ENGINEERING
TOMORROW

Danfoss

DCM™1000

Next Generation Automotive Traction Power Module **Technology Platform**

Designed to meet the future demand of electric vehicle drivetrains

siliconpower.danfoss.com

The acceleration of global warming and pollution as well as international carbon emission targets initiated a process to reduce emissions in all parts of our living. These regulations to reduce pollution have even been further emphasized by the announcement that many large cities around the globe (1, 2, 3) plan to ban all vehicles with Internal Combustion Engines (ICE).

Saving energy, increasing efficiency and reducing emissions are trends that many countries and globally operating companies see as one of their important future targets.

Global trends and policies influence the automotive industry in many ways. Automobiles contribute around 12% of the total global carbon emissions, and many governments have started initiatives to increase the number of cleaner cars by either incentives or local rules and limitations (4).

The diesel emissions scandal and fast-moving digitalization of personal mobility increase the pressure on whole industries to radically change their products, themselves and to develop new technologies and business models to cope with the future challenges.

Automotive drivetrain electrification in vehicles is a part of it. It is expected that in 2035 more than 40% of all vehicles are somehow electrified as BEV or PHEV (6).

The development in battery technology and prices, broader electrification and fast-growing markets like China will push time to market and cost efficient technologies.

Comparing the price of a traditional vehicles with future xEV designs, cost effective and flexible solutions will be needed to deal with expected price pressure and investments.

One way of providing performance and cost efficiency are scalable mechanical and electrical platform solutions, which can be used in a range of different models/passenger cars. By having more of the same in different combinations, costs, development time and time to market can be significantly improved.

DCM™1000

Danfoss Silicon Power actively supports the automotive industry with electronic components, helping to power up future drivetrain applications and achieving the challenging emission goals.

Most electrified vehicle powertrain traction inverter contains a multichip-semiconductor power module. It can comprise of IGBT and Diodes or MOSFET die, where the typical circuit topologies are half-bridges or six-pack.

Within the modules, efficient use of the semiconductors is key for achieving cost competitiveness in hybrid- and electric vehicle traction applications. As semiconductors are the main cost driver in power modules, roughly representing 50% of the module cost, making the most out of the semiconductors without derating and compromising the reliability and lifetime of the module, becomes a key discipline.

Getting the most of the semiconductors requires a multidisciplinary approach addressing material science, new bonding and joining technologies and innovative thermal management technologies; a holistic approach is key to the success of identifying the optimum solution from a technical and commercial aspect.

Danfoss has – through the past years – developed market leading technologies, addressing all the aspects mentioned above. Well known examples are the Danfoss Bond Buffer® (DBB®) (7-12) that combines sintered die attach and copper wire bonding, transfer molding processes for robust packages, to liquid cooling technologies namely ShowerPower® and SP3D® (13-24).

Danfoss introduces the optimized DCM™ 1000 technology platform for traction applications in hybrid electric and battery electric vehicles. Drivetrain inverters are designed to operate under harsh conditions; high temperature cycles, humidity, mechanical shocks and vibrations. The stringent shock and vibration requirements are addressed by the transfer molding process of the power module.

The following overview explains the technologies that are combined in the new DCM™ 1000 technology platform.

Danfoss Bond Buffer® technology (DBB®)

Standard aluminium wire bonding technology is limited by the current carrying capability of the wire. Several manufacturers developed alternatives ranging from the .XT process from Infineon, the SKiN technology from Semikron to the DBB® technology from Danfoss, all of which are copper based.
The DBB® technology enables copper wire bonding on standard semiconductor chips. Thin copper foil (the bond buffer) is sintered on the topside semiconductor metallization upon which copper wire bonding can be attached. Sintering of both bond buffer and chip to substrate are done in the same process step. Danfoss Bond Buffer® (DBB®) enables power cycling capabilities that are 15 times higher than seen in Al wire bonded power modules. This lifetime benefit can be used to operate at higher junction temperatures without need for current derating. Increased power cycling capability also reduces the semiconductor area inside a power module leading to reduced cost. Key is the robust top-side copper to copper contact with lower thermo-mechanical stress as well as lower steady state and transient thermal resistances because of the increased contacting surface. The electrical characteristics are improved as well as the copper foil on top of the die reduces voltage drop and adds thermal buffer and heat spreader. Therefore, conduction losses are reduced and short circuit properties are improved.

