mm each	via PCB four conductors Ø 2.8 mm each
Number of primaries	2	4	4
Maximum primary current [A]	50	85	50
Nominal differential current [mA]	300	1000	300
Measuring range [mA]	850	1700	850
Supply voltage [V]	5		
Supply current typ. [mA]	17		
Output voltage [V]	V_{ref} ± (0.74 x I_{diff} / 300 mA)	V_{ref} ± (1.2 x I_{diff} / 1000 mA)	V_{ref} ± (0.74 x I_{diff} / 300 mA)
Output voltage range [V]	0.5 to 4.5		
Reference voltage	2.5 V internal reference voltage or external reference		
External test-current pin	Integrated in sensor		
Frequency range [Hz]	DC up to 8 kHz		
Measuring error (of nominal) at T_{amb} = 25 °C	< 1.5 %		
Temperature drift [mV / °C] -40 … +85 °C	< 0.1		
Response time [µs] (up to 90 % of nominal diff. current)	< 50		
Isolation strength acc. EN 50178 · system voltage [V] · working voltage [V]	 600 1000		
Qualified acc. to UL	Yes, acc. UL 508		
Image			

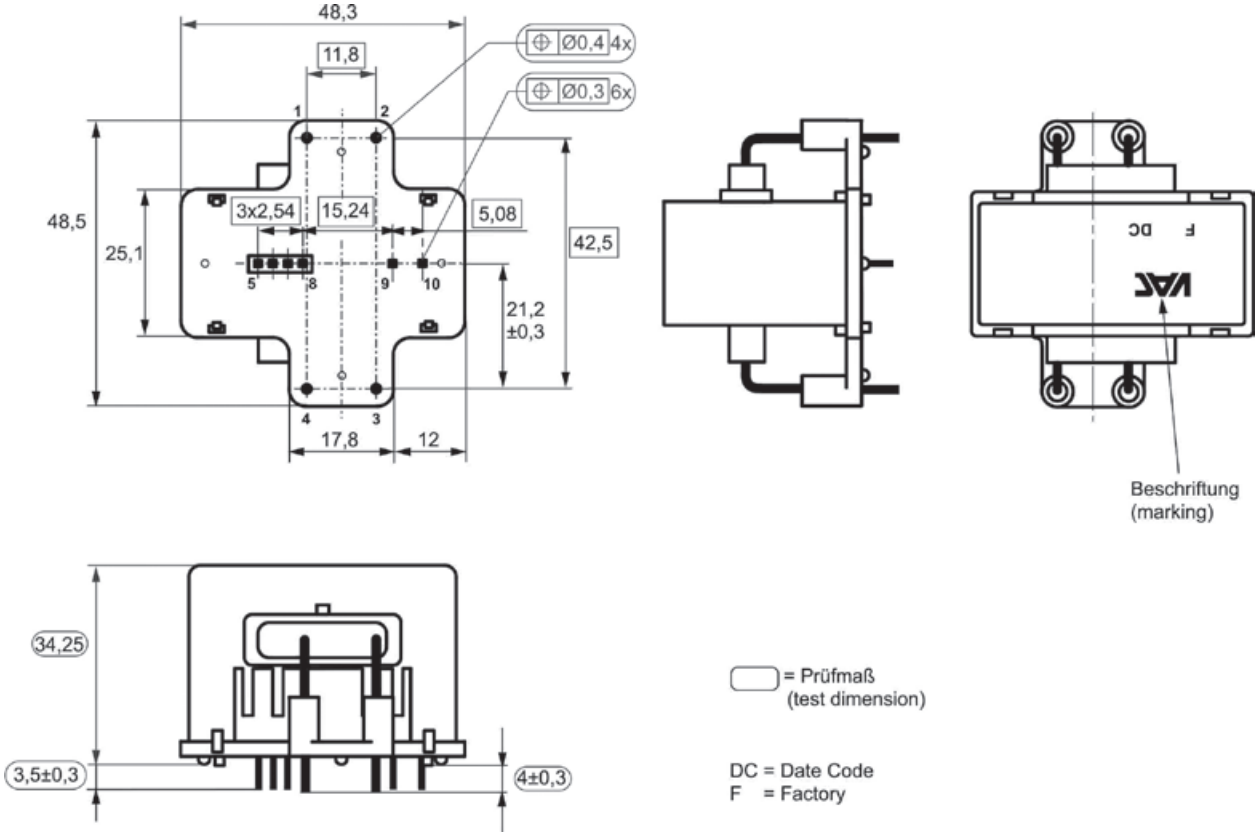
* Information about maximum primary current is only a guideline
** Variants with primary conductor upon request

	… X956	… X960	… X975	T60404-N4641- … X900
	4	5	6	7
	pass through opening	via PCB two conductors Ø 2.8 mm each	via PCB two conductors Ø 2.8 mm each	pass through opening**
	–	2	2	–
	50*	50	50	32*
	300			6
	850			300
	5			5
	17			50
	V_{ref} ± (0.74 x I_{diff} / 300 mA)			–
	0.5 to 4.5			Open Collector
	2.5 V internal reference voltage or external reference			
	Integrated in sensor	no	Integrated in sensor	Test Function
	DC up to 10 kHz			DC up to 2 kHz
	< 1.5 %			
	< 0.1			
	< 35			
	must be ensured by end user with suitable isolation of primary conductors	600 1000		must be ensured by end user with suitable isolation of primary conductors
	Yes, acc. UL 508			Yes, acc. UL 2231
				

MECHANICAL OUTLINES

Drawing no. 1

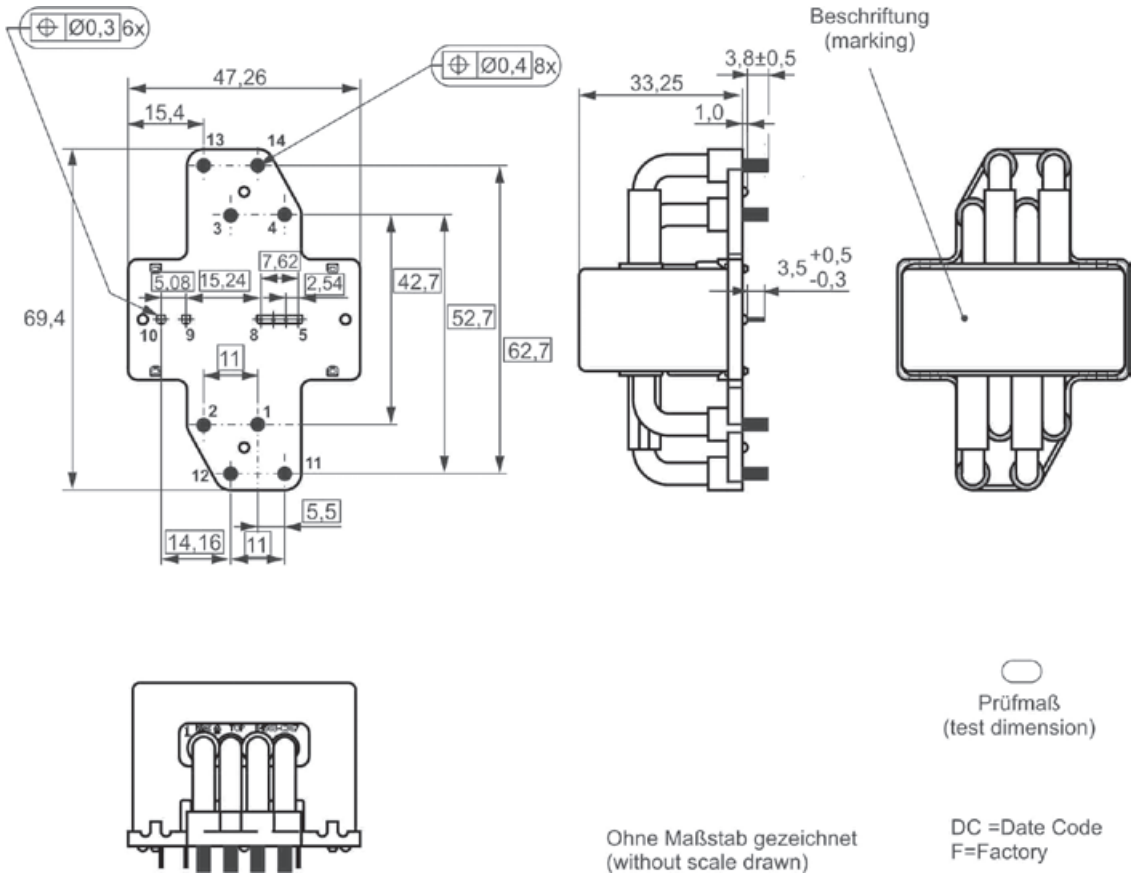
Type
T60404-N4646-X921



Marking	Connections	Pin assignments
UL Mark	1 … 4: Ø 2.8 mm	1 … 4: primary current
Extract item no.	5 … 10: 0.7 x 0.7 mm	9, 10: test-current
F DC, in which		5: V_{out}
F = Factory		6: V_{ref}
DC = Date Code		7: GND
		8: V_c +5 V

Drawing no. 2

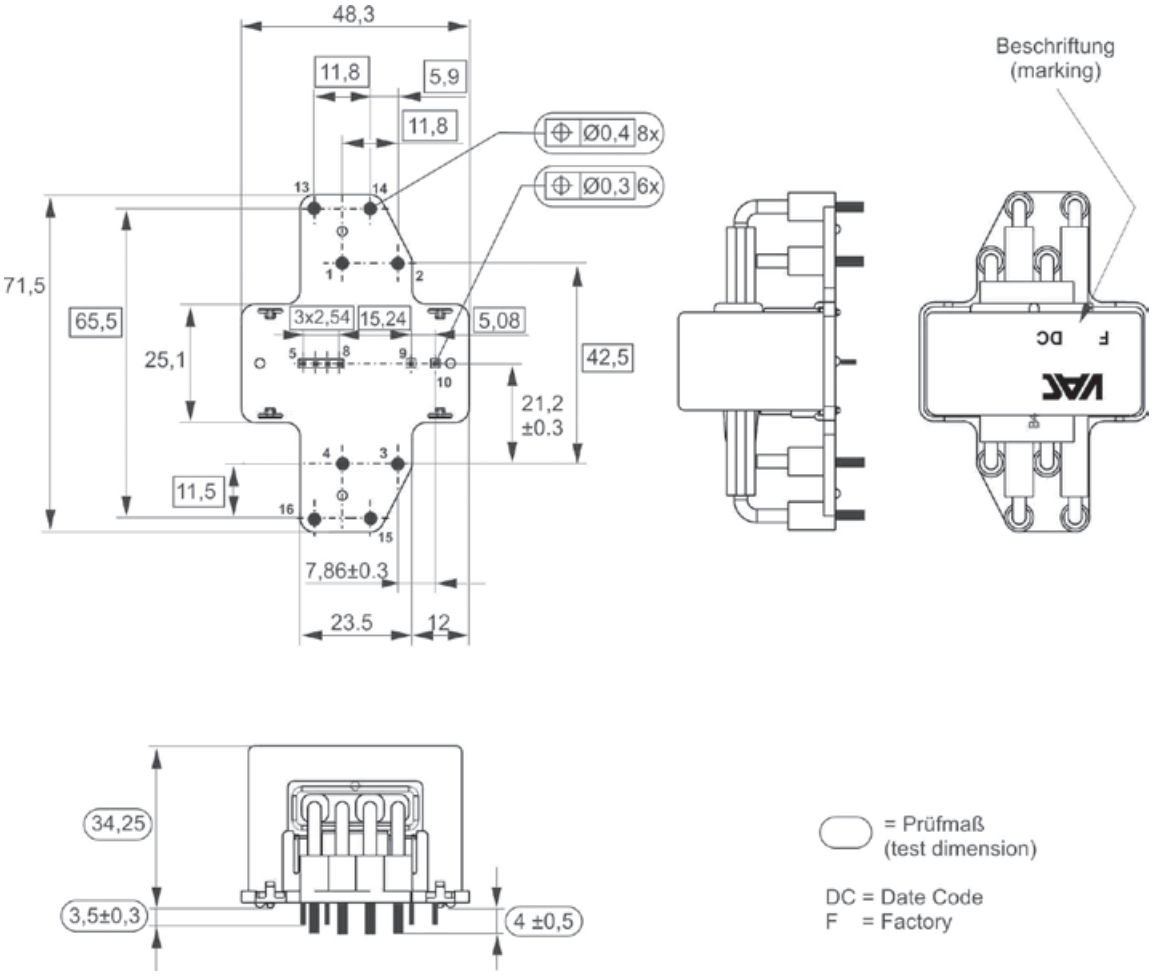
Type
T60404-N4646-X931



Marking	Connections	Pin assignments
UL Mark	1 … 4: Ø 4.5 mm	1 … 4; 11 … 14: primary current
Extract item no.	11 … 14: Ø 4.5 mm	9, 10: test-current
F DC, in which	5 … 10: 0.7 x 0.7 mm	5: V_{out}
F = Factory		6: V_{ref}
DC = Date Code		7: GND
		8: V_c +5 V

Drawing no. 3

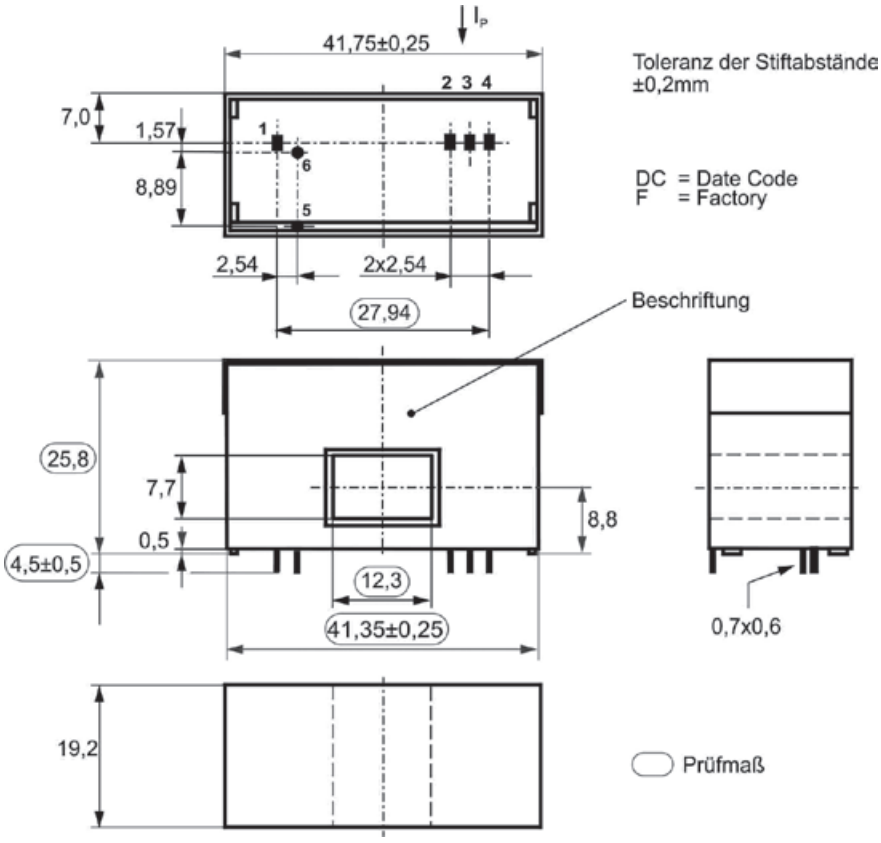
Type
T60404-N4646-X932



Marking	Connections	Pin assignments
UL Mark	1 … 4: Ø 2.8 mm	1 … 4; 13 … 16: primary current
Extract item no.	13 … 16: Ø 2.8 mm	9, 10: test-current
F DC, in which	5 … 10: 0.7 x 0.7 mm	5: V_{out}
F = Factory		6: V_{ref}
DC = Date Code		7: GND
		8: V_c +5 V

Drawing no. 4

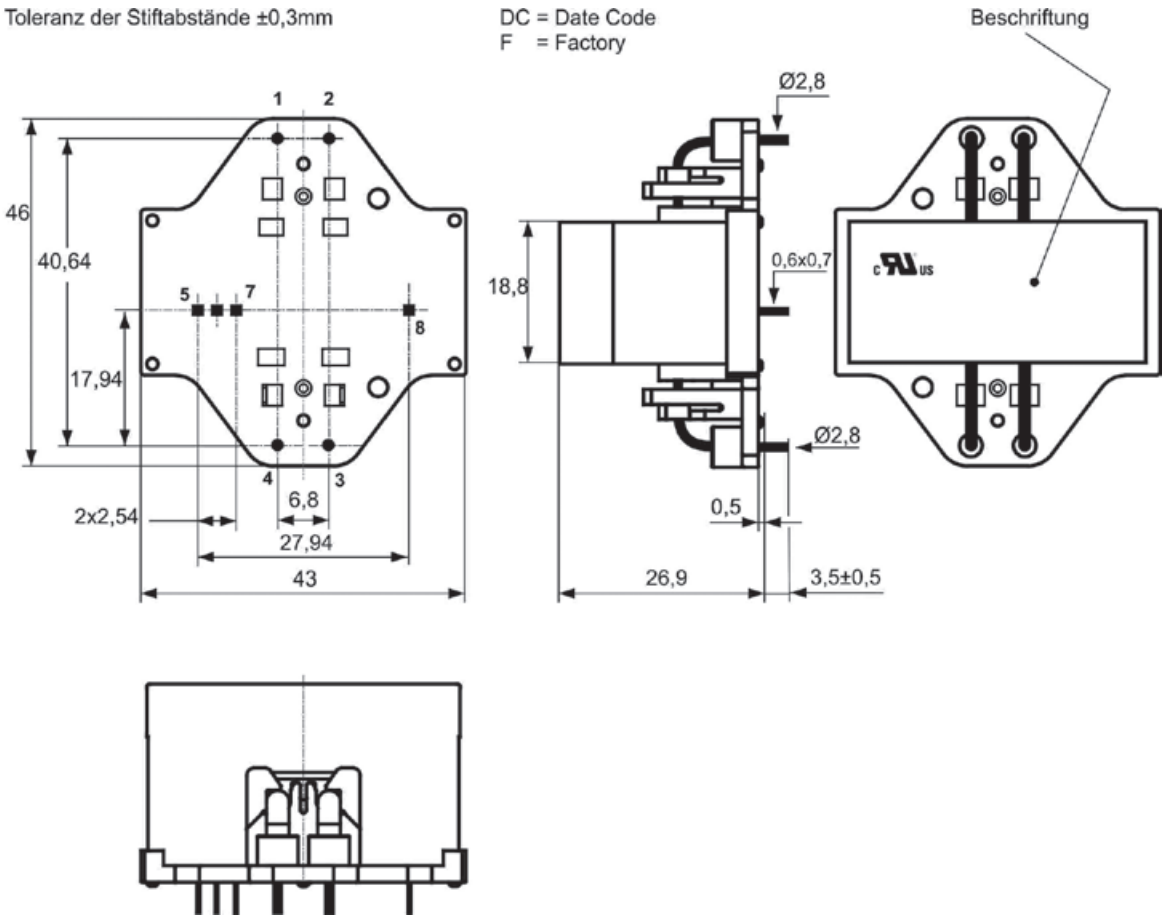
Type
T60404-N4646-X956



Marking	Connections	Pin assignments
UL Mark	1 … 4: 0.7 x 0.6 mm	5, 6: test-current
Extract item no.	5 … 6: Ø 0.8 mm	1: V_c +5 V
F DC, in which		2: GND
F = Factory		3: V_{ref} In/Out
DC = Date Code		4: V_{out}

Drawing no. 5

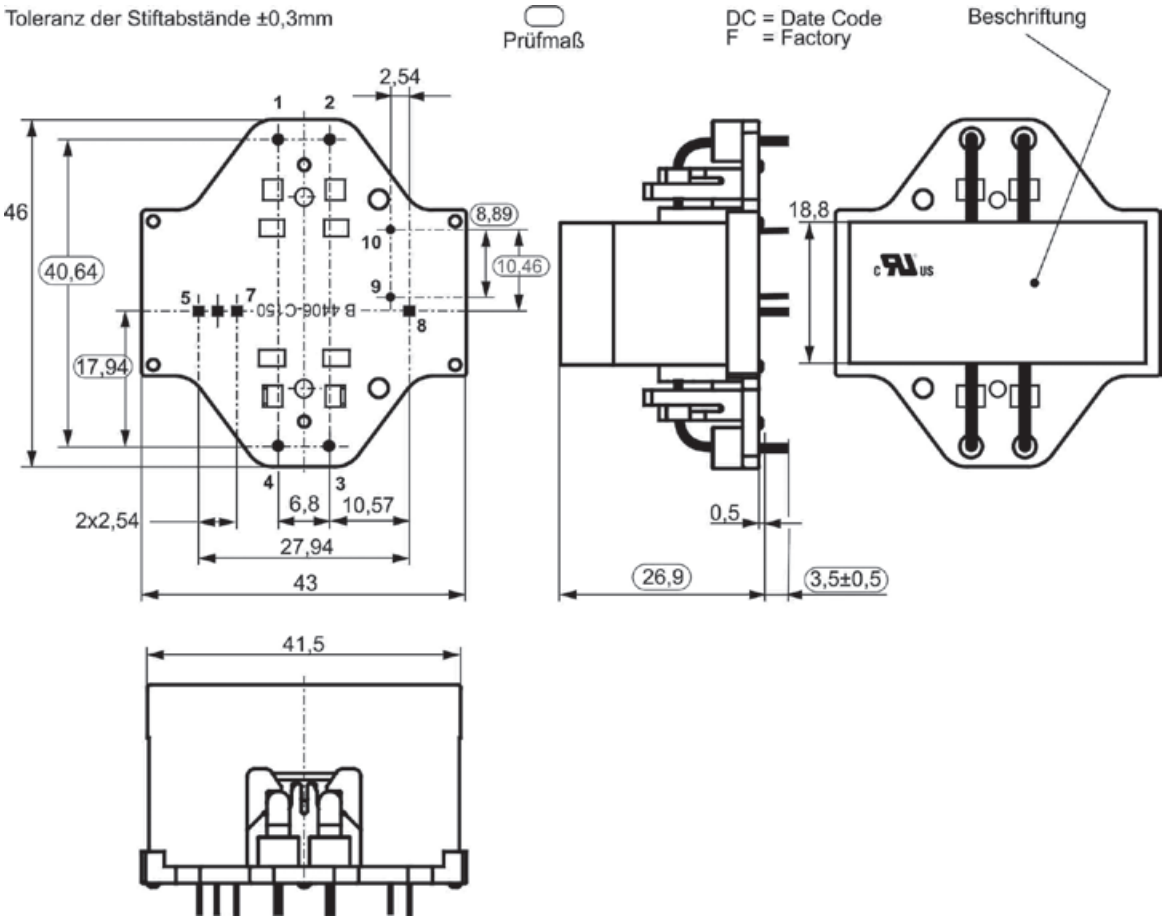
Type
T60404-N4646-X960



Marking	Connections	Pin assignments
UL Mark	1 … 4: Ø 2.8 mm	1 … 4: primary current
Extract item no.	5 … 8: 0.7 x 0.6 mm	5: V_{out}
F DC, in which		6: V_{ref}
F = Factory		7: GND
DC = Date Code		8: V_c +5 V

Drawing no. 6

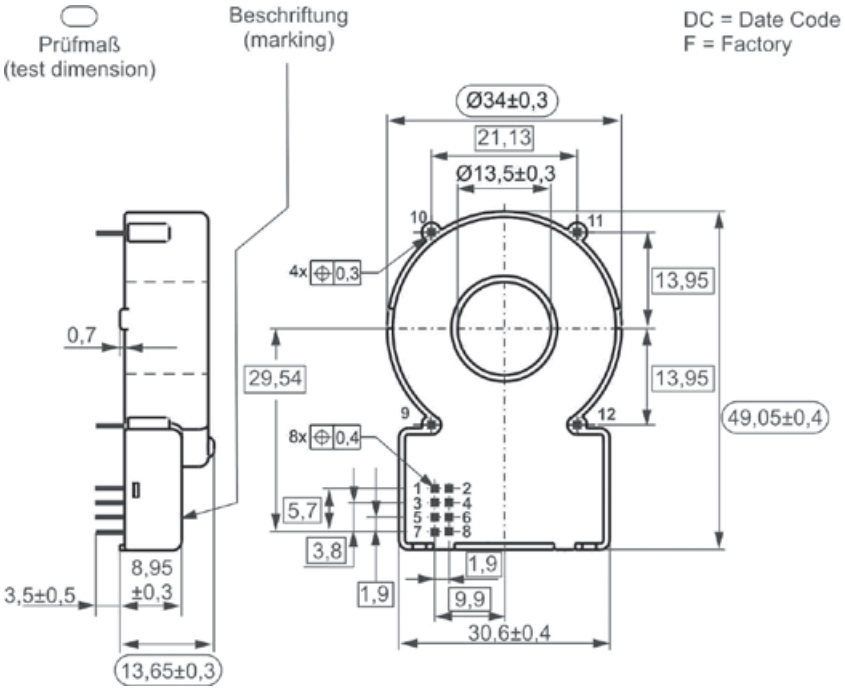
Type
T60404-N4646-X975



Marking	Connections	Pin assignments
UL Mark	1 … 4: Ø 2.8 mm	1 … 4: primary current
Extract item no.	5 … 8: 0.7 x 0.6 mm	9, 10: test-current
F DC, in which	9, 10: Ø 0.8 mm	5: V_{out}
F = Factory		6: V_{ref}
DC = Date Code		7: GND
		8: V_c +5 V

Drawing no. 7

Type
T60404-N4641-X900



Marking	Connections	Pin assignments
UL Mark	1 … 8: 0.5 x 0.5 mm	1: $Error_{out}$
Extract item no.	9 … 12: 0.7 x 0.7 mm	2: $Test_{In}$
F DC, in which		3: $X6_{out}$
F = Factory		4: $X30_{out}$
DC = Date Code		5: GND
		6: V_C +5 V
		7: PWM_{OUT}
		8: N.C.

DI SENSOR FOR IC-CPD APPLICATION

APPLICATIONS AND ADVANTAGES

To satisfy new standards including IEC 62752, charging of electrical vehicles requires differential current sensors to avoid hazardous situations in cases where the vehicle battery (DC) is connected to the home power supply (AC). Generally, AC/DC-sensitive differential current sensors can be used where direct current and alternating current circuits are directly connected and therefore AC/DC leakage currents can occur.

Typically, type A residual current circuit-breakers (RCCBs) are the sole type installed in private households, unable to identify and deactivate DC fault currents. Users seeking to charge an electric vehicle (EV) from a home power supply would therefore require a costly type B RCCB to guarantee safety in the presence of DC fault currents.

By using a VAC DI sensor integrated into an IC-CPD or wall box, customers can save themselves the high costs of installing a type B RCCB to provide all-current sensitivity and electrical safety at low cost.

A single DI sensor monitors simultaneously all currents in phases and neutral conductors sensing AC/DC fault currents. The sensor can activate automatic shut-off in case of hazardous electrical faults or signalize that the switch-off threshold was exceeded to a master device, which will then shut-off the system from the power supply. As the differential currents to be monitored only occur in the event of electrical faults and are extremely low (mA), maximum measurement precision is critical. In addition, a fast response time is required to maintain safety features and prevent humans from getting injured.

FEATURES

- fault current detection according to IEC 62752 or UL 2231
- frequency range DC up to 2 KHz
- load current up to 80 A_{rms} (1-phase) or 3 x 32 A_{rms} (3-phase)
- switching output for 6 mA DC and 30 mA AC (acc. to IEC 62752)
- integrated self-monitoring and test functions
- measurement resolution of 0.2 mA
- variants with pass through opening or with integrated primary conductors
- differential current range 0…300 mA
- robust mechanical design suitable for IC-CPD environmental requirements (e.g. drop test)
- widely usable in harsh electronic environment (e.g. resistant to external magnetic fields)
- total system cost significantly reduced compared to RCD type B

VACUUMSCHMELZE GMBH & CO. KG
GRÜNER WEG 37
D 63450 HANAU / GERMANY
PHONE +49 6181 38 0
FAX +49 6181 38 2645
INFO@VACUUMSCHMELZE.COM
WWW.VACUUMSCHMELZE.COM

VAC MAGNETICS LLC
2935 DOLPHIN DRIVE
SUITE 102
ELIZABETHTOWN, KY 42701
PHONE +1 270 769 1333
FAX +1 270 769 3118
INFO-USA@VACMAGNETICS.COM

VACUUMSCHMELZE SINGAPORE PTE LTD
1 TAMPINES CENTRAL 5, #06-09
CPF TAMPINES BUILDING
SINGAPORE 529508
PHONE +65 6391 2600
FAX +65 6391 2601
VACSINGAPORE@VACUUMSCHMELZE.COM

VACUUMSCHMELZE CHINA MAGNETICS
SHANGHAI SALES OFFICE
ROOM 06, 19F
ZHONGRONG HENGRUI INTERNATIONAL PLAZA
620 ZHANGYANG ROAD, PUDONG DISTRICT
SHANGHAI, PRC 200122
PHONE +86 21 58 31 98 37
FAX +86 21 58 31 99 37
VAC_CHINA@VACUUMSCHMELZE.COM

ALL-CURRENT SENSITIVE DIFFERENTIAL CURRENT SENSORS
EDITION 2016

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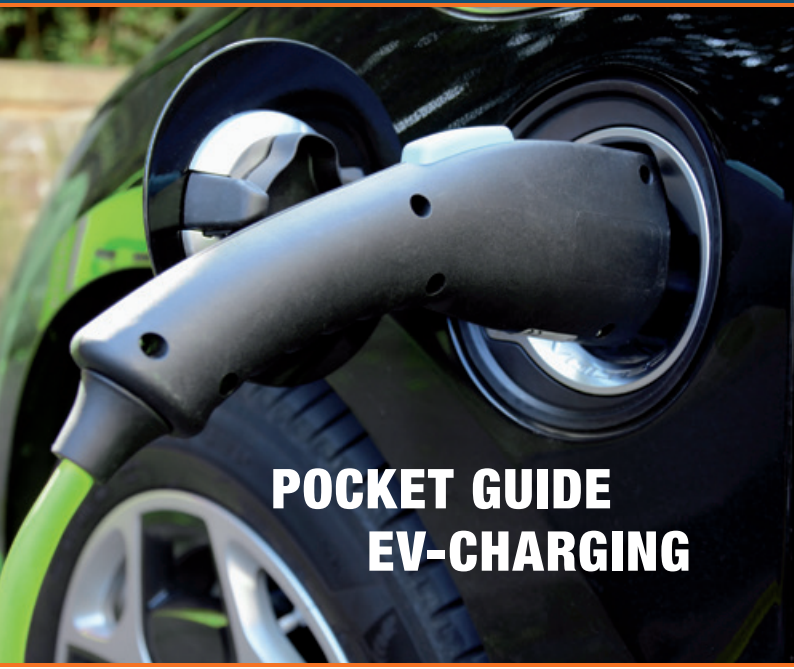
VACUUMSCHMELZE®

ADVANCED MATERIALS – THE KEY TO PROGRESS



POCKET GUIDE EV-CHARGING

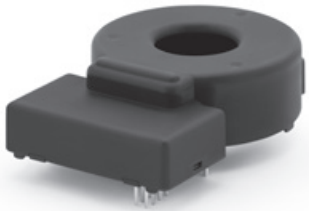
While electric mobility is gaining more and more momentum, the public debates focus on the range of e-cars and the availability of charging points.

The electrical industry is working on different charging modes, each with its own pros and cons. This Pocket Guide about EV charging lines out how VAC's rich portfolio of high performance magnetic components helps to meet the various R&D challenges that different charging modes bring along.

ADVANCED MATERIALS – THE KEY TO PROGRESS

VAC® VACUUMSCHMELZE

CURRENT MEASUREMENT – BEVAC



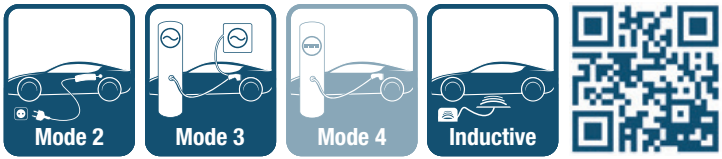
KEY FEATURES

- fault current detection according to IEC 62752, UL 2231 or GB 22794
- two switching outputs according to the switching levels of each standard
- measurement resolution of 0.2 mA

APPLICATION NOTES

By using a VAC DI sensor integrated into an IC-CPD or wall box, the EV charging electronics will provide all-current sensitivity and electrical safety at low cost. In case the sensor detects a DC or rms fault current, the corresponding output will change its state.

Design variants with integrated primary conductors for one or three phase systems are available, together with a pass through variant.



CURRENT MEASUREMENT – CURRENT SENSOR

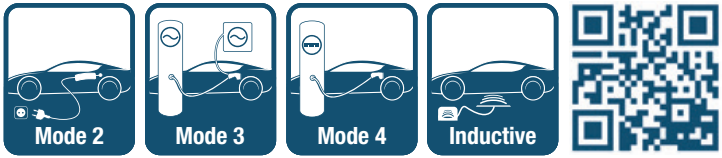
KEY FEATURES

- current sensor series for direct PCB mounting with integrated primary conductors
- wide measurement range of 6 A to 100 A
- +5 V power supply
- closed-loop sensor with magnetic probe and galvanic isolation
- low-cost designs

APPLICATION NOTES

VAC current sensor series offers high accuracy measurement for continuous charging current in very compact design. The sensors cover a wide measurement range and offer an analog linear voltage output. Due to integrated primaries the sensors can be assembled directly onto the PCB.

Higher power range current sensors as panel mounts also available.



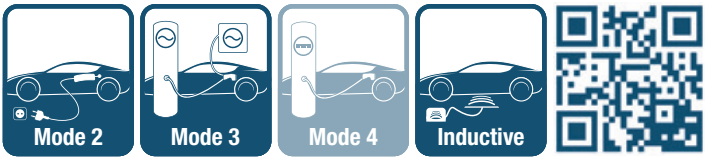
CURRENT MEASUREMENT – CURRENT TRANSFORMER

KEY FEATURES

- highest accuracy and high output signal
- easy mounting due to compact and customized designs
- excellent galvanic separation
- anti-tampering types available with magnetic shielding

APPLICATION NOTES

VAC current transformers (CTs) can be used either for simple monitoring purpose or as a measuring unit if used in EV charging application with metering function. The highly linear characteristic curves allow to use the CT as a precise measurement device and a high transformation ratio (e.g. 1:2500) offers the right output voltage for easy signal processing over the whole current range. Special shielded versions of CTs can be used to prevent metering manipulation.



EMC PRODUCTS

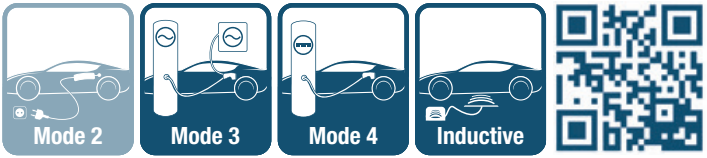
KEY FEATURES

- compact design solutions for high nominal currents
- VAC CMCs fulfil the UL1446 insulation requirements
- environmentally friendly due to high efficiency

APPLICATION NOTES

The general trend to increase switching frequencies in power electronic applications leads to significant network disturbances (EMI). Accordingly, sophisticated EMI filters need to be used following the latest international standards.

VAC offers a broad portfolio of EMC products based on the high permeability nanocrystalline alloy VITROPERM®. The large variety of 1-phase, 3-phase and 4-fold CMCs for various nominal currents, both in upright and low profile design, make them indispensable in EV charging applications.



POWER TRANSFORMER

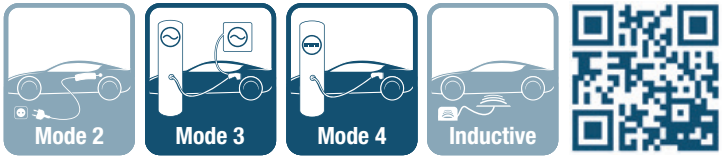
KEY FEATURES

- very high power density
- highest energy efficiency (more than 99 %)
- SiC ready
- full customization possible

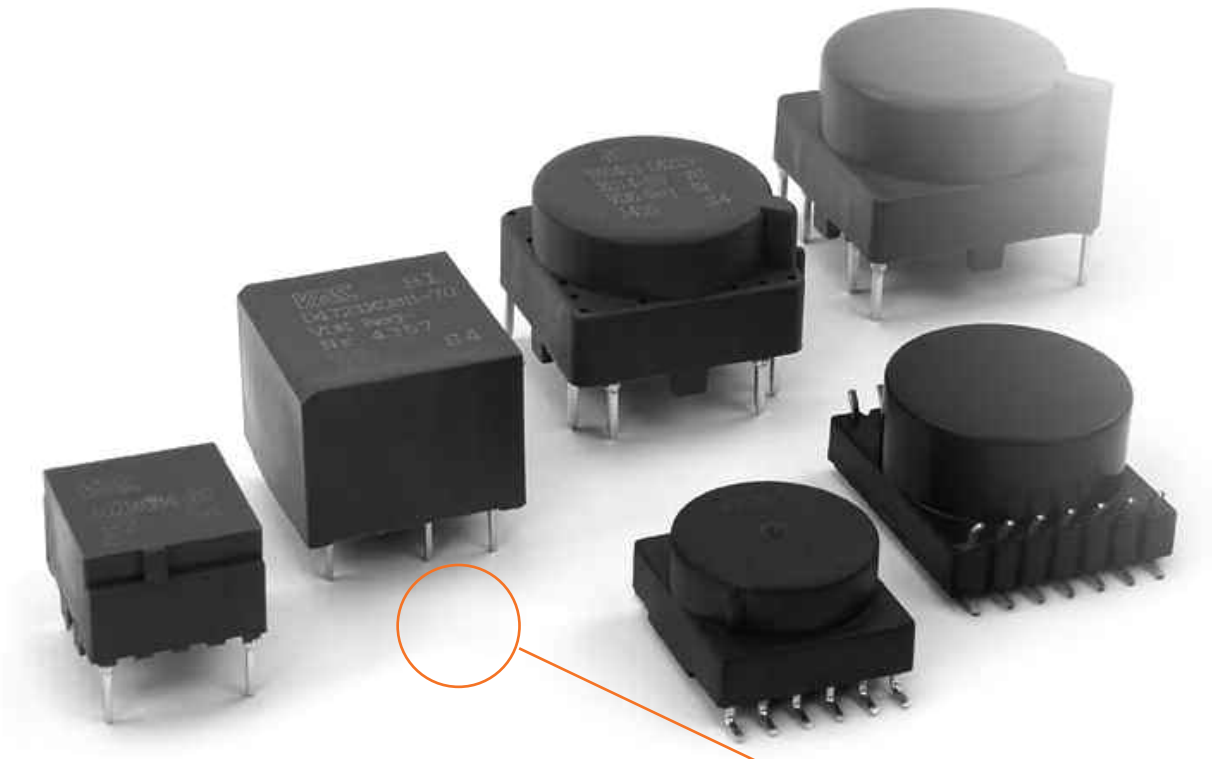
APPLICATION NOTES

VAC power transformers offer transmittable powers of up to 100 kW in extremely compact volumes due to the high saturation flux density of the nanocrystalline alloy VITROPERM®.

Especially for future time-saving high current AC and DC charging solutions (i.e. mode 3 and 4) these power transformers can be applied to ensure a safe galvanic separation between the individual charging points. The transformers are ready to be used with state-of-the-art SiC semiconductors featuring switching frequencies of up to 50 kHz.



DRIVE TRANSFORMERS



ADVANCED MATERIALS – THE KEY TO PROGRESS

VACUUMSCHMELZE

ABOUT THE COMPANY

VACUUMSCHMELZE

Der Fortschritt beginnt beim Werkstoff

Advanced Materials - The Key to Progress

进步始于先进的材料

VACUUMSCHMELZE GmbH & Co. KG is one of the world's leading producers of special metallic materials and related products with exceptional magnetic and physical properties. Our wide range of high quality semi-finished products, parts, components and systems are used in virtually every field of electrical and electronic engineering. This makes us one of the few global companies to offer our customers the complete range of magnetic technology products from a single source – from magnetically soft products to the most powerful permanent magnets in the world.

In all our activities, we benefit from our highly developed material expertise and our decades of experience in magnetic technology. As early as 1923, we became the first company to introduce alloy smelting in a vacuum on an industrial scale and it was from this process that the name VACUUMSCHMELZE was derived.

We are a global company with our headquarters in Hanau, Germany. We currently have over 4500 employees who are spread over production and sales locations in more than 40 countries on every continent, generating annual sales of approximately EUR 350 million.

One of our great strengths is our versatility. All of the world's key industries rely on products and expertise from VACUUMSCHMELZE, with our principal customers active in drive and installation technology, medical technology, renewable energy, automation systems, process and control engineering, measurement technology, as well as the very important automotive and aerospace industries. VAC's custom solutions are developed in close cooperation with customers and reflect a high level of material and application expertise combined with the latest production technology.

Introduction

In recent years, power electronics have had a decisive influence on the technology of electrical energy generation, distribution and conversion. Modern semiconductors enable electrical energy to be controlled and converted rapidly and safely with low losses. Key contributors to progress in this field are turn-off power semiconductors like IGBTs (insulated gate bipolar transistors), MOSFETs (metaloxide semiconductor field-effect transistor) and GTOs (gate turn-off thyristors). VAC products are significant contributors in maintaining efficiency and safety in semiconductor switching and low-loss power transmission.

VAC drive transformers are extensively used in fields of application including:

- Solar inverters
- Converters for wind turbines
- Converters for grid connection, e.g. for renewables or frequency converters with energy recovery
- Converters with high output frequencies
- Servo drives with high switching frequencies for high-speed control
- Electric drives in all power classes
- Uninterruptible power supplies (UPS)
- Switched-mode power supplies
- Control and measurement technology
- Machine tools
- Electric vehicles
- Welding devices
- Medical devices

Renewable energy sources require efficiency, stability and robustness with respect to environmental conditions.

Frequency converters with IGBTs

IGBTs are often used in high-power frequency converters to convert an AC input current at a single frequency (grid frequency 50 Hz or 60 Hz) into an output voltage with variable frequency and amplitude. This voltage is then used to power output devices such as three-phase motors (as in fig. 1).

The grid power is first converted into DC current (using a rectifier or AC-to-DC converter) in an intermediate circuit (DC link or DC bus) with a typical voltage of 600 V or 1200 V. The DC link is connected to a DC-to-AC inverter which produces a controllable output voltage. Both the AC-to-DC converter and the DC-to-AC inverter contain multiple IGBTs (together with diodes and capacitors) operated in bridge circuits, which are supplied as IGBT modules by a number of manufacturers.

However, in solar inverters the DC output from the solar panels serves as a DC link. The DC passes through an inverter, is converted to 50/60 Hz and fed into the grid (see fig. 2).

The above-mentioned high DC link voltages are connected to the IGBTs, which are controlled by low voltage signals (typ. +/-10 V up to 20 V), produced by a measurement and control unit. The contact of the high voltages to the low-voltage side of the control unit must be prevented for the safety of users. Therefore a safe galvanic separation of these circuits is necessary. High voltage tests are applied for verification.

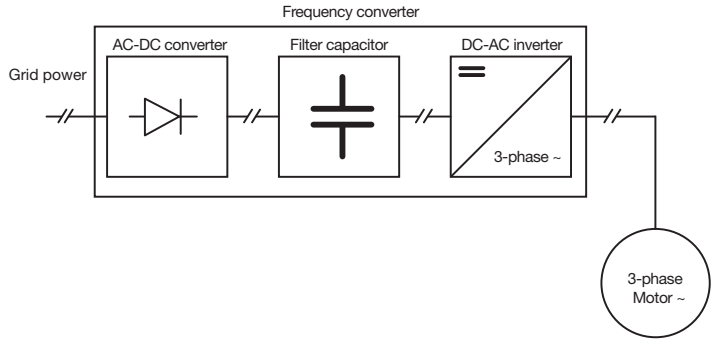


Fig. 1: A frequency converter with AC-to-DC converter and DC-to-AC inverter to power a motor.

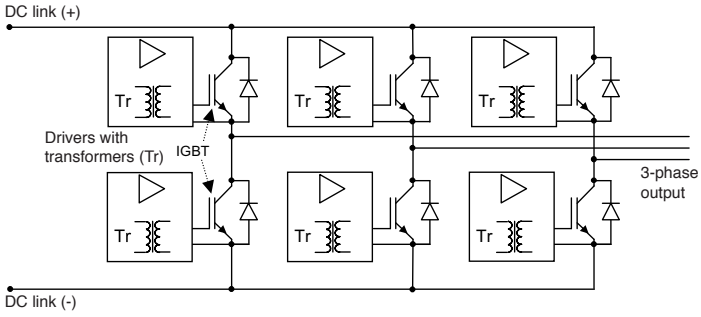


Fig. 2: Schematic diagram of a 3-phase inverter with DC link; when a solar inverter is used, the solar panels feed into the DC link and the 3-phase output is fed into the grid.

Drive transformers provide the galvanic separation of the circuits. The high-voltage tests are described in the relevant international standards (e.g. IEC 61800-5-1, IEC 61558-2, IEC 62109, UL508C, UL1741).

Since 1974, VAC has supplied drive transformers for efficient operation of switched-mode circuits throughout almost all fields of electronics, such as motor control units, wind turbine inverters, power supplies, solar inverters and electric railways.

