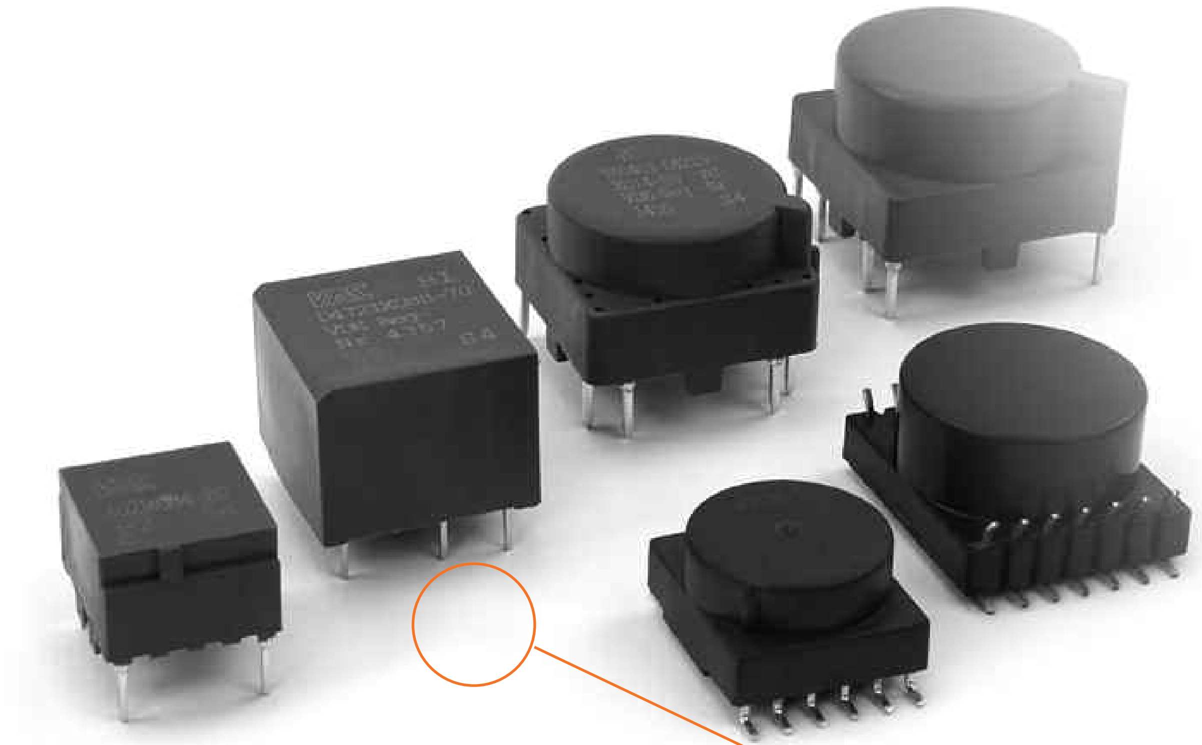