Simulations and measurements have proven that the limits for the "lifetime – output current tradeoff" have been pushed. This means that the lifetime improvement for DBB® over standard wire bonding combined with the improved thermal performance of SP3D® over e.g. pin fin coolers, give an increase of output current of 20-30% over the state-of-the-art automotive traction modules using comparable semiconductor areas. Automotive traction power electronics lifetime requirements have increased dramatically over the last decades as illustrated in the chart below.

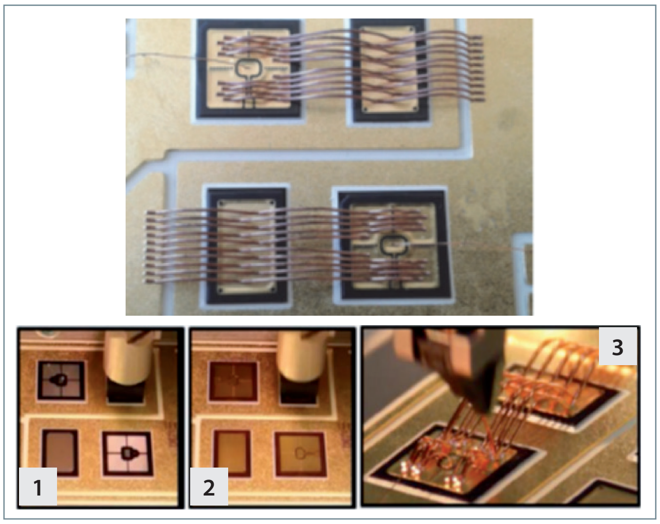


Figure 1: The DBB® principle.
1. Step: Die on DCB 2.Step: Cu-Plate on Die
3. Step: After the sinter process you can bond the surface with heavy Cu-wires

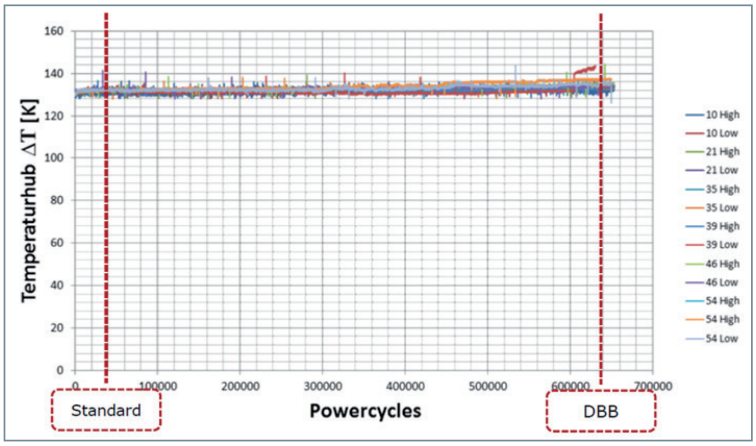


Figure 2: Proven power cycling performance with copper wire-bonds and DBB.

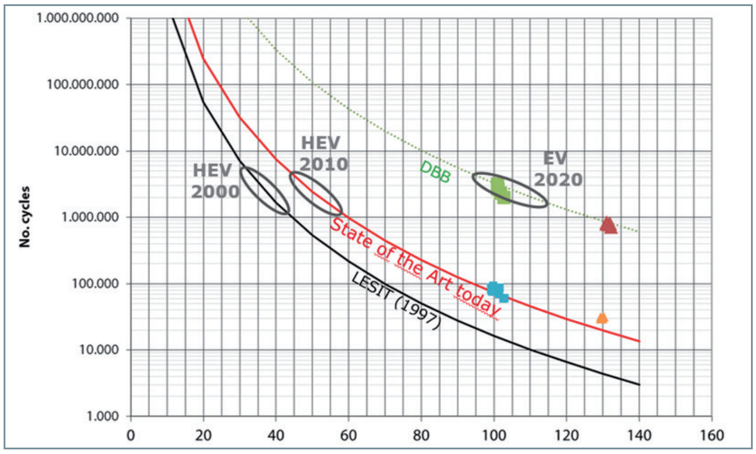


Figure 3: Higher ΔT at uncompromised lifetime.

During year 2000, standard aluminum wire bonding with soldered chips provided sufficient reliability to fulfill automotive lifecycle requirements. During the following decade, the continuous process improvements in the wire bonding technology proved adequate to fulfill the increased performance requirements. But the leap in performance requirements from 2010 to 2020 are so extreme that standard bonding and joining technologies are out of the picture. The improved reliability of DBB®, with a power cycle capability 15 times higher than state of the art technology, meets the requirements, and thus, is the solution for the future.