Advantages of VAC transformers

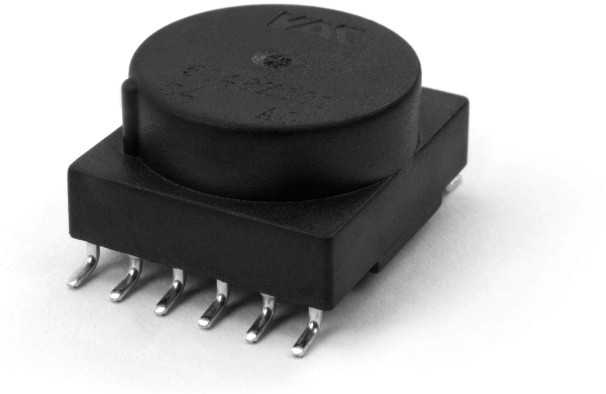
Higher switching frequencies, higher blocking voltages and switching power influence the way a semiconductor is activated and controlled to allow for safe and simple switching. Drive transformers ensure galvanic separation while also supplying the switching signal and /or the energy for the semiconductor drive circuit.

Transformers must meet a number of requirements:

- High insulation strength
- Low coupling capacitance -> high interference resistance
- Compact design
- Low leakage inductance -> high impulse precision
- Transmission of switching power
- Wide range of operating temperature (e.g. -40 °C to +105 °C)
- National and international standards, e.g. EN 50178, IEC 61800, UL508, IEC 62109, UL1741...

Transformer properties:

- Up to 1200 V DC for SMD; up to 8.5 kV_{rms} for PTH
- Low number of turns
- SMD solutions available
- Lower number of turns; high permeability
- Typically 2 to 20 watts
- Low and linear variation of permeability with temperature
- Designs according to relevant standards, properties verified by inspections and type testing



Magnetisation curve and permeability

Core materials are selected on the basis of their suitability for the application. Compared to ferrites, nanocrystalline materials show a narrow hysteresis loop with low remanence ratio (B_r / B_{sat}) and high saturation flux density, as shown in fig. 3. Core losses are low even at switching frequencies of several hundred kilohertz.

The high induction swing of up to 1 Tesla allows transformers to be designed with smaller cores and fewer turns, lowering leakage inductance and coupling capacitance. This results in excellent impulse transmission and thus precise semiconductor switching.

The compact design of the transformers is important to achieve a high packaging density on the PCB.

Cores made of nanocrystalline VITROPERM® have a high linearity of permeability with respect to temperature in comparison to ferrite (see fig. 4).

Inductance and magnetisation currents are thus practically temperature-independent, permitting high-precision signal transmission throughout a wide temperature range (typ. -40 °C ... +120 °C).

Magnetisation curve

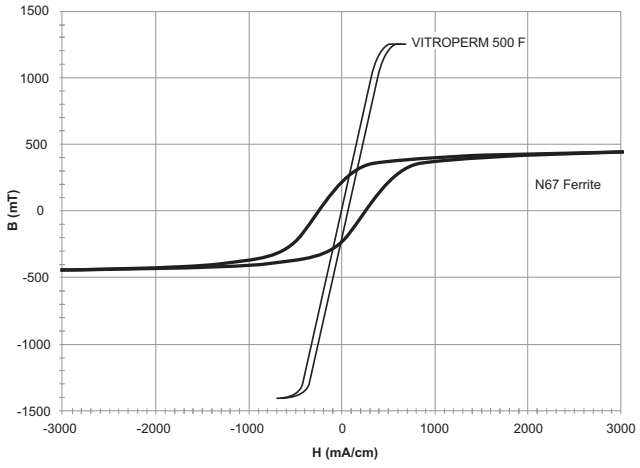


Fig. 3: B(H) Magnetisation curve of VITROPERM 500F compared to a typical ferrite, clearly showing differences in B_S: 1.2 T for VITROPERM 500F compared with 0.43 T for ferrite.

Permeability: temperature dependence

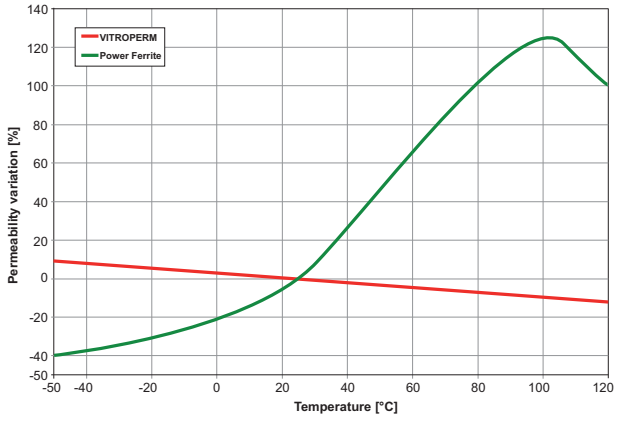


Fig. 4: u(T) Temperature stability of permeability of VITROPERM 500F compared to typical ferrite.

Output testing

At the final inspection, all drive transformers are tested for dielectric strength in accordance with the values stated in the data sheets. Depending on the requirements, a partial discharge(PD) test is conducted. This PD testing is determined by the relevant standards and the applied voltages. For example, to comply with the standard IEC 61800-5-1 the PD test voltage is 20 % higher compared to the European standard EN 50178.

The voltage-time area is generally verified by an impulse test of some parts per batch (AQL).

In addition, type tests are specified in the data sheets. The type tests are required by certain standards and are conducted over longer test periods or using defined high-voltage impulses. Type-tested components are not supplied to customers since the rigorous test conditions may cause damage to the components. Type tests are used to verify the design and as an additional proof of the insulation strength.

VITROPERM® is a registered trade mark of VACUUMSCHMELZE GmbH & Co.KG

VAC offers a wide range of standard transformers listed in the following tables, grouped by the insulation voltage (U_{is}). Please check our website for new models at www.vacuumschmelze.de.

Insulation voltage up to 380 V_{rms}

VAC Product	Model	n	∫Udt	L_P	L_S	C_k	U_P	U_{is}	Dimensions		
									L	W	H
			µVs	mH	µH	pF	kV_{rms}	kV_{rms}	mm	mm	mm
T60403-D4097-X055	PTH	1:1:1	200	6.5	0.3	33	3.1	0.38	14.8	16.6	13.5
T60403-D4097-X058	PTH	1:1:1	260	11	0.35	38	3.1	0.38	14.8	16.6	13.5
T60403-D4097-X064	PTH	1:1.5:1.5	200	2	12	9	3.1	0.38	14.8	16.6	13.5
T60403-D4097-X071	PTH	1:2:2	150	0.37	0.3	90	3.1	0.38	14.8	16.6	13.5
T60403-D4099-X005	PTH	1:1:1	150	2.7	0.3	25	3.1	0.38	16.6	14.8	13.5
T60403-D4099-X006	PTH	1:1:1:1	125	2.4	0.25	28	3.1	0.38	16.6	14.8	13.5
T60403-A4025-X060	PTH	1:1.2:1.2	15	0.3	0.4	15	3.1	0.38	14	9	15
T60403-D4097-X059	PTH	1:1:1	50	0.6	0.25	27	3.1	0.38	14.8	16.6	13.5
T60403-D4097-X063	PTH	1:1:1	260	10	0.5	8	3.1	0.38	14.8	16.6	13.5
T60403-D4215-X022	PTH	1:1:1	500	5	0.9	110	4	0.38	21	21	13.5
T60403-D4721-X012	PTH	1:1	250	1.4	4	110	2.5	0.22	17	17.8	13.5
T60403-F4025-X142	PTH	1:1:1	130	0.8	0.48	91	2.5	0.38	13.2	16.6	10

KEY

∫Udt = Minimum voltage time area at the primary winding in unipolar operation

n = Turns ratio

L_p = Primary inductance (typical value)

L_s = Leakage inductance of primary winding N with secondary winding shorted (typical value)

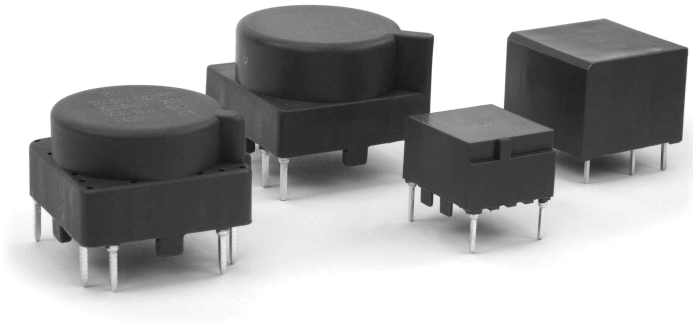
C_k = Coupling capacitance between primary and secondary windings (typical value)

U_{is} = Insulation voltage (operating voltage), effective value between primary and secondary windings

U_p = Test voltage, rms value at 50 Hz between primary and secondary windings

PTH = Pin through hole

SMD = Surface mounted device



Insulation voltage up to 500 V_{rms}

VAC Product	Model	n	∫Udt	L_P	L_S	C_k	U_P	U_{iS}	Dimensions		
									L	W	H
			µVs	mH	µH	pF	kV_{rms}	kV_{rms}	mm	mm	mm
T60403-A4021-X081	PTH	1:1.125	20	0.07	15.5	5	2.5	0.5	12.5	14	10
T60403-A4025-X062	PTH	1:1.2	20	0.5	6	6	3.1	0.5	13.2	16.6	10
T60403-D4615-X007	PTH	1:1:1:1	320	1.7	1	100	4.5	0.5	21	21	13.5
T60403-D4721-X002	PTH	1:1	500	3.6	250	5.5	3.1	0.5	17	17.8	13.5
T60403-D4721-X103	PTH	1:2:2	250	0.85	50	7	3.6	0.5	17	17.8	13.5
T60403-F4021-X088	PTH	1:1.3:1.3	15	0.25	0.2	15	5	0.48	21	21	13.5
T60403-A4025-X046	PTH	1:1:1	7.5	0.015	3	5	3.1	0.5	23.3	16.1	25.4
T60403-D4097-X052	PTH	1:1	260	11	0.45	37	3.1	0.5	14.8	16.6	13.5
T60403-D4215-X014	PTH	1:1:1	170	1.3	0.5	30	4	0.5	20	20	14.5
T60403-F4215-X025	PTH	1:1.4:1.4	200	0.9	5	5	4	0.5	21	21	13.5
T60403-D4721-X001	PTH	1:1:1	250	0.85	28	6	3.6	0.5	17	17.8	13.5
T60403-D4721-X003	PTH	1:1	250	0.85	70	4.7	4	0.5	17	17.8	13.5
T60403-D4721-X005	PTH	2:1	250	3.4	75	5	3.1	0.5	17	17.8	13.5
T60403-D4721-X006	PTH	1:1:1	500	3.1	110	6.5	3.1	0.5	17	17.8	13.5
T60403-D4721-X007	PTH	3:1:1	250	7.6	68	5.5	3.1	0.5	17	17.8	13.5
T60403-D4721-X042	PTH	1:1	250	0.85	70	4.7	4	0.5	17	17.8	13.5
T60403-D4721-X048	PTH	1:1	600	5	360	10	4	0.5	17	17.8	13.5
T60403-D4721-X106	PTH	1:1	500	3.6	290	6	3.1	0.5	17	17.8	13.5
T60403-D4615-X010	PTH	1:1.4:1.4	280	1.7	1	100	4	0.4	21	21	13.5
T60403-D4215-X177	PTH	1:1:1	300	9.25	0.35	80	3.2	0.42	21	20.4	16.5

Insulation voltage 600 V_{rms} to 2000 V_{rms}

VAC Product	Model	n	∫Udt	L_P	L_S	C_k	U_P	U_{is}	Dimensions		
									L	W	H
			µVs	mH	µH	pF	kV_{rms}	kV_{rms}	mm	mm	mm
T60403-F4097-X070	PTH	1.5:1	150	1.215	10	25	3.1	0.9	14.8	16.6	13.5
T60403-F4185-X040	PTH	1:1:1	520	5.5	2	100	5	0.6	27.5	27.6	20
T60403-D4721-X004	PTH	1:1:1	250	0.85	28	6	3.6	0.75	17	17.8	13.5
T60403-D4096-X009	PTH	1/1:1/1	40	0.9	10	7	5	0.75	14.8	16.6	13.5
T60403-D4097-X051	PTH	1:1	100	1.7	0.3	20	3.1	0.7	14.8	16.6	13.5
T60403-F4097-X062	PTH	1:1.65/1.65	16	0.06	0.6	6	6	2	14.8	16.6	13.5
T60403-F4185-X016	PTH	3.1:1:1	800	8.5	70	11	4	1	27.5	27.6	20
T60403-D4215-X030	PTH	1:1:1	500	5	0.8	63	3.5	0.6	21	21	13.5
T60403-D4615-X053	PTH	1:1:1	250	1.7	1	35	5	0.6	22.5	22.5	16.5
T60403-D4615-X054	PTH	1:1.2:1.2	250	1.7	1	35	5	0.6	22.5	22.5	16.5
T60403-D4721-X037	PTH	2:1	250	3.97	75	8	4	0.6	17	17.8	13.5
T60403-D4721-X063	PTH	2.3:1	200	4.5	50	7	3.1	1	17	17.8	13.5
T60403-D4802-X087	PTH	4:1	2500	3	18	58	16	8.35	61	74	90
T60403-F5046-X007	SMD	1:1:1	85	1.40	0.3	13	4.5	1.0	15.2	15.0	9.1

Technical Information

Gate drive topologies

The transformers shall meet a wide range of requirements. These requirements depend on the use of the transformer in the given circuit topology. Fig. 5 (top) shows the simultaneous signal and power transmission across a single transformer.

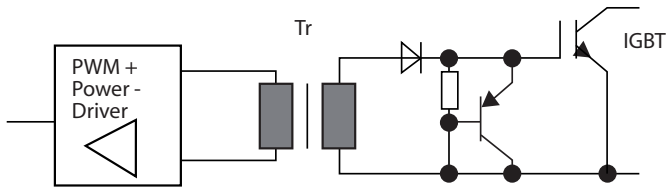
The bottom diagram shows the separate signal and power transmission by means of a power supply and PWM circuit. An optocoupler can be used as an alternative to a signal transformer. However this may reduce the signal quality, e.g. in the presence of high du/dt voltage flanks. High temperatures and other environmental parameters may also reduce the dielectric strength, durability or increase the drift of the semiconductor material.

Drive circuits primarily depend on parameters such as input voltage at the primary winding, pulse frequency and turns ratio.

VAC drive transformers provide highly reliable and stable electrical characteristics. In addition, multiple secondary turns enable multiple IGBTs to be supplied simultaneously and simply with power.

In particular, extremely space-saving, push-pull circuits can be designed using compact transformers with nanocrystalline ring cores.

Drive transformer (Signal + Power)



Drive transformer (Signal) + Drive transformer (Power).

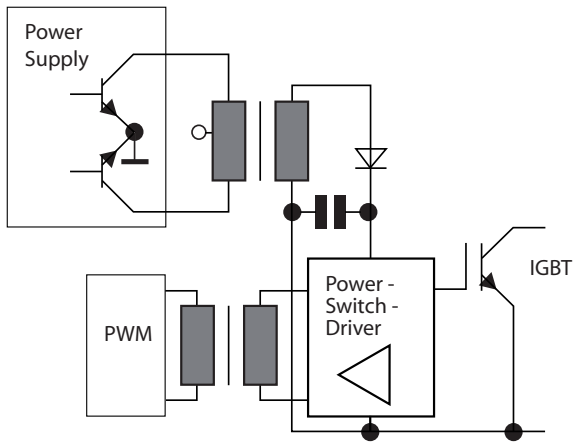


Fig. 5: Signal and power transmission with two configurations.

New circuit principles, e.g. Three-level topology

IGBT modules with three-level topology offer advantages for applications in the kW range. The dielectric strength of the semiconductors is lower than that of conventional circuit designs, so more compact components can be used.

Multi-level topologies generally require a higher number of drive transformers, increasing the importance of more compact designs with ring cores made of nanocrystalline materials.

More modern semiconductor types such as SiC operate at higher frequencies and/or higher voltages which has a direct impact on the drive transformer requirement. As with all topologies, dielectric strength depends on the circuit and the application details. VACUUMSCHMELZE's special insulation methods and vacuum potting technologies produce compact and durable transformer designs.

Important selection criteria for transformers

Voltage and insulation

The selection of drive transformers generally begins with consideration of the permanently applied voltage between the primary and secondary windings. This voltage is given in drive transformer specifications as insulation voltage U_{is} and it determines parameters such as the test voltage, the partial discharge voltage and creepage and clearance distances. Depending on the application, voltage differences may occur between secondary windings and must be considered in the component design. In some standards (e.g. IEC 61800-5-1) the system or grid voltage is important for defining the transformer insulation.

Inductance

VACUUMSCHMELZE drive transformers have a high inductance and therefore low magnetisation currents and a low drop in drive pulse current.

Leakage inductance

Leakage inductance is an indicator for the quality of magnetic coupling of the windings. Low leakage inductance guarantees steep control pulses that keep their shape.
Series or parallel connected IGBTs particularly impose high requirements on the current rise time. The desired low leakage inductance is favoured by a low number of turns such as those achieved by using cores with high saturation flux density.

Voltage time area

In unipolar operation the voltage time area $\int$Udt describes the maximum voltage time integral on the primary winding without a load (fig. 6). The voltage time area determines the modulation of the transformer core with rectangular pulses, approximately according to the formula: $\int Udt = U/2f$.

As fig. 7 shows, in unipolar operation half the hysteresis loop is used. In bipolar operation the voltage time area can be expected to double as the full hysteresis loop is used.

Coupling capacitance

Our drive transformers are characterized by particularly low coupling capacitance values due to a high permeability and a low number of turns. These are measured between the primary and secondary windings.
Especially during the fast switching of IGBTs, a high degree of immunity from interference is required, in order to avoid misfirings occurring in the pulse pauses caused by offset currents, or any feedback to the control end. Due to the minimum coupling capacitance, VAC drive transformers usually do not require electrostatic shielding.

Turns ratio

The turns ratio is determined by the available input voltage (e.g. 15 V) and the required output voltage at multiple windings.
Typical ratios are 1:1; 1:1:1 (one primary, two secondary windings) or 1/1:1/1 where both windings have center taps.

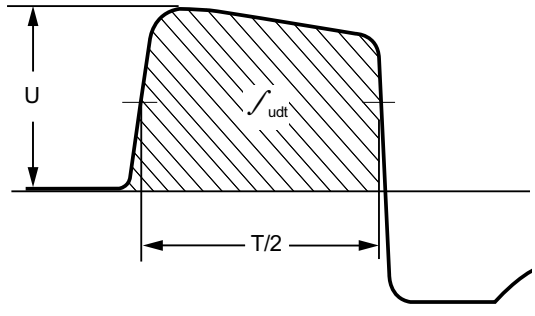


Fig. 6: Explanation of voltage time area.

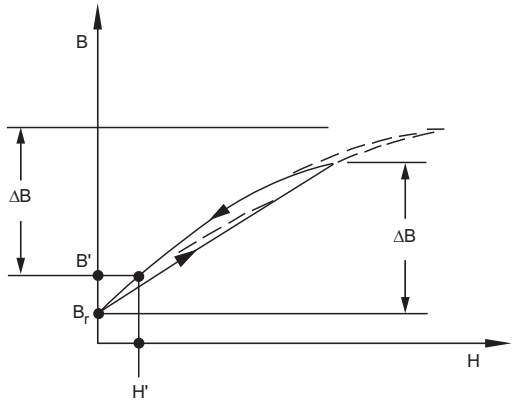


Fig. 7: Hysteresis loop for pulse magnetisation.

VACUUMSCHMELZE GMBH & CO. KG

GRÜNER WEG 37
D 63450 HANAU / GERMANY
TELEPHONE +49 6181 38 0
FAX +49 6181 38 2645
INFO@VACUUMSCHMELZE.COM
WWW.VACUUMSCHMELZE.COM

VAC SALES USA LLC

2935 DOLPHIN DRIVE / SUITE 102
42701 ELIZABETHTOWN KY / USA
TELEPHONE +1 270 769-1333
FAX +1 270 765 3118
INFO-USA@VACUUMSCHMELZE.COM

VACUUMSCHMELZE SALES OFFICE SINGAPORE

61 KAKI BUKIT AVENUE 1
#04-16 SHUN LI INDUSTRIAL PARK
SINGAPORE 417943
TELEPHONE (+65) 63 91 26 00
FAX (+65) 63 91 26 01
VACSINGAPORE@VACUUMSCHMELZE.COM

VACUUMSCHMELZE CHINA MAGNETICS

SHANGHAI SALES OFFICE
ROOM B, 11F, QIAN JIANG TOWER NO. 971
DONGFANG ROAD, PUDONG DISTRIBUTE
SHANGHAI, PRC 200122
P.R. CHINA
TELEPHONE (+86) 21 / 58 31 98 37
FAX (+86) 21 / 58 31 99 37
ELTON.LU@VACUUMSCHMELZE.COM

PKB Drive Transformers Edition 2011

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VACUUMSCHMELZE

ADVANCED MATERIALS – THE KEY TO PROGRESS

GATE DRIVE TRANSFORMERS FOR IGBT

ACC. TO IEC 61558
CERTIFIED BY VDE

INDUSTRIAL APPLICATIONS

MAIN FEATURES

- Large voltage-time area in extremely compact design
- Very low leakage inductance
- Low coupling capacitance
- High insulation strength (reinforced insulation)

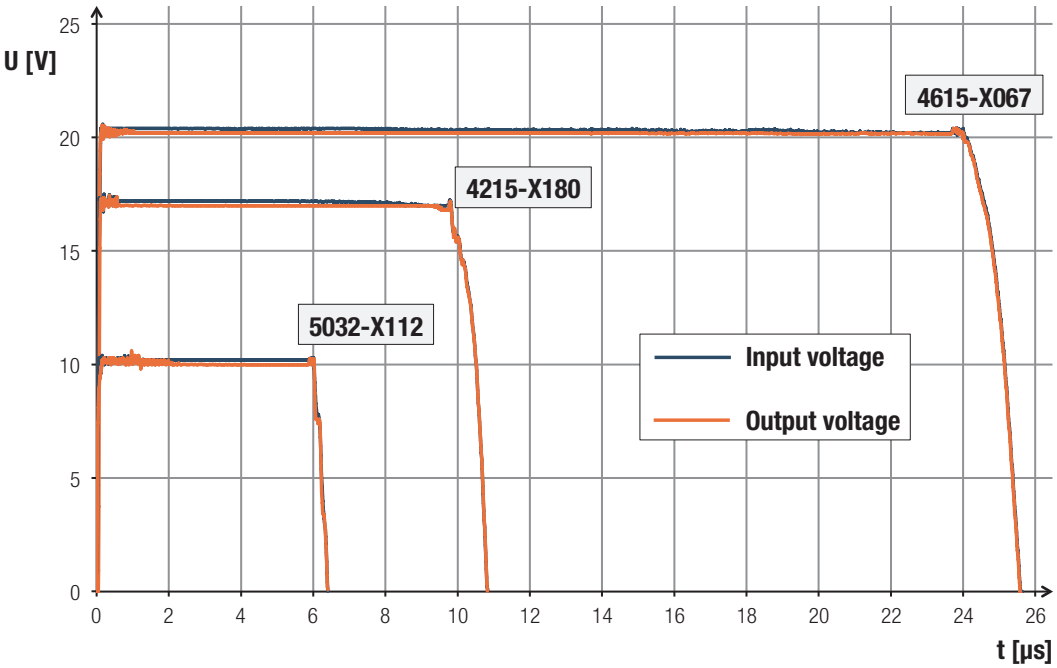
DESCRIPTION

Gate Drive Transformers for IGBT need to ensure excellent switching behavior as well as safe galvanic separation between high and low voltage side.

By using toroidal cores made from nanocrystalline VITROPERM® it is possible to build extremely compact components with high voltage-time area ∫Udt. A broad portfolio of such transformers, designed for different working voltages and frequencies, is available.

With state-of-the-art winding and insulation concepts an optimum between low leakage inductance and low coupling capacitance is achieved. The benefits are highest impulse precision and high interference resistance between high and low voltage side. Consequently, the controlling of IGBT becomes entirely reliable.

TRANSMISSION CHARACTERISTICS



Real lab measurements showing the large voltage-time area and the excellent transmission quality of the components

GATE DRIVE TRANSFORMERS FOR IGBT

MAGNETICAL AND ELECTRICAL PROPERTIES

Part number T60403-F…	n	f kHz	∫Udt µVs	P W	L_1 mH	L_s µH	C_k pF	$U_{is,rms}$ V	$U_{p,rms}$ kV	Design
5032-X112	**1**:1:1	80	60	5	0.7	2.8	3.8	300	5.0	SMD
4215-X180	**1**:1:1	60	170	10	2.98	0.5	20	600	6.75	PTH
4615-X067	**1**:1:1	20	500	10	14.4	1.0	50	600	6.75	PTH

KEY

n = turns ratio (**bold**: primary winding)

f = working frequency

∫Udt = voltage-time area at primary winding in unipolar operation

P = transmittable power

L_1 = primary inductance (typical value)

L_s = leakage inductance of primary winding with secondary windings shorted (typical value)

C_k = coupling capacitance between primary and secondary windings (typical value)

$U_{is,rms}$ = insulation voltage, effective value between primary and secondary windings (identical to 'working voltage')

$U_{p,rms}$ = test voltage, effective value at 50 Hz between primary and secondary windings

SMD = Surface Mounted Device

PTH = Pin Through Hole

NOTES

The latest addition to this range consists of above listed gate drive transformers that are built according to IEC 61558 for "Safety of power transformers, power supplies, reactors and similar products". They all feature reinforced insulation. The fulfillment of IEC 61558-1 and IEC 61558-2-16 is certified by VDE Testing and Certification Institute Offenbach, Germany. Test reports are available upon request.

All transformers are based on VAC's UL1446-certified class F insulation system VAC-ISO-F1 (E329745).

The data sheets can be downloaded from VAC's homepage.

Design modifications are possible upon request.

POSSIBLE APPLICATIONS

- Renewables (i.e. solar inverters, converters for wind turbines or grid connection)
- Power supplies for welding equipment
- Uninterruptable power supplies (UPS)
- Medical devices such as X-rays and laser

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GATE DRIVE TRANSFORMERS FOR IGBT

OPTIMIZED FOR INFINEON'S ECONODUAL™ 3 SERIES

INDUSTRIAL APPLICATIONS

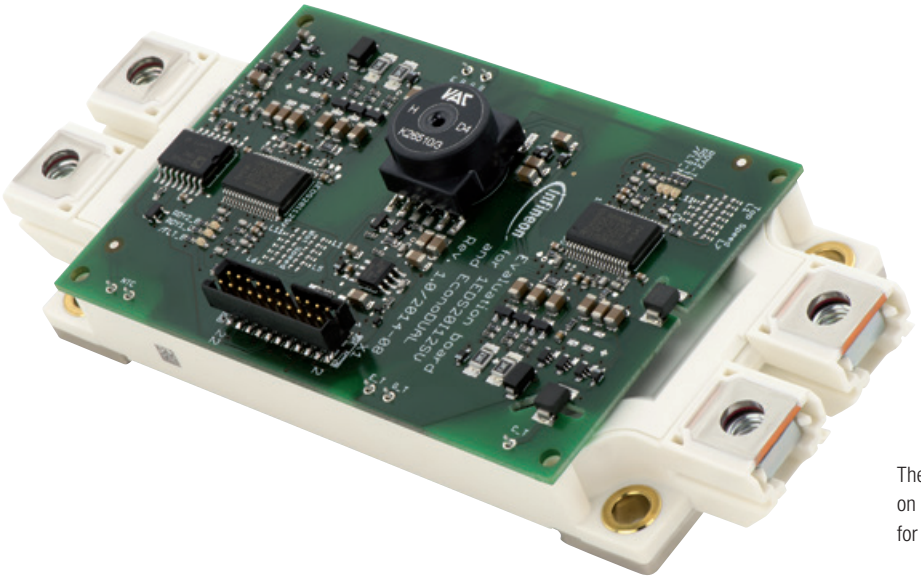
MAIN FEATURES

- Developed for 1200 V IGBT applications
- Low coupling capacitance
- High insulation strength (reinforced insulation)
- Very high corona extinction voltage

DESCRIPTION

Gate Drive Transformers for IGBT are the key element in the driver topology supplying the necessary power for switching and maintaining the safe galvanic separation between the intermediate circuit and the low voltage control side.

By using toroidal cores made from nanocrystalline VITROPERM® it is possible to transmit this power in an extremely compact casing. Advanced insulation and winding concepts ensure highest corona extinction voltages as well as low coupling capacitances.



The new gate drive transformer T60403-F5046-X100 on Infineon's evaluation board EVAL-1EDS20I12SV for the EconoDUAL™ 3 IGBT series

GATE DRIVE TRANSFORMERS FOR IGBT

MAGNETICAL AND ELECTRICAL PROPERTIES

Part number T60403-F…	n	f kHz	∫Udt µVs	P W	L_1 mH	L_s µH	C_k pF	$U_{is,rms}$ V	$U_{TA,rms}$ kV	$U_{p,rms}$ kV	Design
5046-X100	**1**:1.2:1.2	100	80	3	1.4	0.3	12	848	1.25	1.8	SMT

KEY

n = turns ratio (**bold**: primary winding)

f = working frequency

∫Udt = voltage-time area at primary winding in unipolar operation

P = transmittable power

L_1 = primary inductance (typical value)

L_s = leakage inductance of primary winding with secondary windings shorted (typical value)

C_k = coupling capacitance between primary and secondary windings (typical value)

$U_{is,rms}$ = insulation voltage, effective value between primary and secondary windings (identical to 'working voltage')

$U_{TA,rms}$ = corona extinction voltage, effective value at 50 Hz

$U_{p,rms}$ = test voltage, effective value at 50 Hz between primary and secondary windings

SMT = Surface-Mounting Technology

NOTES

The above listed gate drive transformer was developed in close cooperation with Infineon and is optimized for industrial drive applications using 1200 V power modules with current classes up to 900 A. The SMT design allows for time-efficient pick-and-place assembly.

The new evaluation board EVAL-1EDS20I12SV for Infineon's EconoDUAL™ 3 modules is equipped with this gate drive transformer. The corresponding application note can be downloaded from Infineon's homepage.

The transformer is built according to IEC 61800-5-1 for "Adjustable speed electrical power drive systems" and features reinforced insulation.

The data sheet can be downloaded from VAC's homepage.

Part number T60403-F5046-X100 is the successor of part number T60403-D4615-X054.

POSSIBLE APPLICATIONS

- Industrial drives
  (e.g. for elevators, escalators, process automation…)
- Uninterruptable Power Supplies (UPS)
- Smart grid inverters

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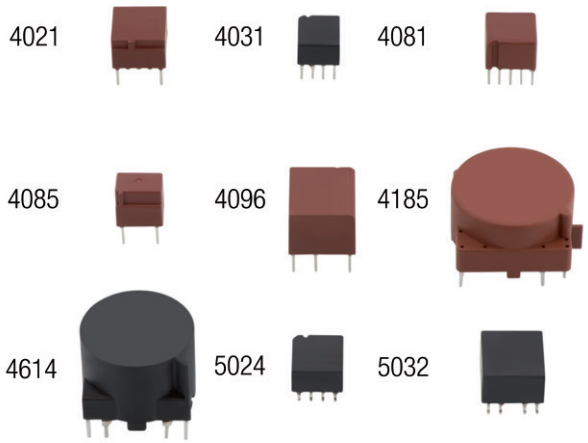
ISOLATION TRANSFORMERS FOR NARROWBAND PLC SYSTEMS

INDUSTRIAL APPLICATIONS

MAIN FEATURES

- Excellent transmission characteristics
- High mains current capability, low THD
- Matching with all leading IC (modulation methods FSK, DCSK and OFDM)
- Compliant with all PLC standards (HomePlug, CENELEC ...)
- Compact designs in THT and SMT housings
- Insulation according to IEC 60950, UL 1950 and IEC 61558

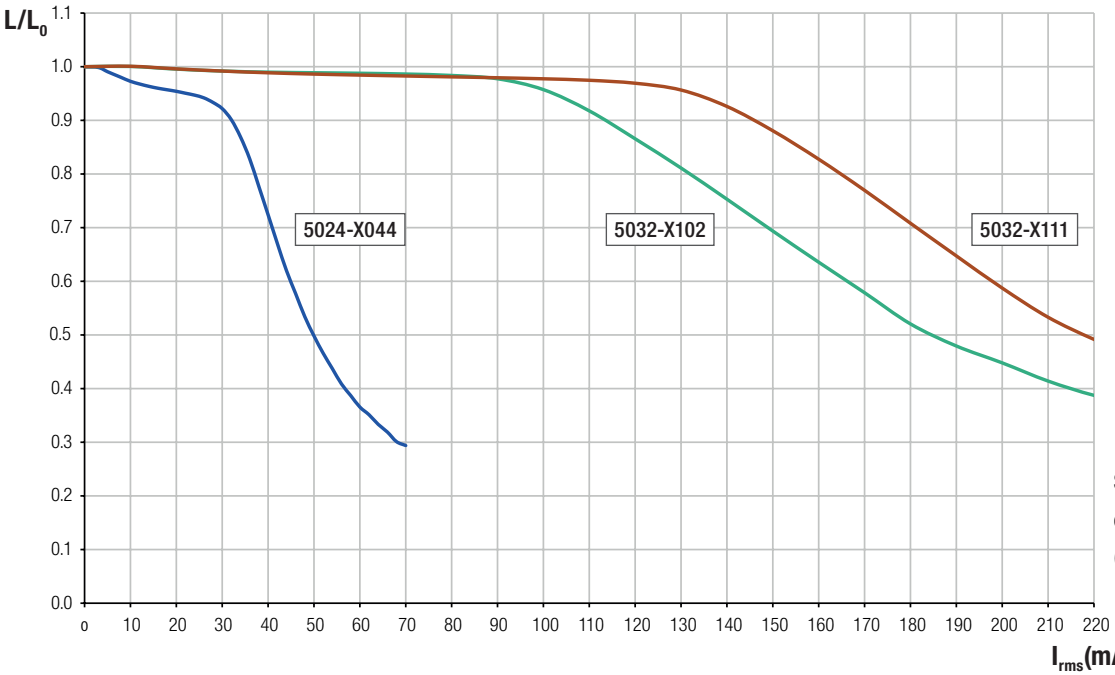


DESCRIPTION

Power line communication (PLC) is a type of communication technology that enables the use of existing wiring infrastructure to transfer data and information over power lines. PLC is one of the favored technologies for reliable, cost-effective and high-performance communication networking technology in multiple domains.

For narrowband PLC systems where the operating frequency may be up to 500 kHz isolation transformers based on amorphous VITROVAC® or nanocrystalline VITROPERM® offer excellent transmission characteristics, high robustness against EMC interferences and safe galvanic insulation.

MAINS CURRENT CAPABILITY



Saturation characteristics of PLC transformers (examples)

MAGNETIC AND ELECTRICAL PROPERTIES

Part number T60403-K…	n	I_{rms} mA	L_m mH	L_s µH	C_k pF	R_{Cu} Ohm	$U_{is,rms}$ V	$U_{p,rms}$ kV	extra feature
Operational Isolation									
THT Design									
4021-X142	1.68:**1**	50	0.43	6	17	0.17	100	1.5	compact flat
SMT Design									
5024-X097	1.68:**1**	50	0.43	6	17	0.17	100	1.5	ultra-compact
5032-X104	1:**1**	90	0.5	6.6	15	0.09	100	1.0	compact
5032-X111	2:**1**	130	0.3	5.8	7	0.17	300	3.0	compact
IEC 60950									
THT Design									
4021-X144	1.37:**1**	120	0.43	1	35	0.22	450	5.1	compact flat
4021-X145	1.7:**1**	130	0.34	1	30	0.20	450	5.1	compact flat
4021-X146	1:**1**	100	0.68	1	35	0.26	450	5.1	compact flat
4081-X004	1:**1**	30	1.4	0.8	25	0.20	400	4.0	ultra-compact flat
4081-X007	2:**1**	35	0.9	0.3	25	0.11	250	5.5	ultra-compact flat
4081-X008	1.36:**1**	32	1.2	0.4	25	0.13	250	5.5	ultra-compact flat
4085-X004	1:**1**	30	1.4	0.8	25	0.20	300	4.0	ultra-compact upright
4096-X046	1:**1**	30	1.3	1	12	0.15	500	6.0	standard
4185-X047	1:**1**	50	1.4	0.8	15	0.20	400	10.0	high voltage
4614-X010	1:1:**2**	250	0.44	0.9	60	0.02	450	5.1	high current
SMT Design									
5024-X044*)	1:**1**	30	1.4	0.3	25	0.20	250	5.5	ultra-compact
5024-X078	1:**1**	15	2.5	0.9	50	0.30	250	3.0	ultra-compact
5024-X079	2:**1**	30	1.4	0.5	50	0.12	400	3.0	ultra-compact
5024-X090	1:1:**2**	35	0.88	0.4	30	0.10	400	3.0	ultra-compact
5024-X092**)	1:1:**2**	100	0.7	1	40	0.50	400	4.0	ultra-compact
5024-X099**)	1:1:**2**	100	0.7	1	40	0.50	400	3.0	ultra-compact
5024-X100	1:4:**4**	30	1.56	1	25	0.15	400	3.0	ultra-compact
5032-X102	1:1:**2**	100	0.7	1	30	0.23	450	5.1	compact
5032-X114	1:1.15:**1.62**	120	0.54	1	30	0.22	450	5.1	compact

*) UL 1950 certified

**) extended performance in the low frequency range

IEC 61558									
THT Design									
4031-X009	2:**1**	5	1.0	0.17	17	0.08	300	4.2	compact cubic
4096-X047	1:**1**	-	1.3	10	5	0.20	500	6.0	standard

TRANSFORMER SELECTION

The transformers have been designed to be compatible with PLC chipsets of various IC manufacturers. Depending on individual operating and/or mounting conditions a preselection may be made.

Part number T60403-K…	Atmel ATPL230A ATPL250A	Cypress CY8C56** CY8C58**	Enverv EV80*0	Maxim MAX2990 MAX2991	ON Semi AMIS 49587 NCN 49597 NCN 49599	Renesas M16C/6S	STM ST7538 ST7540 ST7570 ST7580 ST7590 STComet	TI F28PLC83 F28PLC35	Yitran IT800	Others various
Operational Isolation										
THT Design										
4021-X142										x
SMT Design										
5024-X097										x
5032-X104										x
5032-X111					x					
IEC 60950										
THT Design										
4021-X144										x
4021-X145										x
4021-X146										x
4081-X004	x	x				x				
4081-X007										x
4081-X008										x
4085-X004	x	x				x				
4096-X046				x						
4185-X047	x	x				x				
4614-X010			x				x			
SMT Design										
5024-X044*)	x	x				x				
5024-X078										x
5024-X079										x
5024-X090			x			x			x	
5024-X092**)						x	x		x	
5024-X099**)						x	x		x	
5024-X100	x									
5032-X102			x			x	x		x	
5032-X114								x		

*) UL 1950 certified

**) extended performance in the low frequency range

IEC 61558

THT Design

4031-X009					x					
4096-X047				x						

ISOLATION TRANSFORMERS FOR NARROWBAND PLC SYSTEMS

KEY

n = turns ratio (**bold**: mains side winding)

I_{rms} = max mains current (50/60Hz; related to mains side winding)

L_m = inductance of mains side winding (minimum value)

L_s = leakage inductance of mains side winding with IC side winding(s) shorted (typical value)

C_k = coupling capacitance between mains side winding and IC side winding(s) (typical value)

R_{Cu} = DC resistance of mains side winding (typical value)

$U_{is,rms}$ = insulation voltage, effective value between mains side winding and IC side winding(s) (identical to 'working voltage')

$U_{p,rms}$ = test voltage, effective value at 50 Hz between mains side winding and IC side winding(s)

THT = Through Hole Technology

SMT = Surface-Mounting Technology

NOTES

A part of above listed isolation transformers are built according to IEC 60950 for "Safety of Information technology equipment" or IEC 61558 "Safety of power transformers, power supplies, reactors and similar products". They all feature reinforced insulation. The classification to overvoltage category, pollution degree and insulation material group may be taken from the data sheet.

The data sheets can be downloaded from VAC's homepage.

Design modifications are possible upon request.

POSSIBLE APPLICATIONS

- Smart Grid
- Automated Meter Infrastructure (AMI)
- Indoor Networking / Home Automation
- Remote monitoring & control

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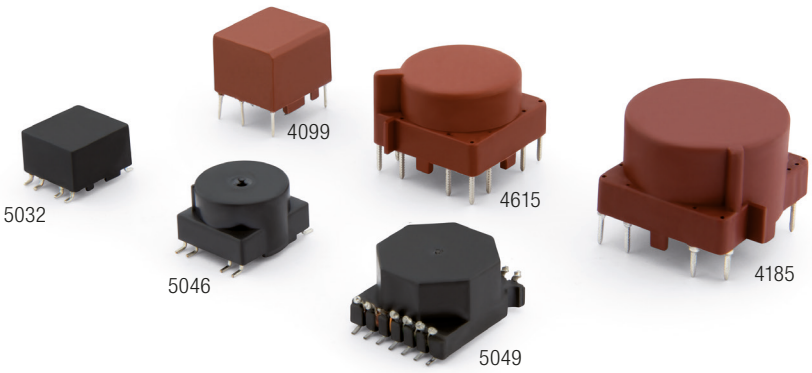
GATE DRIVE TRANSFORMERS FOR IGBT

ACC. TO IEC 61800

INDUSTRIAL APPLICATIONS



MAIN FEATURES

- Low coupling capacitance
- High insulation strength (reinforced insulation)
- Very high corona extinction voltage
- Compact designs in THT and SMT casings

DESCRIPTION

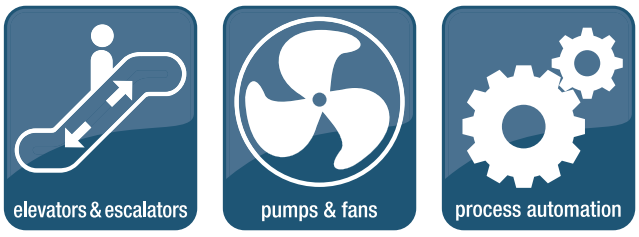
In modern variable-frequency drives (VFD) IGBT are used in the inverter stage for frequency conversion. The corresponding Gate Driver Circuit needs to supply the necessary power for switching. In medium to high power applications DC/DC converters are usually used for this purpose.

Gate Drive Transformers for IGBT are the key element in these converters maintaining the safe galvanic separation between the intermediate circuit and the low voltage control side.

By using toroidal cores made from nanocrystalline VITROPERM® it is possible to transmit the required switching power in extremely compact casings saving valuable PCB space. Advanced insulation and winding concepts ensure highest corona extinction voltages as well as low coupling capacitances.

A large portfolio for typical working voltages between 500 V and 1200 V is available. The transformers feature different transmission ratios and voltage-time areas for demanding applications.

DESIGNED FOR INDUSTRIAL DRIVES



GATE DRIVE TRANSFORMERS FOR IGBT

MAGNETIC AND ELECTRIC PROPERTIES

Part number T6040…	n	f kHz	∫Udt µVs	P W	L_1 mH	L_s µH	C_k pF	$U_{is,rms}$ V	$U_{TA,rms}$ kV	$U_{p,rms}$ kV	Design
3-F5046-X100	**1**:1.2:1.2	100	80	3	1.4	0.3	12	848	1.25	1.8	SMT
3-F5046-X007	**1**:1:1	100	85	6.5	1.4	0.3	13	848	1.25	4.5	SMT
3-F4099-X011	**1**:1:1	100	85	8	0.95	2.4	2.5	500	0.95	4.5	THT
2-C4615-X070	**1**:**1**:1.11:1.11	90	100	8	0.8	13	5	900	1.36	5	THT
3-F5046-X008	**1**:1:1:1	100	110	4.5	2.32	6.7	9	848	1.25	4.5	SMT
3-D4615-X047	**1**:1:1	100	250	10	3	0.25	25	848	1.25	5	THT
2-C4615-X065	**2.9**:1:1	100	340	42	14.5	9	10	1200	1.8	2.2	THT
3-F4185-X046	**2**:1	20	500	20	22	4	40	1200	1.5	5	THT

KEY

n = turns ratio (**bold**: primary winding)

f = working frequency

∫Udt = voltage-time area at primary winding in unipolar operation

P = transmittable power

L_1 = primary inductance (typical value)

L_s = leakage inductance of primary winding with secondary windings shorted (typical value)

C_k = coupling capacitance between primary and secondary windings (typical value)

$U_{is,rms}$ = insulation voltage, rms value between primary and secondary windings (identical to 'working voltage')

$U_{TA,rms}$ = corona extinction voltage, rms value

$U_{p,rms}$ = test voltage, rms value between primary and secondary windings

SMT = Surface-Mounting Technology

THT = Through Hole Technology

NOTES

The latest addition to this range consists of above listed gate drive transformers that are built according to IEC 61800-5-1* for "Adjustable speed electrical power drive systems". They all feature reinforced insulation. The specified corona extinction voltages are being tested at 100 %.

* Please contact VAC for more detailed information on the conformity to UL 61800.

All components can be operated at temperatures up to 105 °C.

The data sheets can be downloaded from VAC's homepage.

Design modifications are possible upon request.

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POWER TRANSFORMERS

INDUSTRIAL APPLICATIONS

MAIN FEATURES

- Very high power density (total power up to 100 kW)
- High insulation strength and corona extinction voltage possible
- Highest energy efficiency (more than 99 %)
- Highest reliability over wide temperature range

DESCRIPTION

State-of-the-art DC/AC and DC/DC converters for high power applications enable high output power levels utilizing switching frequencies up to 50 kHz and more. Therefore sophisticated magnetic transformers are required to maintain safe galvanic separation between the input and output.