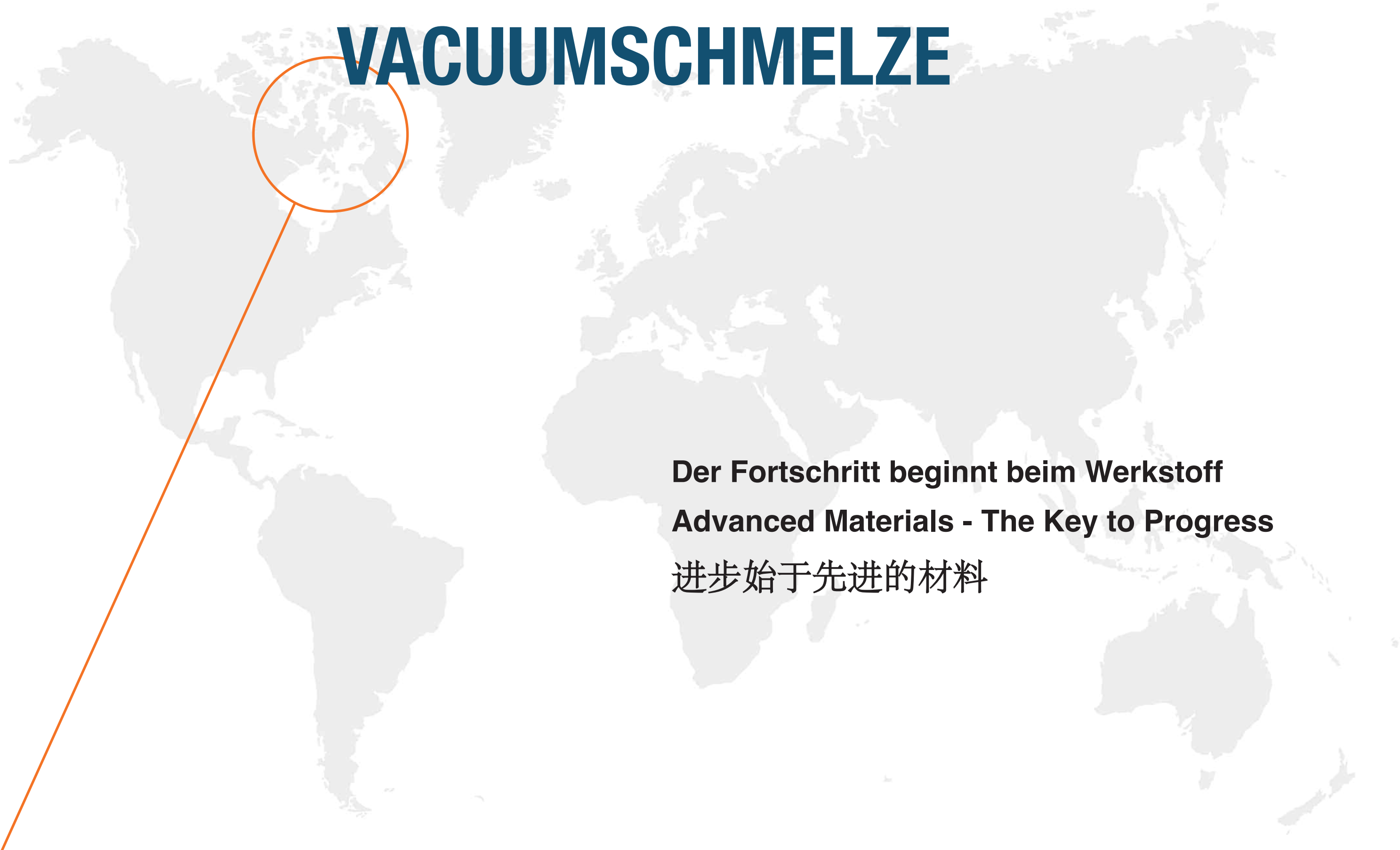
DRIVE TRANSFORMERS