ShowerPower® and SP3D®

ShowerPower® is a liquid cooling concept designed for direct liquid cooling of flat baseplate based power modules. ShowerPower® coolers for standard modules, like P3 module and EconoPlus modules, have been in production for the last decade. ShowerPower coolers® are widely used in industrial and renewable applications. More specifically, more than 30 GW of renewable power conversion capability is today cooled by ShowerPower®. Furthermore, ShowerPower® has a flawless track record for more than 10 years with no failures due to cooling, coolant leakage or clogging.
The key advantage is highly efficient direct liquid cooling without temperature gradients across the power module baseplate.
The core of the concept is a part comprising several meandering cooling channels that guide the coolant along the surface to be cooled.

Because of tolerance issues, there will be a small gap or bypass between the ShowerPower® insert and the surface to be cooled. The gap is a few hundred microns wide.

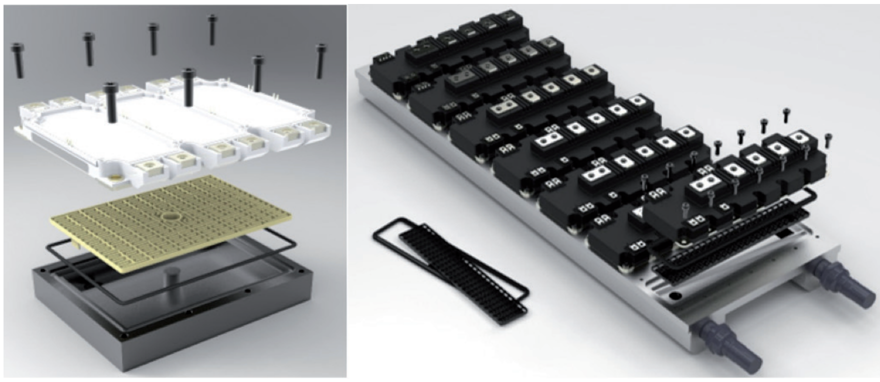


Figure 4: ShowerPower® for the EconoPlus module and for the P3 module

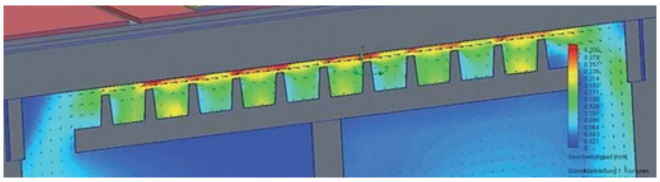


Figure 5: The bypass.

CFD investigations have demonstrated that a bypass of 200-500µm improves the thermal performance and reduces the differential pressure drop. The exact value depends on the current design boundary conditions and design goals.

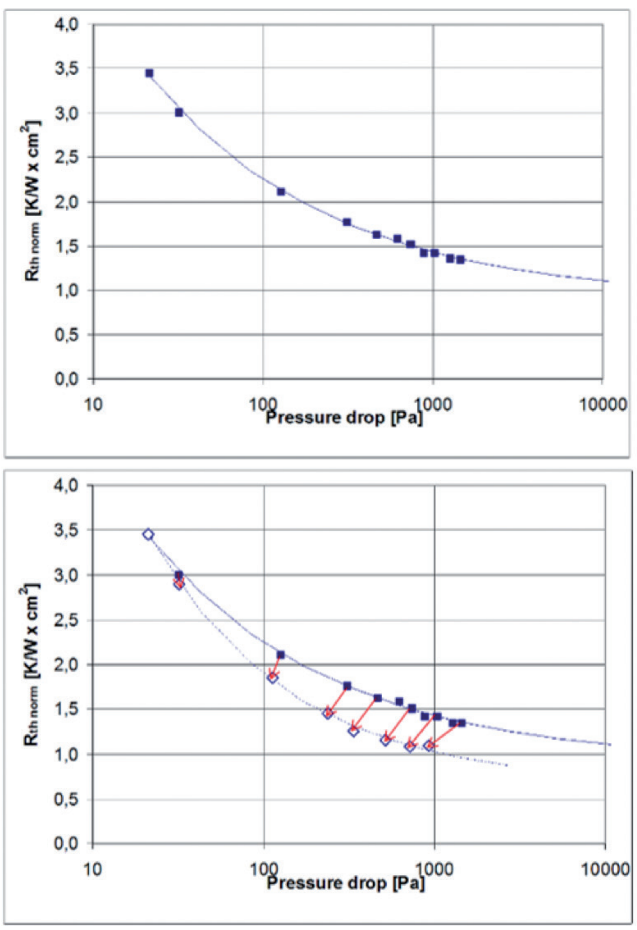


Figure 6: CFD simulations on a family of meander channel geometries, without and with a bypass.
As seen in figure 6, the bypass has a positive impact.