VAC power transformers offer transmittable powers of up to 100 kW in extremely compact volumes due to the high saturation flux density of the nanocrystalline alloy VITROPERM®. Depending on the required insulation level, the highest corona extinction voltages can be realized with modern winding techniques.

POSSIBLE APPLICATIONS

POWER TRANSFORMERS

CONSTRUCTIONAL BASICS

All VAC power transformers are based on toroidal cores made of VITROPERM 500 F. This nanocrystalline alloy offers excellent soft magnetic properties combined with lowest losses. The size and number of cores will be determined on the basis of the required power, working frequency, input voltage level, duty cycle and cooling conditions.

For modern designs, high frequency litz wire is used for the windings. Depending on the necessary insulation strength and the partial discharge requirements, different insulation methods are used. After winding, the transformer will be put into a cylindrical aluminum casing of the required size. The top of the casing is typically open.

Due to the almost zero magnetostriction of VITROPERM, it is possible to use a very strong and highly insulation epoxy resin, ensuring safe encapsulation of the transformer.

TYPICAL CHARACTERISTICS

Electric properties		
P	kW	3…100
f	kHz	5…60
$U_{1, rms}$	V	< 1,000
$I_{2, rms}$	A	< 500
$U_{is,rms}$	V	< 4,000
$U_{TA, rms}$	V	< 6,000

Magnetic properties		
n	typical	**1**:1 – **6**:1
L_1	mH	5…30
L_s	µH	1…10

Design parameters		
T_a	°C	-40…+70
T_{op}	°C	< 130
m	kg	2…30

The data in the table only represents typical characteristics – if you have different requirements (e.g. higher power or input voltage), please contact us directly.

TYPICAL VOLUME AND POWER

The following table gives an overview of the typical transmittable powers that can be achieved with differently sized casings. The power level is higher if the insulation voltage is below 1 kV:

Diameter [mm]	Height [mm]	Volume [l]	Transmittable power [kW] if $U_{is,rms}$	
			< 1 kV	> 1 kV
76	44	0.25	4	–
130	90	1.2	15	10
157	125	2.3	30	20
220	160	6	100	50

Assumptions: T_a = 55 °C (forced cooling), duty cycle 50 %, f = 25… 40 kHz

The data in the table only represents typical characteristics – details of size, insulation methods and cooling techniques need to be discussed thoroughly.

KEY

P = transmittable power

f = working frequency

$U_{1, rms}$ = input voltage, rms value

$I_{2, rms}$ = output current, rms value

$U_{is,rms}$ = insulation voltage, rms value between primary and secondary windings

$U_{TA,rms}$ = corona extinction voltage, rms value

n = turns ratio (**bold**: primary winding)

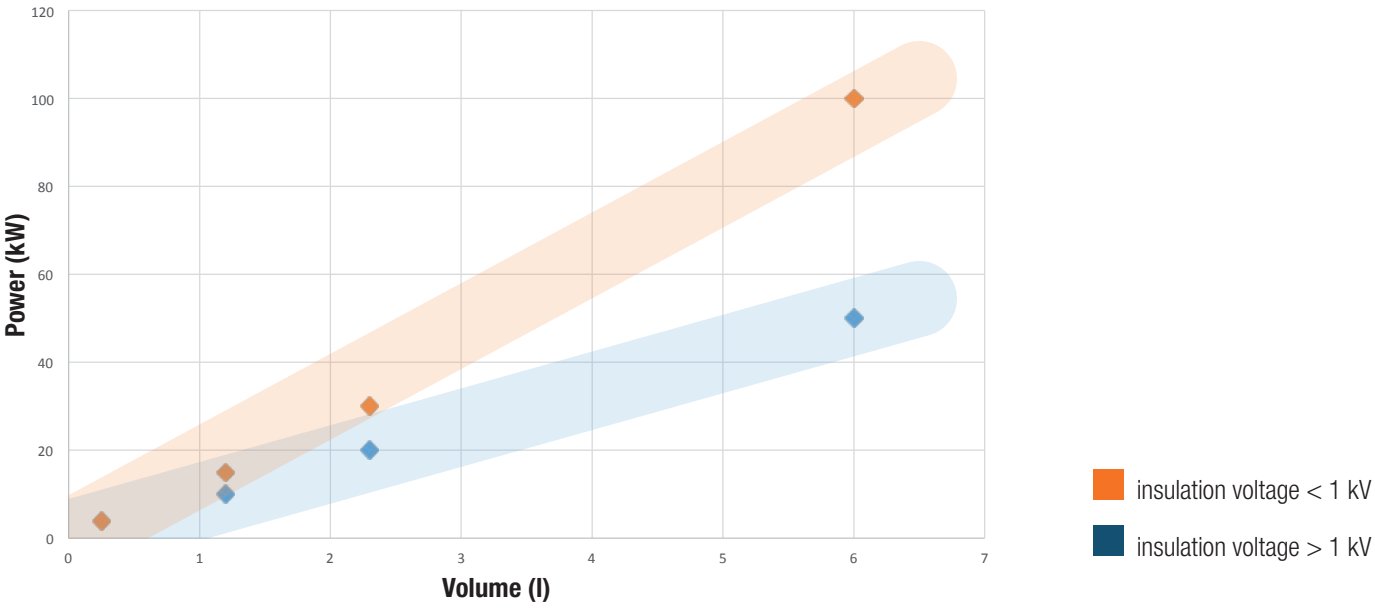
L_1 = primary inductance (typical value)

L_s = leakage inductance of primary winding with secondary windings shorted (typical value)

T_a = ambient temperature

T_{op} = operation temperature

m = weight of transformer



POWER TRANSFORMERS

CIRCUIT TOPOLOGIES

VAC power transformers are primarily optimized for hard switching full-bridge converter topologies, enabling the transmission of high power with highest efficiency. The common pursuit to reduce the losses in the semiconductors has resulted in many resonant topologies in recent years. In particular, the so called quasi-resonant systems have emerged with sinusoidal current and rectangular voltage, typically using Zero Current Switching (ZCS). It has to be considered that a certain percentage of reactive power will circulate in the system requiring more powerful transformers. The benefits of lower semiconductor switching losses need to be balanced against the necessary higher volume of the power transformer.

With the latest SiC semiconductors and their extremely low switching losses, conventional hard switching topologies might regain their position as a favoured solution.

COOLING

With an internal efficiency of more than 99 %, VAC power transformers are highly energy efficient. Nevertheless, cooling of the dissipated heat is still required – the following cooling techniques are widely used:

1. Pure convectional cooling
2. Forced air cooling
3. (Water) cooled base plate

In the case of low transmittable powers, convectional cooling might be sufficient, but the ambient temperature in close vicinity to the transformer must be monitored carefully. If forced air cooling is applied, casings with cooling fins should be used. Water cooled base plates are typically used in very compact designs where no sufficient air flow can be established. This issue has to be considered from the very beginning of the design stage, as the dominant heat transport needs to go through the base of the transformer.

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COMMON MODE SUPPRESSION CHOKES IN NANOCRYSTALLINE VITROPERM

for Automotive Applications

New Model Range of Common Mode Chokes for Automotive Applications

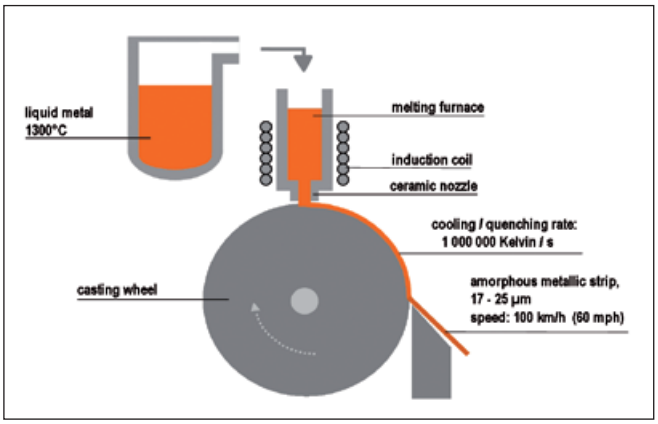
- Developed for DC/DC converters in hybrid and electric vehicles
- Automotive qualified in compliance with AECQ200
- Ambient temperature: T_a = -40 °C…+115 °C
- Max. operating temperature with limited duration: T_{op} = 160 °C
- Rated insulation voltage: U_i = 525 V_{RMS} (functional insulation, pollution degree 1)
- Manufacture conforming to "Technical Cleanliness" according VDA Volume 19

General Advantages and Benefits of Nanocrystalline Chokes

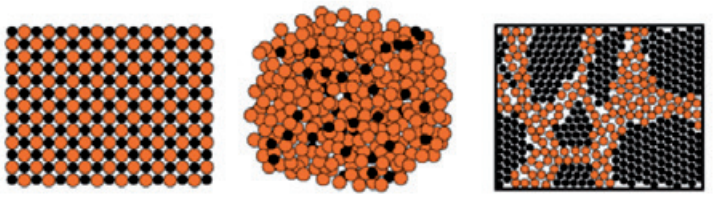
- **Small size**
  → High μ, high B_S
- **Suitable for high currents and/or high voltages**
  → High μ, high B_S, optimized core design
- **Single-stage filter concepts possible**
  → Extreme broadband attenuation behaviour, high permeability, low capacitance designs, slow μ decline towards higher frequencies, low Q factor in the 150 kHz range
- **High efficiency, low dissipation loss**
  → Low number of windings necessary for high L, filter stage reduction
- **Suitable for high and low ambient temperatures and high operating temperatures**
  → High Curie temperature, material properties (μ, B_s, λ_s) virtually independent of temperature
- **„Easy filter design"**
  → material properties (μ, B_s, λ_s) virtually independent of temperature, constant impedance over a wide common mode current range due to linear magnetization curve
- **Optimally adapted solutions for various applications available**
  → Various μ levels, various VITROPERM alloys

VITROPERM: Making the most of iron

The nanocrystalline VITROPERM® alloys are materials based on Fe, Si and B with additions of Nb and Cu. By using rapid solidification technology they are manufactured as thin ribbons in their final thickness of approximately 20 µm. The ribbons are then processed on special winding machines into toroidal tape-wound cores in the size range from 2 mm to 600 mm (external diameter). For the formation of the nanocrystalline microstructure, the still amorphous ribbons in the as-manufactured state undergo heat treatment at 500 °C to 600 °C, resulting in a two-phase structure with fine crystalline grains (mean diameter 10-40 nm) embedded in a residual amorphous phase. This structural feature is the prerequisite for achieving the highest permeability and the lowest coercive field strength values. In addition, the low ribbon thicknesses and the relatively high electrical resistance of 1.1-1.2 µΩm ensure the lowest eddy current losses and the exceptional frequency response of the permeability. The combination of these properties together with a saturation flux density of 1.2 T and favourable thermal properties make the nanocrystalline, soft magnetic state-of-the-art VITROPERM material the universal solution for EMC problems, superior in many ways to conventional ferrite and amorphous material solutions.



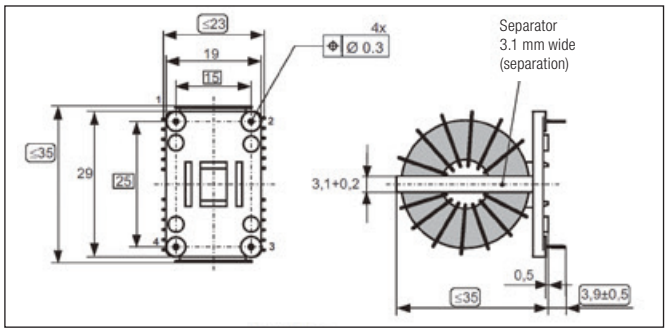
Rapid solidification technology for the manufacture of metal ribbons with an amorphous (vitreous) structure



Crystalline Structure | Amorphous Structure | Nanocrystalline Microstructure

Nanocrystalline cores and components have already been used with great success for many years in common mode suppression chokes (CMC) in automotive applications due to their superior soft magnetic properties. Through the use of cost-effective alloying elements (Fe based) and modern large-scale series production, VITROPERM has already established itself as a competitive solution in many diverse applications.

Type 1: Dimensions 35 mm x 23 mm x 35 mm

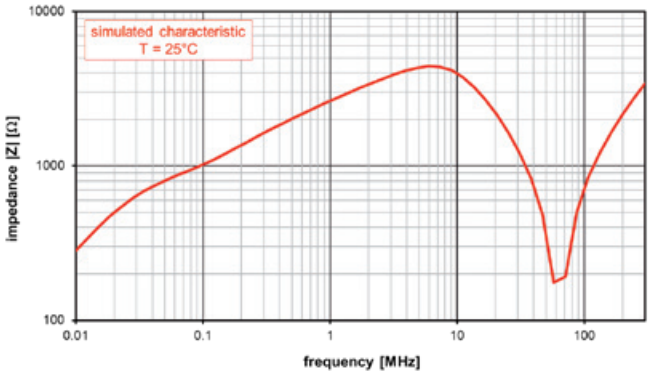


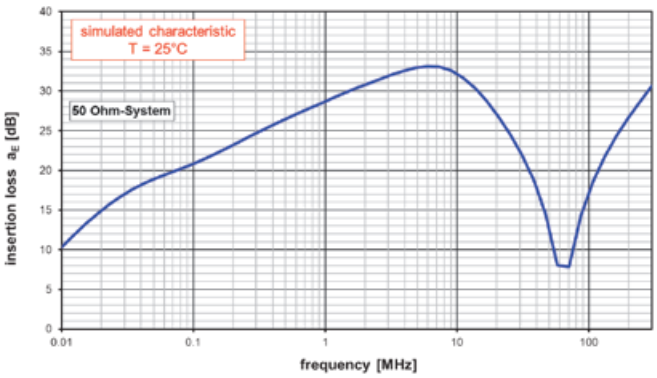
Type T60405-R…	Dimensions l x b x h [mm]	Core (magn.) Ext. Dia x int. Dia x h [mm]	Windings Ø [mm]	Windings No. of Wind.	I_N [A]	L [mH] 10 kHz	L [mH] 100 kHz	|Z| [Ω] 10 kHz	|Z| [Ω] 100 kHz	$I_{unbal.}$ [mA] 10 kHz	$I_{unbal.}$ [mA] 100 kHz	$I_{unbal.}$ [mA] DC
6127-X010	35 x 23 x 35	25 x 16 x 10	1.12	2 x 20	8	26.8	6.2	1,770	6,630	16	33	14
6127-X011			1.18	2 x 18	9	21.7	5.0	1,440	5,320	18	36	16
6127-X012			1.25	2 x 16	10	17.1	4.0	1,130	4,180	20	41	18
6127-X013			1.32	2 x 14	11	13.1	3.1	867	3,180	23	47	20
6127-X014			1.4	2 x 13	12	11.3	2.7	748	2,730	24	50	22
6127-X007			1.5	2 x 11	13	8.1	1.9	535	1,930	29	59	26
6127-X008			1.6	2 x 10	14.5	6.7	1.6	442	1,590	32	65	28
6127-X006			1.8	2 x 8	19.4	4.3	1.0	284	1,030	40	81	35
6127-X009			1.9	2 x 7	21	3.3	0.8	216	780	45	93	40

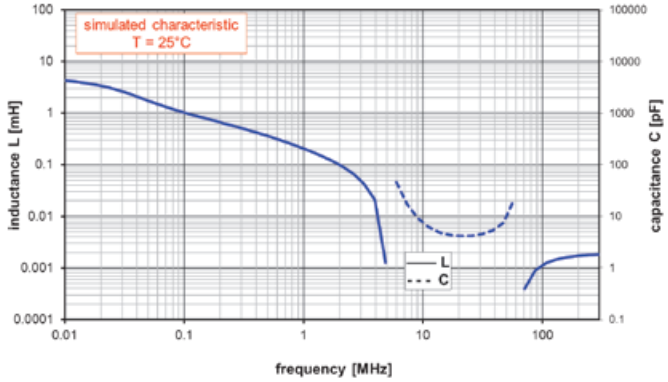
Other designs available on request.

Example: T60405-R6127-X006

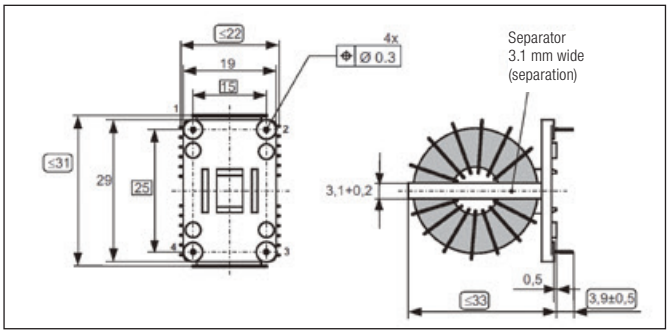
R_{Cu} = 3.4 mΩ (typical value) m ≈ 40 g







Type 2: Dimensions 31 mm x 22 mm x 33 mm

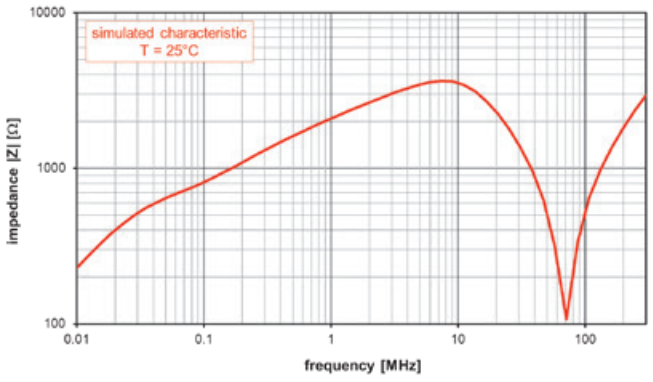


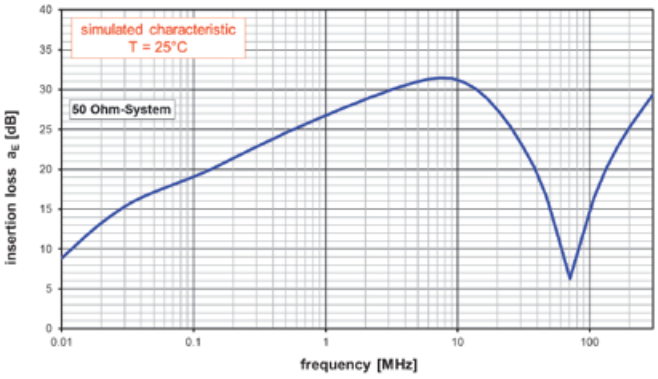
Type T60405-R...	Dimensions l x b x h [mm]	Core (magn.) Ext. Dia x int. Dia x h [mm]	Windings Ø [mm]	Windings No. of Wind.	I_N [A]	L [mH] 10 kHz	L [mH] 100 kHz	|Z| [Ω] 10 kHz	|Z| [Ω] 100 kHz	$I_{unbal.}$ [mA] 10 kHz	$I_{unbal.}$ [mA] 100 kHz	$I_{unbal.}$ [mA] DC
6127-X015	31 x 22 x 33	21.5x15.6x10.3	1.12	2 x 16	8	13.8	3.2	914	3,310	18	36	16
6127-X016			1.18	2 x 14	9	10.5	2.5	696	2,530	20	41	18
6127-X017			1.25	2 x 13	9.5	9.1	2.1	602	2,180	22	44	19
6127-X018			1.32	2 x 11	11	6.5	1.5	431	1,540	25	52	23
6127-X019			1.4	2 x 10	12	5.4	1.3	356	1,280	28	58	25
6127-X020			1.5	2 x 9	14	4.4	1.0	288	1,030	31	64	28
6127-X005			1.6	2 x 8	15.2	3.4	0.8	228	820	35	72	31

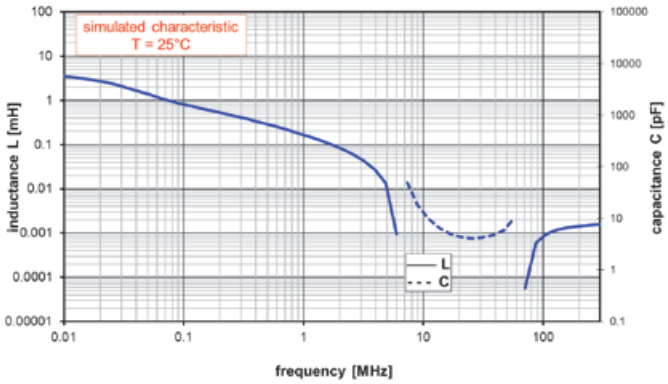
Other designs available on request.

Example: T60405-R6127-X005

R_{Cu} = 3.6 mΩ (typical value) m ≈ 20 g







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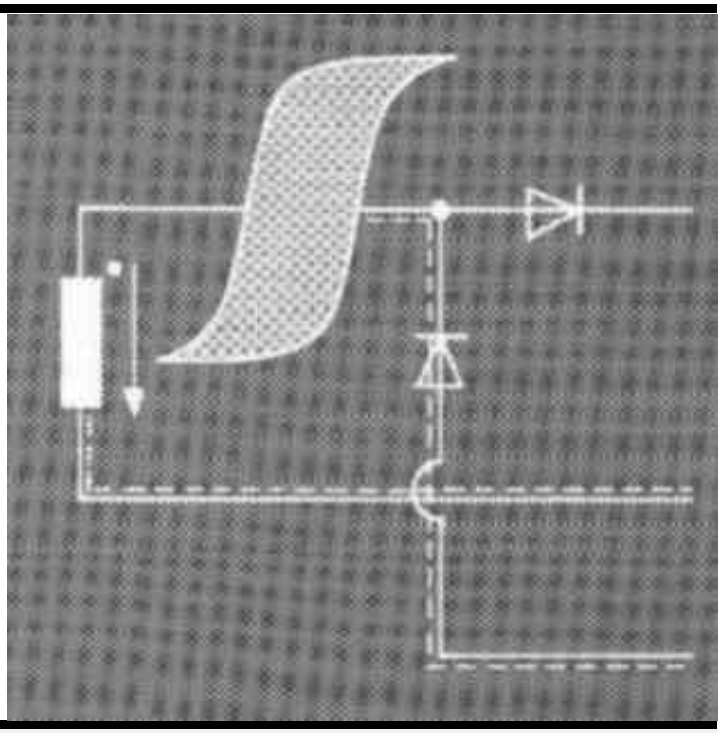
VACUUMSCHMELZE

Tape-Wound Cores for Magnetic Amplifier Chokes

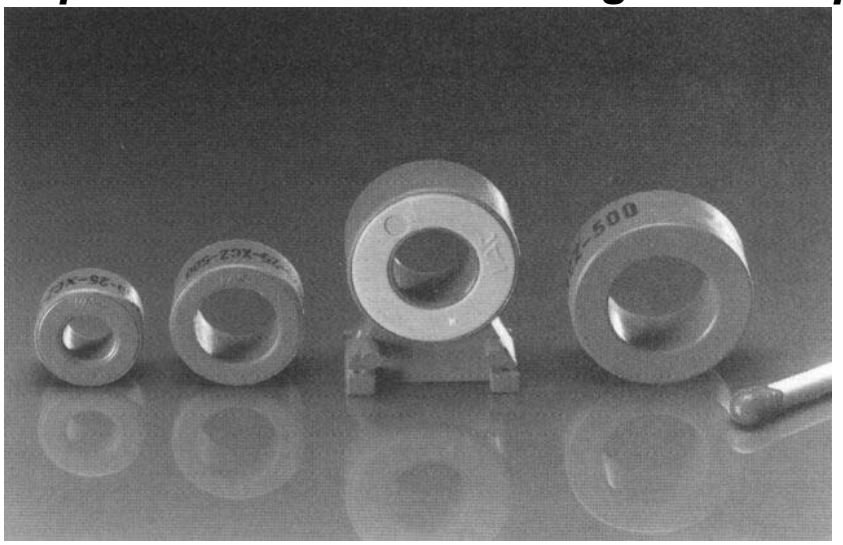
VITROVAC 6025 Z



Edition 1998 **PK-002**

VITROVAC 6025 Z

Tape-Wound Cores for Magnetic Amplifier Chokes



The world's first amorphous saturable reactor cores. Highly reliable and most efficient since 15 years.

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1. General Info on the Mag Amp Principle

1.1 The Core Solution for Output Control

The magnetic amplifier (Mag Amp) control technique has become the synonym for reliability in the old 50 Hz days and still is in modern switched-mode power supplies. Nowadays, Mag Amps are mainly used in switched-mode power supplies with multiple outputs to control the output voltages. Push - pull, forward and - more recently - fly-back converter principles with Mag Amp regulation have become established.

In most power supplies only one secondary output voltage is regulated closed-loop to the primary, other secondaries remain open-loop. The dynamic properties of these outputs are determined by the load and the primary switch. To control various different output voltages, independently from one another, different regulation principles are used. Conventional linear regulators reduce efficiency and are often limited to output currents of one or two amperes. Electronic regulators are more efficient but require more parts in the circuitry and are therefore more expensive and less reliable.

The Mag Amp regulation principle offers a low cost, efficient and, owing to the simple design, reliable solution to these problems. It meets the increasing demands on modern switched-mode power supplies excellently. An efficiency level of more than 90% can be realized even at higher switching frequencies. The low RF interference level is advantageous to the suppression filter.

The most popular and particularly economic magnetic amplifiers are those with a performance range from approx. 20 to above 150 W per output, for currents between approx. 1 and 30 A. With the new generation of ultracompact low voltage ICs (2.9 V, 3.3 V) suitable small Mag Amp cores are available at attractive prices.

1.2 Cores from VAC

With increasing frequencies core properties have become more and more important. It is now almost 15 years since one of VAC's innovative customers ran tests using the Co-based amorphous VITROVAC 6025Z - at that time VAC's most innovative core material.

The performance of VITROVAC 6025Z cores was convincing right from the start. Since then the cores have been continuously improved and, nowadays more than ever represent a state-of-the-art alloy for modern power supply output regulation.

This brochure describes VAC's standard types of VITROVAC 6025 Z cores, their magnetic properties, testing methods and guaranteed values, gives some hints on how to select the core size and number of turns, as well as how to estimate core and copper losses, wire diameter, reset current and temperature rise.

VAC, a Siemens subsidiary, is the number 1 supplier in Europe for amorphous and nanocrystalline cores and inductive components using these cores. Fields of application for VAC cores and components are transformers and chokes for digital communication equipment, SMP's and converters up to several 10kW of power. VAC is certificated according to ISO 9000 since 1993.

1.3 Basic Principle of Operation

The heart of a Mag Amp-choke is a toroidal core made from a soft-magnetic alloy with rectangular hysteresis loop and, in most cases, just one winding for operation and control currents. The specification requirements with regard to choke material are very high. In addition to low magnetic reversal losses (effect on heat build-up, control current, efficiency), a markedly rectangular hysteresis loop featuring high remanence (effect on control range) and good saturation behaviour is required. For this reason, amorphous Co-based alloys such as VITROVAC 6025 Z have been accepted worldwide as ideal materials for this application.

The function of the Mag Amp can be described as a high speed on/off switch similar to a switching transistor. The rectangular B-H loop is causally related to two operating states. The switch is open as long as the choke is magnetized and the current flow to the output is blocked. As soon as the core material is saturated, the switch is on and current starts to flow to the output. This effect is based on a rapid change in impedance IZI (or inductivity L or permeability μ) of the choke across 3-4 orders of magnitude when going into saturated condition.

This switching function is used for pulse width control of the voltage pulse induced in the respective secondary winding (before this pulse is rectified and smoothed by the output filter). Figure 1 provides an illustration of the operating principle. Intervention takes place at the leading edge of the pulse by delaying the voltage rise for the time period Δt_{Reg} . This ,,off"-state is switched in the ,,on" position when the core reaches saturation. By modifying the duration of Δt_{Reg} it is possible to achieve an exact regulation of the output voltage. If for example the output voltage becomes too high, the delay time at the leading edge of the pulse increases and as a consequence the output voltage decreases until the desired value is reached. Following the law of induction, Δt_{Reg} can be adjusted by varying the operating point A on the hysteresis loop (see Figure 2), respectively its flux density swing ΔB_{Reg}:

$$\Delta t_{Reg} = \frac{N \times A_{Fe} \times \Delta B_{Reg}}{\hat{u}}$$

$$\Delta t_{Reg} = \frac{N \times \Phi_{Reg}}{\hat{u}}$$

N represents the number of turns, A_{Fe} the effective magnetic cross-section, and û is the voltage applied. $\phi_{Reg} = A_{Fe} \times \Delta B_{Reg}$ is designated as magnetic flux from operation point to saturation.

During the switch-off period of the primary switching transistor the reset of the Mag Amp from saturation to the operating point A is achieved by applying a current in the opposite direction. Some remarks on the regulation circuitry are given in Appendix 4.3. Figure 1 illustrates the waveforms of voltage and current for a single forward transformer with a duty cycle of 0.5 at different positions of the circuitry. u1 represents the transformer output voltage. Waveform u_{MagAmp} shows the voltage applied to the Mag Amp. Please note that the volt second products of reset (,,reset area") and the following delay period (,,delay area") are equal. The voltage at the output side of the Mag Amp is given in waveform u2 with u2 = u1 - u_{MagAmp}. The rectified voltage at the input of the smoothing filter is shown as u3.

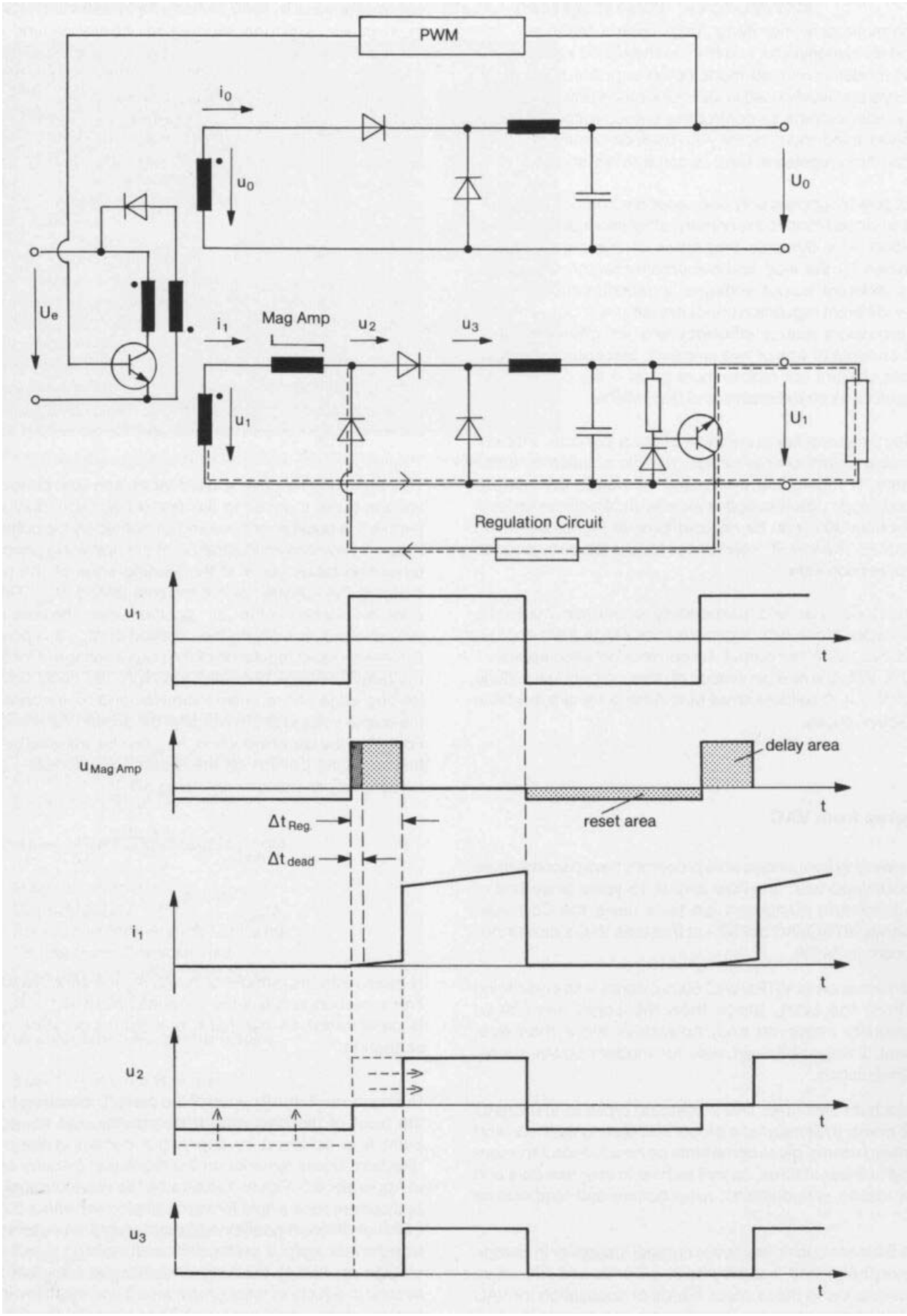


Figure 1: Basic Operating Principle of Magnetic Amplifier Regulation

The "dead time" defined as Δt_{dead} in Figure 1 occurs due to the non-ideal characteristics of real magnetic materials regarding the difference between remanence and saturation (even if, e.g., amorphous metals have already come very close to this ideal). The magnetic core will always be magnetized from remanence to saturation even if no control current is applied. During this period the voltage is blocked.

Dead time is dependent on remanence flux density swing ΔB_{rs} and, of course, on the magnetic cross-section and number of turns. Naturally, this additional voltage drop needs to be taken into account when defining the transmitter output voltage. The latter has a major influence on the design of the choke, i.e. cross-section and number of turns.

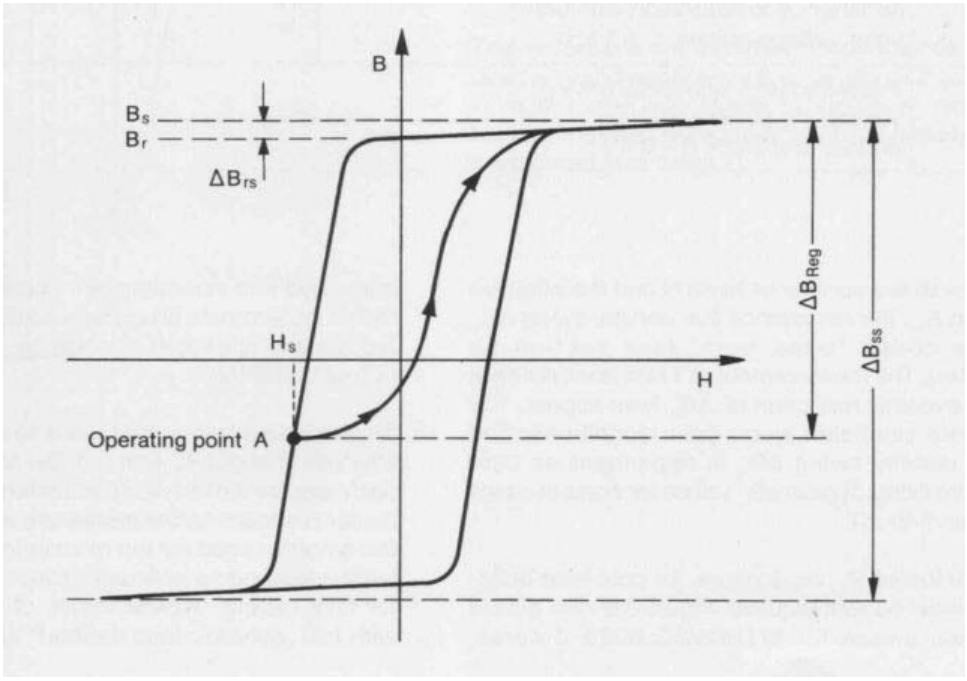


Figure 2: Operating on the B-H Loop of the Magnetic Core

2. Properties of VITROVAC 6025 Z Cores

2.1 Magnetic Properties

Table 1: Magnetic Properties of VITROVAC 6025 Z Cores (typical values)

Property	Term	Typical Value
Saturation flux density (25 °C)	B_s	0.58 T
Saturation magnetostriction (25 °C)	λ_s	< $0.2x10^{6}$
Curie temperature	Tc	240 °C
Bipolar flux density swing (25 °C)	ΔB_{ss}	1.15T
Bipolar flux density swing (90 °C)	ΔB_{ss}	1.0T
Bipolar flux density swing (120 °C)	ΔB_{ss}	0.8 T (min.)

2.2 Magnet Quality

The magnet quality defines test conditions, test scope, and permitted limiting values to ensure proper operation of Mag Amp chokes with VITROVAC 6025 Z cores. The relevant core properties are:

- **total flux ϕ_{ss}** => to avoid voltage drop at low loads
- **squareness of the hysteresis loop B(H)** => to avoid voltage drop at full loads
- **cores losses** => to avoid excessive temperature rise

The total magnetic flux of each single core produced by VAC is measured on-line during core production. Testing conditions and limiting values for the squareness of the hysteresis loop and the core losses are defined in our magnetic quality XCZ-500 shown below. Additionally, a data sheet for each core size can be supplied.

Table 2: Magnetic quality XCZ-500:

Testing property	Testing method	Testing value			
		cased cores		coated cores	
		outer diameter > 12,5 mm:	outer diameter < 12,5 mm:	outer diameter > 12,5 mm:	outer diameter < 12,5mm:
squareness	measurement of the residual flux density swing ΔB_{rs} from remanence to saturation with unipolar voltage pulses, fp = 1 kHz	< 50mT	< 75mT	<80mT	<140mT
core losses P_{Fe}	measured with sinusoidal driving voltage (f = 50 kHz) and flux density amplitude B_{max} = 0.4 T	< 65 W/kg		< 75 W/kg	

When multiplied with the number of turns N and the effective iron cross-section A_{Fe}, the remanence flux density swing ΔB_{rs} determines the choke "dead time" (see section on dimensioning notes). The measurement at 1 kHz does not take into account the dynamic reduction of ΔB_{rs} from approx. 100 kHz, and therefore simulates worst case conditions. The remanence flux density swing ΔB_{rs} is dependent on core dimension and core fixing. Typical ΔB_{rs} values for cores in cases are between 15 and 40 mT

Magnetic reversal losses P_{Fe} are a gauge for core heat build-up as well as the reset current required. Figure 3 shows typical magnetic reversal losses for VITROVAC 6025 Z cores, measured with sine-shaped induction. In practice, somewhat higher losses are to be expected for unfavourable voltage form factors and operation of cores far into their saturation (high output currents).

An alternative testing method is to drive the cores with a field strength of about 80 A/m (= 1 Oe) and a frequency of 100 kHz and measure the relevant parameters directly from the dynamic hysteresis loop. As the results are influenced by the quality of the amplifier used for the measurement, we prefer to use this testing method for characterization of the cores only, and not for final testing. Typical values of VITROVAC 6025 Z cores with this “dynamic loop method" are indicated in Figure 4.

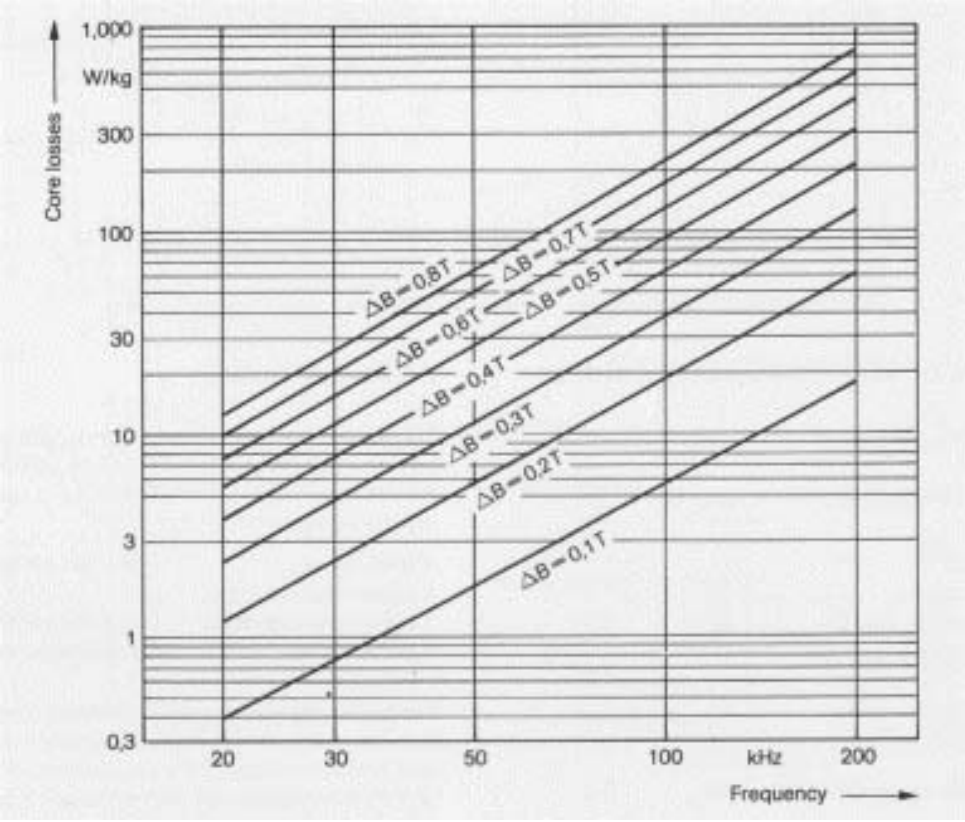


Figure 3: Typical Core Losses of VITROVAC 6025 Z Cores

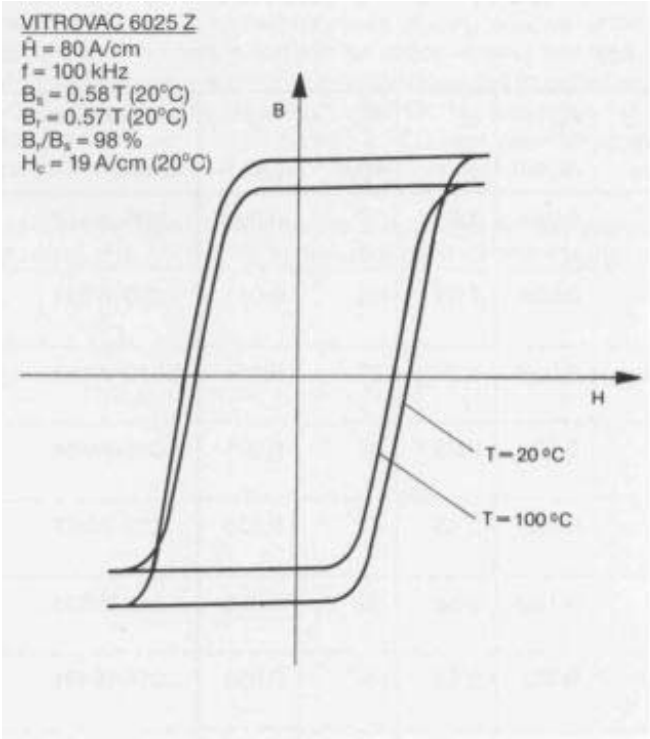


Figure 4: Dynamic Hysteresis Loop (Typical Values)

2.3 Application Temperature Limit and Temperature Characteristics

VITROVAC 6025 Z tape-wound cores have been designed for an upper continuous operating temperature of 90 °C. At higher temperatures, irreversible changes in dynamic coercive force might occur to a minor extent; however, up to approx. 120 °C these are usually within the typical variation range of magnetic characteristics.

The reversible temperature dependence of core losses, coercivity and remanence flux density swing ΔB_{rs} are negligible in most cases (see Figure 5). However, please note that at higher temperatures a lower total flux density swing has to be considered (see Table 1).