ADVANCED MATERIALS – THE KEY TO PROGRESS

VAC 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.

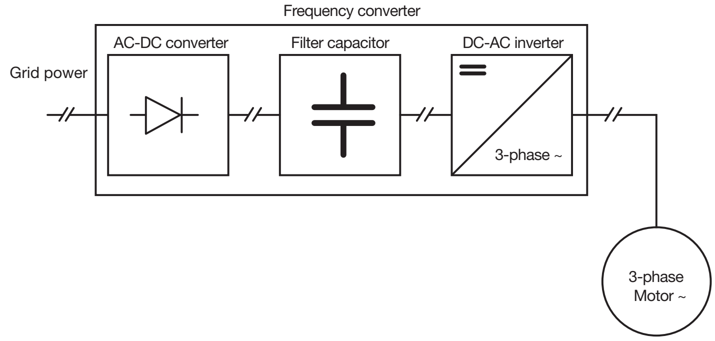


Fig. 1: A frequency converter with AC-to-DC converter and DC-to-AC inverter to power a motor.

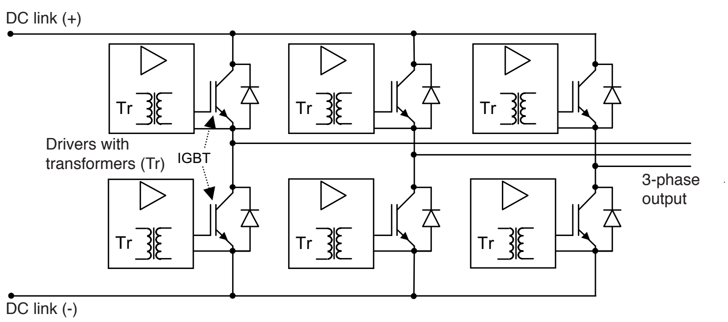


Fig. 2: Schematic diagram of a 3-phase inverter with DC link; when a solar inverter is used, the solar panels feed into the DC link and the 3-phase output is fed into the grid.

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

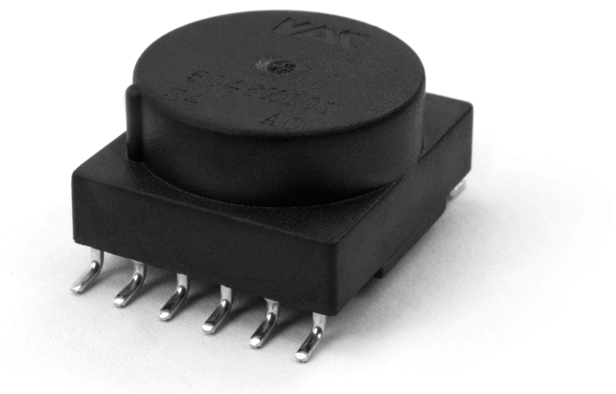
Higher switching frequencies, higher blocking voltages and switching power influence the way a semiconductor is activated and controlled to allow for safe and simple switching. Drive transformers ensure galvanic separation while also supplying the switching signal and /or the energy for the semiconductor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

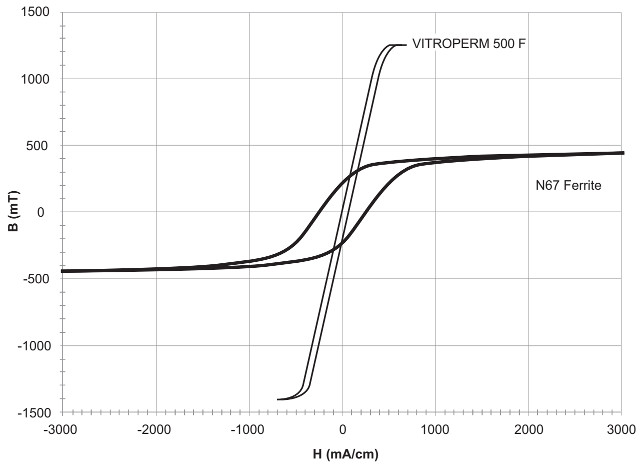


Fig. 3: B(H) Magnetisation curve of VITROPERM 500F compared to a typical ferrite, clearly showing differences in B_S: 1.2 T for VITROPERM 500F compared with 0.43 T for ferrite.

Permeability: temperature dependence

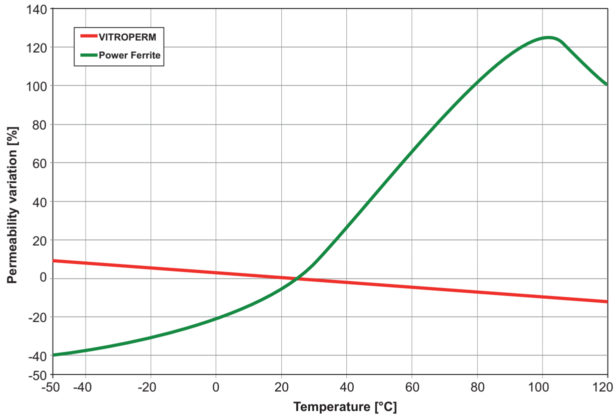


Fig. 4: u(T) Temperature stability of permeability of VITROPERM 500F compared to typical ferrite.