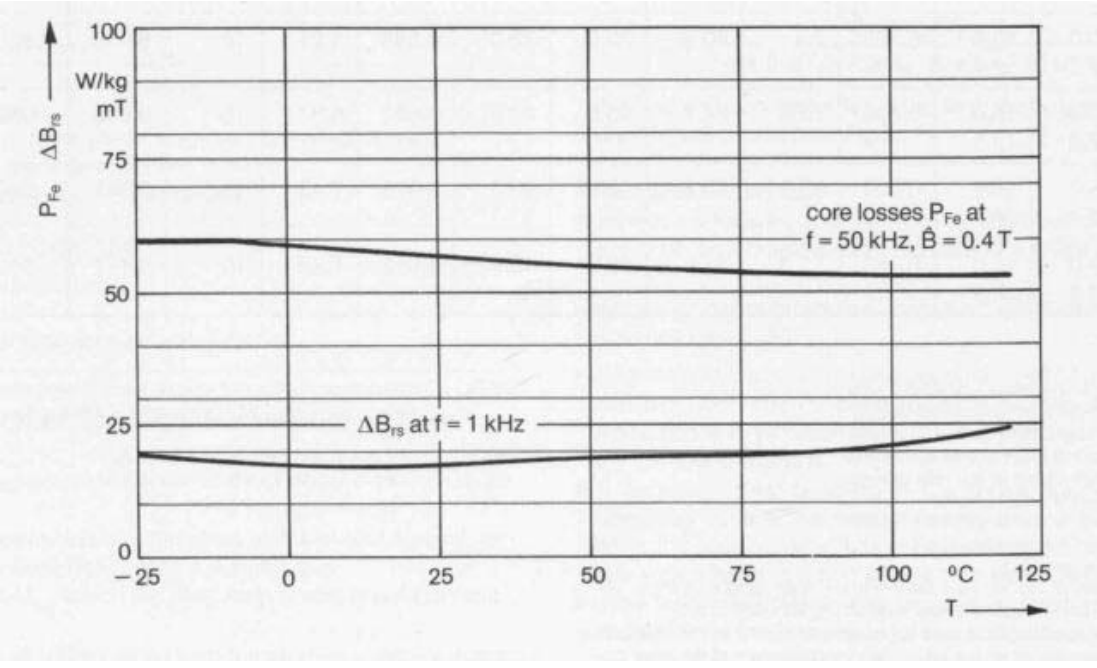


Figure 5: Reversible Temperature Dependence of Core Losses P_{Fe} and Remanence Flux Density Swing ΔB_{rs}

2.4 Core Design and Standard Sizes

Table 3: VITROVAC 6025 Z cores for Mag Amps, standard sizes, Fix 022

d_1 D_1 mm	d_2 D_2 mm	h_1 H_1 mm	A_{Fe} cm^2	l_{Fe} cm	m_{Fe} g	ϕ_{ss} (25°C) µWb	ϕ_{ss},min (90°C) µWb	A_{Cu} cm^2	l_{Cu} cm	R_{th} K/W	W_axA_{Fe} cm^4	part number T60006-E4
8.0 9.7	4.6 3.1	4.0 5.1	0.054	1.98	0.8	6.2	5.4	0.019	1.91	79	0.004	...008-W462
10.0 11.6	8.0 6.5	4.0 5.1	0.032	2.83	0.7	3.7	3.2	0.082	2.01	56	0.011	...010-W534
10.1 11.6	6.9 5.5	4.5 6.0	0.058	2.67	1.2	6.7	5.8	0.059	2.24	57	0.014	...010-W663
12.8 14.7	9.5 7.9	3.2 4.8	0.042	3.50	1.1	4.8	4.2	0.121	2.23	44	0.021	...012-W464
12.0 14.0	8.0 6.6	4.5 6.2	0.072	3.14	1.7	8.3	7.2	0.085	2.45	47	0.025	...012-W547
12.5 14.0	10.0 8.5	5.0 6.8	0.050	3.53	1.4	5.8	5.0	0.140	2.56	42	0.028	...012-W535
14.0 15.5	8.0 6.5	4.5 5.7	0.108	3.46	2.9	12.4	10.8	0.082	2.53	44	0.036	...014-W481
16.0 17.9	10.0 8.2	6.0 8.2	0.144	4.08	4.5	16.6	14.4	0.131	3.20	34	0.076	...016-W536
17.5 19.1	12.5 10.9	6.0 8.1	0.120	4.71	4.4	13.8	12.0	0.231	3.30	30	0.112	...017-W537
19.0 21.2	15.0 13.0	5.0 7.3	0.080	5.34	3.3	9.2	8.0	0.329	3.17	27	0.106	...019-W539
19.0 21.2	15.0 13.0	10.0 12.3	0.160	5.34	6.6	18.4	16.0	0.329	4.25	24	0.212	...019-W540
20.0 22.6	12.5 10.3	8.0 10.2	0.240	5.1	9.4	27.6	24.0	0.206	4.05	26	0.200	...020-W538
25.0 27.9	16.0 13.6	10.0 12.5	0.360	6.44	17.9	41.4	36.0	0.360	4.96	19	0.523	...025-W541
25.0 27.7	20.0 17.1	10.0 12.9	0.200	7.1	10.9	23.0	20.0	0.568	4.91	18	0.459	...025-W542
30.0 32.8	20.0 17.6	10.0 12.5	0.400	7.85	24.2	46.0	40.0	0.602	5.37	16	0.973	...030-W543
40.0 43.1	25.0 22.4	15.0 18.5	0.900	10.2	70.8	103.5	90.0	0.975	7.43	11	3.547	...040-W544
40.0 43.3	32.0 28.8	15.0 18.3	0.480	11.3	41.8	55.2	48.0	1.612	7.30	10	3.127	...040-W545

d_1 = nominal external diameter of core
d_2 = nominal internal diameter of core
h_1 = nominal height of core
D_1 = maximal external diameter of case
D_2 = minimal internal diameter of case
H_1 = maximal height of case
A_{Fe} = effective iron cross-section in cm^2
l_{FE} = mean iron path length in cm
m_{Fe} = core mass in g
A_{Cu} = effective copper cross-section in cm^2 (calculated by using a copper fill factor 0.33 and a remaining hole ratio of 0.5. The remaining hole ratio is the internal diameter of the wound core (remaining hole) divided by the interior diameter of the case)
l_{Cu} = mean length of a copper turn in cm
R_{th} = heat transfer resistance of an open wound choke with free convection in K/W

W_axA_{Fe} = core area product in cm^4, used in some other methods of Mag Amp choke design. W_a is the available winding area of the case in cm^2
ϕ_{ss} = total flux in µWb with $\phi_{ss} = 2 \times B_s \times A_{Fe}$.
$\phi_{ss, min}$ = total flux in µWb (minimum value at 90°C)

Updated core range and most popular standard sizes can be seen under http://www.vacuumschmelze.com

The standard core sizes for Magnetic Amplifiers are preferably supplied in plastic protective cases, adding silicone rubber (Fix 022). This finish is suitable for direct winding and offers optimum mechanical protection for the core, and thus the best magnetic properties. The resins used for the core cases fulfil for the most part UL94V-0 (with 130°C heat resistance), in particular cases UL94HB (with 120°C heat resistance).

As a further type of finish we are able to offer an epoxy resin coating (Fix 350). Due to the reduction of the magnetic properties this type of fixing is only to be recommended if special core sizes are required.

2.5 Order Information

For your orders please use our part numbers as given in Table 3.

In addition to the delivery of cores, we also offer the possibility of purchasing already wound cores (components). You will find information on these in our product sheet PB-410-2.

3. How to calculate a Mag Amp Choke

Although the Mag Amp choke is a very simple inductive component consisting of a core and some copper turns only, careful consideration of all influencing parameters is necessary to achieve a cost optimized design without too high temperature rise of the choke.

variables:
effective cross-section A_{Fe} (core size) number of turns N wire diameter d_{Cu} winding area A_{Cu}
influencing factors:
circuit design output voltage U_1 voltage drops in magnetic amplifier controlled circuit voltage drops in main circuit possibly: short-circuit-proof design
to be taken into account:
magnetic core losses copper losses dead time" of magnetic amplifier choke

3.1 Selection of Core Size and Number of Turns

Starting parameters are

- the wire size (which is determined by the output current, for example current density S = 4 A/mm^2) and

- the voltage U_{Reg} which the Mag Amp choke should control.

U_{Reg} can be calculated for a given transformer output voltage $\hat{u}_{min}$ where there are no short-circuit requirements by:

$$U_{Reg} = \alpha \times \tau_{max} \times \hat{u}_{min} - U_1$$

and for a short-circuit-proof design by:

$$U_{Reg} = \alpha \times \tau_{max} \times \hat{u}_{min}$$

τ_{MAX} is then the maximum duty cycle ratio of the primary switching transistor, α = 1 for forward converter principle, α = 2 for push-pull.

If the transformer voltage is not fixed, Appendix 4.2 gives some hints on how to find a suitable value.

- The required number of turns can be calculated by:

$$N \geq \frac{10 \times U_{Reg}\,(V)}{\alpha \times 0.8(T) \times K \times A_{Fe}\,(cm^2) \times f\,(kHz)}$$

K is a correction factor for ΔB to limit the temperature rise due to core losses (see Figure 6).

- start with a small core
- increase core size, until the required number of turns can easily be distributed around the core in a single layer.

Now “empirical optimization" can start. Here, the following notes may be helpful:

- If the magnetic amplifier choke becomes too hot during open circuit or short-circuit operation, iron losses are the reason. A solution is to increase either the iron cross-section A_{Fe} or the number of turns N.
- If excessive heat build-up in the choke during full load operation occurs, the copper losses are too high. In this case, the wire diameter has to be increased. The next core size with a larger winding area is then perhaps necessary.
- “Too high" secondary voltages of the transformer cause excessive full load operation losses. If this occurs the choke will still need to correct this "excess" voltage, even under full load operating conditions, thus causing additional losses. A correction of the turn ratio (if possible) can solve this problem. Please see also Appendix 4.2.

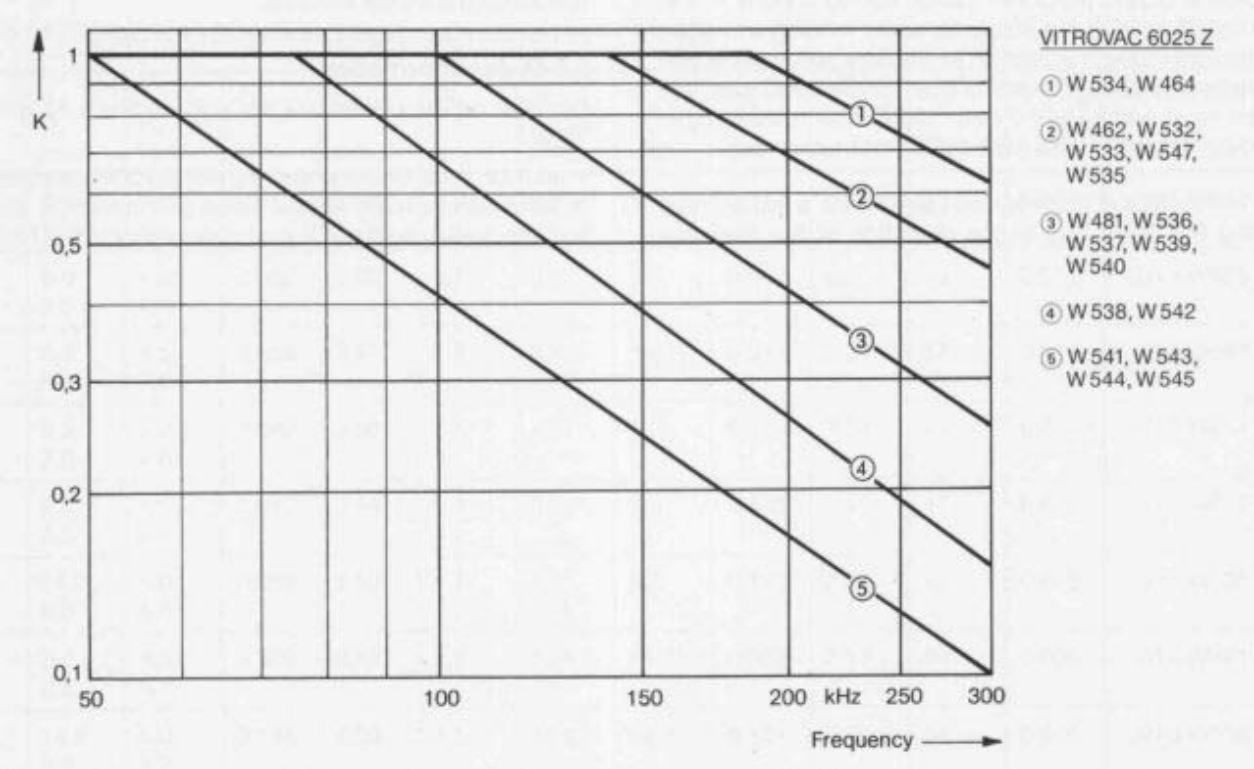


Figure 6: Empirical Correcting Factor K for a Temperature Rise of about 30 K

3.2 Estimation of the Control Current

The control current I_s is given by:

$$I_s = \frac{H_s\,(mA/cm) \times l_{Fe}\,(cm)}{N}$$

The reset field strengh H can be estimated by:

$$\Delta B_{Reg}\,(T) = \frac{10 \times U_{Reg}\,(V)}{\alpha \times N \times A_{Fe}\,(cm^2) \times f\,(kHz)}$$

with:

$$H_s\,(mA/cm) \approx 0.47 \times f\,(kHz)^{1.25} \times \frac{\Delta B_{Reg}\,(T)}{0.8}$$

3.3 Example:

Single forward converter principle; transformer output voltage (amplitude) $\hat{u}_{min}$ = 12 V; switching frequency f = 150 kHz; duty cycle τ_{max} = 0.5; output current I_1 = 10 A (RMS); U_1 = 3.3 V.

Not short-circuit proof:

- Required cross section per wire with current density S = 4 A/mm^2: 2.5 mm^2
- Voltage which the Mag Amp choke should control:

$U_{Reg} = \alpha \times \tau_{max} \times \hat{u}_{min} - U_1$

U_{Reg} = 1 x 0.5 x 12 V – 3.3 V = 2.7 V

First approach with core T60006-E4008-W462:

8 x 4.6 x 4 mm
A_{Fe} = 0,054 cm^2
l_{Fe} = 1.98 cm
K = 1 (value taken from fig. 6)

Short-circuit proof:

- Required cross section per wire with current density S = 4 A/mm^2: 2.5 mm^2
- Voltage which the Mag Amp choke should control:

$U_{Reg} = \alpha \times \tau_{max} \times \hat{u}_{min}$

U_{Reg} = 1 x 0.5 x 12 V = 6 V

First approach with core T60006-E4012-W535:

12.5 x 10 x 5 mm
A_{Fe} = 0,05 cm^2
l_{Fe} = 3.53 cm
K = 1 (value taken from fig. 6)

• Minimum number of turns:

$$N \geq \frac{10 \times U_{Reg}\,(V)}{\alpha \times 0.8\,(T) \times K \times A_{Fe}\,(cm^2) \times f\,(kHz)}$$

$$N \geq \frac{10 \times 2.7\ V}{1 \times 0.8\ T \times 1 \times 0.054\ cm^2 \times 150\ kHz} = 4.2$$

The available copper winding area A_{Cu} according to Table 3 is about 2 mm^2. Thus there is no possibility to wind 5 turns of copper wire with cross section 2.5 mm^2.

Next approach with core T60006-E4012-W535:

12.5 x 10 x 5 mm

A_{Fe} = 0.05 cm^2
l_{Fe} = 3.53 cm
K = 1 (value taken from fig. 6)

• Minimum number of turns:

$$N \geq \frac{10 \times 2.7\ V}{1 \times 0.8\ T \times 1 \times 0.05\ cm^2 \times 150\ kHz} = 4.5$$

The available copper winding area A_{Cu} according to Table 3 is about 14 mm^2. Empirical testing now can start with this core.

• Calculation of required control current

$$\Delta B_{Reg}\,(T) = \frac{10 \times U_{Reg}\,(V)}{a \times N \times A_{Fe}\,(cm^2) \times f\,(kHz)}$$

$$\Delta B_{Reg}\,(T) = \frac{10 \times 2.7\ V}{1 \times 5 \times 0.05\ cm2 \times 150\ kHz} = 0.72\ T$$

$$H_s\,(mA/cm) \approx 0.47 \times f\,(kHz)^{1.25} \times \frac{\Delta B_{Reg}\,(T)}{0.8}$$

$$H_s\,(mA/cm) \approx 0.47 \times 150^{1.25}\ kHz \times \frac{0.72\ T}{0.8}$$

$$H_s\,(mA/cm) \approx 222\ \frac{mA}{cm}$$

$$I_s = \frac{H_s\,(mA/cm) \times l_{Fe}\,(cm)}{N}$$

$$I_s = \frac{(222\ mA/cm \times 3.53\ cm)}{5} = 157\ mA$$

Allow for some margin.

• Minimum number of turns:

$$N \geq \frac{10 \times 6\ V}{1 \times 0.8\ T \times 1 \times 0.05\ cm^2 \times 150\ kHz} = 10$$

The available copper winding area A_{Cu} according to Table 3 is about 14 mm^2. Thus there is no possibility to wind 10 turns of copper wire with cross section 2.5 mm^2.

Next approach with core T60006-E4017-W537:

17.5 x 12.5 x 6 mm

A_{Fe} = 0.12 cm^2
l_{Fe} = 4.71 cm
K = 0.6 (value taken from fig. 6)

• Minimum number of turns:

$$N \geq \frac{10 \times 6\ V}{1 \times 0.8\ T \times 0.6 \times 0.12\ cm^2 \times 150\ kHz} = 7$$

The available copper winding area A_{Cu} according to Table 3 is about 23.1 mm^2. Empirical testing now can start with this core.

• Calculation of required control current

$$\Delta B_{Reg}\,(T) = \frac{10 \times 6\ V}{1 \times 7 \times 0.12\ cm2 \times 150\ kHz} = 0.48\ T$$

$$H_s\,(mA/cm) \approx 0.47 \times 150^{1.25}\ kHz \times \frac{0.48\ T}{0.8}$$

$$H_s\,(mA/cm) \approx 148\ \frac{mA}{cm}$$

$$I_s = \frac{(148\ mA/cm \times 4.71\ cm)}{7} = 100\ mA$$

Allow for some margin.

4. Appendix

4.1 Core and Copper Losses in Theory

Before or in addition to experimental testing, the following approximation formula can be used to check the temperature rise due to core and copper losses:

Core losses P_{Fe} (approximation):

P_{Fe} (W / kg) = 0.021 x f^2 x ΔB_{Reg}^2 + 0.109 x $f^{1.5}$ x $\Delta B_{Reg}^{1.5}$

with f in kHz and ΔB_{Reg} in T.

Temperature rise ΔT_{Fe}:

ΔT_{Fe} (K) = R_{th} (K / W) x P_{Fe} (W / kg) x m_{Fe} (kg)

Copper losses P_{Cu} (approximation not considering skin and proximity effects):

$$P_{Cu}\,(W) \approx \frac{I_{out}\,(A)^2 \times N^2 \times l_{Cu}\,(cm) \times \rho_{Cu}\,(\Omega m)}{20 \times A_{Cu}\,(cm^2)}$$

Temperature rise ΔT_{Cu}:

$$\Delta T_{Cu}\,(K) = R_{th}\,(K/W) \times P_{Cu}\,(W)$$

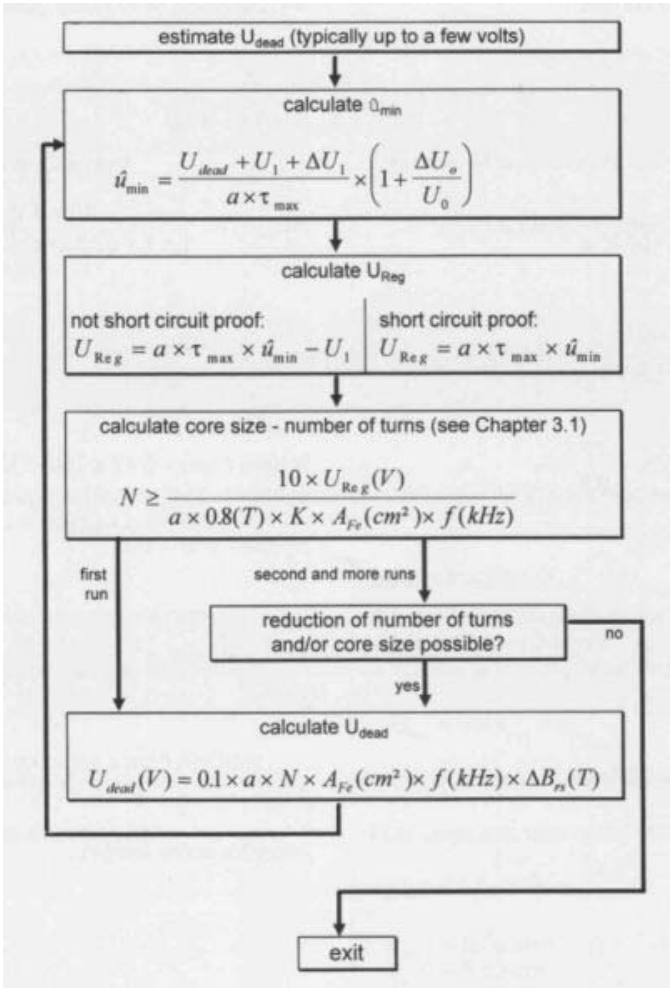
I_{out} is the maximum output current (direct current). Approximate values of the heat-transfer resistance of an open wound choke R_{th} with regard to free convection are listed in Table 3, as well as A_{Fe}, A_{Cu}, l_{Fe}, and l_{Cu}. The specific electrical resistance of copper ρ_{Cu} is given for T= 80-100 °C as ρ = 2.3 µΩm.

The total losses will be smaller than the sum of magnetic reversal losses and copper losses as in full load operation (maximum copper losses) the control current and thus ΔB_{Reg} and P_{Fe} will be particularly low. Theoretical definition of the worst case, i.e. the operating condition with maximum total losses, is difficult; for this reason, we recommend proceeding empirically.

4.2 Notes on more Theoretical Fine Tuning

Some more theoretical ,,fine tuning" is possible, if the transformer output voltage can be adjusted. Then, the following iteration process may be used.

Please see Figure 7 for explanation of the voltages and voltage drops in a typical SMP's configuration.



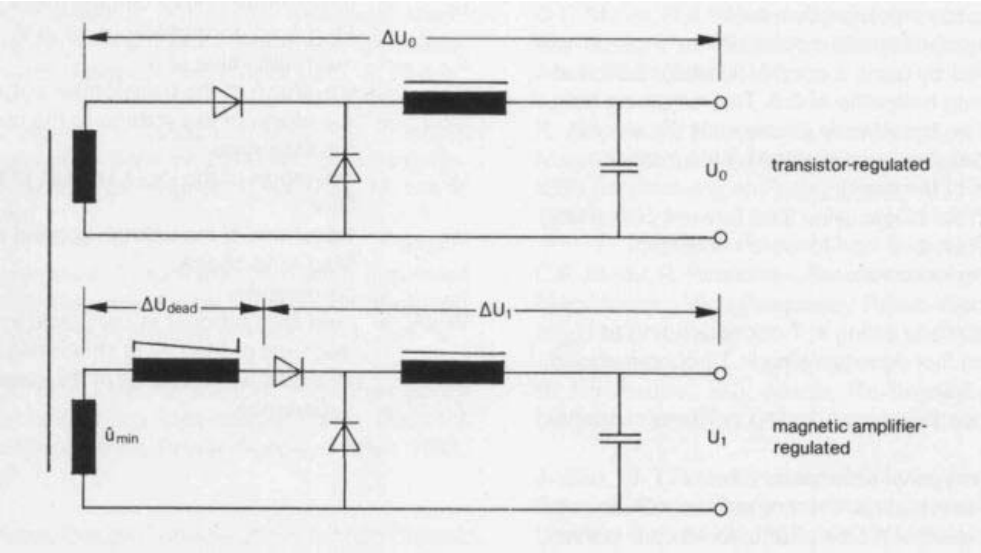


Figure 7: Principle Circuit with Voltages and Voltage Drops

4.3 Notes on Regulation Circuits

Several different principles of regulation circuits are well-established. To describe them all would be beyond the scope of this brochure. The interested readers are referred to the relevant literature. In the following, some general remarks are given and two well known principles are summarized.

The volt seconds applied to the Mag Amp during the switch-off period of the transformer secondary circuit adjust the operating point of the Mag Amp due to the desired delay of the following pulse. This is done by either ”voltage-" or “current-reset". The preferred type of reset depends mainly on the design of the reset circuit and its output impedance, respectively.

For example with a shunt controller 1C 431 very precise regulation circuitries are possible which are easy to implement and attractive in price. Very compact Mag Amp regulated switch mode power supplies in a modular design can easily be realized by using an integrated controller. The UC1838 for example has been designed specifically as a controller for Mag Amp switching regulators and provides a low-cost, easy to use, single chip solution.

5. Definition of Terms

A_{Fe} = effective iron cross-section in cm^2

A_{Cu} = effective copper cross-section in cm^2 (calculated by using a copper filling factor 0.33 and a remaining hole ratio of 0.5. The remaining hole ratio will be the internal diameter of the wound core (remaining hole) divided by the interior diameter of the case)

a = factor = 1 for single cycle feed forward converters, = 2 for push-pull feed forward converters

B_s = saturation induction

B_r = remanence

ΔB_{Reg} = the flux density swing in T corresponding to U_{Reg}

ΔB_{ss} = maximum flux density swing in T (recommended: $\Delta B_{ss} \leq 0.8$ T)

ΔB_{rs} = remanence flux density swing in T (see magnetic quality)

$\hat{B}$ = flux density amplitude (peak value) in T

d_1 = nominal external diameter of unfixed core in mm

d_2 = nominal internal diameter of unfixed core in mm

D_1 = nominal external diameter of fixed core in mm

D_2 = nominal internal diameter of fixed core in mm

f = frequency in kHz

f_p = pulse repetition frequency in kHz

H_1 = nominal height of fixed core in mm

h_1 = nominal height of unfixed core in mm

H_s = reset field strength in mA/cm

I_{out} = maximum output current (direct current) in A

I_s = control current in mA

i1 = waveform of the current of the Mag Amp regulated circuit

K = correcting factor for taking into account magnetic reversal and copper losses (see Figure 6)

l_{Cu} = mean length of a copper winding in cm

l_{Fe} = mean iron path length in cm

λ_s = saturation magnetostriction

m_{Fe} = core mass in g

N = number of turns

P_{Fe} = magnetic reversal losses of the core in W/kg

P_{Cu} = copper losses of the winding in W

Φ_{ss} = total flux in µWb with $\Phi_{ss} = 2 \times B_s \times A_{Fe}$

$\Phi_{ss,min}$ = total flux in µWb (minimum value at 120°C)

Φ_{Reg} = magnetic flux corresponding to ΔB_{Reg}

ρ_{Cu} = specific electrical resistance of copper ($\rho_{Cu} \approx 2.27*10^{-5}\ \Omega$m at T = 80-100 °C)

R_{th} = heat-transfer resistance of an open wound choke with free convection in K/W

S = max. permissible current density of wire

T_C = Curie temperature

ΔT_{Fe} = maximum excess temperature of the core in K

ΔT_{Cu} = maximum excess temperature of the winding in K

Δt_{Reg} = delay time of the Mag Amp choke corresponding to ΔB_{Reg}

Δt_{dead} = dead time of the core corresponding to ΔB_{rs}

τ_{max} = maximum pulse duty ratio of the primary switching transistor

U_{Reg} = maximum voltage in V to be controlled by the magnetic amplifier choke

U_0 = nominal output voltage in V (Figure 1 and 7) of main output (transistor regulated)

U_1 = nominal output voltage in V (Figure 1 and 7) of magnetic amplifier regulated output

ΔU_0 = voltage drops in V (Figure 1 and 7) in main circuit

ΔU_1 = voltage drops in V (Figure 1 and 7) in magnetic amplifier-regulated circuit (without voltage drop across the magnetic amplifier choke)

ΔU_{dead} = minimum voltage drop in V across magnetic amplifier choke („dead time“)

$\hat{u}$ = transformer output voltage (peak value) for the Mag Amp controlled output in V

$\hat{u}_{min}$ = minimum value of $\hat{u}$

u1 = waveform of the transformer output voltage

u2 = waveform of the voltage at the output side of the Mag Amp

u3 = waveform of the input voltage of the smoothing filter

u_{MagAmp} = waveform of the voltage applied to the Mag Amp choke

μ = permeability

W_a*A_{Fe} = core area product in cm^4, used in some other methods of Mag Amp choke design. W_a is the available winding area of the case in cm^2

Z = impedance

6. Relevant Publications

R. Hiramatsu, K. Harada, T. Ninomiya, Switched Mode Converter Using High-Frequency Magnetic Amplifier, Powerconversion International, March-April 1980, S. 75-82

R. Hiramatsu, K. Harada, I. Sasada, A Magnetic Amplifier Controller of Amorphous Cores for a 200 kHz Switching Regulator, IEEE Transactions on Magnetics, Vol. Mag. 18. No. **6,** 1982,S. 1764-1766

S. Takeda, K. Hasegawa, T. Yamada, Designing Improved Saturable Reactors Regulators with Amorphous Magnetic Materials, Proceedings of Powercon 9, 1982, C1-1, S. 1-12

M. Yamaguchi, K. Murakami, T. Kikuchi, High Frequency Characteristics of Amorphous Tape-Wound Cores Used for Controlling a Switched-Mode Power Supply, Intelec 1983, Tokyo, S. 400-407

T. Koyashiki, T. Okata, Design Considerations in Multi-Output DC-DC Converters with Magnetic Amplifiers, Intelec 1983, Tokyo, S. 388-394

R.J. Taylor, Optimizing High Frequency Control Magamp Design, Proceedings of Powercon 10, 1983, A-1, S. 1-12

U. Schwarz, Multiple Output Switch Mode Power Supplies Using Saturable Reactor Control, Intelec 1985, Munchen, S. 339-344

C.E. Mullett, R. Hiramatsu, An Improved Parallel Control Circuit for Saturable Reactor Output Regulators in High-Frequency Switched-Mode Converters, IEEE APEC Proceedings, April, 1986

C.E. Mullet, R.A. Mammano, Using an Integrated Controller in the Design of Mag-Amp Output Regulators, Unitrode Application Note U-109

K. Harada, T. Nabeshima, R. Hiramatsu, On the Control of Magnetic Amplifiers for High Frequency DC to DC Converters, IEEE Transactions on Power Electronics, Vol. PE-2, No.#, July 1987

C.E. Mullet, R. Hiramatsu, Recent Advances in High Frequency Mag. Amps., High Frequency Power Conversion, Washington, 1987

R. Hiramatsu, H.J. Marik, Re-Entrant Characteristik of Magnetic Amplifier: A New Analysis,Powercon 1988, Kyoto

J. Lee, D. Chen, C. Jamerson, MagAmp Post Regulator, Practical Considerations to Allow Operation Under Extreme Loading Conditions, IEEE APEC Conference, 1988

C. Jamerson, D. Chen, Techniques for Reduction of Required Headroom in High Frequency MagAmp Post Regulators, HFPC, June 1991 Proceeding

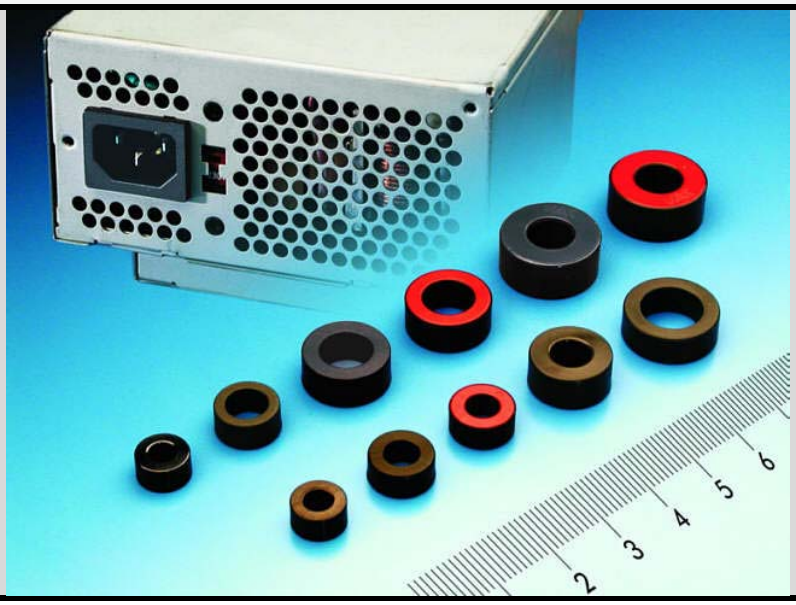
J. S. Elias, Amorphous Magnetic Materials - Part II: High-Frequency Mag-Amp Output Regulator, PCIM issue September 1993

J. S. Elias, Amorphous Magnetic Materials - Part III: High-Frequency Mag-Amp Output Regulator - Reset and Control Circuit Designs , PCIM issue October 1993

New

Tape-Wound Cores for Magnetic Amplifier Chokes

nanocrystalline VITROPERM 500 Z



New core material

VITROPERM® 500 Z - a new class of Fe-based nanocrystalline soft magnetic material developed specially for use in Saturable Reactors and Magnetic Amplifiers is another innovative development by VACUUMSCHMELZE GmbH & Co. KG to meet the ever increasing demands of the marketplace.

Benefits of nanocrystalline MagAmp cores

- ☑ **high squareness** – enabling good regulation behaviour and reduced dead-time of MagAmp Choke
- ☑ **very high induction swing** - high magnetic flux in small core sizes
- ☑ **extended temperature range** up to 120°C
- ☑ **low coercivity** - enabling small reset currents
- ☑ **low core losses** – for operation at high frequencies

➨ **reduction of weight, volume and costs**

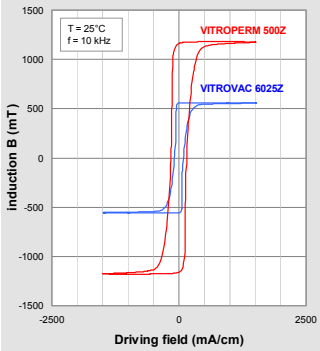
This newly developed material complements the already existing amorphous material - Co-based high-squareness VITROVAC® 6025 Z. This is presently being widely used in Magnetic Amplifier Chokes (MagAmps) for secondary output voltage regulation in various kinds of SMPS with multiple outputs.

Making use of the specific material properties of nanocrystalline VITROPERM 500 Z enables reliable MagAmp circuits with good performance in smallest component sizes at significantly reduced costs. Thus, the MagAmp Regulation principle becomes even more attractive in future projects.

The unique property profile of nanocrystalline VITROPERM with flat hysteresis loop prooved to be the most advantageous core material in noise suppression and power conversion, as well as current detection in many different industrial and domestic applications. It combines excellent soft magnetic properties with a very high saturation induction of 1.2 Tesla making this nanocrystalline material all the more interesting where volume and cost matter most.

Furthermore, the thermal stability of the nanocrystalline structure is superior to amorphous materials thereby allowing continuous operating temperatures of up to 120°C and more. With these unbeatable properties, our new square-loop VITROPERM 500 Z with its very high remanence ratio (low ΔB_{rs}, high squareness) is the ideal choice for engineers to design MagAmp circuits which are highly reliable and cost-effective.

Material data, magnetic properties	VITROPERM 500 Z#	VITROVAC 6025 Z	typ. hysteresis loops
Material base	nanocrystalline Fe-based	amorphous Co-based	
Saturation flux density (25°C), B_s	1.2 T	0.58 T	
Bipolar flux density swing (25°C), $\Delta B_{ss,\ 25°C}$	2.35 T	1.15 T	
Bipolar flux density swing (90°C) , $\Delta B_{ss,\ 90°C}$	2.15 T	1.0 T	
Squareness, B_r / B_s (typical value)	> 94%	> 96%	
Core losses P_{Fe} (typ. value at f = 50 kHz, ΔB = 0.8 T)	100 W/kg	60 W/kg	
Static coercivity H_c	< 10 mA/cm	3 mA/cm	
Saturation magnetostriction (25°C)	< 0.5 x 10^{-6}	< 0.2 x 10^{-6}	
Curie temperature, T_c	> 600°C	240°C	
Continuous upper operation temperature	120°C	90°C	
Specific electrical resistivity	1.20 µΩm	1.35 µΩm	
Density	7.35 g/cm³	7.70 g/cm³	



All material data are typical values and preliminary. Deviations to these material characteristics are permitted due to product shape and size.

The following table describes our standard core series of nanocrystalline VITROPERM 500 Z cores. As this standard core range is supplemented continuously, we recommend to contact us for an updated list or to visit our web page: www.vacuumschmelze.com

Core type series of nanocrystalline VITROPERM 500 Z MagAmp cores

core dimensions $d_{a,Core}$ x $d_{i,Core}$ x h_{Core}	finished dimensions (limiting values)			core cross-section	mean core path length	core mass	total flux [1] 25°C	total flux [1] 90°C	core area [2] product	eff. Cu-winding area	mean Cu-path length	heat transfer Resis-tance	part number, order code
	O.D.	I.D.	H	A_{Fe}	l_{Fe}	m_{Fe}	ϕ_{ss}	$\phi_{ss,\ 90°C}$	$W_a \times A_{Fe}$	A_{Cu}	l_{Cu}	R_{th}	
	mm	mm	mm	cm²	cm	g	µWb	µWb	cm⁴	cm²	cm	K/W	T6000...
10×7×4.5	11.7	5.5	6.1	0.054	2.67	1.1	12.7	11.9	0.013	0.059	2.27	57	6-L2010-**W759**
11×8×4.5	14.1	6.6	6.3	0.054	2.98	1.2	12.7	11.9	0.018	0.085	2.53	46	6-L2011-**W760**
12×8×4.5	14.1	6.6	6.3	0.072	3.14	1.7	16.9	15.8	0.025	0.085	2.53	46	6-L2012-**W761**
12.5×10×4.5	14.1	8.5	6.8	0.045	3.53	1.2	10.6	9.9	0.026	0.140	2.59	42	6-L2012-**W762**
12.8×9.5×3.2	14.7	7.9	4.8	0.042	3.50	1.1	9.9	9.3	0.021	0.121	2.26	44	6-L2012-**W803**
16×10×6	18.0	8.0	8.1	0.144	4.08	4.3	33.8	31.7	0.072	0.124	3.25	34	6-L2016-**W763**
16.5×12.5×6	19.1	10.9	8.1	0.096	4.56	3.2	22.6	21.1	0.090	0.231	3.30	30	6-L2016-**W764**
17.5×12.5×6	19.1	10.9	8.1	0.120	4.71	4.2	28.8	26.4	0.112	0.231	3.30	30	6-L2017-**W765**
19×15.2×4.5	21.2	12.9	7.2	0.068	5.37	2.7	16.1	15.0	0.089	0.323	3.28	27	6-L2019-**W766**
20×15×8	22.6	10.3	10.2	0.160	5.50	6.5	37.6	35.2	0.133	0.206	4.08	26	6-L2020-**W767**
20×12.5×8	22.6	10.3	10.2	0.240	5.11	9.0	56.4	52.8	0.200	0.206	4.08	26	6-L2020-**W768**

[1] $\Phi_{ss} = 2 \times B_s \times A_{Fe}$ [2] $W_a \times A_{Fe}$: core area product in cm⁴, W_a is the available winding area of the case

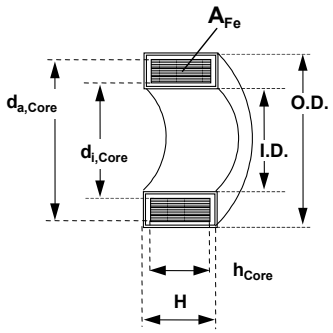
Our MagAmp cores of VITROPERM 500 Z are preferrably supplied in plastic protection boxes, adding silicone rubber (Fix 022). The new material can be identified according to following color scheme:

Plastic case: - dark grey (all)

Plastic cover: - black (W759, W761, W762, W763, W765, W766, W768)
- brown (W760, W764, W767)

Our plastic boxes are suitable for direct winding (even with thick copper wires) and offer optimum mechanical protection for the nanocrystalline core material. This guarantees best magnetic properties. All materials are according UL94V-1/0 (UL-file no. E41871).

Epoxy coated and further core sizes are available upon request.



Magnetic quality, Test specification

Testing property	Testing method, Test conditions	Testing value cased cores
• **squareness ΔB_{rs}**	measurement of residual flux density swing ΔB_{rs} from remanence to saturation with unipolar current pulses (corr. $\hat{H}$ = 200 A/m), repetition frequency f_p = 1 kHz.	**≤ 150 mT**
• **core losses P_{Fe}**	measured with sinusoidal driving voltage (f = 50 kHz) and flux density amplitude swing ΔB = 0.8 T.	**≤ 120 W/kg**

The Magnetic Quality defines test conditions, test scope and permitted limiting values during final inspection of VITROPERM 500 Z cores.

Additionally, the total magnetic flux of each single core is measured on-line during core production to ensure proper and reliable operation in MagAmp Choke applications.

Frequency behavior of P_{Fe}, H_c and ΔB_{rs} of nanocrystalline VITROPERM 500 Z MagAmp cores (T = 25°C)

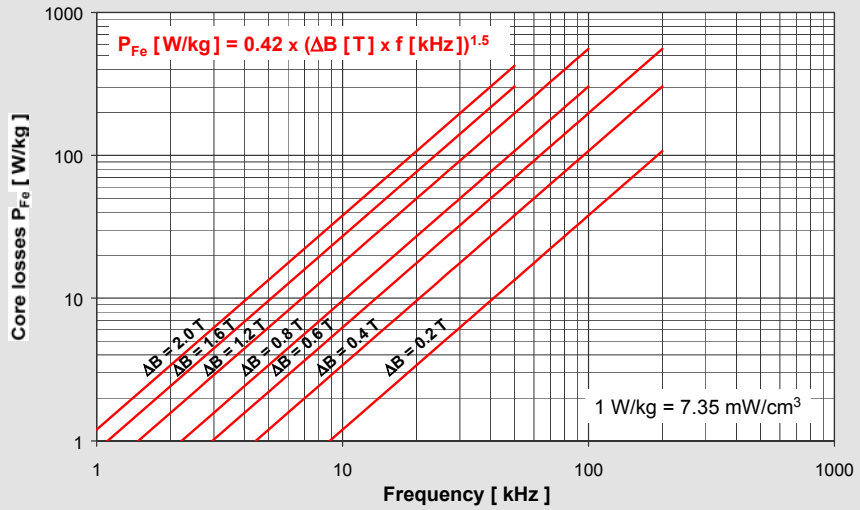
The plotted magnetic reversal losses (core losses) P_{Fe} are measured with sine-wave induction.

Typical values for frequencies up to about 200 kHz can be determined from the graph directly or calculated with the help of the following estimation formulae:

$$P_{Fe}\ [\ W/kg\ ] = 0.42 \times (\ \Delta B \times f\ )^{1.5}$$
$$P_{Fe}\ [\ mW/cm^3\ ] = 3.09 \times (\ \Delta B \times f\ )^{1.5}$$

with flux density swing ΔB in T and frequency f in kHz.

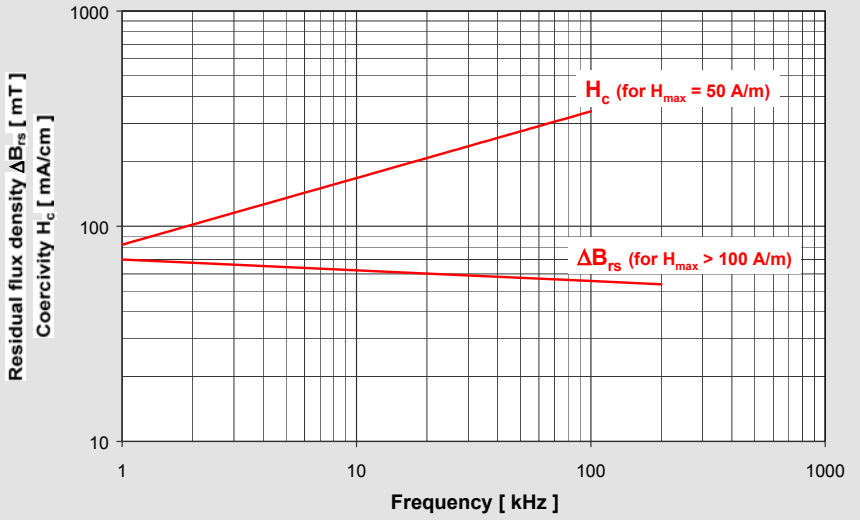
However, unfavorable voltage wave form factors or operation of the cores far into their saturation can, in practice, offer somewhat higher losses.



The pronounced squareness of the hysteresis loop of nanocrystalline VITROPERM 500 Z MagAmp cores will improve even further with increasing frequency by a dynamic reduction of the residual flux density ΔB_{rs}.

Typical ΔB_{rs} values are between 50 and 70 mT at switching frequencies of 100 kHz, which corresponds to a squareness ratio of > 94%. These properties enable short „dead times“ in MagAmp chokes and thus good regulation behavior even at high switching frequencies.

MagAmp cores of nanocrystalline VITROPERM 500 Z offer reasonably small H_c values enabling small reset currents of the regulation circuit.

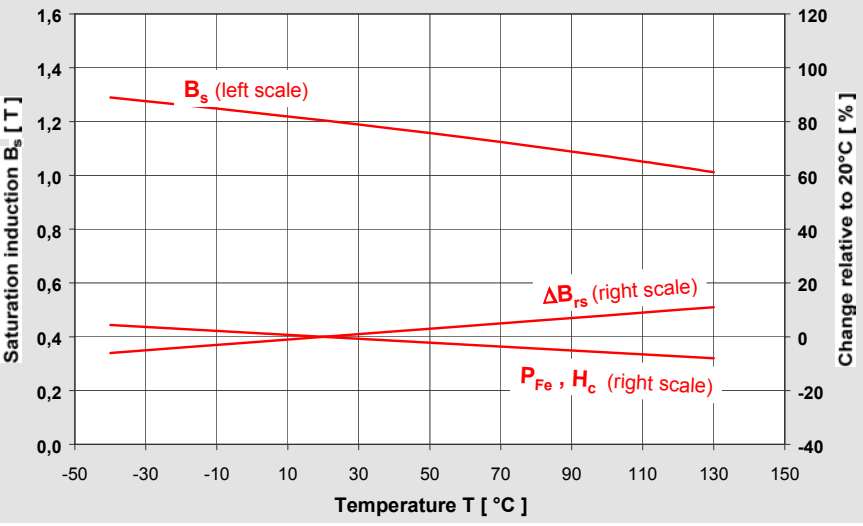


Thermal stability of nanocrystalline VITROPERM 500 Z MagAmp cores

VITROPERM 500 Z tape-wound cores can be operated at upper continuous temperatures of 120°C and „hot spot“ temperatures of up to 140°C due to the excellent thermal stability of the nanocrystalline material structure.

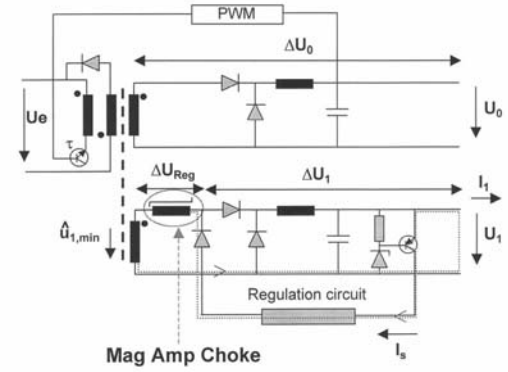
Even at operational temperatures of 120°C, the saturation induction of VITROPERM 500 Z exceeds 1.0 T, allowing max. bipolar flux density swings of about 2.0 T.

The reversible temperature changes of coercivity H_c, core losses P_{Fe} and residual flux density ΔB_{rs} are typically below 10 - 15% in the temperature range from - 40°C to + 130°C.

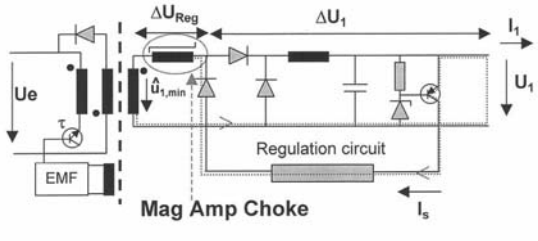


All material data are typical values and preliminary. Deviations to these material characteristics are permitted due to product shape and size.

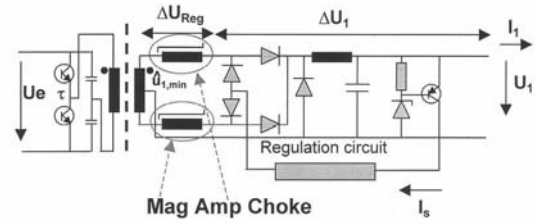
Application Notes, Design Informations and further Calculation formulae



Forward Converter with MagAmp Choke, Master – Slave Type



Forward Converter with MagAmp Choke, Modular SMPS Type



Push-Pull Converter with 2 MagAmp Chokes, Half-Bridge

Some different calculation methods are commonly used for MagAmp Choke design. The most important core data are given in the type series table (see previous page). More detailed application and calculation notes are described in our leaflet PK-002 (Tape-Wound Cores for Magnetic Amplifier Chokes, VITROVAC 6025 Z). The following calculation steps* should be used for a first selection of cores made of VITROPERM 500 Z and winding for short circuit proof designs. More accurate results are possible with our design software tool VAC MagAmp Calculator* (operating under Microsoft EXCEL® 97/ 2000).

1. Determine wire current density S (typically S = 5 – 10 A/mm^2) and calculate wire size and wire cross section a_{Cu}:

$$a_{Cu}\,[mm^2] = \frac{I_{1,RMS}\,[A]}{S\,[A/mm^2]}$$

2. Calculate regulation voltage U_{Reg} of MagAmp Choke:
τ_{max} = max. pulse duty ratio of primary switch, $\hat{u}_{1,min}$ = peak value of transformer output voltage
(α = 1 for forward converters, α = 2 for push pull converters with 2 MagAmps)

$$U_{Reg}\,[V] = \alpha \times \tau_{max} \times \hat{u}_{1,min}\,[V]$$

3. Select core (start with small core) and calculate no. of turns (min. value):

$$N \geq \frac{10 \times U_{Reg}[V]}{\alpha \times 2.0\,[T] \times A_{Fe}\,[cm^2] \times f\,[kHz]}$$

4. Check winding space of selected core (A_{Cu} [cm^2] ≥ a_{Cu} [cm^2] x N) or recalculate min. no. of turns for next bigger core size.

5. Calculate regulation flux density swing ΔB_{Reg}
(criterion: $\Delta B_{Reg} < (2 \times B_S) - \Delta B_{rs}$)

$$\Delta B_{Reg}\,[T] \geq \frac{10 \times U_{Reg}[V]}{\alpha \times N \times A_{Fe}\,[cm^2] \times f\,[kHz]}$$

6. Calculate temperature rise

of winding ΔT_{Cu} ($\rho_{Cu} \approx 2.27 \times 10^{-6}$ Ωm)

$$\Delta T_{Cu}[K] = \frac{R_{th}[K/W] \times I_{1,RMS}[A]^2 \times N^2 \times l_{Cu}[cm] \times \rho_{Cu}[\Omega m]}{20 \times A_{Cu}[cm^2]}$$

and core ΔT_{Fe}

$$\Delta T_{Fe}[K] = 0.42 \times m_{Fe}[kg] \times R_{th}[K/W] \times \Delta B_{Reg}[T]^{1.5} \times f[kHz]^{1.5}$$

7. Estimate reset current I_S:

$$I_S\,(mA) \approx \frac{25 \times \Delta B_{Reg}[T]^{0.45} \times f\,[kHz]^{0.53} \times l_{Fe}[cm]}{N}$$

8. Experimental testing*.

Design Examples of MagAmps* (Forward Converter, short circuit proof design, 100 kHz, τ_{max} = 0.4, ambient temperature 45 – 50°C)

	$I_{1,max}$ = 10 A	$I_{1,max}$ = 15 A	$I_{1,max}$ = 20 A	$I_{1,max}$ = 25 A	$I_{1,max}$ = 30 A
U_1 = 3,3 V	W759, N = 10 W760, N = 11	W759, N = 8 W760, N = 9	W759, N = 6 W760, N = 7 W761, N = 7	W760, N = 6 W761, N = 6	W760, N = 5 W761, N = 5 W762, N = 6
U_1 = 5 V	W759, N = 11 W760, N = 12 W761, N = 12	W759, N = 9 W760, N = 10 W761, N = 10	W760, N = 8 W761, N = 8	W761, N = 6 W762, N = 8 W764, N = 8	W764, N = 8 W763, N = 6 W765, N = 8
U_1 = 12 V	W761, N = 14 W764, N = 20	W764, N = 16 W763, N = 12	W764, N = 14 W765, N = 14	W765, N = 12 W766, N = 15 W767, N = 12	W768, N = 10

* Experimental circuit testing is recommended in any case

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Advanced Materials – The Key to Progress

Postfach 2253 / P.O.B. 2253
D-63412 Hanau
☎ (**49) 6181 / 38-0
Fax (**49) 6181 / 38-2780
E-Mail: Info@vacuumschmelze.com
http://www.vacuumschmelze.com

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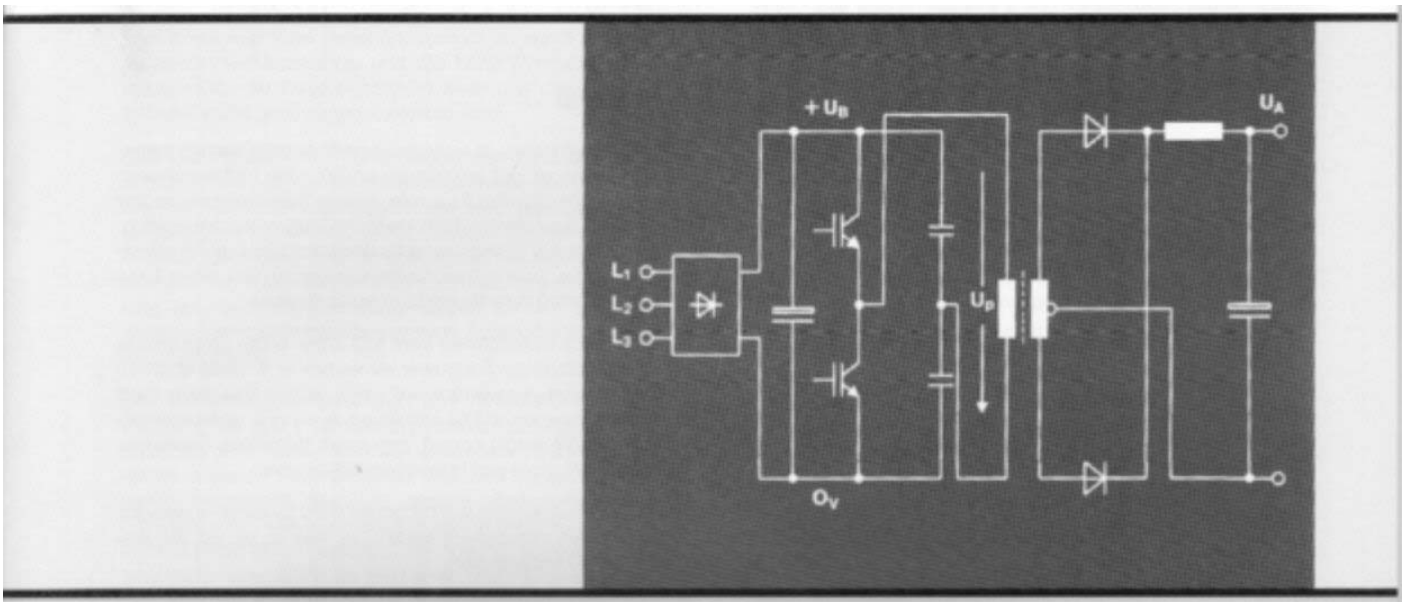
VITROPERM 500 F • VITROVAC 6030 F

Ringbandkerne in Leistungsübertragern für getaktete Stromversorgungen

Tape-Wound Cores in Power Transformers for Switched Mode Power Supplies



Edition 2003

PK-003

VITROPERM 500 F und VITROVAC 6030 F

Ringbandkerne in Leistungsübertragern für getaktete Stromversorgungen

Tape-Wound Cores in Power Transformers for Switched Mode Power Supplies

1. Allgemeines

Der Leistungsübertrager in einer getakteten Stromversorgung transformiert Ströme sowie Spannungen und sorgt für die galvanische Trennung von Stromkreisen. Er ist in der Regel das technisch anspruchsvollste induktive Bauelement. Wegen der sehr unterschiedlichen Anforderungen ist eine Standardi-sierung nahezu ausgeschlossen, d.h., der Leistungsübertrager wird fast immer gerätespezifisch dimensioniert.

Die übertragenen Leistungen reichen von wenigen Watt bis in den kW-Bereich. Unterhalb etwa 50 Watt setzt man Sperr-wandler ein, darüber Durchflußwandler. Bei diesen wiederum dominiert bis ca. 500 W der Eintakt-Durchflußwandler, darüber der Gegentaktwandler.

Die Schaltfrequenzen werden bestimmt durch die Verluste der Halbleiter und der induktiven Bauelemente sowie durch die Erfordernisse der Funkentstörung.

Beim Aufbau des Übertragers spielen die geforderten Ein- und Ausgangsgrößen zunächst die Hauptrolle. Ebenso wichtig sind aber auch die räumlichen Verhältnisse (vorgegebene Maximalabmessungen in jeder Richtung), die Isolationserfor-dernisse sowie Normen und Vorschriften.

Als Kernformen kommen E-Kerne (bei großen Leistungen auch Kombinationen aus U- und I-Kernen) und Ringkerne zum Einsatz. Die Frage, welche Kernform vorzuziehen Ist, kann nicht generell beantwortet werden. In letzter Zeit ist jedoch ein gewisser Trend hin zu Ringkernen erkennbar.

2. Werkstoffvorteile

Bei technisch anspruchsvollen Lösungen sind metallische Ringbandkerne aus dem nanokristallinen Werkstoff VITROPERM 500 F und dem amorphen Material VITROVAC 6030 F gegenüber Ferriten im Vorteil.

Beide Werkstoffe bieten durch ihre flachen Hystereseschleifen ohne nennenswerte Remanenz sowie die hohe Sättigungs-induktion einen großen unipolaren Induktionshub. Bei 100 °C beträgt er für VITROPERM 500 F ca. 1 T bzw. ca. 0,7 T für VITROVAC 6030 F (Ferrite sind nur bis ca. 0,25 T aussteuer-bar). Das führt zu einer kleinen Baugröße und einem niedrigen Gewicht.

1. General

Power transformers in a switched power supply system transform currents as well as voltages and provide for the galvanic separation of circuits. As a rule, power transformers are the inductive components which are technically most demanding. The great variety in requirements does not allow much standardization, i.e. power transformers will in almost every case be dimensioned in relation to a specific device.

The transformed power ranges from just a few watts up to the kilowatt range. Below approximately 50 watts flyback converters are used; feed forward converters at higher power. And here, up to approximately 500 W, single ended converters dominate; above 500 W, push-pull converters will be used.

Switching frequencies will be determined by semiconductor and inductive component losses, as well as by the requirements of RFI suppression.

For transformer design, the required input and output values will initially play the most important part. But just as important will be space considerations (specified maximum dimensions in each direction), insulation requirements, as well as standards und regulations.

With regard to core shapes, E-cores (for larger power even combinations of U- and I-cores) as well as toroidal cores are used. The question which type of core form is to be preferred cannot be answered in general. However, recently a certain trend towards toroidal cores has become recognizable.

2. Advantages of Materials

For technically demanding solutions, however, metallic tape-wound cores made of the nanocrystalline VITROPERM 500 F and the amorphous material VITROVAC 6030 F are more advantageous than ferrites.

Both materials offer a high unipolar induction swing due to their flat hysteresis loops without remarkable remanence at a high saturation induction. The unipolar induction swing reaches approximately 1 T in case of VITROPERM 500 F and 0.7 T in case of VITROVAC 6030 F at 100°C (ferrites can only be driven up to approximately 0.25 T). This enables small transformer size and low weight.

VITROPERM 500 F ist der ideale Werkstoff für Gegentaktwandler. Hier vermindert die flache Schleife bei hohem Induktionshub die Gefahr der einseitigen Kernsättigung durch temporär unterschiedliche Spannungszeitflächen der Ansteuerspannung. Dadurch kann mit höheren Permeabilitäten gearbeitet werden, die zu weiteren Vorteilen führen. VITROVAC 6030 F wird durch die hohe unipolare Aus-steuerbarkeit in Verbindung mit seiner eher niedrigen Permeabilität (gutes Rückstellverhalten) zum optimalen Werkstoff für Eintaktdurchflußübertrager.

Unsere Materialien besitzen zudem niedrige Verluste. Die Ummagnetisierungsverluste bei 100 kHz, 0,2 T und Raumtemperatur betragen ca. 40 mW/g bei VITROVAC 6030 F und ca. 35 mW/g bei VITROPERM 500 F. Ferrite liegen hier mit ca. 80 - 180 mW/g deutlich höher. Die Kupferverluste können vom Anwender klein gehalten werden, da durch den großen nutzbaren Induktionshub und die hohe Permeabilität, also Induktivität, die Windungszahlen klein und die Kupferquerschnitte somit groß dimensionierbar sind.

Bei hoher Aussteuerung kann ein weiter Frequenzbereich genutzt werden. Neben vergleichsweise niedrigen Verlusten trägt dazu bei, daß die Hauptinduktivität nur eine geringe Frequenzabhängigkeit besitzt und die Streuinduktivitäten durch die Ringkerngeometrie und die niedrigen Windungs-zahlen klein sind. Hierdurch ist auch die magnetische Kopp-lung gut. Überspannungsspitzen an den Schalttransistoren können klein gehalten werden. Außerdem ist das äußere Streufeld gering.

Die Anwendungstemperaturen von VITROVAC 6030 F und VITROPERM 500 F reichen typischerweise von -40°C bis +120°C. Die hohe maximale Betriebstemperatur führt zu einem weiteren Volumenvorteil und wird möglich durch die große thermische Stabilität unserer Werkstoffe und ihrer Eigenschaften. Die Kernverluste von VITROVAC 6030 F und VITROPERM 500 F nehmen bei 100 °C gegenüber Raumtemperatur um ca. 3% ab. Ferrite zeigen im gleichen Temperaturbereich starke, vom Material abhängige Schwan-kungen. Meist liegt hier das Verlustminimum bei etwa 80°C, die steile Zunahme bei höheren Temperaturen erschwert die empirische Optimierung der Übertrager. Die Abnahme des nutzbaren Induktionshubes zu hohen Temperaturen hin ist bei unseren Werkstoffen mit ca. 10% bei 100°C gegenüber Raumtemperatur gering. Ferrite fallen hier um 20 bis 30% ab. Die Permeabilität ändert sich bei VITROVAC 6030 F und VITROPERM 500 F bis 100°C um weniger als 10%, bei Ferriten ist der Verlauf meist nicht kontinuierlich, die Schwankungsbreite beträgt ca. 50%.

Die Vorteile nanokristalliner und amorpher Ringbandkerne in Leistungsübertragern können wie folgt zusammengefasst werden:

- **Geringes Volumen bzw. Gewicht** durch:
  - hohe Aussteuerbarkeit und
  - geringe spezifische Verluste des Kernmaterials.
- **Großer Temperaturbereich von – 40 bis + 120°C**, sehr geringe Temperaturabhängigkeit der Werkstoffeigenschaften
- **Reduzierter Aufwand für Funkentstörung** durch
  - niedrige Schaltfrequenzen.
  - luftspaltlose Kernformen (minimale Streufelder).
- **Niedrige Halbleiterverluste** durch niedrige Schaltfrequenzen (möglich durch hohen Induktionshub).

VITROPERM 500 F suits ideally for push-pull converters. Operating at high induction swings, the flat hysteresis loop reduces the hazard of core saturation in the event of temporarily varying voltage time integrals of the drive signal. This enables the use of high permeabilities resulting in further benefits. VITROVAC 6030 F is the best choice for single ended forward converters because of its combination of high unipolar induction swing and fairly low permeability (for fast demagnetization in the pulse pause).

In addition, our materials are characterized by low losses. Core losses at 100 kHz, 0.2 T, and room temperature will be approximately 40 mW/g for VITROVAC 6030 F, and approximately 35 mW/g for VITROPERM 500 F. With approximately 80 - 180 mW/g, ferrites suffer significantly higher losses. Copper losses can be kept small by users due to the large usable induction swing and high permeability, i.e. inductivity, the number of turns will be small and copper cross-sections can thus be dimensioned to be quite large.

A wide frequency range can be used at even high induction swing. Beside low core losses, the main inductance of a VITROVAC or VITROPERM transformer will be dependent on frequency to a very small extent only, and as leakage inductances will be small due to the toroidal geometry and the low number of turns possible. This results in good magnetic coupling properties, and excess voltage peaks on switching transistors can be kept small. Moreover, there will be a low external leakage field.

The application temperatures of VITROVAC 6030 F and VITROPERM 500 F typically range from -40°C to +120°C. This high maximum operating temperature provides a further volume advantage and is made possible by the large thermal stability of our materials and their properties. Core losses of VITROVAC 6030 F and VITROPERM 500 F will decrease by 3% at 100 °C, when compared to room temperature. The core losses of ferrites vary strong in the given temperature range. In most cases, minimum loss will occur at approximately 80°C; the steep increase at higher temperatures makes empirical optimization of transformers very difficult. Our materials feature a very low decrease in usable induction swing within the high temperature range, i.e. approximately 10% at 100°C when compared to room temperature. Ferrites will decrease by 20 to 30%. For VITROVAC 6030 F and VITROPERM 500 F, permeability will change by less than 10% in temperatures up to 100°C; for ferrites, the curve will usually be discontinuous, with a 50% fluctuation margin (approx.).

The benefits of nanocrystalline and amorphous tape-wound cores in switched-mode power transformers can be summarized as follows:

- **Low volume and weight** due to:
  - high flux density and
  - low specific losses of the core material.
- **Wide temperature range from – 40 up to + 120°C**, material properties very stable in the operational temperature range.
- **Less filtering and RFI noise suppression** due to
  - low switching frequencies.
  - core design without airgap (smallest stray fields).
- **Low semiconductor switch losses** by low operational frequencies due to high induction flux density.

3. Kerne für Hochleistungsübertrager im Kilowatt-Bereich

Aufgrund der Entwicklungen auf dem Gebiet der Leistungshalbleiter werden gegenwärtig auch Stromversorgungen im kW-Bereich in getakteter Ausführung entwickelt.

Anwendungsgebiete sind zur Zeit:

- **Telekommunikation** (Stromversorgungen für die Amtstechnik, Mobilfunk)
- **Bahntechnik, Flurfördertechnik** (Batterieladegeräte)
- **Schweißtechnik** (getaktete Stromrichter)

Zukünftig werden verstärkt hinzukommen:

- **Elektrofahrzeuge** (Batterieladegeräte, Motorwechsel-richter)
- **Solartechnik** (Wechselrichter)
- **Induktionsöfen**

Die Schaltungstechnik unterscheidet sich nicht grundsätzlich von derjenigen für kleinere Leistungen. Allerdings liegen die Schaltfrequenzen in der Regel noch deutlich niedriger. Arbeitsprinzip ist meist der Gegentaktwandler.

Leistungsübertrager mit Kernen aus VITROPERM 500 F bietet hier Volumen- und Größenvorteile oftmals um den Faktor 2 und mehr gegenüber Ferriten!

In der folgenden Tabelle sind einige typische Kerngrößen und die mit ihnen erzielbare Übertragungsleistung aufgeführt. Diese Angaben können natürlich nur Richtwerte sein.

Randbedingungen sind:
Frequenz f = 20 - 50 kHz, Umgebungstemperatur T < 60 °C, zulässige Erwärmung ΔT = 50 K. Ausführung vergossen.

Kernabmessungen d1 x d2 x h1 [mm]	Leistung Gegentaktübertrager ca. [W] VITROPERM 500 F
50x40x20	1 300 - 2 500
52x40x25	2 000 - 3 500
55x40x25	2 500 - 4 000
63x50x25	2 500 - 4 000
80x63x25	4 000 - 6 500
100x80x25	6 000 - 10 000
100x80x25 x 2	12 000 - 20 000
130x100x25	11 000 - 18 000
130x100x25 x 2	16 000 - 26 000
130x100x25 x 3	22 000 - 35 000
130x100x25 x 4	26 000 - 40 000

Eine aktuelle Typenübersicht finden Sie auf unserer Internetseite unter http://www.vacuumschmelze.com.

3. Cores for High Performance Power Transformers within the Kilowatts Range

In line with developments in the area of power semiconductors, switched mode power supplies for kW-range applications are currently being developed.

Known areas of application currently are:

- **telecommunications** (telephone exchange power supplies, Base Stations)
- **railways technology,** mechanical handling equipment technology (battery charging devices)
- **welding technology** (switched mode Converters)

In future, these will increasingly be extended to:

- **electric vehicles** (battery charging devices, motor inverters)
- **solar technology** (inverters)
- **induction heating**

Circuit engineering is not fundamentally different from that used for lower performance power transformers – usually at lower switching frequencies. The principle of operation will mostly be of the push-pull converter type.

Power Transformers with Cores made of VITROPERM 500 F frequently offers volume and size advantages over ferrites by a factor 2 and more!

The table below lists some typical core sizes and the transmitted power values these can achieve, although these data naturally are for guidance only.

Preconditions are:
Frequency f = 20 - 50 kHz, ambient temperature T < 60 °C, permitted heating ΔT = 50 K. Moulded design.

Core Dimensions d1 x d2 x h1 [mm]	Power: Push-Pull Converter, approx. [W] VITROPERM 500 F
50x40x20	1 300 - 2 500
52x40x25	2 000 - 3 500
55x40x25	2 500 - 4 000
63x50x25	2 500 - 4 000
80x83x25	4 000 - 6 500
100x80x25	6 000 - 10 000
100x80x25 x 2	12 000 - 20 000
130x100x25	11 000 - 18 000
130x100x25 x 2	16 000 - 26 000
130x100x25 x 3	22 000 - 35 000
130x100x25 x 4	26 000 - 40 000

For an up-to datel type list please visit our home page http://www.vacuumschmelze.com .

4. Dimensionierung von Leistungsübertragern

Eine erste Grobdimensionierung kann mit unserer Unterstützung erfolgen. Bitte füllen Sie hierzu das beiliegende Blatt „Checkliste Kerne für Leistungsübertrager" aus.

Grundsätzliche Zusammenhänge:

Die an der Primärwicklung anliegende Spannung bewirkt einen Stromfluß und somit gemäß der ersten Maxwell'schen Gleichung ein magnetisches Feld im Innern der Primärspule. Dieses magnetische Feld führt zu einer Induktionsänderung im Kern, wodurch in der Sekundärwicklung gemäß der zweiten Maxwell'schen Gleichung eine im Verhältnis der Windungszahlen transformierte Spannung induziert wird.

Ein idealer Kernwerkstoff würde infolge seiner unendlich hohen magnetischen Leitfähigkeit den von der Primärwicklung erzeugten magnetischen Fluß so führen, daß er mit allen Windungen der Sekundärwicklung des Übertragers verkettet ist. Die Eingangsgrößen von Strom und Spannung würden sich dann lediglich durch das Windungszahlenverhältnis von den Ausgangsgrößen unterscheiden.

Beim realen Übertrager sind jedoch Verluste und parasitäre Kapazitäten durch Kernwerkstoff und Wicklung zu berücksichtigen.

Durch den primären Kupferwiderstand R_p reduziert sich die an der Hauptinduktivität L anliegende Spannung, und nur diese erzeugt das magnetische Feld im Kern. Eine zusätzliche Reduzierung der Eingangsspannung erfolgt durch die primäre Streuinduktivität L_S, da ein Teil des von der Primärwicklung erzeugten Flusses nicht mit der Sekundärwicklung verkettet ist.

Die im Kernwerkstoff entstehenden Ummagnetisierungsverluste werden im Ersatzschaltbild durch einen Parallelwiderstand R zur Hauptinduktivität L berücksichtigt. Der sekundäre Laststrom I_s führt ebenso wie der Primärstrom I_p zu einem Spannungsabfall am sekundären Wicklungswiderstand R_s und an der sekundären Streuinduktivität L_s. Da die Spannungsabfälle vom Laststrom I_s und die Impedanz der Streuinduktivität zusätzlich von der Frequenz abhängig sind, schwankt die Ausgangsspannung eines Übertragers immer last- und frequenzabhängig (Innenwiderstand des Übertragers).

4. Design Calculation of Power Transformers

First transformer design calculations are possible with our support. If you require our support, please complete the enclosed "Check List for Power Transformers".

Basic Principles:

The voltage applied to the primary winding causes a current to flow, and thus according to the first Maxwell equation a magnetic field to arise inside the primary coil. This magnetic field leads to a change of induction in the core, which, according to the second Maxwell equation will induce a voltage transformed in proportion to the number of turns.

Due to its infinitely high magnetic conductivity, an ideal core material would carry the magnetic flux, generated by the primary winding, such that it is interlinked with all turns of the transformers secondary winding. Current and voltage input values would then differ from output values in relation to turns ratio only.

For a real transformer, however, losses and parasite capacities due to core material and windings need to be taken into consideration.

Due to the primary copper resistance R_p, the voltage applied to the main inductance L will reduce, and it is only this voltage which will generate the magnetic field inside the core. A further reduction of input voltage will be effected by primary leakage inductivity L_S, as a part of the magnetic flux generated by the primary winding will not be linked with the secondary winding.

Core losses arising in the core material will be taken into account in the equivalent circuit diagram by means of a parallel resistor R to the main inductance L. The secondary load current I_s, as well as primary current I_p, will cause a voltage drop on secondary winding resistor R_s and on secondary leakage inductivity L_s. As these voltage drops of load current I_s and leakage inductance impedance will additionally be dependent on frequency, the output voltage of a transformer will always vary in relation to load and frequency (intrinsic resistance of transformer).

Vorgehen bei der Dimensionierung:

Bei der vorgegebenen maximalen Übertemperatur läßt sich für jeden Kernwerkstoff und jede Kernabmessung eine **optimale Induktion ΔB_{opt}** und eine **optimale Stromdichte $S_{eff,opt}$** errechnen, bei der die übertragbare Leistung einen Maximalwert erreicht:

Design Calculation Procedure:

For a specified maximum temperature rise, an **optimum induction ΔB_{opt}** and an **optimum current density $S_{eff,opt}$** can be calculated for each core material and each core size, where transferable power reaches a maximum value:

$$\Delta B_{opt} = \Delta B_0 \times \left(\frac{2 \times \Delta T}{(2+Z) \times R_{th} \times m_{Fe} \times P_0 \times \left(\frac{F}{F_0}\right)^X \times \left(\frac{f}{f_0}\right)^Y} \right)^{\frac{1}{Z}}$$

$$S_{eff,opt} = \sqrt{\frac{Z \times \Delta T}{(Z+2) \times R_{th} \times \rho_{Cu} \times l_{Cu} \times A_{Cu} \times 10^4}}$$

P_0	[W/kg]	Maximale spezifische Ummagnetisierungsverluste bei f_0, ΔB_0 und F_0 VITROVAC 6030 F : 140 W/kg VITROPERM 500 F : 110 W/kg
m_{Fe}	[kg]	Kernmasse
f	[kHz]	Betriebsfrequenz
f_0	[kHz]	Bezugsfrequenz VITROVAC 6030 F: 70 kHz; VITROPERM 500 F: 100 kHz
ΔB_0	[T]	Bezugsinduktionshub VITROVAC 6030 F : 0,6 T VITROPERM 500 F : 0,6T
F		Formfaktor (Spannungsform). Für Rechtecke gilt: $F = \frac{1}{\sqrt{2 \times \tau}}$
F_0		Bezugsspannungsform (Sinus, F_0 = 1,11)
X,Y,Z		Exponenten bei obigen f_0, ΔB_0 und F_0, werkstoffabhängig: VITROVAC 6030 F: X=1,62; Y= 1,83; Z = 2,15 VITROPERM 500 F: X=1,60; Y=1,80; Z=2,08
ΔT	[K]	Übertemperatur
R_{th}	[K/W]	Wärmeübergangswiderstand des Übertragers. Richtwerte für unsere Typenkerne: siehe Tabelle am Ende dieser Schrift.
ρ_{Cu}	[Ωcm]	spezifischer Kupferwiderstand (1,786 x 10^{-6} x (1+T_{max} / 235))
A_{Cu}	[cm^2]	Kupferquerschnitt
l_{Cu}	[cm]	mittlere Länge einer Kupferwindung.

P_0	[W/kg]	Max. specific core losses at f_0, ΔB_0 and F_0 VITROVAC 6030 F : 140 W/kg VITROPERM 500 F : 110 W/kg
m_{Fe}	[kg]	core mass
f	[kHz]	operating frequency
f_0	[kHz]	reference frequency VITROVAC 6030 F: 70 kHz; VITROPERM 500 F: 100 kHz
ΔB_0	[T]	reference induction swing VITROVAC 6030 F : 0.6 T VITROPERM 500 F : 0.6T
F		form factor (voltage form). For rectangular wave form: $F = \frac{1}{\sqrt{2 \times \tau}}$
F_0		reference voltage form (Sinus, F_0= 1.11)
X,Y,Z		exponents at above f_0, ΔB_0 und F_0, dependent on material: VITROVAC 6030 F: X=1.62; Y=1.83; Z=2.15 VITROPERM 500 F: X=1.60; Y=1.80; Z=2.08
ΔT	[K]	temperature rise
R_{th}	[K/W]	thermal resistance of transformer to ambient. Reference values for our type cores: see table at the end of this brochure.
ρ_{Cu}	[Ωcm]	specific copper resistance (1.786 x 10^{-6} x (1+T_{max} / 235))
A_{Cu}	[cm^2]	copper cross section
l_{Cu}	[cm]	mean winding turn length.

Die **übertragbare Leistung P_{max} [W]** wird errechnet nach:

The **transferable power P_{max} [W]** will then be calculated:

$$P_{max} = 10 \text{ x } k \text{ x } f \text{ x } A_{Fe} \text{ x } A_{Cu} \text{ x } \Delta B_{opt} \text{ x } S_{eff,opt}$$

A_{Fe}	[cm^2]	Eisenquerschnitt
ΔB	[T]	Induktionshub des Kernwerkstoffes ($\Delta B <= 2 \times B_{max}$)
S_{eff}	[A/mm^2]	effektive Stromdichte
k		Leistungsfaktor (vom Schaltungsprinzip abhängig)

A_{Fe}	[cm^2]	iron cross section
ΔB	[T]	induction swing of core material ($\Delta B <= 2 \times B_{max}$)
S_{eff}	[A/mm^2]	effective current density
k		power factor dependent on circuit principle.

Für **Eintaktdurchflußübertrager** gilt:

For **single-ended forward transformers** applies

$$k = 1 / (2 \times \sqrt{\tau_m})$$

Für **Gegentaktübertrager** gilt:

For **push-pull transformers** applies:

Schaltungsaufbau / circuit principle	***k =***
	$\frac{1}{\sqrt{2 \times \tau_m}}$
	$\frac{2}{\sqrt{2 \times \tau_m} + \sqrt{2 \times \tau_m + 1}}$
	$\frac{2}{2 \times \sqrt{\tau_m} + \sqrt{2 \times \tau_m}}$
	$\frac{2}{2 \times \sqrt{\tau_m} + \sqrt{2 \times \tau_m + 1}}$

τ_m	mittl. Tastverhältnis der Eingangsspannung
τ_{max}	maximalesTastverhältnis der Eingangsspannung (Vorgabewert)
$U_{E,min}$ [V]	minimale Eingangsspannung (Vorgabewert)
$U_{E,max}$ [V]	maximale Eingangsspannung (Vorgabewert)

τ_m	mean pulse duty ratio of input voltage
τ_{max}	maximum pulse duty ratio of input voltage (specified value)
$U_{E,min}$ [V]	minimum input voltage (specified value)
$U_{E,max}$ [V]	maximum input voltage (specified value)

Die **Primärwindungszahl Np** wird so festgelegt, daß die angelegte Primärspannung U_E [V] im Kern eine magnetische Induktion erzeugt, die ΔB_{opt} nicht übersteigt:

The **primary number of turns Np** will be determined such that the applied primary voltage U_E [V] will generate a magnetic induction in the core, which does not exceed ΔB_{opt}:

$$N_p = (\tau_{max} \times U_{E,min} \times 10) / (f \times A_{Fe} \times \Delta B_{opt})$$

Die **Sekundärwindungszahl N_s** wird nach folgender Beziehung festgelegt:

The **secondary number of turns N_s** will be determined according to the following equation:

$$N_s = ((U_A + \Delta U) \times N_p) / (\tau_{max} \times U_{E,min}) \ *$$

* gilt für Eintakt-Durchflußwandler. Bei Gegentakt-Durchfluß-wandlern ist N_s zu halbieren

converters, divide N_s in half

U_A [V] Ausgangsgleichspannung. Nicht berücksichtigt wurden Spannungsabfälle über den Kupferwider-ständen der Wicklungen sowie über den Gleich-richterdioden.

U_A [V] DC Output voltage. Voltage drops across winding resistance and rectifier diodes have not been taken into account.

* applies to single-ended forward converters. For push-pull

ΔU [V] Spannungsabfälle über den Kupferwiderständen der Wicklungen und über den Gleichrichterdioden.

ΔU [V] voltage drops across the copper resistances of the windings and across the rectifier diodes.

Weiterführende Anwendungshinweise für den Einsatz von VITROPERM 500 F:

Induktivität des Übertragers:

Da die Permeabilität bei VITROPERM 500 F um ca. den Faktor 10 höher liegt als bei einem typischen Ferritwerkstoff, bedeutet dies eine größere Hauptinduktivität und somit niedrigere Magnetisierungsströme. Bei unipolarer Aussteuerung (Eintakt-Durchflussübertrager) ist das Rückstellverhalten in der Impulspause problematisch. Bei bipolarer Aussteuerung (Gegentakt Durchflussübertrager) ist dies jedoch unkritisch. Hier ist lediglich auf gute Symmetrie in der Ansteuerung zu achten, da unterschiedlich große Spannungszeitflächen im Ansteuersignal (Gleichstromanteil) den hochpermeablen Kernwerkstoff schnell in die Sättigung treiben. Für die anderen Fälle steht unser Werkstoff VITROVAC 6030 F zur Verfügung.

Arbeitsfrequenz:

Die Werkstoffvorteile des VITROPERM 500 F kann der Schaltungsentwickler nur dann voll ausnutzen, wenn er auf sie eingeht. Aufgrund des hohen möglichen Induktionshubes ist deshalb oft eine niedrigere Schaltfrequenz möglich als bei Verwendung eines Ferritwerkstoffes. Diese wiederum macht den Einsatz preiswerter Standardhalbleiter möglich und senkt den Aufwand für die Funkentstörung.

Transformatoraufbau:

Umfangreiche Erfahrungen liegen seitens der VAC vor. Primär- und Sekundärbewicklung werden meist mit Litze aufgebaut, die Anschlüsse mit Kabelschuhen versehen. Die Isolationsforderungen werden durch den Einsatz spezieller Kunststoffteile zur Distanzierung der Wicklungen und durch den Vakuumverguss mit einem gefüllten und damit wärmeleitenden Epoxid-Harz erfüllt. Ein Aluminiumgehäuse dient als stabiler Schutz und es lässt sich auf einem Kühlkörper montieren.

Typische Schaltungstopologien:

Abhängig von der übertragenen Leistung, den Ein- und Ausgangsspannungen und Strömen sowie der Kostensituation wurden primärseitig die Schaltungsarten Halb- und Vollbrücke bisher am häufigsten verwirklicht. Bei Leistungen bis ca. 15 kW dominiert die Halbbrücke, darüber üblicherweise die Vollbrücke. Sekundärseitig kommt bei niedrigen Spannungen (bis ca. 20 V) meist die Mittelpunktgleichrichtung, darüber die Brückengleichrichtung zum Einsatz.

Additional Application Notes for the use of VITROPERM 500 F:

Transformer inductance:

As the permeability for VITROPERM 500 F is higher by an approximate factor 10 than for a typical ferrite material, this means that there is a higher main inductance resulting in lower magnetization currents. In the case of unipolar drive control (single-ended forward converter), the reset behavior in the impulse pause is problematical. However, in the case of bipolar drive control (push-pull converters) this is uncritical. Here, users must ensure only that there is a good symmetry in the drive control, as various different voltage time areas in the drive signal (appearance of DC) will fast drive the highly permeable core material into saturation. For all other cases, our material VITROVAC 6030 F is available.

Operating frequency:

The circuit designer can only make full use of the material advantages offered by VITROPERM 500 F, if special provision is made for them. Therefore, due to the high possible flux density, often a lower switching frequency is possible than when a ferrite material is used. This lower switching frequently allows the use of low cost standard semiconductors and reduces the cost for RFI noise suppression.

Transformer setup:

VAC has comprehensive experience in this field. Primary and secondary windings are usually built up from stranded wire, terminals are fitted with cable lugs. The insulation requirements are met by the use of special plastic components for spacing the windings and by vacuum molding with a filled and thus heat-conducting epoxy resin. An aluminium housing is used for solid protection, and it can be mounted on a heat sink.

Typical switching topologies:

Depending on the power transformed, input and output voltages and currents, as well as the cost situation, the switching types half and full bridge so far have been implemented most frequently at the primary side. Up to approximately 15 kW, the half bridge type dominates. At higher power, the full bridge type is more common. At the secondary side, for low voltages (up to 20 V approximately), usually center-tap rectification is used; for higher voltages bridge rectification is used.

Beispiele / Examples:

5. Typenreihen Ringbandkerne aus VITROVAC 6030 F und VITROPERM 500 F

Innerhalb der nachfolgenden Typenreihe finden Sie Ringbandkerne, mit denen sich Übertrager von ca. 100 Watt bis 20000 Watt und mehr realisieren lassen. Sollte der für Ihre Anwendung optimale Kern nicht enthalten sein, so fragen Sie uns bitte an.

Werkstoffdaten#		VITROVAC 6030 F	VITROPERM 500 F
Sättigungsinduktion*	B_s	0,82T	1,2T
Sättigungs-magnetostriktion*	λ_s	$< 0{,}2 \times 10^{-6}$	$< 0{,}5 \times 10^{-6}$
Curietemperatur*	T_c	365 °C	600 °C
Max. unipolarer Induktionshub bei Raumtemperatur*	ΔB	0,75 T	1 T
Impuls Permeabilität (t_d = 10 µs; ΔB = 0,5T)**	μ_p	≥ 2 100	
Impuls Permeabilität (t_d = 20 µs; ΔB =1 T)***	μ_p		≥ 10 000
Ummagnetisierungs-verluste (f = 100 kHz sinus; B_{max} = 0,3T)	P_{Fe}	≤ 140 W/kg	≤ 110 W/kg

für ungeteilte runde Ringbandkerne
* Typische Werte
** Grenzwerte lt. VAC Magnetqualität XDF-535 (VITROVAC 6030 F)
*** Grenzwerte lt. VAC Magnetqualität LHF-582 (VITROPERM 500 F)

5. Type Series Tape-Wound Cores made of VITROVAC 6030 F and VITROPERM 500 F

Within the following type series, you will find toroidal cores suitable for implementing transformers from approx. 100 watts up to 20000 watts and higher. If you do not find the optimum core for your application, please contact us directly.

Material Data#		VITROVAC 6030 F	VITROPERM 500F
Saturation Induction*	B_s	0.82T	1.2T
Saturation Magnetostriction*	λ_s	$< 0.2 \times 10^{-6}$	$< 0.5 \times 10^{-6}$
Curie Temperature*	T_c	365 °C	600 °C
Max. unipolar Induction Swing at Room Temp.*	ΔB	0.75 T	1 T
Pulse Permeability (t_d = 10 µs; ΔB = 0.5T)**	μ_p	≥ 2 100	
Pulse Permeability (t_d = 20 µs; ΔB = 1 T)***	μ_p		≥ 10 000
Magnetic Reversal Losses (f = 100 kHz sinus; B_{max} = 0.3T)	P_{Fe}	≤ 140 W/kg	≤ 110 W/kg

for toroidal uncutted tape-wound cores
* Typical values
** Limiting values according to VAC's magnetic quality XDF-535 (VITROVAC 6030 F)
*** Limiting values according to VAC's magnetic quality LHF-582 (VITROPERM 500 F)

Nennmaße Rated Dim's d1 x d2 x h1 [mm x mm x mm]	Grenzmaße Limiting Dim's d3 x d4 x h2 [mm x mm x mm]	A_{Fe} [cm2]	l_{Fe} [cm]	A_L typ* [µH]	A_L typ** [µH]	m_{Fe}* [g]	m_{Fe}** [g]	A_{Cu} [cm^2]	l_{Cu} [cm]	R_{th} [K/W]	Bestellbez. / Ordering Code VITROPERM 500 F T60004-	VITROVAC 6030 F T60004-
16x10x6	17.6x8.3x8	0.14	4.08	11	1.3	4.3	4.6	0.20	3.18	33	L2016-**W373**	E3016-F002
20x12.5x8	22x10.5x10	0.24	5.11	14	1.8	9.0	9.5	0.32	3.97	23	L2020-**W374**	E3020-F008
25x16x10	27x14x12	0.36	6.44	17	2.1	17	18	0.58	4.80	16	L2025-**W375**	E3025-F006
30x20x15	32.3x17.8x17.8	0.57	7.85	20	2.7	33	37	0.93	6.41	11	L2030-**W376**	E3030-F003
40x25x15	42.3x22.5x17.3	0.86	10.2	23		64		1.49	7.21	7.5	L2040-**W433**	
50x40x20	52.3x37.1x22.8	0.76	14.1	15		79		4.05	9.0	4.5	L2050-**W434**	
52x40x25	54.3x37.1x27.8	1.14	14.5	22		121		4.05	10.2	4.1	L2052-**W827**	
55x40x25	57.5x37.1x27.8	1.43	14.9	26		156		4.05	10.5	3.9	L2055-**W848**	
63x50x25	65.6x46.6x27.8	1.24	17.8	19		161		6.40	11.1	3.1	L2063-**W435**	
80x63x25	82.6x59.3x27.8	1.62	22.5	20		267		10.4	12.6	2.2	L2080-**W436**	
100x80x25	104.5x74.5x28.5	1.90	28.3	19		395		16.4	14.6	1.6	L2100-**W342**	
130x100x25	135.5x94.5x28.5	2.85	36.1	22		757		26.3	17.2	1.1	L2130-**W352**	
160x110x25	165x105x28.5	4.75	42.5	31		1480		32.5	19.9	0.8	L2160-**W758**	

* VITROPERM 500 F ** VITROVAC 6030 F

Eine aktuelle Typenübersicht finden Sie auf unserer Internetseite unter http://www.vacuumschmelze.com.

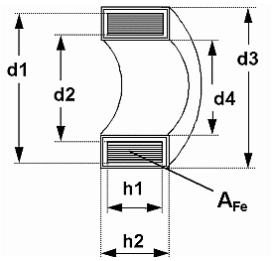
d1 = Nennaußendurchmesser Kern
d2 = Nenninnendurchmesser Kern
h1 = Nennhöhe Kern
d3 = max. Außendurchmesser incl. Beschichtung
d4 = min. Innendurchmesser incl. Beschichtung
h2 = max. Höhe incl. Beschichtung .
A_{Fe} = Effektiver Eisenquerschnitt
l_{Fe} = Eisenweglänge
A_L = Induktivität für N =1. Typische Werte für diese Werkstoffe bei f =10 kHz und geringer Aussteuerung (VITROVAC 6030 F: µ = 3000; VITROPERM 500 F: µ = 22000). Keine Garantiewerte.
m_{Fe} = Eisenmasse
A_{Cu} = möglicher Kupferquerschnitt bei einem Kupferfüllfaktor von 0,5
l_{Cu} = mittlere Windungslänge
R_{th} = Werte gelten für ein gedachtes Bauelement mit dem jeweiligen Kern und einer typischen Bewicklung. Ausführung im Vergußgehäuse, montiert auf einer Platine. Die Werte sind für Kern- und Kupferverluste anwendbar, jedoch nur als grobe Richtwerte.

Please visit our home page http://www.vacuumschmelze.com for an up-to date type list.

d1 = nominal outer core diameter
d2 = nominal inner core diameter
h1 = nominal core height
d3 = max. outer diameter with epoxy coating
d4 = min. inner diameter with epoxy coating
h2 = max. height with epoxy coating
A_{Fe} = effective iron cross section
l_{Fe} = mean iron path length
A_L = Inductance with a single turn. Typical values for these materials at 10 kHz and small excitation (VITROVAC 6030 F: µ = 3000, VITROPERM 500 F: µ = 22000). No guaranteed values.
m_{Fe} = iron mass
A_{Cu} = possible winding cross section at a mean winding factor of 0.5
l_{Cu} = mean winding turn length
R_{th} = These values are calculated on the basis of an imaginary component using this core and typical windings. The make is thought as a moulded design, mounted on a PCB. The values are for core- and copper losses, but are understood as a rough orientation only.