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.

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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)

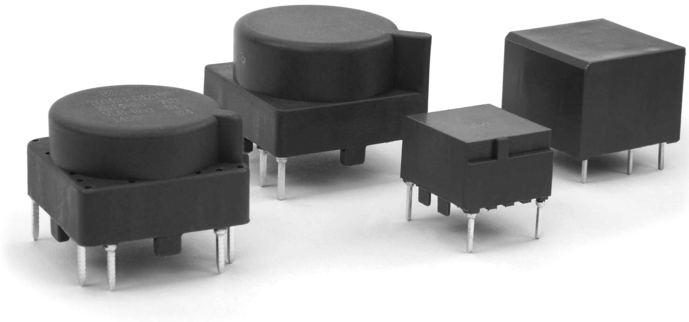
C_k = Coupling capacitance between primary and secondary windings (typical value)

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	$\int Udt$	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

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.

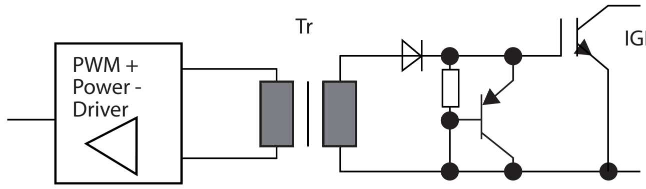
Drive circuits primarily depend on parameters such as input voltage at the primary winding, pulse frequency and turns ratio.

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.

Gate drive topologies

Drive transformer (Signal + Power)



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

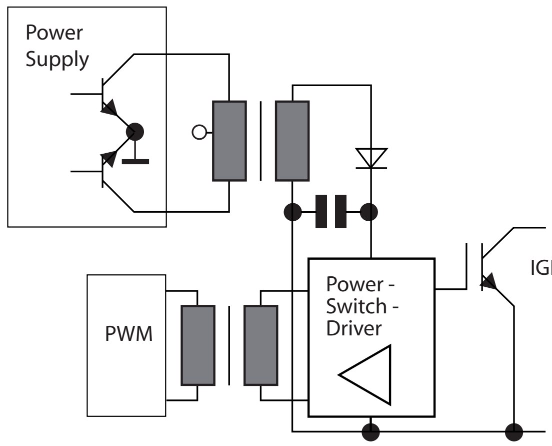


Fig. 5: Signal and power transmission with two configurations.

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.

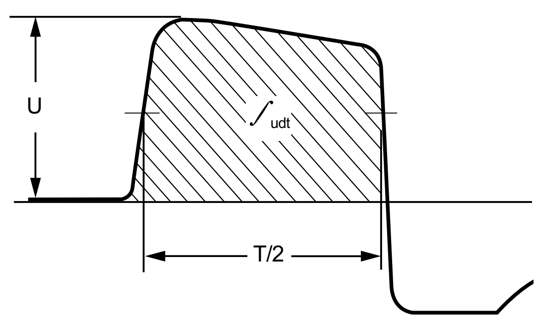


Fig. 6: Explanation of voltage time area.

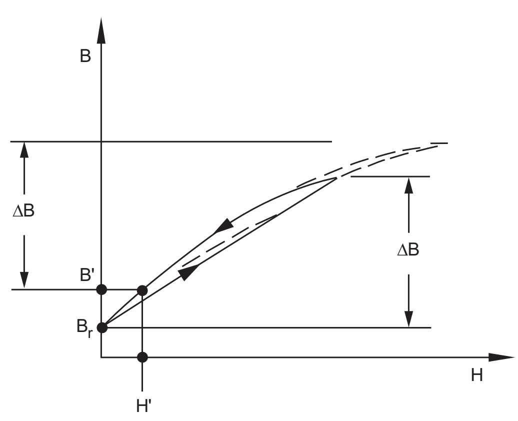


Fig. 7: Hysteresis loop for pulse magnetisation.

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