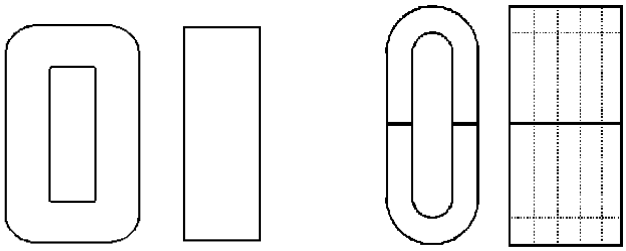
5.1 Kernausführung

Als Standard fertigen wir geschlossene Ringbandkerne. Sonderkerne in Oval- oder Rechteckform in geteilter oder ungeteilter Ausführung sind auf Wunsch ebenfalls herstellbar. Bitte sprechen Sie uns bei Interesse an.



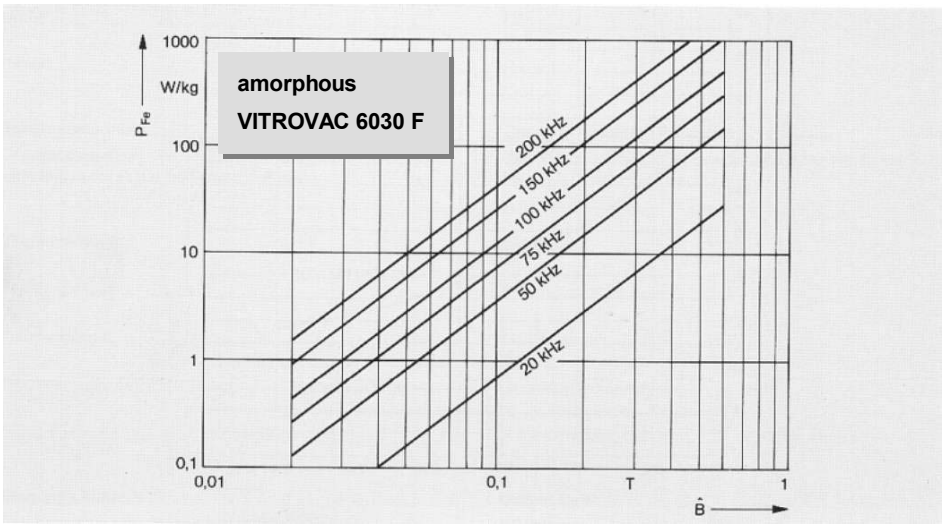
5.1. Core designs

Our standard designs are toroidal uncutted tape-wound cores. Special shapes in oval or rectangle design with or without cut can be produced, too. Please contact us for further informations.



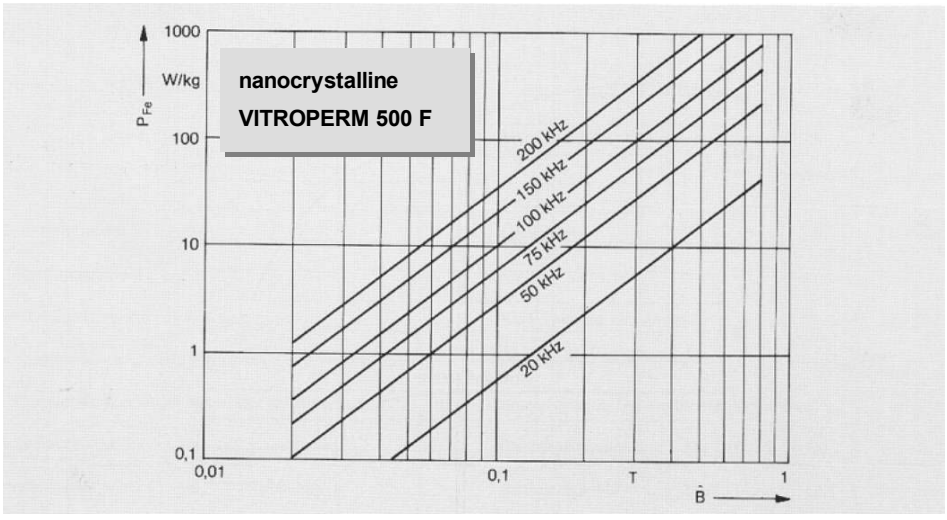
6. Magnetische Eigenschaften

6. Magnetic Properties



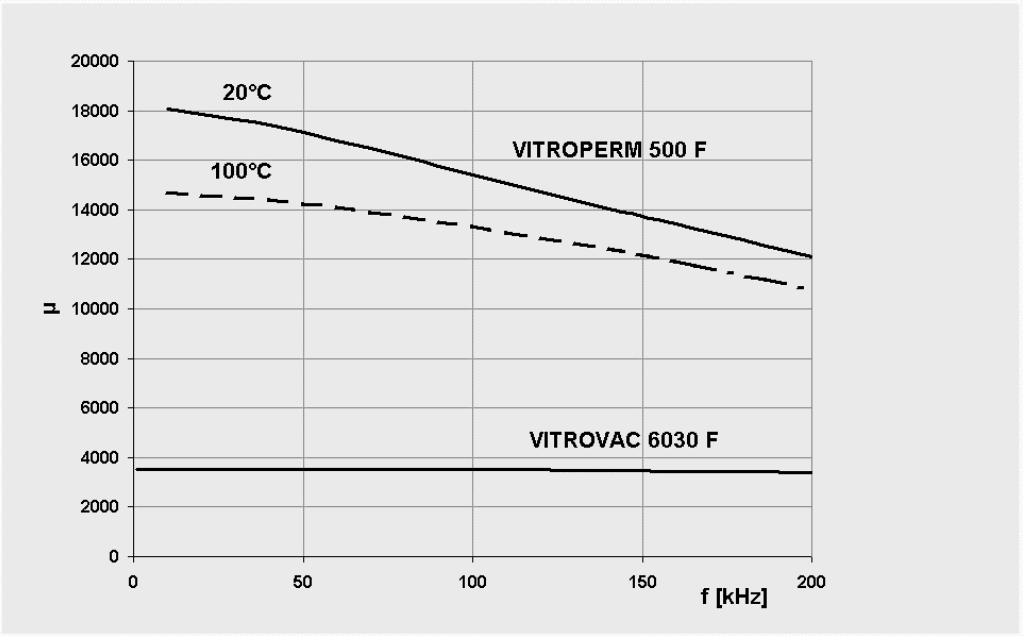
Typischer Verlauf der Ummagnetisierungsverluste über der Flußdichte von Ringbandkernen (ungeteilt) aus **VITROVAC 6030 F** bei verschiedenen Frequenzen. T_u = 25 °C.

Typical curve for magnetic reversal losses versus flux density of ungapped **VITROVAC 6030 F** tape-wound cores at various frequencies. T_u = 25°C.



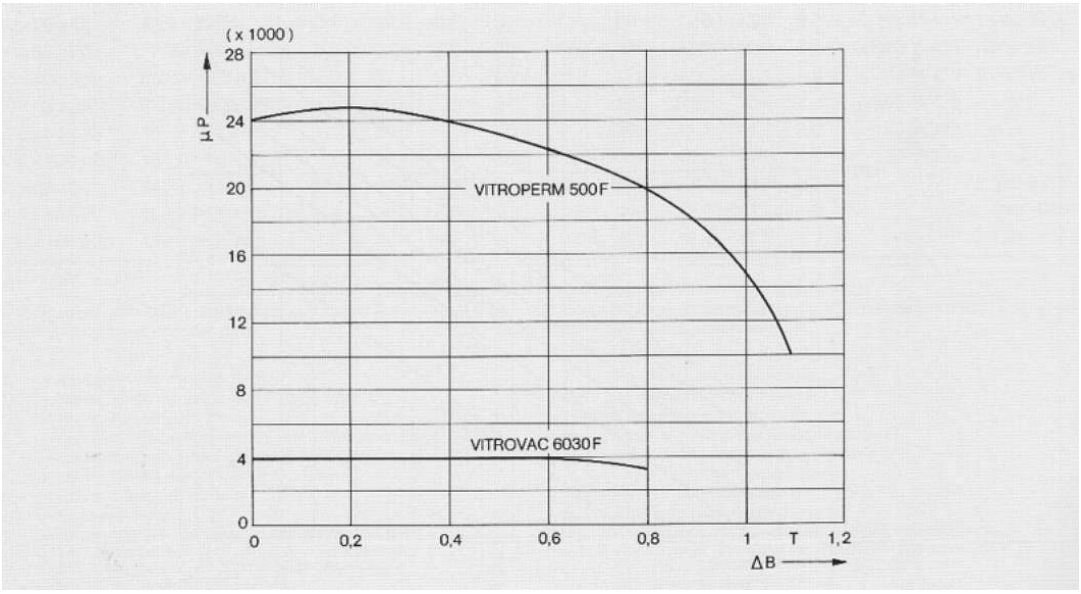
Typischer Verlauf der Ummagnetisierungsverluste über der Flußdichte von Ringbandkernen (ungeteilt) aus **VITROPERM 500 F** bei verschiedenen Frequenzen. T_u = 25 °C.

Typical curve for magnetic reversal losses versus flux density of ungapped **VITROPERM 500 F** tape-wound cores at various frequencies. T_u = 25 °C.



Typischer Verlauf der Permeabilität über der Frequenz von Ringbandkernen aus VITROPERM 500 F / VITROVAC 6030 F (T_u = 25 °C). H_{max} = 4 mA/cm.

Typical curve of permeability versus frequency of VITROPERM 500 F / VITROVAC 6030 F (T_u = 25 °C), H_{max} = 4 mA/cm.



Typischer Verlauf der Impulspermeabiliiät über dem Induktionshub von Ringbandkernen aus VITROPERM 500 F / VITROVAC 6030 F. Impulsdauer t_d = 5 μs. Wiederholfrequenz f_p = 1 kHz. T_u =25°C.

Typical curve for pulse permeability versus flux density swing of VITROPERM 500 F / VITROVAC 6030 F tape wound cores. Pulse duration t_d = 5 μs. Repeating frequency f_p = 1 kHz. T_u = 25°C.

VACUUMSCHMELZE GmbH & Co. KG

VACUUMSCHMELZE

Advanced Materials – The Key to Progress

Postfach 2253 / P.O.B. 2253
D-63412 Hanau
☎ (**49) 6181 / 38-0
Fax (**49) 6181 / 38-2075
E-Mail: Info@vacuumschmelze.com
http://www.vacuumschmelze.com

Checkliste*: Kerne für Leistungsübertrager*

Firma:

Name:

Projekt:

Schaltungsprinzip: (bitte auswählen)

[ ] Gegentaktwandler

[ ] Eintakt-Durchflußwandler

Bitte Skizze mit Prinzipschaltung beifügen.

Eingangsdaten:

min. Eingangsspg. $U_{E,min}$ = _____V

max. Eingangsspg. $U_{E,max}$ = _____ V

Arbeitsfrequenz f = _____ kHz

Tastverhältnis τ <= _____ (x 2 bei Gegentakt)

Ausgangsdaten:

Gleichspannungen	Spannungsabfälle (über Dioden usw.)*	Ströme
U_1= _____ V	ΔU_1= _____V	I_1 = _____ A
U_2=_____ V	ΔU_2= _____V	I_2 = _____ A
U_3 =_____ V	ΔU_3= _____V	I_3 = _____ A
U_4 =_____ V	ΔU_4= _____V	I_4 = _____ A
U_5 =_____ V	ΔU_5= _____V	I_5 = _____ A

* z.B.1V (2 x 0,5 V) für zwei Low-Drop Dioden im Strompfad.

Sonstige Daten:

Umgebungstemperatur Tu _____ °C

Besondere Umweltanforderungen: _____

Vorgesehene Ausführung: vergossen [ ] unvergossen [ ]

voraussichtlich benötigte Jahresstückzahl: ca. _____St.

Preisvorgabe für Kern ca. (EUR) _____

Angebot gewünscht? Ja [ ] Nein [ ]

Muster gewünscht? Ja [ ] Nein [ ]

Folgende Angaben werden wir nach Berechnung treffen:
Kern: Abmessungen, Material, Qualität, Fixierung.

Check List: Cores for Power Transformers

Company:

Name:

Project:

Circuit Engineering Principle: (please select)

[ ] Push Pull Converter

[ ] Single-Cycle-Feed-Forward Converter

Please add sketch of circuit.

Input data:

Min.Input Volt. $U_{E,min}$ = _____ V

Max. Input Volt. $U_{E,max}$ = _____V

Operating Frequency f = _____ kHz

Pulse Duty Ratio τ <= _____ (x 2 for push-pull)

Output Data:

DC voltages	Voltage drops (across diodes etc.)*	Currents
U_1= _____ V	ΔU_1= _____V	I_1 = _____ A
U_2=_____ V	ΔU_2= _____V	I_2 = _____ A
U_3 =_____ V	ΔU_3= _____V	I_3 = _____ A
U_4 =_____ V	ΔU_4= _____V	I_4 = _____ A
U_5 =_____ V	ΔU_5= _____V	I_5 = _____ A

*e.g. 1V (2 x 0.5 V) for two low-drop diodes in the current path

Other Data:

Ambient Temperature Tu _____°C

Environmental requirements: _____

Design: moulded [ ] non-moulded [ ]

Annual quantity approx.: _____ pcs

Target Price for Core (EUR): _____

Quotation required? Yes [ ] No [ ]

Sample required? Yes [ ] No [ ]

On calculation, we will determine the following details:
Core: dimenslons, material, quality, fixation.

CURRENT TRANSFORMERS AND POWER LINE TRANSFORMERS FOR SMART METERING

CURRENT TRANSFORMERS FOR ELECTRONIC ELECTRICITY METERS
PLC TRANSFORMERS FOR AUTOMATIC METER READING

ADVANCED MATERIALS – THE KEY TO PROGRESS

VACUUMSCHMELZE

THE COMPANY
VACUUMSCHMELZE

The company has a staff of approximately 4.500, is represented in 40 countries spread across all continents and currently registers a turnover of more than EUR 350 million. The headquaters and operational center of VAC is in Hanau, Germany. The company also has production plants in Slovakia, Finland, Malaysia and China.

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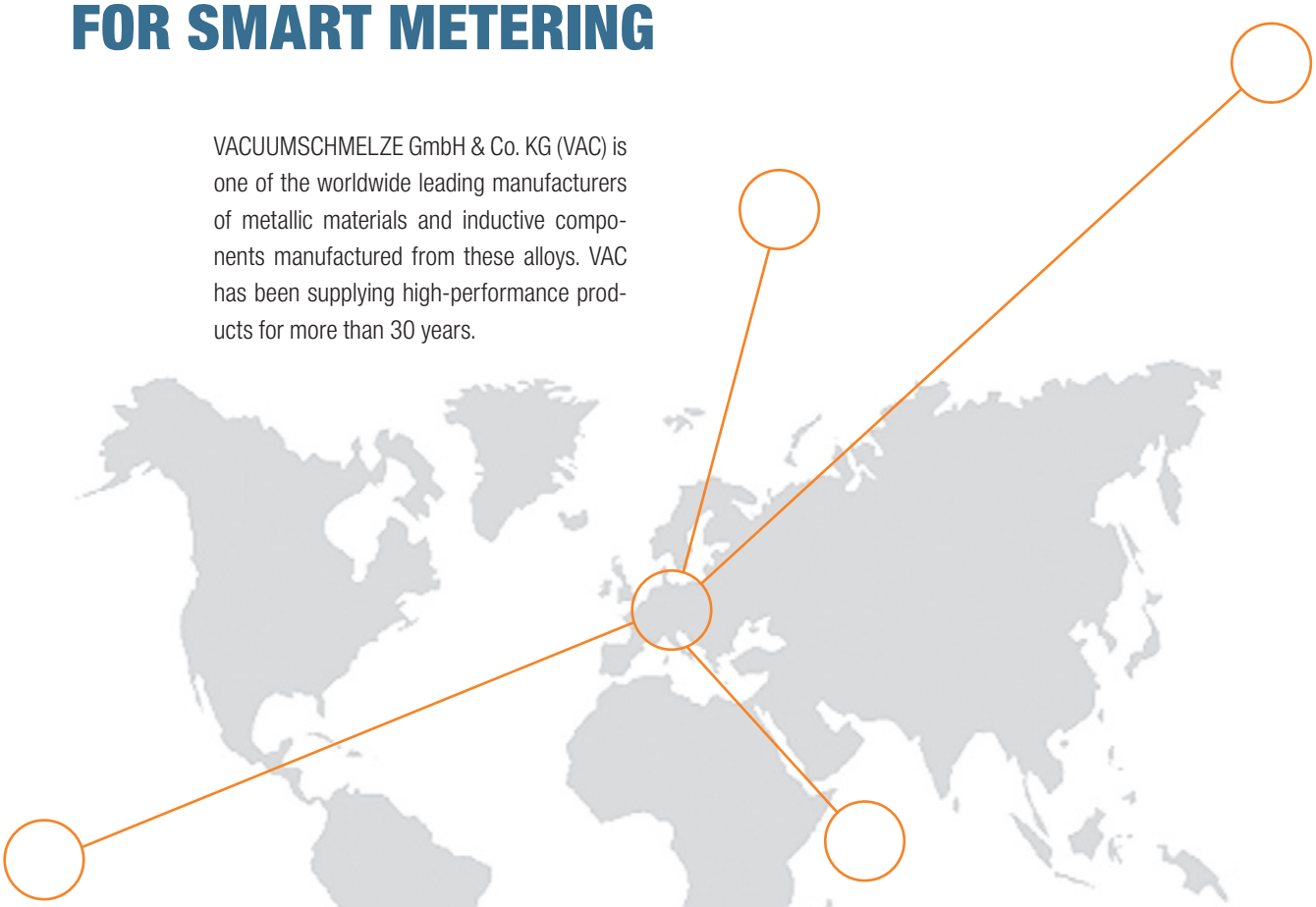
CURRENT TRANSFORMERS AND POWER LINE TRANSFORMERS FOR SMART METERING

VACUUMSCHMELZE GmbH & Co. KG (VAC) is one of the worldwide leading manufacturers of metallic materials and inductive components manufactured from these alloys. VAC has been supplying high-performance products for more than 30 years.



SMART METERING

For more than ten years we have focused on high-precision current transformers for use in electronic electricity meters. Developing and improving our own materials like VITROVAC® and VITROPERM®, produced by rapid solidification technology, we are in a leading position to serve the metering industry with high-performance current transformers.

Our R&D and Engineering departments can provide outstanding competence in designing cores and components for the metering industry worldwide. In total more than 30 million meters operate with VAC materials.

Technical standards define requirements for accuracy for measuring of power in different operation modes. In Europe and other non-European countries these are usually the standards IEC 62053 -21, -22, -23 and, for the American market, the standards of the ANSI C12.xx series.

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CURRENT TRANSFORMERS FOR SMART METERING

MEASUREMENT PRINCIPLES

The key component in smart meters is the current transducer. There is a number of functional principles for implementation of the current transducer.

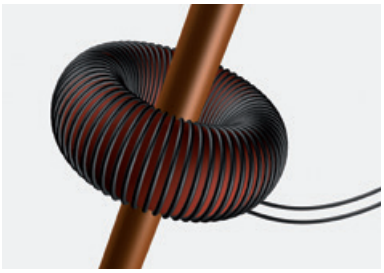
The shunt resistor is a favourite choice because of its very low cost and good linearity, but designers have to be aware of its disadvantages. Because of the regulations concerning maximum power consumption (2 W per phase acc. to IEC 62053 -21, -23), its resistance is limited to some hundreds of $\mu\Omega$. This low value results in very low secondary voltages at low primary currents.

These have to be very carefully filtered and amplified to keep the meter's specified accuracy in the low current level. Heat dissipation within the meter is another critical point to be considered. In cases of multi-phase meters or single-phase meters with external interface, additional galvanic separation has to be provided to prevent hazardous operation or short-circuit conditions between the phases. In most cases optocouplers and separation transformers will additionally be needed, increasing the meter's overall cost.

Another favourite principle is the Rogowski coil, which does not exhibit saturation effects due to its coreless operation. The disadvantage of this is common to all open magnetic circuits and results in very interference-sensitive operation. Costly shielding has to be provided to keep measurement errors small at low primary currents. Designs using Hall sensor devices have to be clearly separated: the low-cost types can suffer from ageing effects which can deteriorate accuracy over time; stabilised designs will control these effects, but at the cost of complicated compensation circuitry.

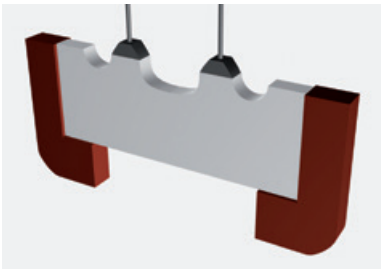
OVERVIEW OF ESTABLISHED MEASUREMENT PRINCIPLES IN ELECTRICITY METERS

- Current Transformers



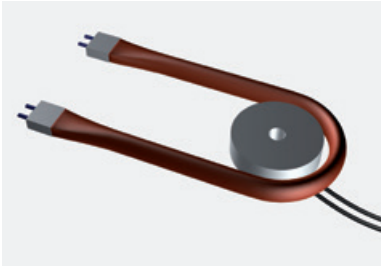
Safe Galvanic Separation
High Dynamic Range

- Shunt



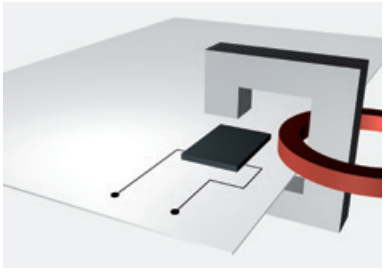
Low Dynamic Range
No Galvanic Separation

- Rogowski



Coreless Coil
Very Small Signals
Requires Integrator

- Hall Sensor



Semiconductor Material
Material Ageing
Complex Signal Processing

In comparison to other principles, toroidal-core current transformers with low burden resistors have several obvious advantages:

• closed magnetic circuit:	less sensitive to interference fields usually no shielding required
• magnetic function principle without semiconductors:	high long-term stability no need for additional circuitry
• simple assembly involving few parts:	low assembly expenses, compact designs attractive prices easy to mount

Characteristics	Current Transformer	Shunt	Rogowski Coil	Hall Sensor
Dynamic Range / Linearity	+	+	+	+
Temperature Stability	+	0	++	+
Corrosion / Reliability	++	--	++	++
Energy Dissipation	++	--	++	++
Galvanic Insulation	++	--	++	++
Output Signal Level	++	-	0	0
Mounting	++	+	--	--
Sensitivity against external AC + DC Fields	0	-	--	--

++ : excellent + : good 0 : average - : weak -- : disadvantageous

The properties of the toroidal core current transformers, such as maximum transmissible primary current, amplitude and phase error as well as linearity, are basically determined by the material used for the magnetic core. The three areas of application mentioned place different demands on the respective materials:

For meters according to IEC 62053-22 and ANSI C12.xx, the best materials are those with high permeability in connection with the comparatively high flux density ranges of the metallic materials and only slight changes in properties as a function of the temperature. Current transformers with high-grade amorphous VITROVAC or nanocrystalline VITROPERM alloys from VAC offer extra advantages to the users:

- very small and high linear phase and amplitude error
- easily compensable phase error
- extreme low temperature dependence

Meters according to IEC 62053 -21, -23 must have tolerance to DC current components (‚direct current tolerance') which can saturate conventional current transformers when unipolar alternating currents occur, e.g. from power supply units with primary side diodes.

Magnetic cores made of very linear but still highly excitable amorphous and nanocrystalline low permeability alloys from VAC are used for this. These provide the current transformer with excellent properties:

- standard compliant DC tolerance without air gap
- negligible small amplitude error
- extreme linear, easily compensable phase curve
- low temperature dependence

PRINCIPLE OF CIRCUITRY

Phase and amplitude errors are critical for electricity measurement accuracy when current transformers are used. With meters of medium accuracy without DC tolerance, both have very low absolute values and can therefore be easily compensated by a simple correction in the circuit.

Current transformers with DC tolerance have the special feature of a relatively high absolute phase error value at high constancy, whereas the amplitude error is negligibly small. This causes an energy measurement error which varies only slightly with the primary current and which adopts impermissibly high values on complex loads (e.g. inductive load with $\cos \varphi = 0.5$) if the phase error is not carefully compensated.

Since the specified scatter of the secondary inductance L cannot be reduced at will, the phase error of the individual current transformer is scattered to the same extent. An individual correction is therefore recommended to stay reliably within the error limits. This can be performed with a suitable digital signal processor (DSP) which is digitally adjusted to the implemented current transformer in a calibration run at a single current value (e.g. at I_b). Particularly high accuracy can be achieved when the phase error curve is measured at several currents and is approximated between these for correction.

This is often impossible, or only possible to a certain extent, in devices with DSPs of a simple internal structure. Here correction is possible by means of an RC low-pass connected in series with the analogue current measuring input (see page 9). Because of the scatter of the L-values, adapted use of grouped C-values may be necessary.

If further modifications of the operating parameters are necessary, we offer recalculation of the error characteristics upon request.

SUMMARIZED OVERVIEW OF 60 A AND 100 A CURRENT TRANSFORMERS

60 A and 100 A are the most important current ranges worldwide. The following table shows available variations for both current ranges:

I_{max}	Order Code T60404-		Design		Alloy			Shielding	DC Tolerance
			Wire	Pin	VITROPERM	VITROPERM Compact	VITROVAC		
60 A 100 A	...E4624-X... ...E4626-X...	101	X				X		X
		501					X		X
		121	X		X				X
		521		X	X				X
		131	X			X			X
		531		X		X			X
		151	X				X	X	X
		171	X			X		X	X
		002	X		X				
		502		X	X				

BLOCK DIAGRAM OF AN ELECTRONIC ELECTRICITY METER

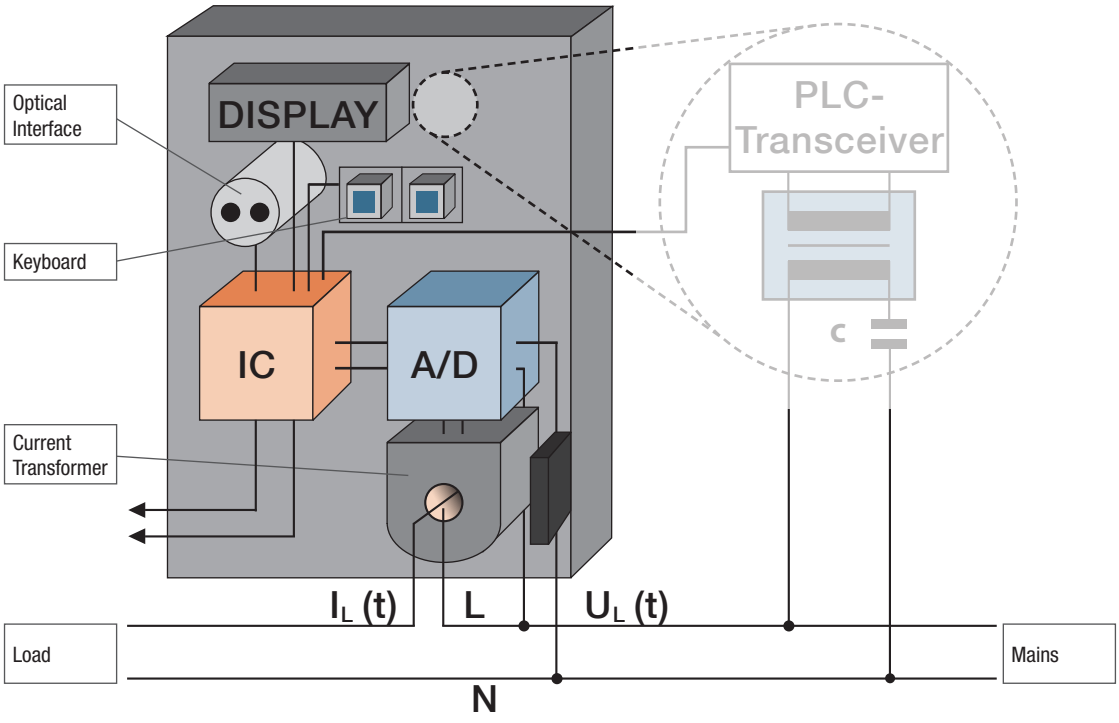


TABLE 1: CURRENT TRANSFORMERS WITH DC TOLERANCE ACCORDING TO IEC – BASED ON VITROVAC

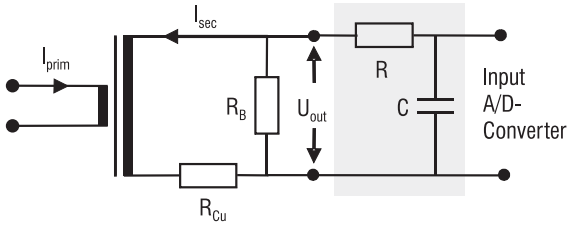
Order Code T60404-...	Error Curves [fig./ page]	Primary Current Range		Ratio	Phase Error	Characteristic Values				Dimensions			
		I_{max} [A_{rms}]	$\hat{I}_{peak}$ [A_{0p}]	1 : [ ]	φ(I) [°]	L [H]	R_{DC} [Ω]	R_B [Ω]	U_B [V_{rms}]	Inner dia. Ø [mm]	Width D [mm]	Heigth H [mm]	Pin/ Wire
...E4622-X101	1/17	20	20	2500	3.62	4.6	54	37.5	0.3	5	28.5	14.5	Wire
...E4623-X101	2/17	40	40	2500	4.15	3.7	66	18.8	0.3	5.5	28	16	Wire
...E4624-X101	3/18	60	60	2500	4.06	3.0	55	12.5	0.3	8	30.5	15	Wire
...E4624-X501	3/18	60	60	2500	4.06	3.0	55	12.5	0.3	8.5	31	14	Pin
...E4625-X101	4/18	80	80	2500	5.15	2.4	59	9.4	0.3	8	30.5	15	Wire
...E4625-X501	4/18	80	80	2500	5.15	2.4	59	9.4	0.3	8.5	31	14	Pin
...E4626-X101	5/19	100	100	2500	4.48	2.1	44	7.5	0.3	9.5	35	15	Wire
...E4626-X501	5/19	100	100	2500	4.48	2.1	44	7.5	0.3	11.5	34	14	Pin
...E4627-X101	6/19	120	120	2500	4.07	1.8	34	6.25	0.3	12	39	18	Wire

TABLE 2: CURRENT TRANSFORMERS WITH DC TOLERANCE ACCORDING TO IEC – – BASED ON VITROPERM

Order Code T60404-...	Error Curves [fig./ page]	Primary Current Range		Ratio	Phase Error	Characteristic Values				Dimensions			
		I_{max} [A_{rms}]	$\hat{I}_{peak}$ [A_{0p}]	1 : [ ]	φ(I) [°]	L [H]	R_{DC} [Ω]	R_B [Ω]	U_B [V_{rms}]	Inner dia. Ø [mm]	Width D [mm]	Heigth H [mm]	Pin/ Wire
...E4622-X121	7/20	20	20	2500	2.0	9.23	70.6	37.5	0.3	5	30.9	16.0	Wire
...E4623-X121	8/20	40	40	2500	2.1	6.5	60	18.75	0.3	7	33.8	16.9	Wire
...E4624-X121	9/21	60	60	2500	2.3	5.05	51.5	12.5	0.3	8	37.5	18.1	Wire
...E4624-X131	10/21	60	60	2500	3.5	3.8	71.5	12.5	0.3	8	32.7	16.3	Wire
...E4624-X531	10/21	60	60	2500	3.5	3.8	71.5	12.5	0.3	8	32.7	16.3	Pin
...E4625-X121	11/22	80	80	2500	2.4	3.5	42	9.38	0.3	10	40.8	18.5	Wire
...E4625-X131	12/22	80	80	2500	3.4	3.33	62	9.38	0.3	9	36.8	17.4	Wire
...E4626-X121	13/23	100	100	2500	2.4	2.77	35.5	7.5	0.3	10.5	43.2	19.8	Wire
...E4626-X131	14/23	100	100	2500	3.3	3.1	49	7.5	0.3	9	38.1	17.7	Pin
...E4626-X531	14/23	100	100	2500	3.3	3.1	49	7.5	0.3	9	38.1	17.7	Pin
...E4627-X121	15/24	120	120	2500	4.1	3.1	37	6.25	0.3	12.5	45.5	19	Wire

APPLICATION NOTE:
RC COMPONENTS FOR COMPENSATION OF PHASE ERROR

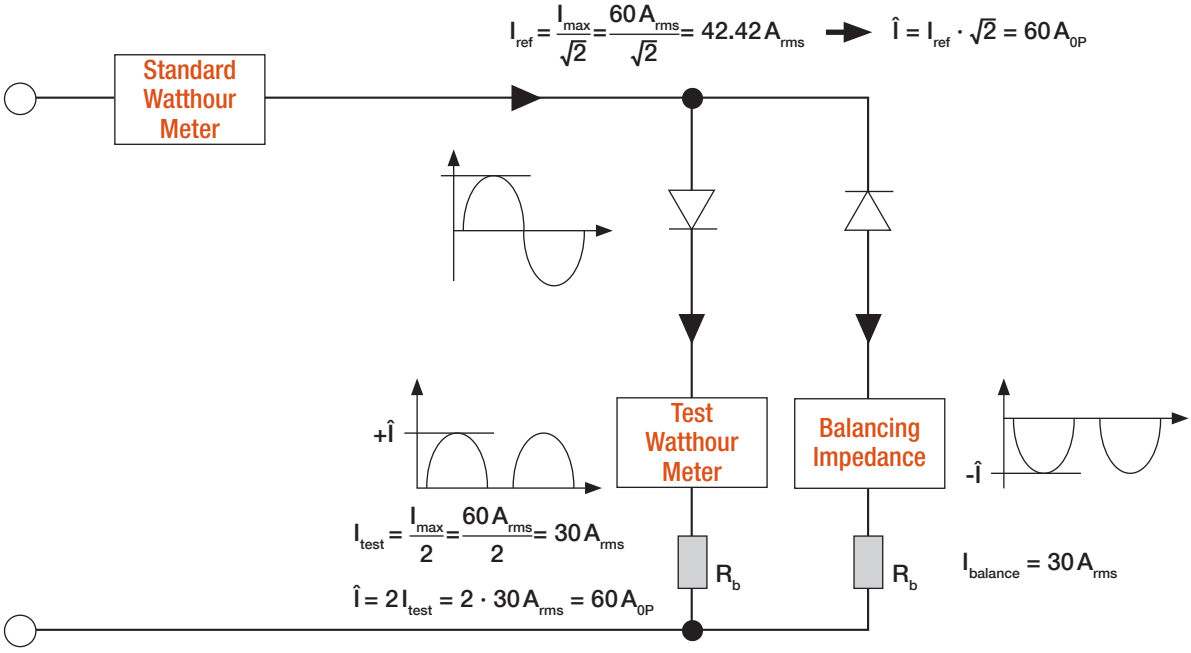
The excellent soft magnetic properties of the VAC core material for DC-tolerant CTs leads to a negligible small amplitude error as well as to extremely low and linear temperature dependence. Due to the low permeability, a phase error of typically 4° to 5° occurs which is easy to compensate on account of its high constancy of typically +/- 0.05°. Compensation can be effected digitally by appropriate correction in the microprocessor and analogously by a RC low-pass in front of the input of the A/D converter. A number of major metering chip providers supply tailored solutions for optimum performance and accuracy in combination with these CT types.



$$C = (R_{CU} + R_B) / \omega^2 \cdot R \cdot L$$

Condition for value of R:
RB <<R<<IZI of converter;
typical value R = 1 kΩ
Typ. C values: 150 ... 300 nF

DC TOLERANCE TEST ACCORDING TO IEC 62053-21, -23



The diagram above shows a typical test of DC tolerance of a 60 A electricity meter. The Balancing Impedance is another meter from the same series. During this test, the meter shows 30 A_{rms}, which is equal to 60 A_{0P}, for only half-rectified sinusoidal currents.

TABLE 3: SHIELDED CURRENT TRANSFORMERS FOR ANTI-TAMPERING

Order Code T60404-...	Error Curves [fig./ page]	Primary Current Range I_{max} [A_{rms}]	$\hat{I}_{peak}$ [A_{0p}]	Ratio 1 : [ ]	Phase Error φ(I) [°]	Characteristic Values L [H]	R_{DC} [Ω]	R_B [Ω]	U_B [V_{rms}]	Dimensions Inner dia. Ø [mm]	Width D [mm]	Heigth H [mm]	Pin/ Wire
...E4622-X011	20/26	6	-	2000	0.37	105	115	100	0.3	5.5	28	15.9	Wire
...E4622-X012	21/27	6	-	2000	0.17	238	115	100	0.3	5.5	28	15.9	Wire
...E4623-X171	8/20	40	40	2500	2.1	6.5	60	18.75	0.3	6	38.5	20	Wire
...E4624-X151	3/18	60	60	2500	4.06	3.0	55	12.5	0.3	8	32.9	17.1	Wire
...E4624-X171	9/21	60	60	2500	3.5	3.8	71.5	12.5	0.3	8	36.9	19.2	Wire
...E4625-X151	4/18	80	80	2500	5.15	2.4	53.5	9.4	0.3	8	32.9	17.1	Wire
...E4626-X151	5/19	100	100	2500	4.48	1.97	55	7.5	0.3	9.5	35.8	17.2	Wire

TYPICAL CHARACTERISTIC OF THE AMPLITUDE ERROR IN THE FIELD OF A PERMANENT MAGNET

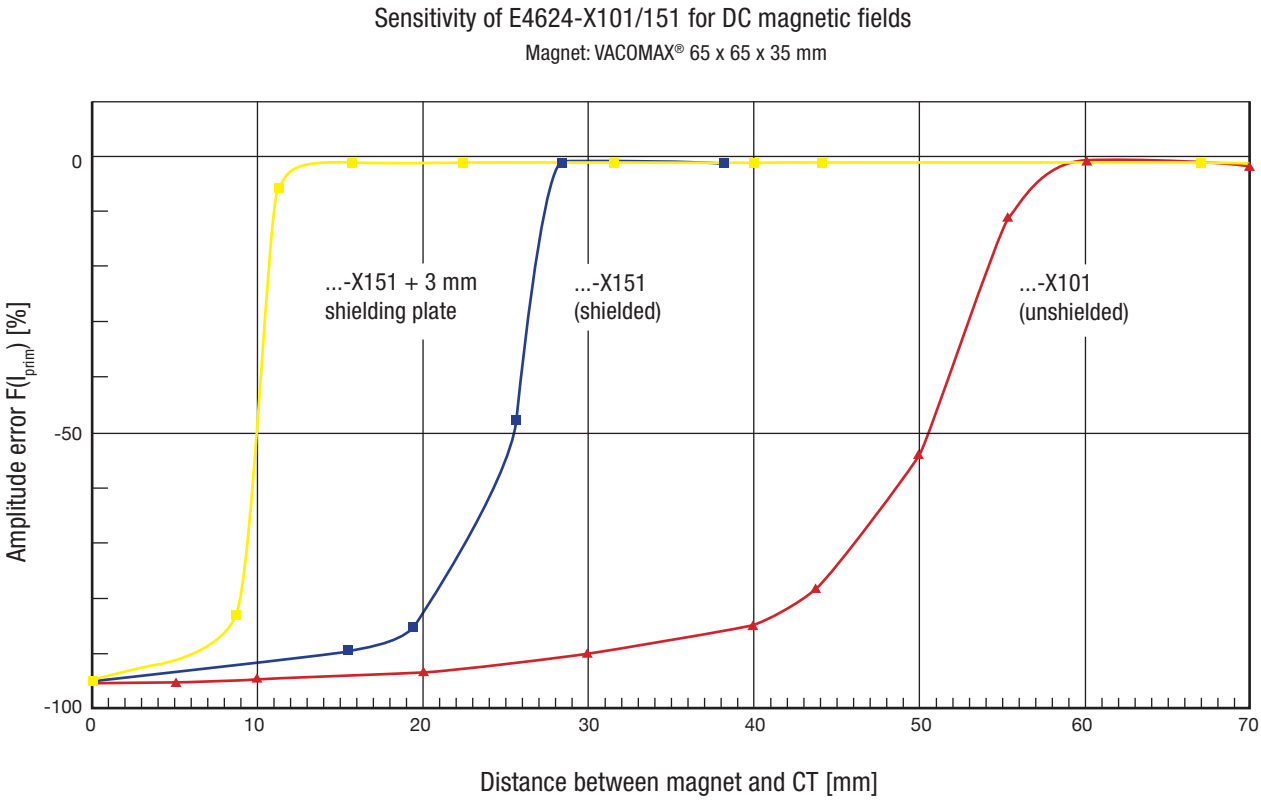


Diagram above shows a comparison of different shielding configurations. For optimum protection against external magnetic fields CTs from …–X151 series and a 3 mm shielding plate are needed.

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TABLE 4: CURRENT TRANSFORMERS WITHOUT DC TOLERANCE FOR DIRECT CONNECTION

Order Code T60404-...	Error Curves [fig./ page]	Primary Current Range		Ratio	Phase Error	Characteristic Values				Dimensions			
		I_{max} [A_{rms}]	$\hat{I}_{peak}$ [A_{0p}]	1 : [ ]	φ(I) [°]	L [H]	R_{DC} [Ω]	R_B [Ω]	U_B [V_{rms}]	Inner dia. Ø [mm]	Width D [mm]	Heigth H [mm]	Pin/ Wire
...E4622-X002	16/24	20	-	2500	0.18	113	54	37.5	0.3	5	28.5	14.5	Wire
...E4623-X002	17/25	40	-	2500	0.12	155	61	18.8	0.3	5.5	28	16	Wire
...E4624-X002	18/25	60	-	2500	0.13	122	55	12.5	0.3	8	30.5	15	Wire
...E4624-X502	18/25	60	-	2500	0.13	122	55	12.5	0.3	8.5	31	14	Pin
...E4626-X002	19/26	100	-	2500	0.11	97	44	7.5	0.3	9.5	35	15	Wire
...E4626-X502	19/26	100	-	2500	0.11	97	44	7.5	0.3	11.5	34	14	Pin

TABLE 5: CURRENT TRANSFORMERS WITHOUT DC TOLERANCE FOR INDIRECT CONNECTION

Order Code T60404-...	Error Curves [fig./ page]	Primary Current Range		Ratio	Phase Error	Characteristic Values				Dimensions			
		I_{max} [A_{rms}]	$\hat{I}_{peak}$ [A_{0p}]	1 : [ ]	φ(I) [°]	L [H]	R_{DC} [Ω]	R_B [Ω]	U_B [V_{rms}]	Inner dia. Ø [mm]	Width D [mm]	Heigth H [mm]	Pin/ Wire
...E4629-X007	20/26	6	-	2000	0.37	105	112	100	0.3	7.0	23.0	11.0	Wire
...E4622-X501	20/26	6	-	2000	0.37	110	115	100	0.3	6.3	24.5	11.5	Pin
...E4629-X010	21/27	6	-	2000	0.17	238	114	30	0.3	7.0	23	11	Wire
...E4622-X503	21/27	6	-	2000	0.17	238	114	100	0.3	6.3	24.5	11.5	Pin
...E4658-X043	22/27	6	-	1500	0.4	35	46	75	0.3	5.0	16.8	9	Pin

TABLE 6: CURRENT TRANSFORMERS FOR ANSI MARKET

Order Code T60404-...	Error Curves [fig./ page]	Primary Current Range		Ratio	Phase Error	Characteristic Values				Dimensions			
		I_{max} [A_{rms}]	$\hat{I}_{peak}$ [A_{0p}]	1 : [ ]	φ(I) [°]	L [H]	R_{DC} [Ω]	R_B [Ω]	U_B [V_{rms}]	Inner dia. Ø [mm]	Width D [mm]	Heigth H [mm]	Pin/ Wire
...E4629-X007	23/28	20	-	2000	0.21	105	112	30	0.3	7.0	23.0	11.0	Wire
...E4622-X501	23/28	20	-	2000	0.21	110	115	30	0.3	6.3	24.5	11.5	Pin
...E4629-X010	24/28	20	-	2000	0.17	238	114	30	0.3	7.0	23.0	11.0	Wire
...E4622-X503	24/28	20	-	2000	0.17	238	114	30	0.3	6.3	24.5	11.5	Pin
...E4627-X001	25/29	200	-	1000	0.11	24.6	13.5	1.5	0.3	8.5	30.0	17.5	Wire
...E4628-X001	26/29	320	-	1000	0.10	22	12.7	0.94	0.3	11.0	35.0	18.5	Wire

EXPLANATIONS OF TABLES 1 TO 6:

Noted values are typical at room temperature (25 °C)

All types are designed as bar-type CTs with one primary turn ($N_1 = 1$).

I_{max} = maximum AC primary current with defined errors

$\hat{I}_{peak}$ = max. half wave rectified AC amplitude without saturation (for Class 1 meter (IEC 62053 -21, -23): $F(\hat{I}_{max}) < 3\,\%$)

φ (I) = max. phase error for $I < I_{max}$

F(I) = max. amplitude error for $I < I_{max}$

N_2 = number of secondary turns

L = inductance at moderate excitation level (I < Imax)

R_{DC} = winding resistance

R_B = burden resistor

U_B = output voltage across burden resistor R_B at I_{max}

Ø = diameter of centre hole

D = maximum width of component in mm

H = maximum thickness of component in mm

For further details please see datasheets, which are provided on www.vacuumschmelze.com.

EXAMPLES FOR CUSTOMISED CURRENT TRANSFORMER DESIGNS

In addition to the illustrated standard types, customised developments (see above) are also possible when sufficiently large quantities are needed. Please ask for our latest CT checklist, fill out as completely as possible and send it back to us.

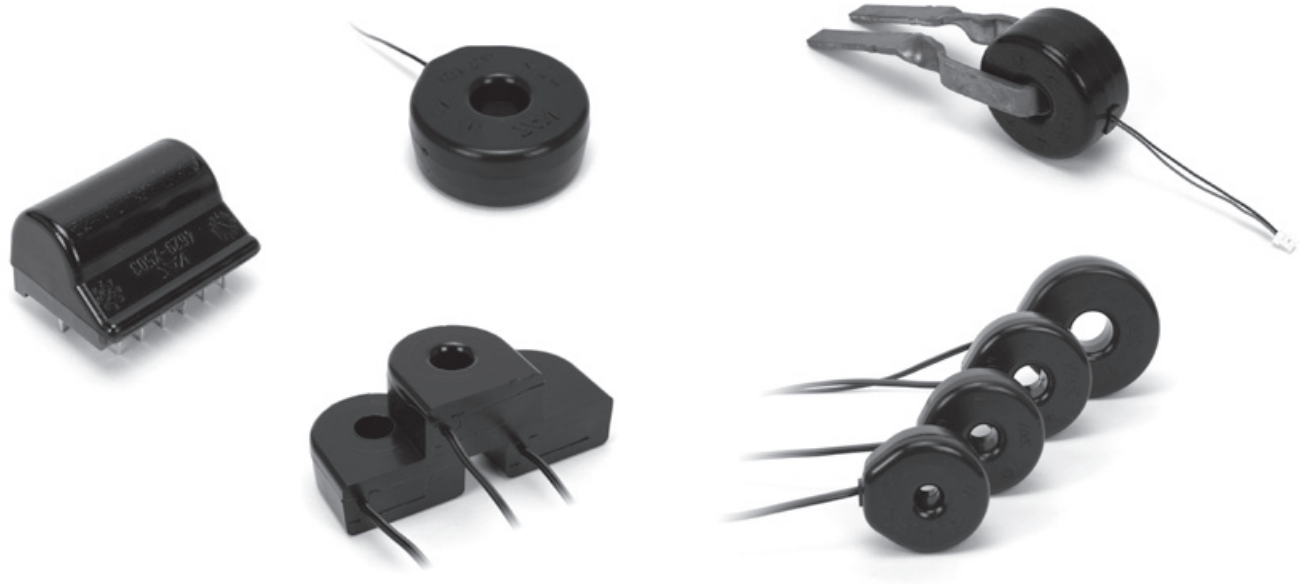
If the sensitivity of the current transformer to external magnetic fields in special applications is still too high, we recommend shielded versions of CTs (see table 3 on page 10). If required, for anti-tampering issues each CT can be encapsulated with a pair of deep drawing caps.

For additional protection against manipulation by external fields from permanent magnets, a metal plate may be placed between CT and the magnet (see diagram on page 10).

DIELECTRIC STRENGTH TEST:

For standard type housings the following values are valid for the insulation between a bare copper primary conductor and the secondary winding (different test values on request):

$U_{p\,rms}$ = 2,5 kV (50 / 60 Hz, 1 min) and
$U_{p\,max}$ = 6 kV (1,2 µs / 50 µs – test pulse)



PLC TRANSFORMERS FOR SMART METERING

In the years to come, 'Smart Grids' will take on greater significance and electronic electricity meters newly installed for this purpose will increasingly be networked to enable processes including remote meter reading.

Electronic electricity meters must therefore be able to communicate, and secure data transfer must be guaranteed. Various communication technologies are available for Automatic Meter Reading (AMR). In the case of wired transfer technologies, power line communication (PLC) is one of the favoured technologies.

VAC component characteristics are aligned and optimized for low EMC interference, low distortion and high dielectric strength. These key parameters for PLC transformers offer particularly significant advantages for users with respect to secure data transmission.

BLOCK DIAGRAM OF AN ELECTRONIC METER WITH PLC READ-OUT SYSTEM

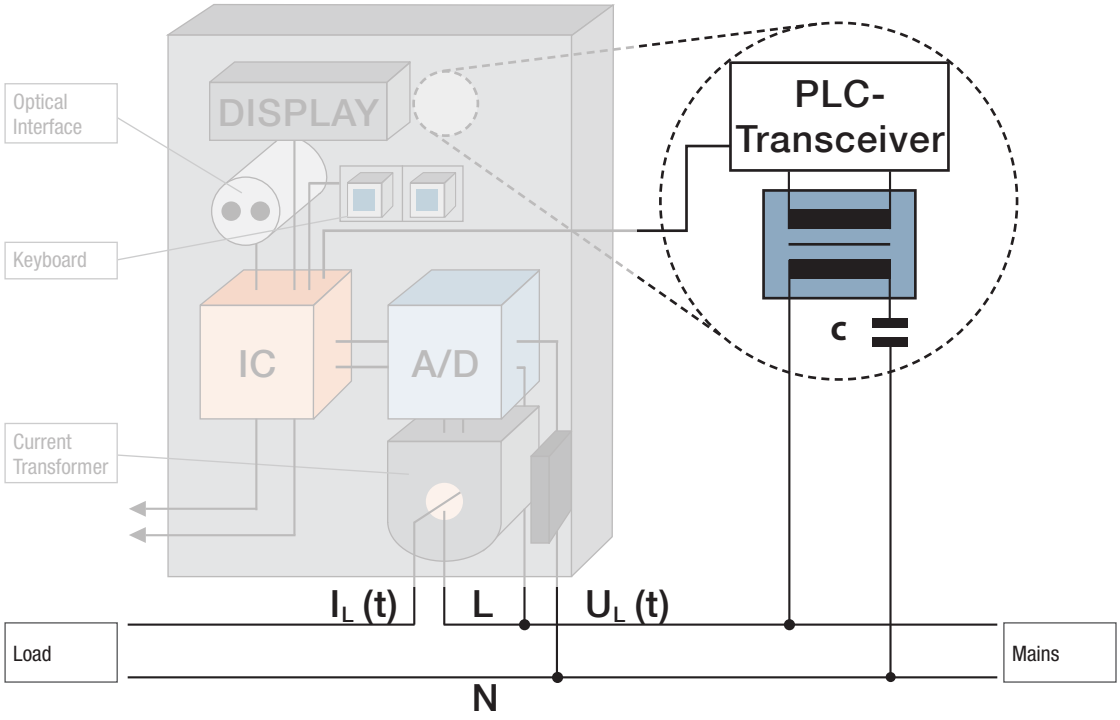


TABLE 7: PLC TRANSFORMERS FOR METERING APPLICATIONS

Order Code T60403-K…	Turns Ratio	L [mH]	R_{cu} [mΩ]	L_s [µH]	Capacitor C_K [pF]	HV Test* [kV_{rms}]	Design**
5024-X044	1:1	1.4	200 : 200	0.3	25	6	SMD
4081-X004	1:1	1.4	200 : 300	0.3	25	4	PTH flat
4085-X004			200 : 300				PTH upright
5024-X078	1:1	2.5	200 : 300	0.9	50	3	SMD
4096-X046	1:1	1.3	100 : 150	1	12	6	PTH
4096-X047	1:1	1.3	100 : 200	10	5	6	PTH
4096-X048	1:1	1.3	100 : 200	10	5	6	PTH
4021-X139	1.67:1	0.5	300 : 200	5	5	6	PTH
5024-X097	1.68:1	1.2	220 : 160	5.8	17	1.5***	SMD
4031-X009	2:1	1.0	140 : 80	0.67	17	4	PTH
5024-X079	2:1	1.4	350 : 120	2	50	3	SMD
5024-X090	1:1:2	0.88	100 : 100 : 100	0.4	30	3	SMD
5024-X092****	1:1:2	0.7	250: 250 : 500	0.99	37.5	4	SMD
5024-X099****	1:1:2	0.7	250 : 250 : 500	0.99	37.5	3	SMD
5032-X102	1:1:2	0.7	135 : 135 : 230	0.73	25.27	7.5	SMD

* = reinforced insulation according to EN60950
** = mechanical outline; for details see VAC datasheet (available upon request)
*** = operational insulation
**** = extended performance in the low frequency range

TABLE 8: PLC TRANSFORMERS CROSS REFERENCE LIST

Order Code T60403-K…	Echelon		Maxim	On Semi	Renesas	STM		TI	Yitran
	PLT-21 PLT-22	PLT3120 PLT3150	MAX2990 MAX2991	AMIS 49587	M16C/6S	ST7536 ST7537	ST7538 ST7540	C2000	IT800
5024-X044	X	X			X	X	X		X
4081-X004	X	X			X	X	X		X
4085-X004									
5024-X078	X	X					X		X
4096-X046	X	X	X				X		X
4096-X047	X	X					X		X
4096-X048			X						
4021-X139	X	X					X		
5024-X097	X	X							
4031-X009				X			X		
5024-X079				X					
5024-X090		X			X		X		X
5024-X092*		X			X		X	X	X
5024-X099*		X			X		X	X	X
5032-X102					X				X

* = extended performance in the low-frequency range

TYPICAL TEMPERATURE DEPENDENCE OF PHASE AND AMPLITUDE ERRORS

Fig. 1: 20 A with DC Tolerance, T60404-E4622-X101

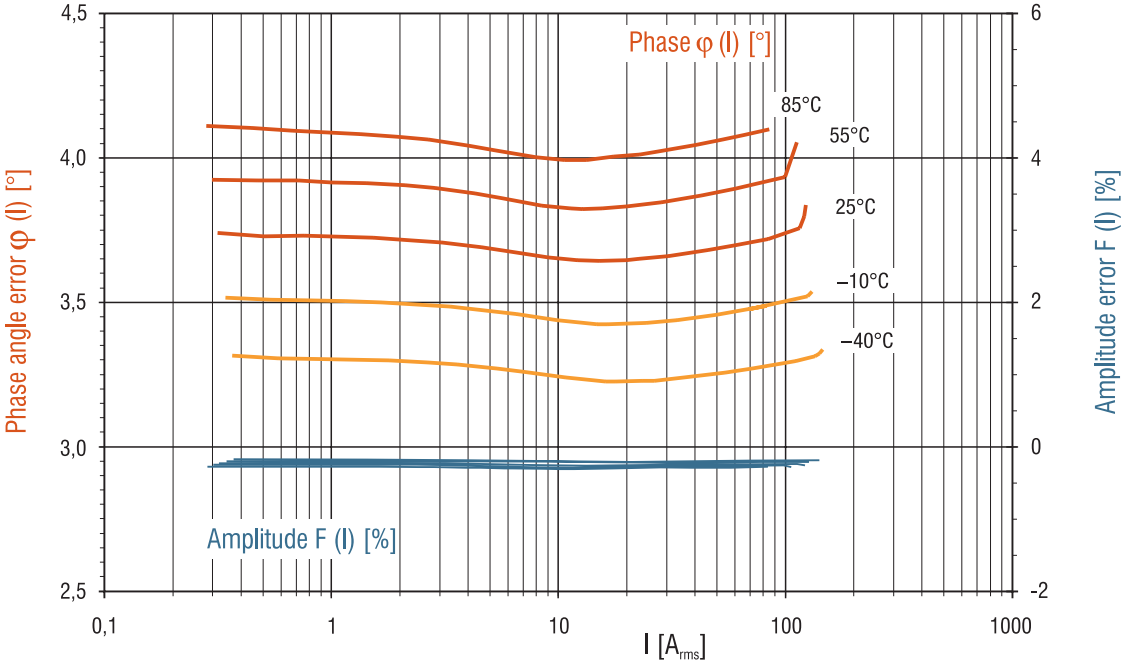


Fig. 2: 40 A with DC Tolerance, T60404-E4623-X101

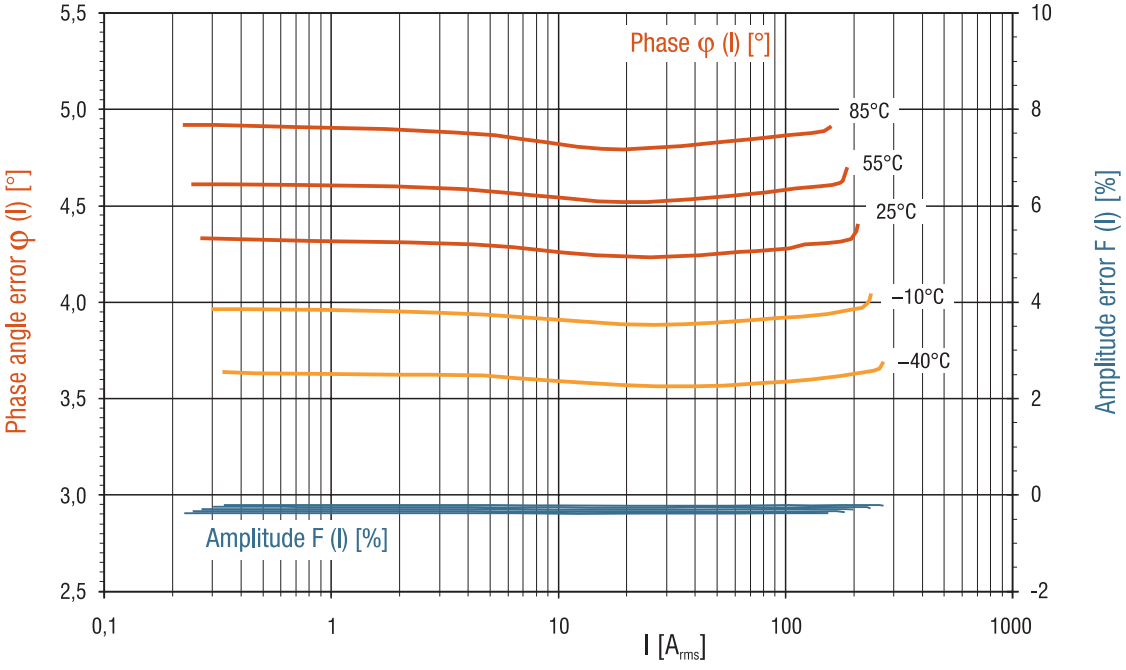


Fig. 3: 60 A with DC Tolerance, T60404-E4624-X101/-X501/-X151

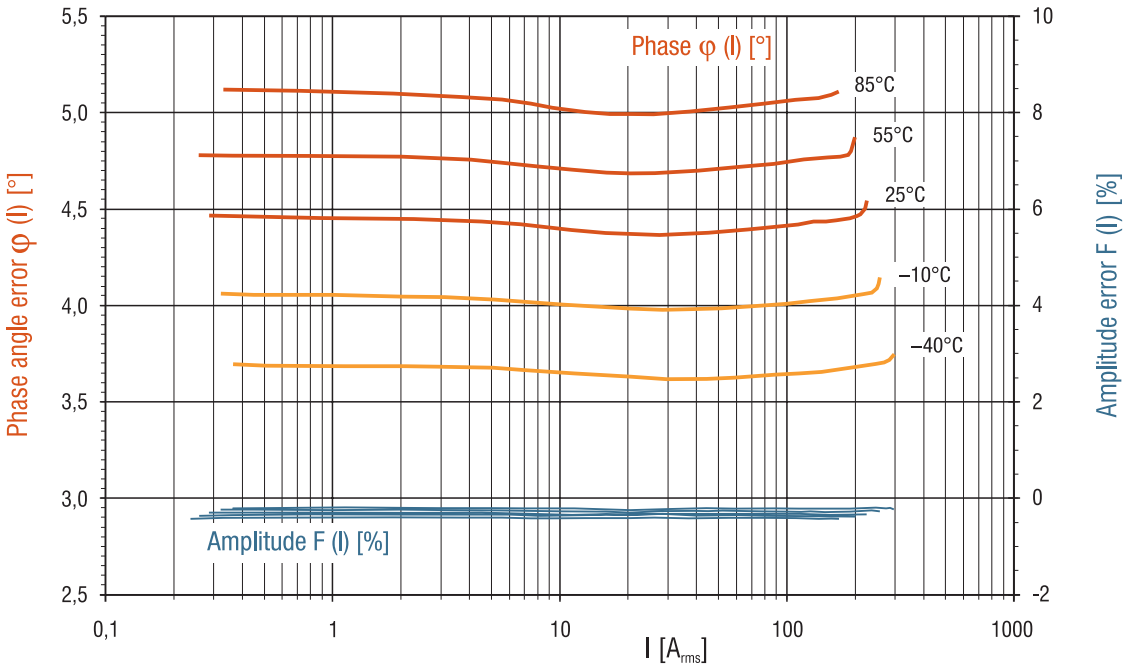


Fig. 4: 80 A with DC Tolerance, T60404-E4625-X101/-X501/-X151

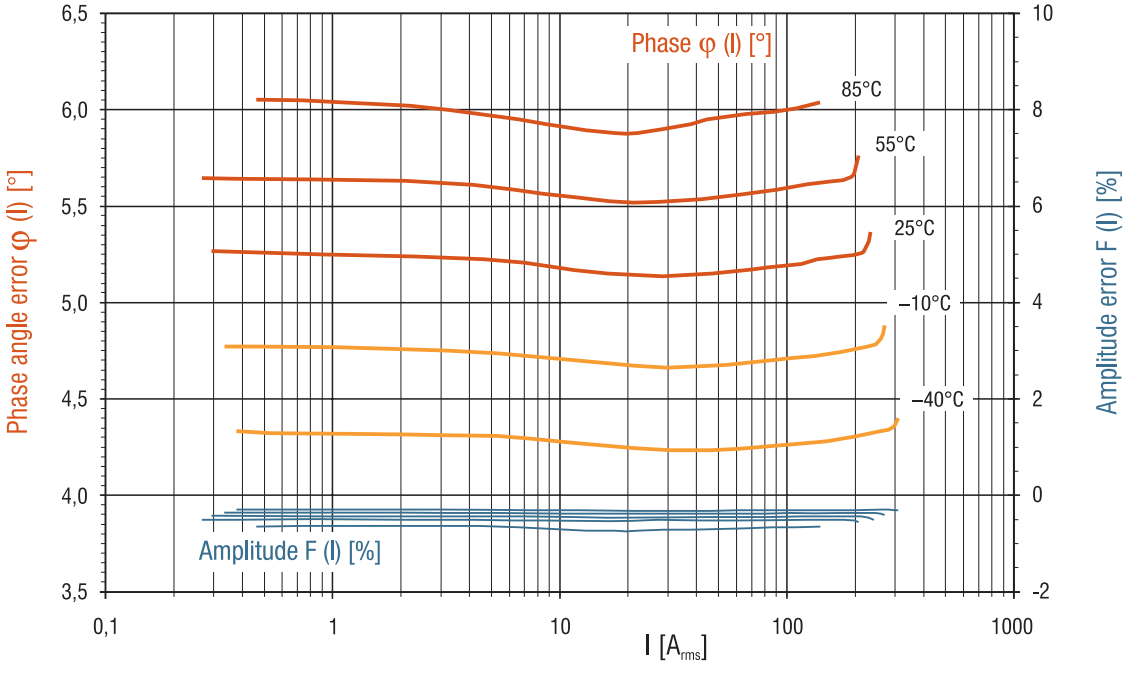


Fig. 5: 100 A with DC Tolerance, T60404-E4626-X101/-X501/-X151

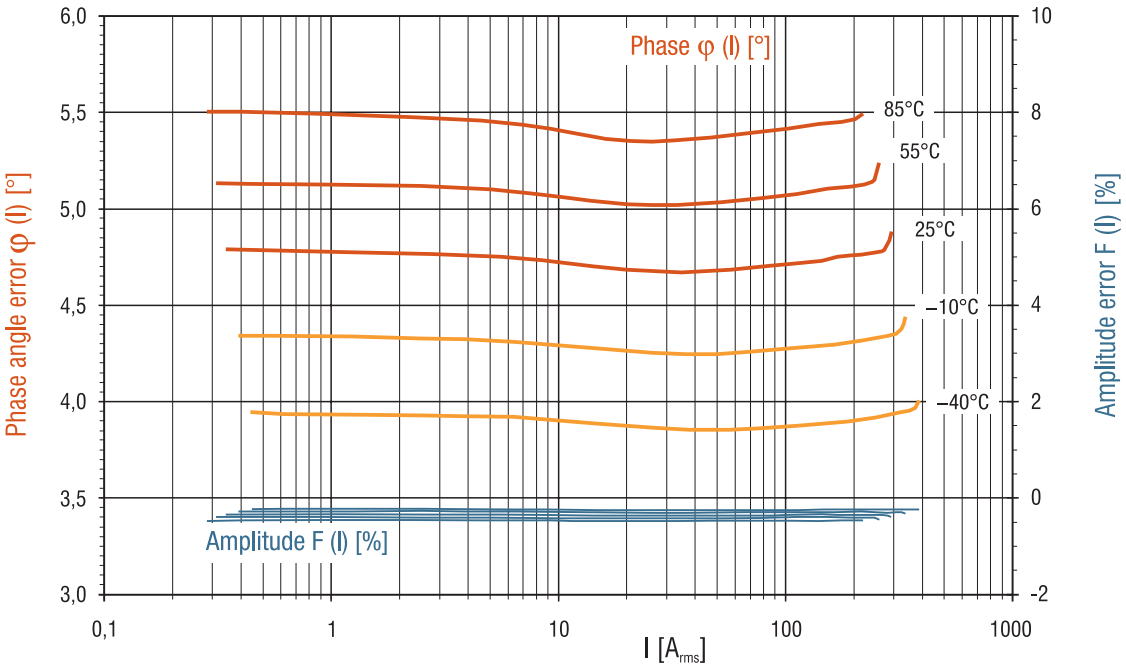


Fig. 6: 120 A with DC Tolerance, T60404-E4627-X101

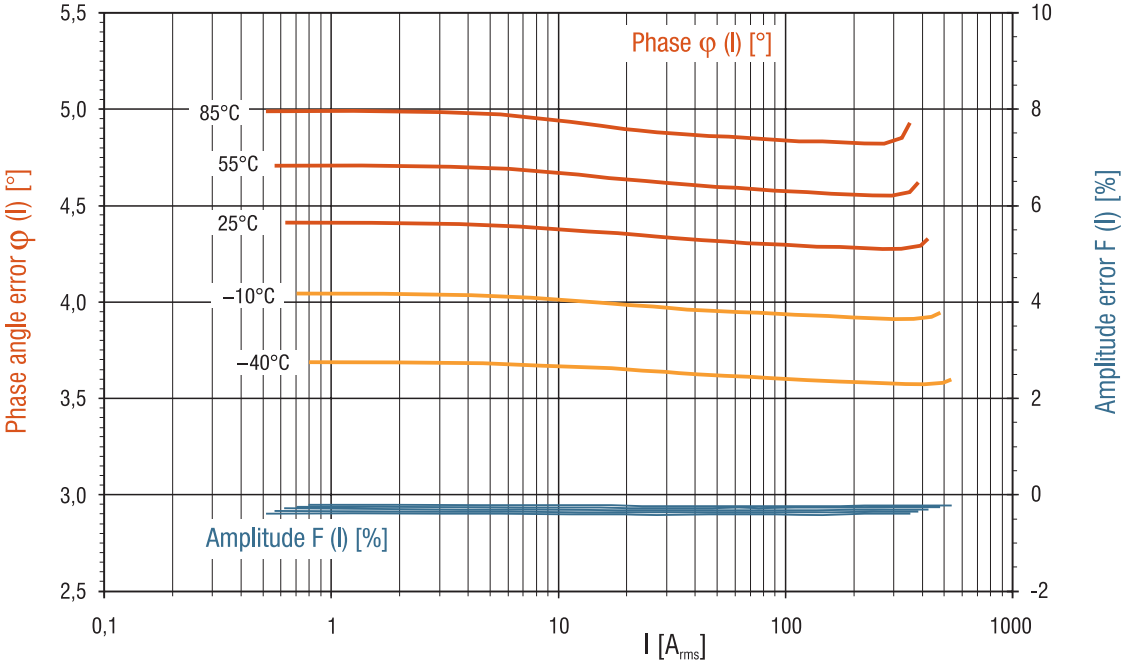


Fig. 7: 20 A with DC Tolerance, T60404-E4622-X121

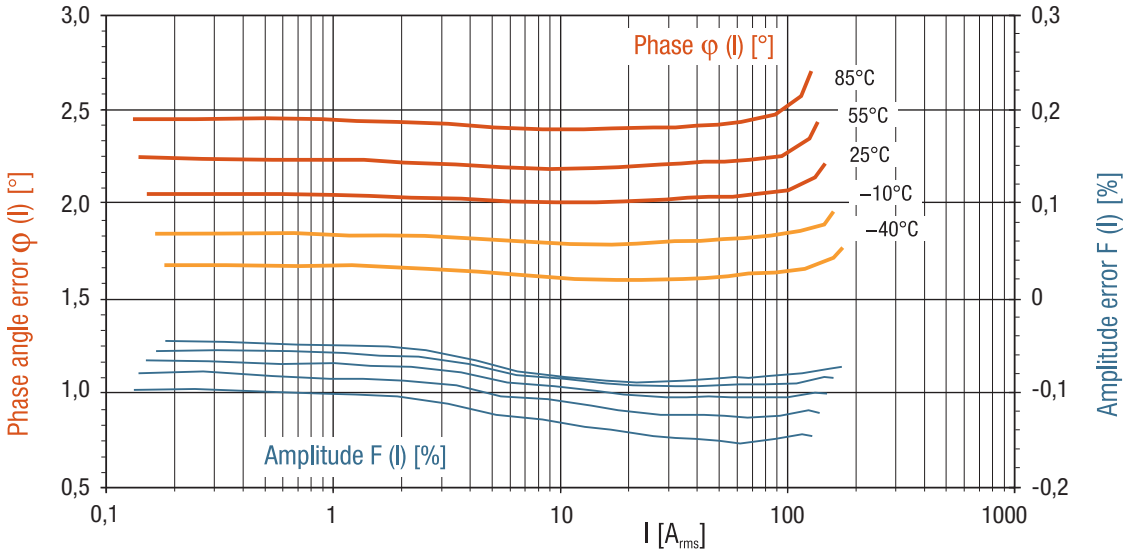


Fig. 8: 40 A with DC Tolerance, T60404-E4623-X121/-X171

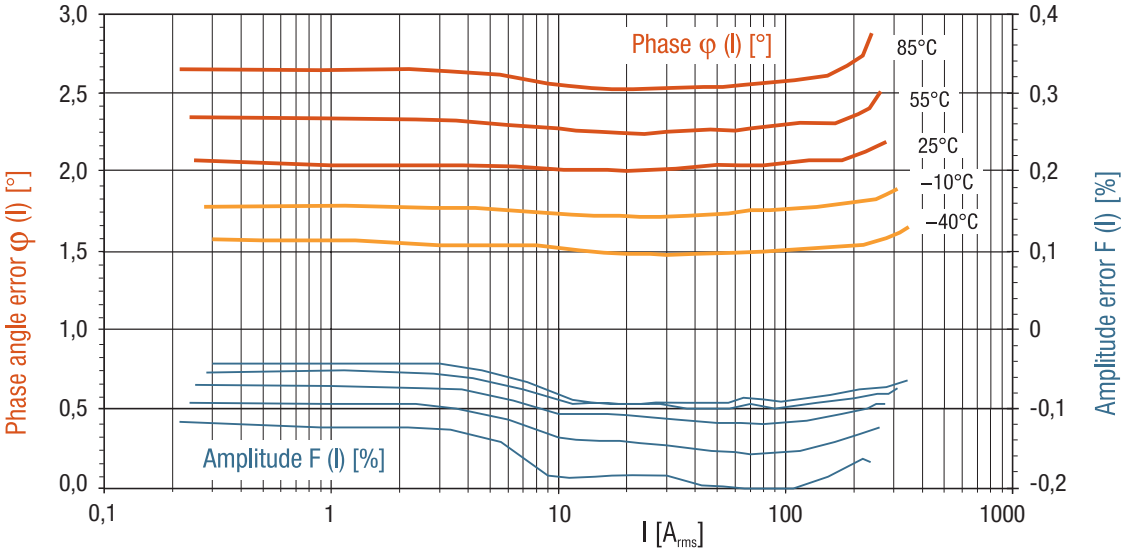


Fig. 9: 60 A with DC Tolerance, T60404-E4624-X121/-X171

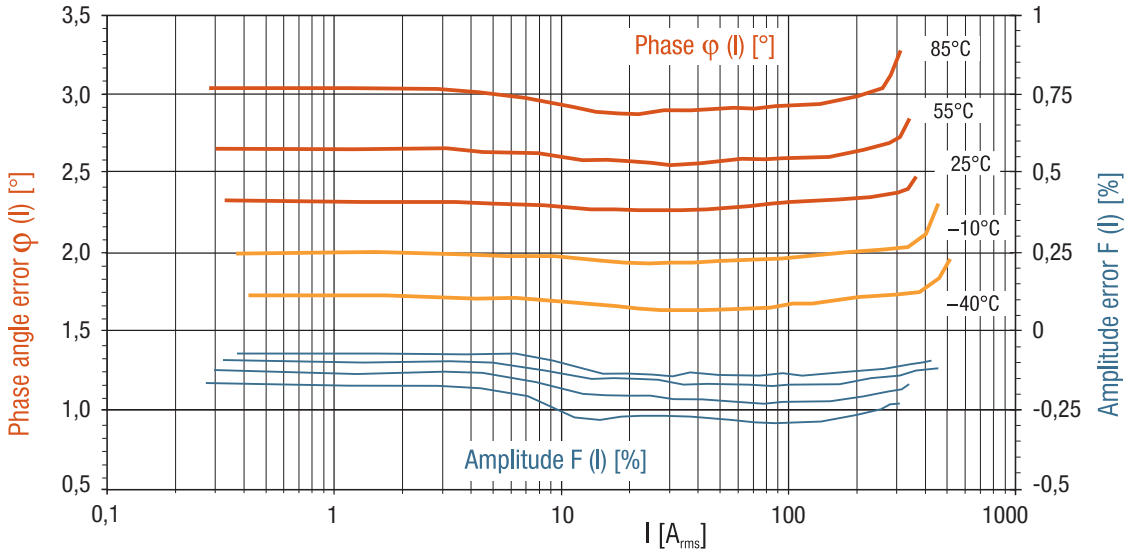


Fig. 10: 60 A with DC Tolerance, T60404-E4624-X131/-X531

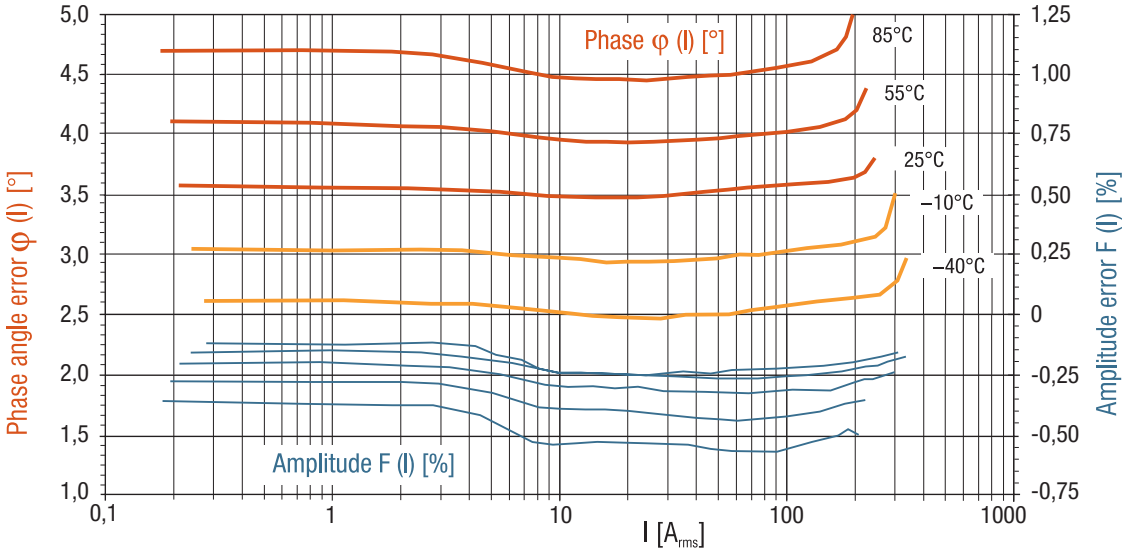


Fig. 11: 80 A with DC Tolerance, T60404-E4625-X121

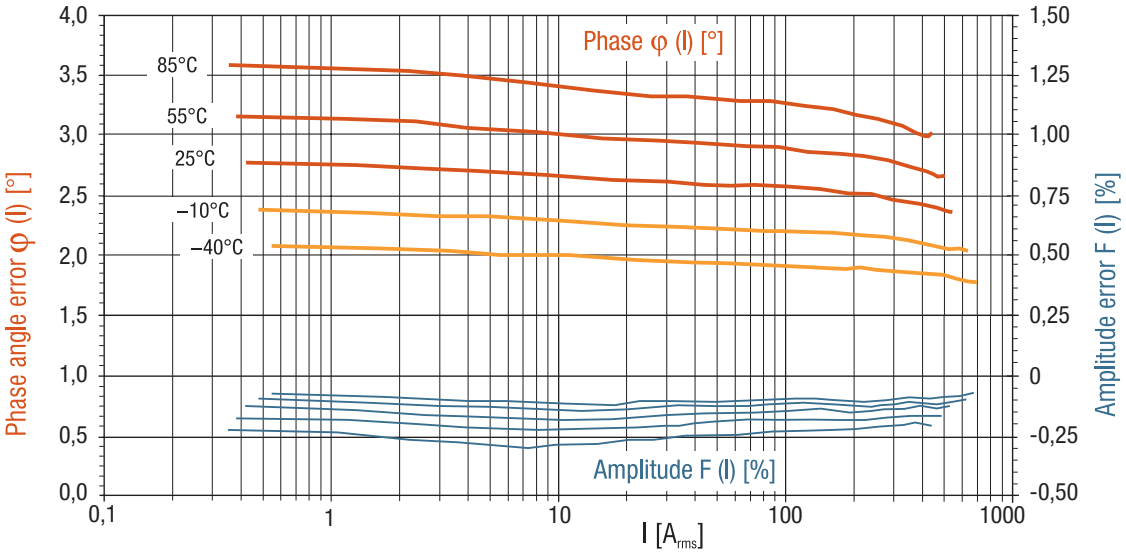


Fig. 12: 80 A with DC Tolerance, T60404-E4625-X131/-X531

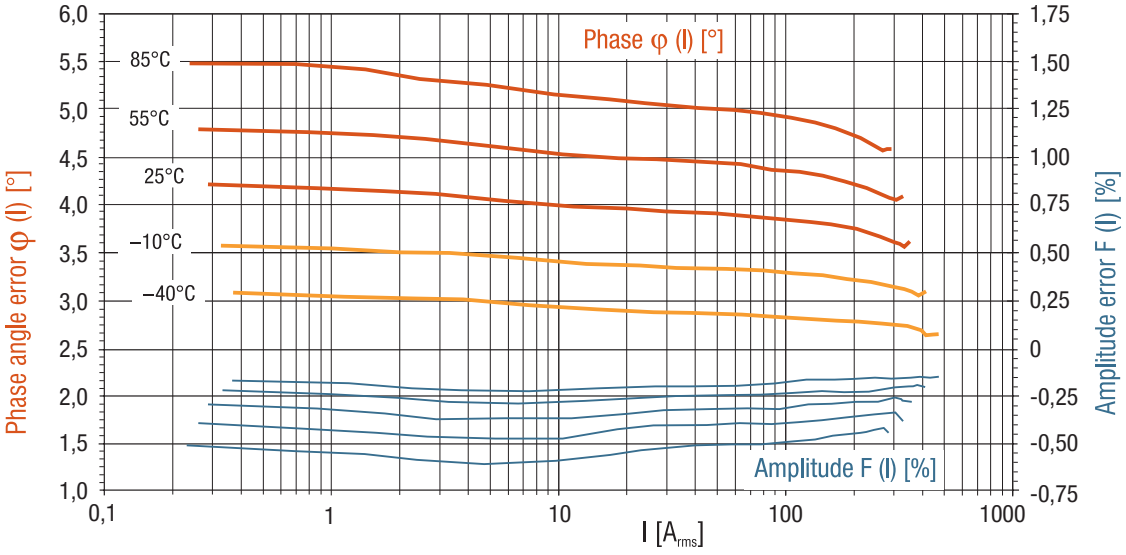


Fig. 13: 100 A with DC Tolerance, T60404-E4626-X121

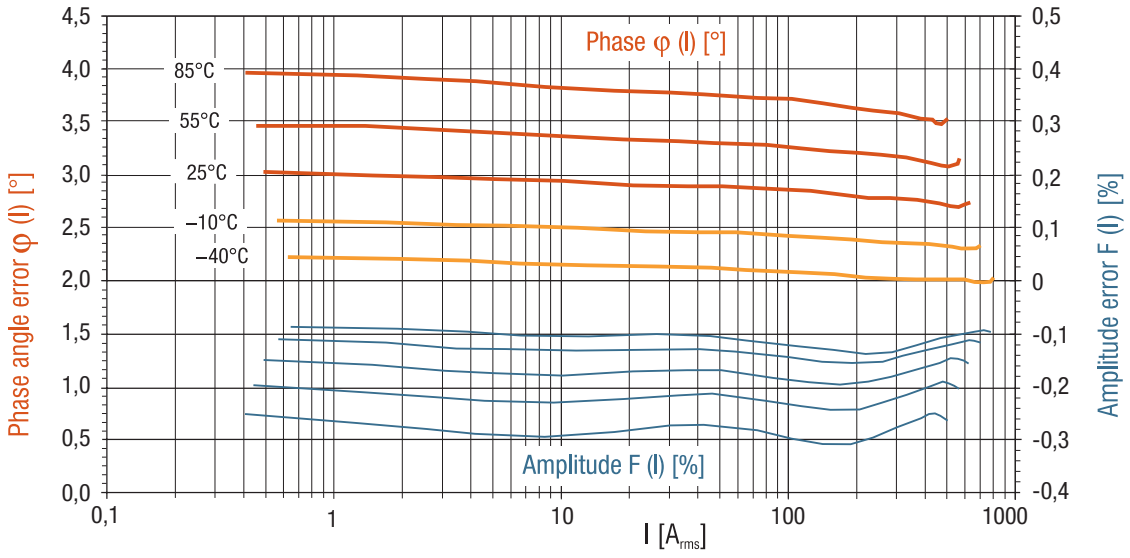


Fig. 14: 100 A with DC Tolerance, T60404-E4626-X131/-X531

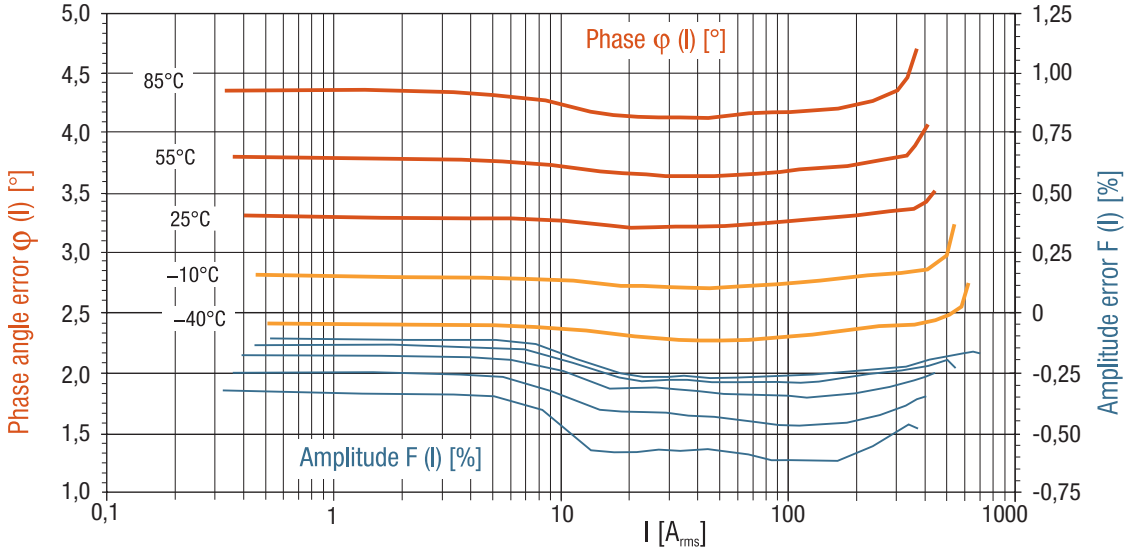


Fig. 15: 120 A with DC Tolerance, T60404-E4627-X121

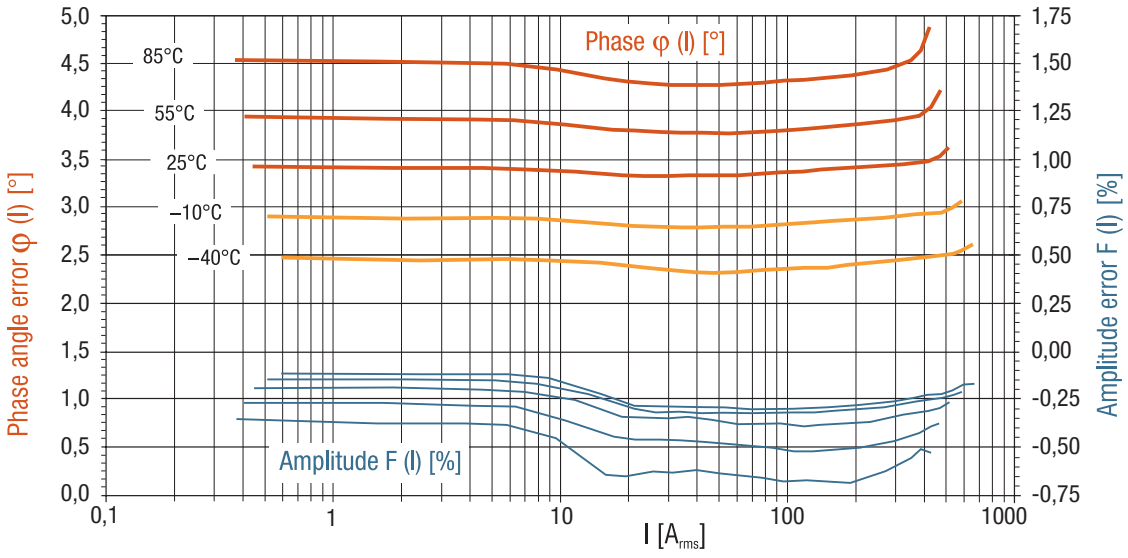


Fig. 16: 20 A, T60404-E4622-X002

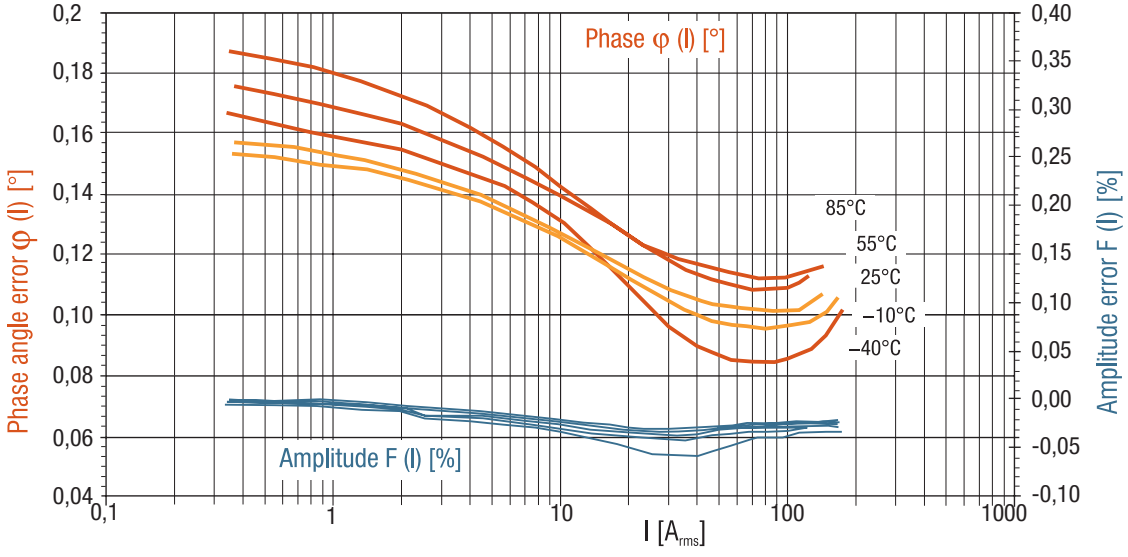


Fig. 17: 40 A, T60404-E4623-X002

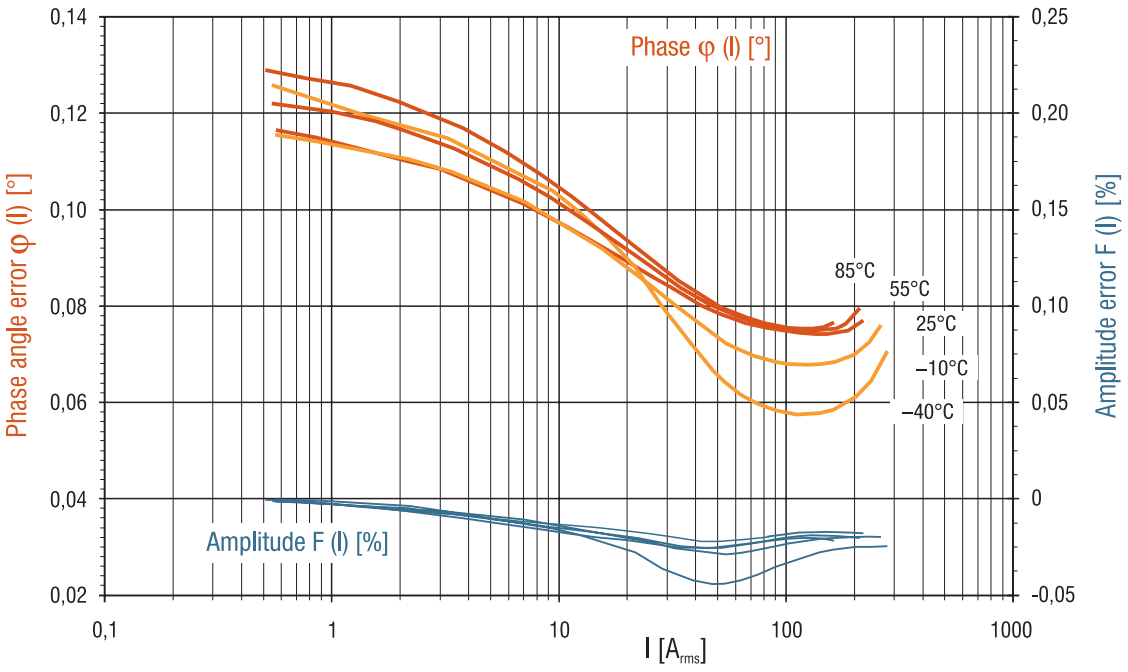


Fig. 18: 60 A, T60404-E4624-X002/-X502

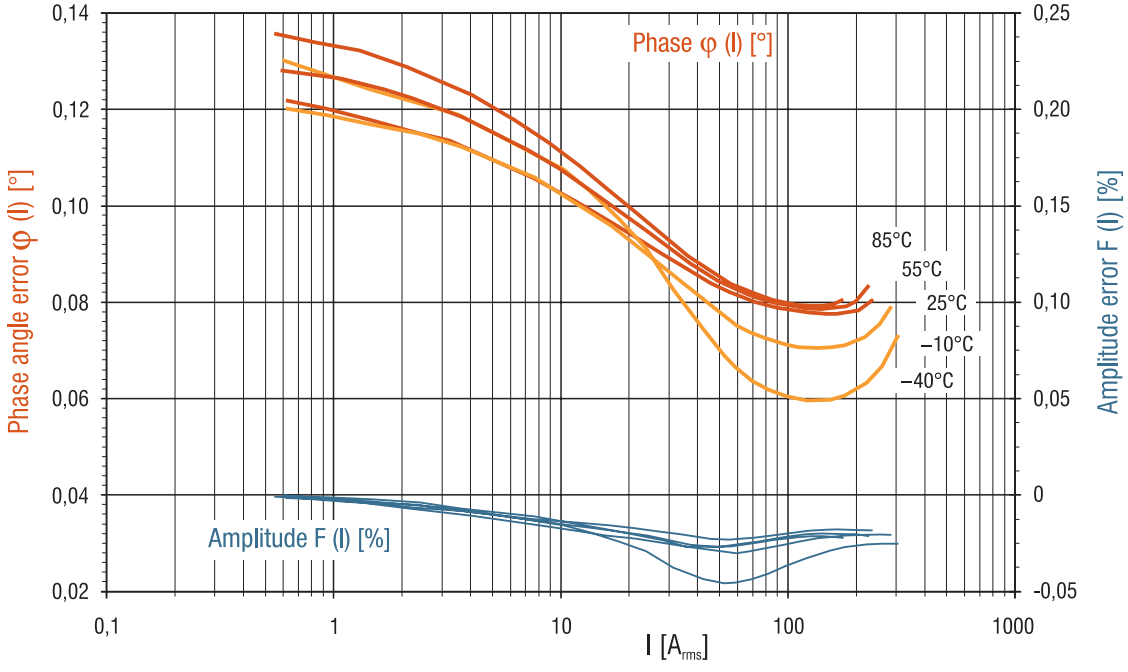


Fig. 19: 100 A, T60404-E4626-X002/-X502

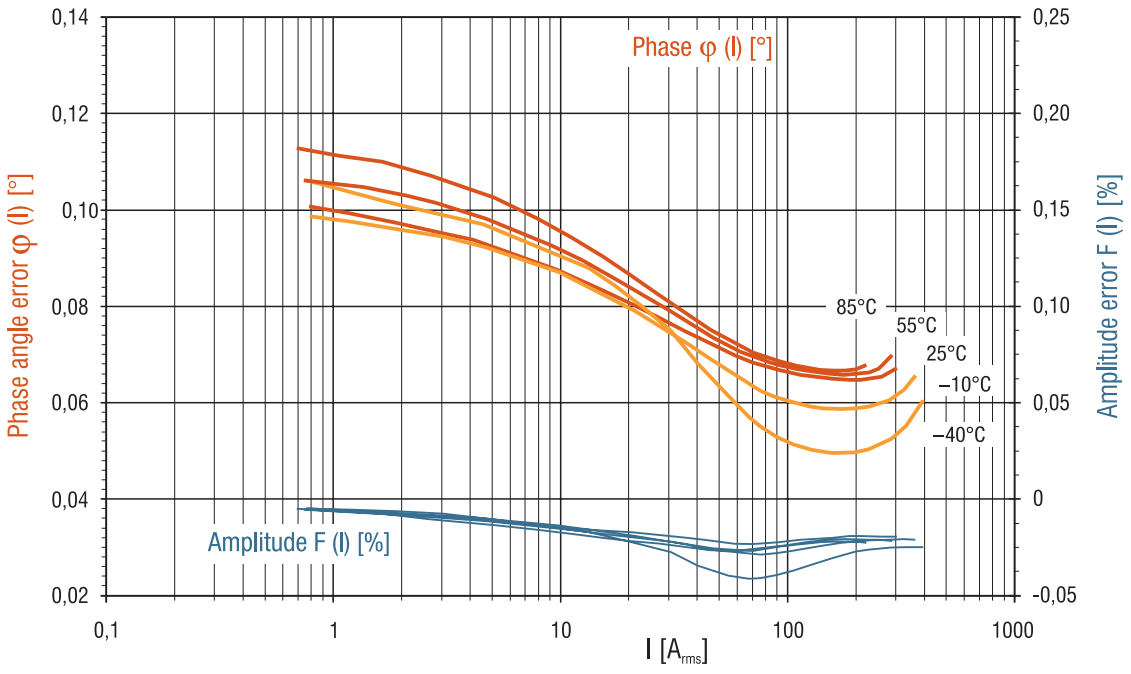


Fig. 20: 6 A, T60404-E4629-X007, 4622-X501, 4622-X011

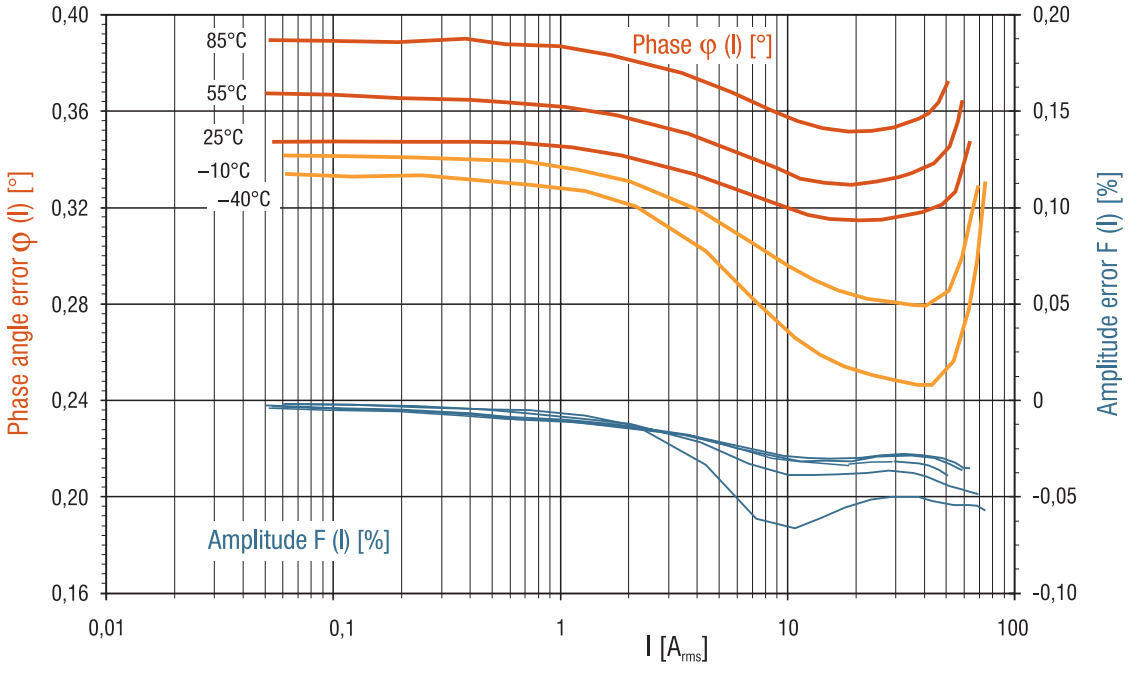


Fig. 21: 6 A, T60404-E4629-X010, 4622-X503, 4622-X012

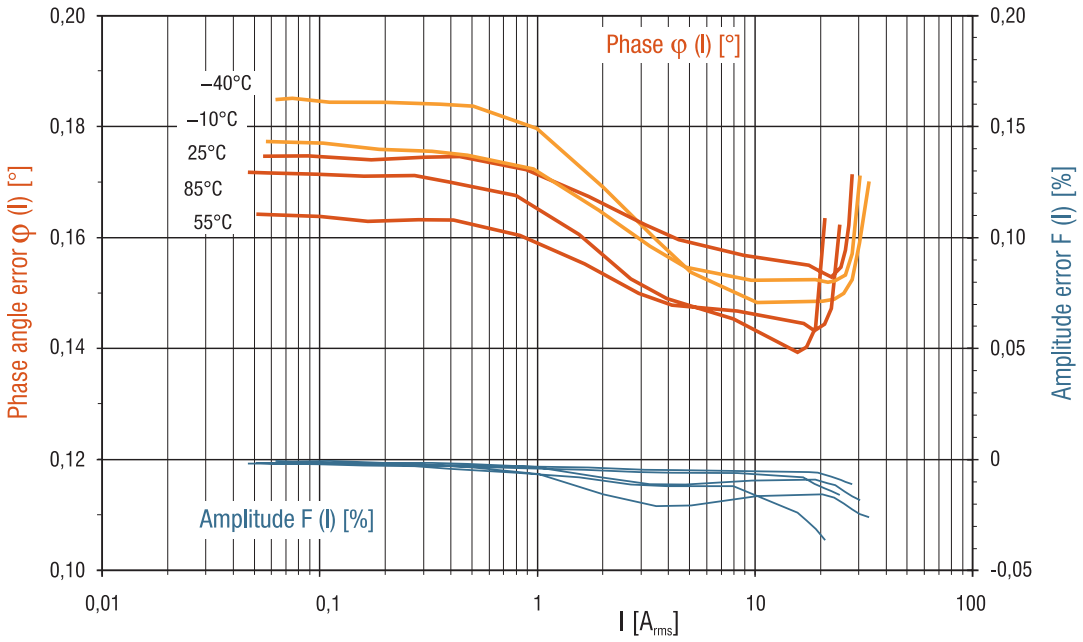


Fig. 22: 6 A, T60404-E4658-X043

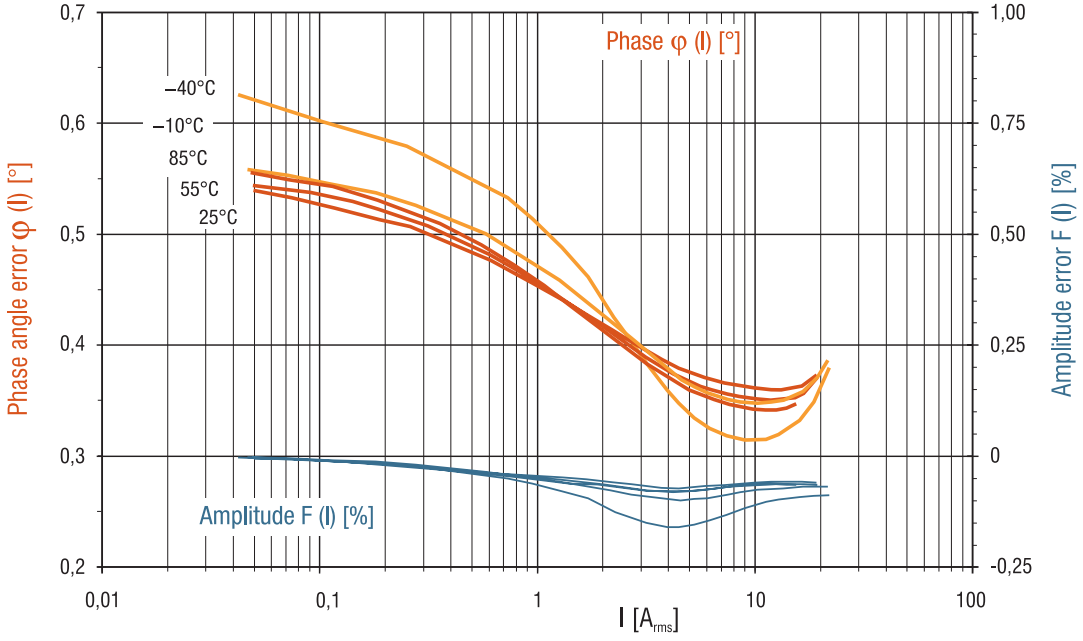


Fig. 23: 20 A, T60404-E4629-X007, 4622-X501

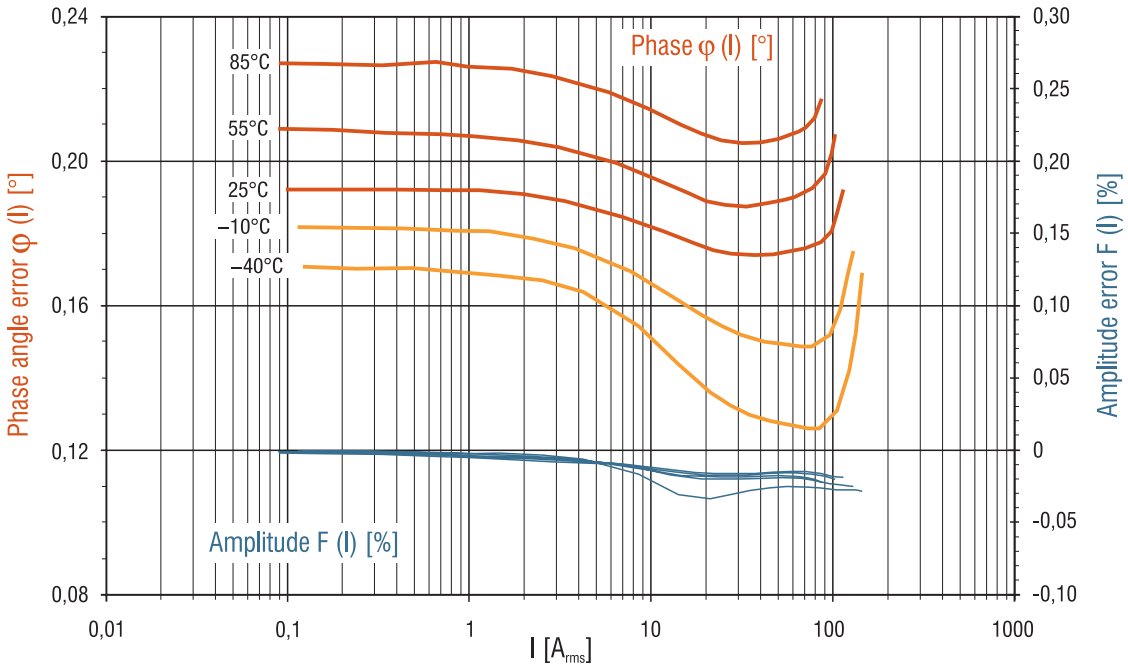


Fig. 24: 20 A, T60404-E4629-X010, 4622-X503

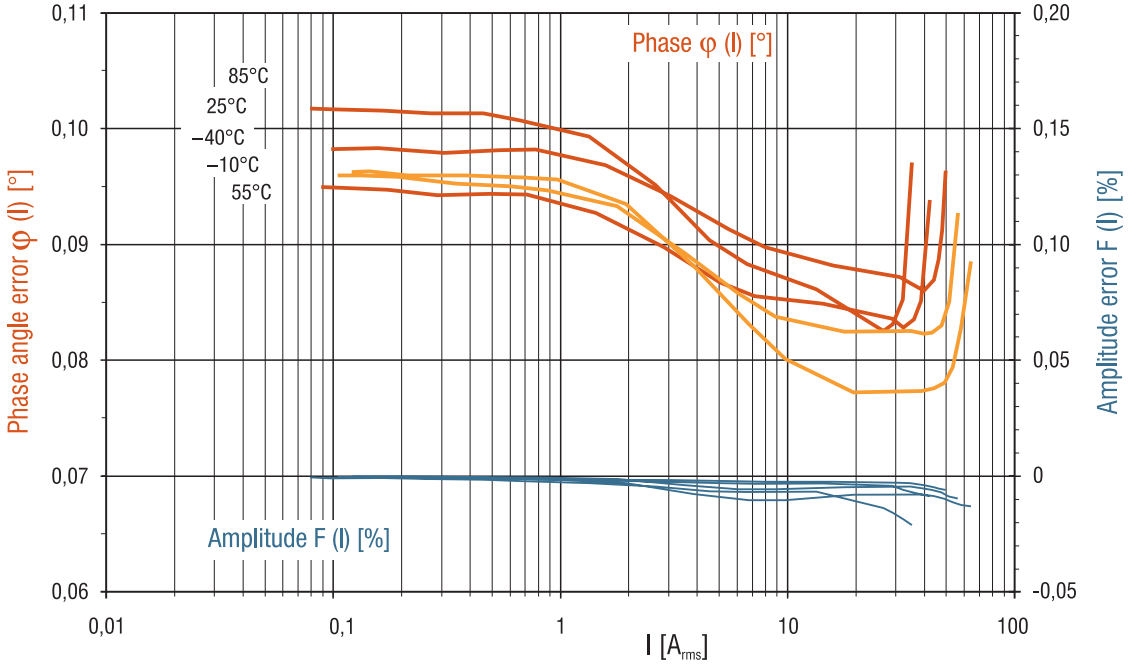


Fig. 25: 200 A, T60404-E4627-X001

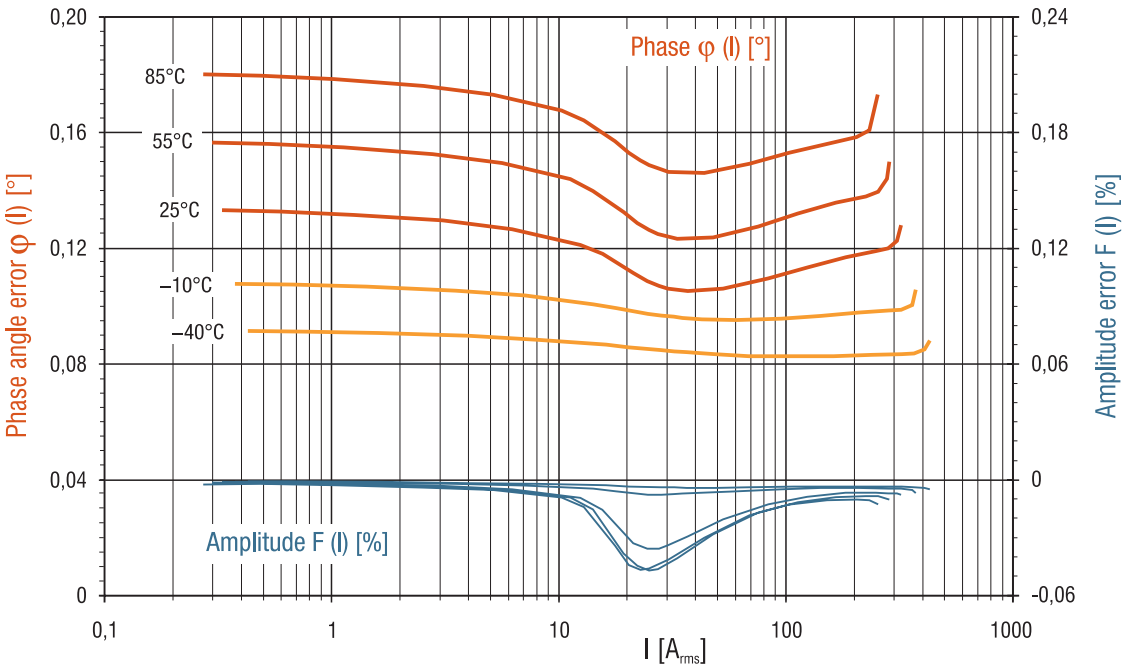
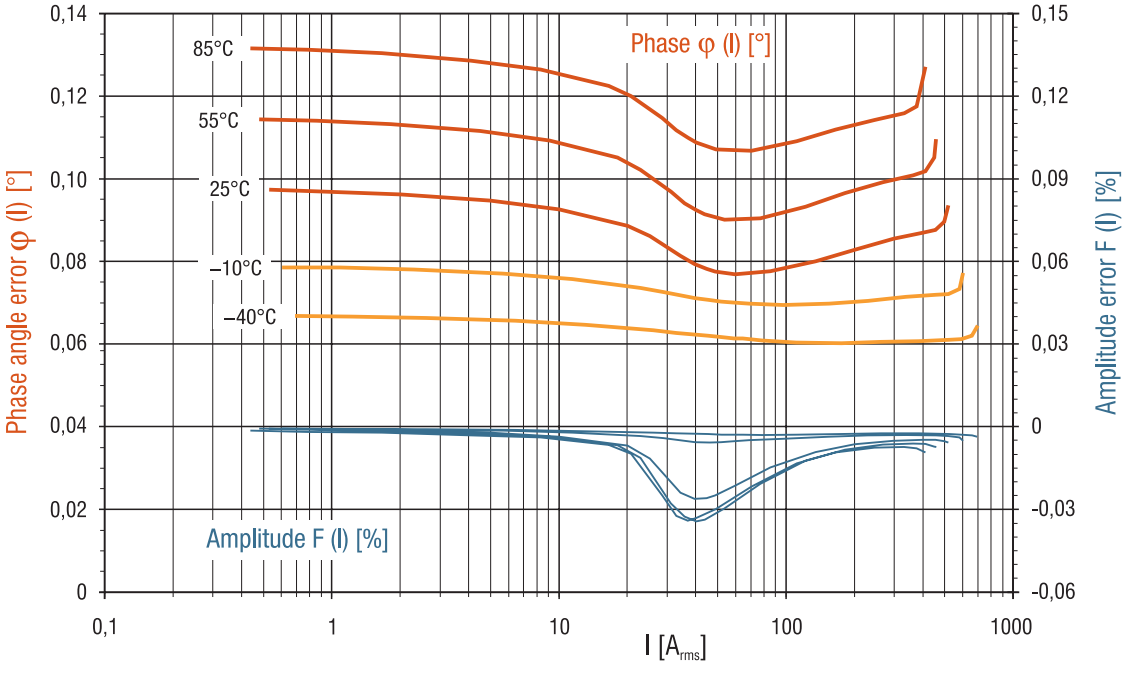
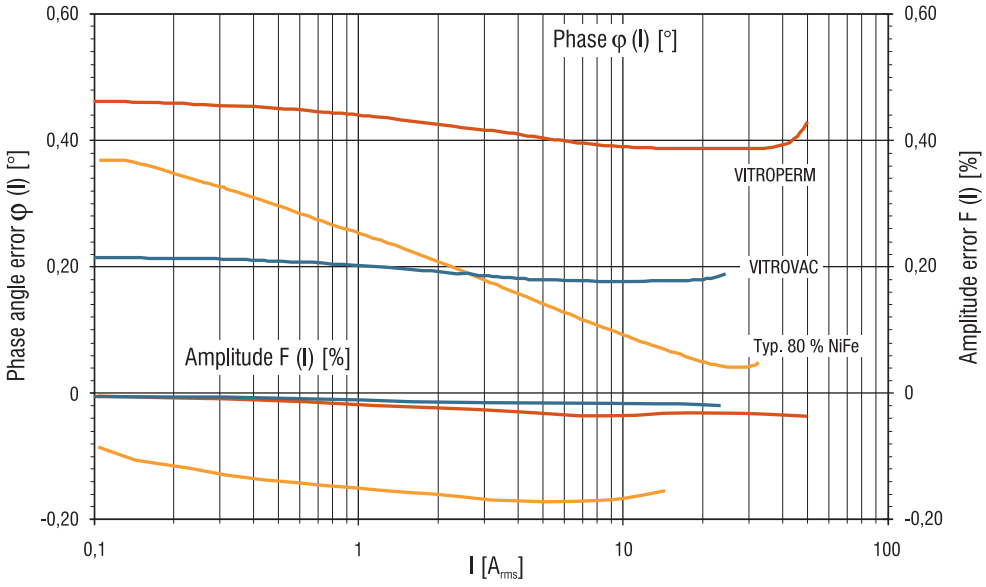


Fig. 26: 320 A, T60404-E4628-X001



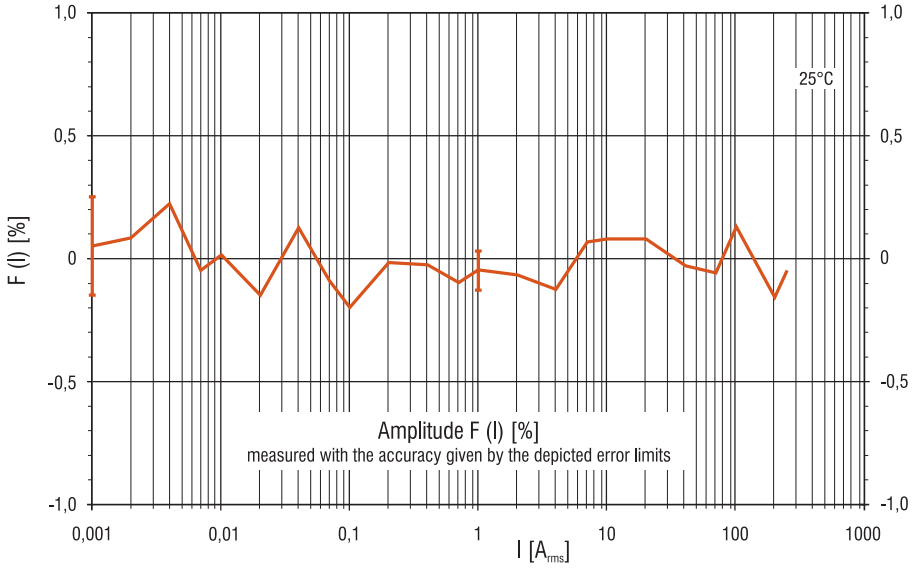
TYPICAL LINEARITY BEHAVIOUR OF DIFFERENT VAC CORE MATERIALS

Classical crystalline 80 % NiFe vs. rapid solified VAC alloys



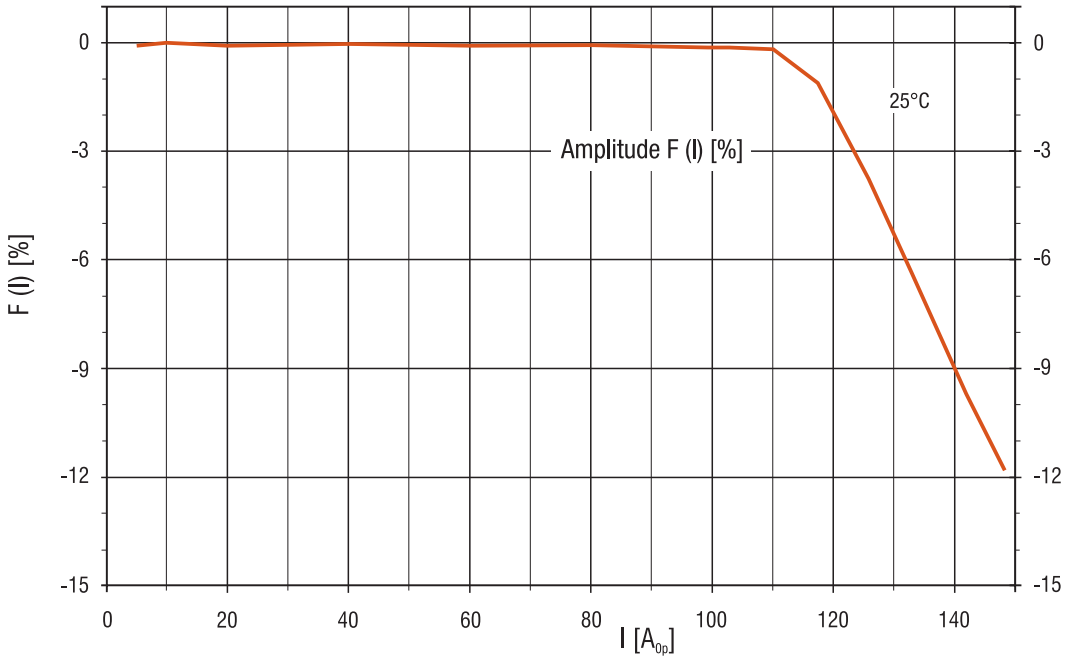
TYPICAL CHARACTERISTIC OF AMPLITUDE ERROR VS. PRIMARY CURRENT

100 A, T60404-E4626-X101/-X501



TYPICAL CHARACTERISTIC OF AMPLITUDE ERROR VS. UNIPOLAR (HALF-WAVE RECTIFIED) PRIMARY CURRENT

100 A, T60404-E4626-X101/-X501



APPENDIX A

RECOMMENDATION: ENSURING THE MEASURING ACCURACY OF ELECTRICITY METERS

1. MEASURING SENSITIVITY FOR LOW LOADS

According to table 6 of IEC 62053-21 the percentage error limits for meters of class 1 (balanced loads) are specified as follows:

Value of current for direct connected meters for meters of class 1	Percentage error limits
$0.05\ I_b <= I <= 0.1\ I_b$	+/-1.5 %
$0.1\ I_b <= I <= I_{max}$	+/-1.0 %

There are no limits specified in the low load range below 0.05 I_b (e.g. for accurate metering of stand-by modus of electronic devices, low energy lamps…).

For specification of meters with I_b=5 A and balanced loads (IEC) we therefore recommend supplementing these requirements by low load conditions as follows:

Current	Value of current for direct connected meters	Percentage error limits for meters of class 1
$0.05\ A <= I < 0.25\ A$	$0.01\ I_b <= I <= 0.05\ I_b$	+/-1.5 %
$0.25\ A <= I <= I_{max}$	$0.05\ I_b <= I <= I_{max}$	+/-1.0 %

This condition will ensure fair measuring accuracy in the low load range.

2. DC IN THE AC CURRENT CIRCUIT

According to table 8 of IEC 62053-21 with respect to DC components the limits of variation in percentage error shall be as follows:

Influence quantity	Value of current for direct connected meters	Power Factor	Limits of variation in percentage error for meters of class	
			1	2
DC and even harmonics in the AC current circuit	$\frac{I_{max}}{\sqrt{2}}$	1	3.0	6.0

This condition does not represent realistic loading where very often inductive load condition (power factor <<1) occurs simultaneously with DC-content of the current waveform (e.g. hair-dryers, vacuum cleaners …).

We therefore recommend supplementing the DC tolerance requirements by inductive load conditions as follows:

Influence quantity	Value of current for direct connected meters	Power Factor	Limits of variation in percentage error for meters of class	
			1	2
DC and even harmonics in the AC current circuit	$\frac{I_{max}}{\sqrt{2}}$	1 0.5 inductive	3.0	6.0

This condition will ensure reliable measuring accuracy independently from power factor and DC components.

3. IMMUNITY AGAINST EXTERNAL MAGNETIC FIELDS

According to table 8 of IEC 62053-21 the immunity of meters against external magnetic fields shall be as follows:

Influence quantity	Value of current		Power Factor	Limits of variation in percentage error for meters of class	
	for direct connected meters	for transformer operated meters		1	2
Continuous magnetic induction of external origin	I_b	I_n	1	2.0	3.0
Magnetic induction of external origin 0.5 mT	I_b	I_n	1	2.0	3.0

The conditions specified are adequate for normal environmental conditions.

In recent years requirements concerning much stronger fields have been discussed by metering regulators to also take into account potential tampering with meters. These requirements led to considerable efforts by meter manufacturers, e.g. encapsulation of the meter's susceptible components against strong rare earth magnets using magnetic shielding.

However, it must be realised that not only permanent magnets, but also coils creating AC magnetic fields can potentially be used for tampering and that ultimately any measurement principle including the 'old' Ferraris meter can be manipulated in one way or the other. Of course, counter-measures such as magnetic shielding are also available for each measurement method. In the long run, the competition between factors such as increasing magnet dimensions and increasing shielding efforts cannot be won by any one of the parties involved, but does increase meter costs significantly.

We therefore recommend introducing electronic means to detect tampering attempts and taking corresponding measures inside the meter's electronics and communication system, while retaining the specifications cited above for field immunity requirements.

For example, external magnetic influences of extreme field strength, clearly indicating tampering attempts, could be detected by cost-effective electronic sensors and generate an alarm signal at the front panel. Additionally, the alarm status should be stored within the meter's data memory and, if a data exchange module is installed, communicated via the data interface to the data collection and evaluation site of the energy supplier.

APPENDIX B

DIFFERENCE FROM COMBINED CORE CTS

In recent years CTs based on cores with two parts known as combined cores have appeared on the market. One part of the core is highly permeable while the second one is a low-permeable core for DC tolerance according to IEC 62053 -21, -23.

At conditions with power factor $\cos\varphi < 1$ and appearance of half rectified sinusoidal currents in the electricity grid, errors in measuring power can increase up to 18 %.

The pictures below show the differences between 'Single' and 'Combined' cores.

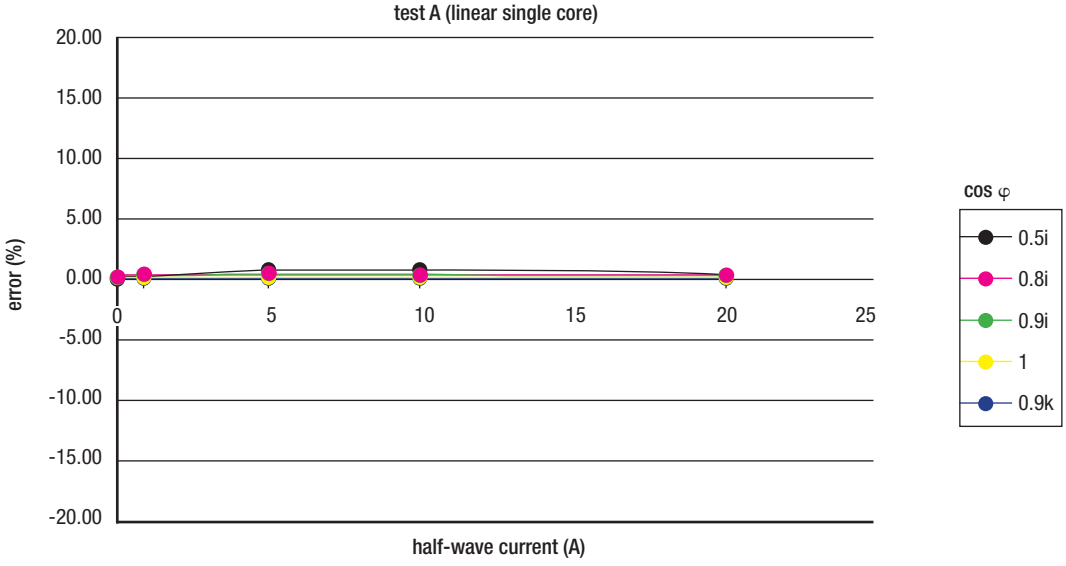
SINGLE-CORE CT

HOMOGENOUS CORE (VAC – TYPE, HIGH LINEARITY):

• best linearity in amplitude and phase

Meter with high-linearity CT measures correctly!

Measurement accuracy: current IEC- test and proposal



• IEC-test $\cos\varphi = 1$

fine

• proposal $\cos\varphi \neq 1$

Error data between +0.6 % and -0.3 %

Result: Power measurement independently from load and DC components!

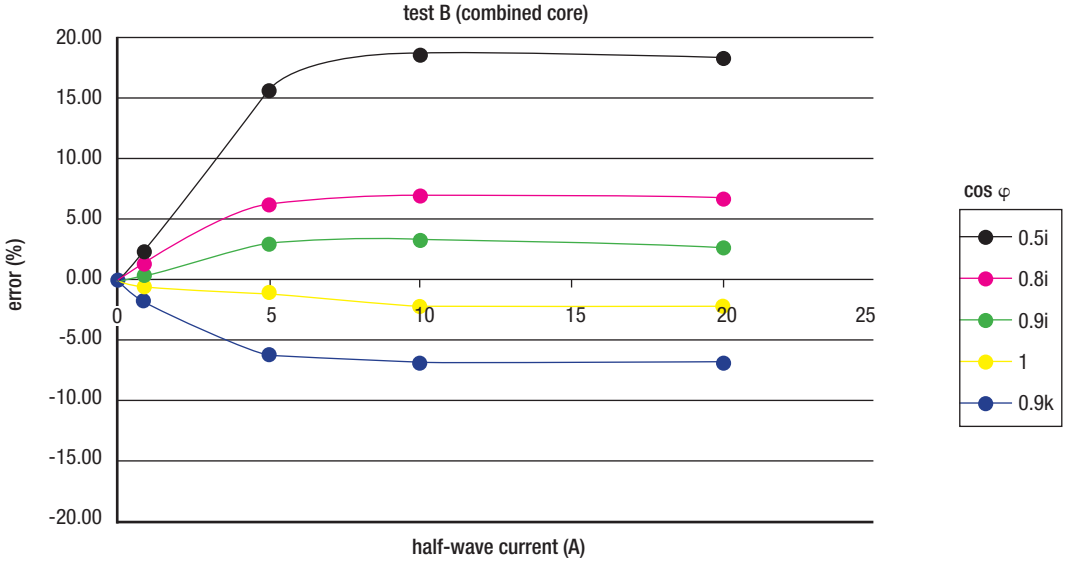
COMBINED CORE CT

COMBINED CORE (2 CORE PARTS):

- one high-permeability core part for AC operation
- one non-linear low permeability core part for operation under DC components

Meter with combined core CT behaves very sensitive.

Measurement accuracy: current IEC-test and proposal



- IEC-test $\cos\varphi = 1$

satisfactory

- proposal $\cos\varphi \neq 1$

Error data between +18 % and -7,5 %

Result: Power measurement depends strongly on load phase and DC components!

VACUUMSCHMELZE GMBH & CO. KG

P.O. BOX 2253
GRÜNER WEG 37
D 63412 HANAU / GERMANY
PHONE +49 6181 38 0
FAX +49 6181 38 2645
INFO@VACUUMSCHMELZE.COM
WWW.VACUUMSCHMELZE.COM

VAC SALES USA LLC

2935 DOLPHIN DRIVE
SUITE 102
ELIZABETHTOWN, KY 42701
PHONE +1270 769 1333
FAX +1270 765 3118
INFO-USA@VACUUMSCHMELZE.COM

VACUUMSCHMELZE
SALES OFFICE SINGAPORE

1 TAMPINES CENTRAL 5, #06-10/11
CPF TAMPINES BUILDING
SINGAPORE 529508
PHONE +65 6391 2600
FAX +65 6391 2601
VACSINGAPORE@VACUUMSCHMELZE.COM

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VACUUMSCHMELZE

ADVANCED MATERIALS – THE KEY TO PROGRESS

MATERIAL INFORMATION

NANOCRYSTALLINE CUT CORES

MADE OF VITROPERM® 500 FOR TRANSFORMERS

Applications:

- High frequency, high power transformers for converters in drives, traction, power supplies, welding, induction heating

Key Properties:

- Lower losses than other materials, due to nanocrystalline rapid solidified alloy with thickness of approx. 18 µm
- Low audible noise due to lower magnetostriction compared to other materials
- High flux density material (1.2 Tesla)

VITROPERM – typical data

Saturation flux density	B_S = 1.2 T
Coercivity (static)	H_C < 3 A/m
Saturation magnetostriction	λ_S=10^{-8}….10^{-6}
Electrical resistivity	ρ ~ 115 µΩcm
Curie temperature	T_C > 580 °C
Material permeability	μ_i = 20000... 50000*
Core losses (2500Hz, 0.5 T)	P_{Fe} ⩽ 1 W/kg*
Tape thickness:	approx. 18 µm
Material Composition:	$(FeSi)_{89}(BNbCu)_{11\ At.-\%}$

* Toroidal core without air gap

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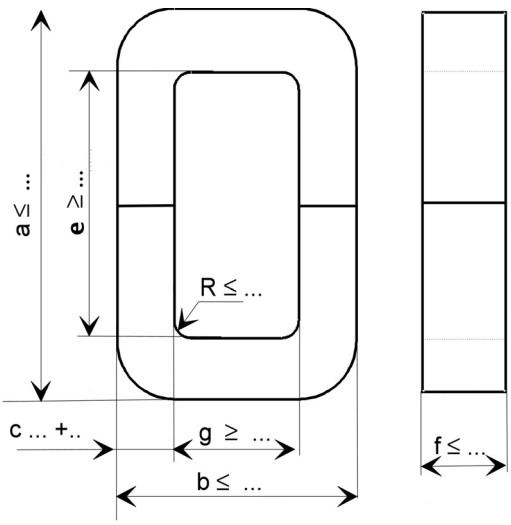
ADVANCED MATERIALS – THE KEY TO PROGRESS



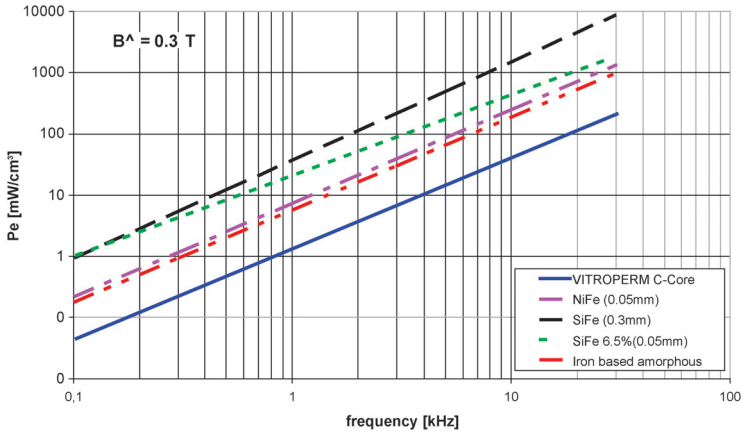


Fig. 1: Losses vs. frequency of cut cores (airgap closed) made of different materials.

Part number	Weight	Iron cross section A_{Fe}	Mean iron path length l_{Fe}	Limiting dimensions (for 2 U-shaped halves)					
T60102-L2…	g	cm^2	cm	Length a / mm	Width b / mm	Window length e / mm	Window width g / mm	Leg width c / mm	Height f / mm
…083-W156	378	2.8	18.2	83.7	48.4	50.5	16	15.8	26.6
…130-W157	941	4.5	28.4	130.0	76.0	78.0	25.0	24.7	26.6
…198-W171	1,680	5.3	43.2	198.0	115.0	118.0	38.0	37.6	21.6
…157-W159	1,360	5.4	34.2	157.5	90.0	95.0	30.0	29.6	26.6
…157-W158	1,570	6.2	34.2	157.5	90.0	95.0	30.0	29.6	31.6
…198-W160	2,520	7.95	43.2	198.0	115.0	118.0	38.0	37.6	31.6

VACUUMSCHMELZE GmbH & Co. KG
Grüner Weg 37
D-63450 Hanau
Tel.: +49 6181/38-0
Fax: +49 6181/38-2645
info@vacuumschmelze.com
www.vacuumschmelze.com

Storage conditions for inductive components

Inductive components can be stored under normal industrial conditions. Typically functionality and magnetic properties show only a negligible aging effect. However, some processing properties may be influenced by storage conditions and storage duration.

In general, attention should be focused on the solderabilityand particularly the short-term temperature resistance of SMD components during the reflow process. Storage needs to be avoided at locations where the solderability might be negatively influenced by harmful atmospheric conditions.

Investigations have shown that component processing is possible within a minimum period of 2 years under the following conditions:

SMD - components

Temperature: - 5 °C ... + 40 °C
Humidity (rel) : 10 % - 60 %

All other components

Temperature: -5 °C ... + 40 °C
Humidity (rel) : 10 % - 75 %

For some products, higher values for temperature and humidity are possible. These values are indicated in the data sheet of the relevant product.

Furthermore the packaging material is to protect against humidity and condensation before and during storage.

Special package is used for components with enhanced sensitivity against humidity. Please contact us if you have any questions.

VACUUMSCHMELZE GmbH & Co. KG
Grüner Weg 37 D-63450 Hanau
Postbox 22 53 D-63412 Hanau
Phone: +49 6181 38-0
Fax: +49 6181 38-2645
E-Mail: info@vacuumschmelze.com
http://www.vacuumschmelze.com

Liable Partner (Persönlich haftende Gesellschafterin):
VAC Finanzierung GmbH
Registered at Registergericht Hanau HRB 91707
Registered Office: Hanau

Management Board (Geschäftsführung):
Dr. Hartmut Eisele, Dr. Frank Steibert,
Stephen D. Dunmead, Valerie Gentile Sachs

Registered at Registergericht Hanau HRA 5479
Registered Office: Hanau

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