TAKE TOMORROW'S CARS TO THE NEXT LEVEL

- *The answers to power-electronic challenges are*
- *High power density*
- *Improved robustness*
- *Cost-efficient performance*

One explanation for the improved performance is the swirl effect in the cooling channels. The flow in the channels is laminar because of the relative low Reynolds numbers. This is good from a pressure drop perspective but not so good regarding cooling efficiency because of classical build-up of boundary layers that inhibit effective heat transfer. But the changes of direction of the flow force the fluid flow into a rotation, or swirl, due to the conservation of momentum. The phenomenon is often observed in rivers. Though in the small meandering channels seen here, the effect is difficult to observe.

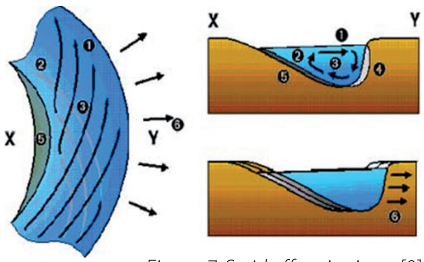
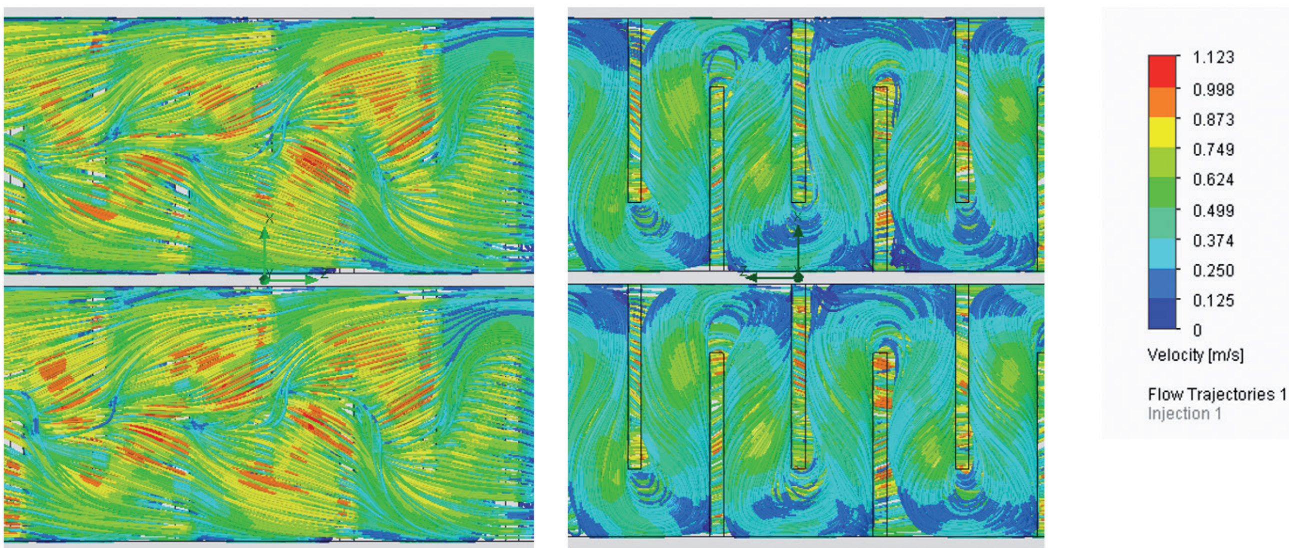


Figure 7: Swirl effect in rivers [0]

The bypass creates a flow transverse to the flow direction in the meandering channels thereby amplifying the swirl effect, see the figures below; this means that cold coolant is constantly brought in contact with the surface to be cooled.



Enhancing the efficient cooling area by transferring the meandering channels from the plastic part to the baseplate itself almost doubles the effective heat transfer coefficient and thereby reduces the thermal resistance junction to coolant by 25%. This also offers a current carrying capability that is roughly 25% higher than for standard ShowerPower®. The concept is called ShowerPower® 3D or SP3D® for short. Further information on ShowerPower® and SP3D® can be found here (15-24).

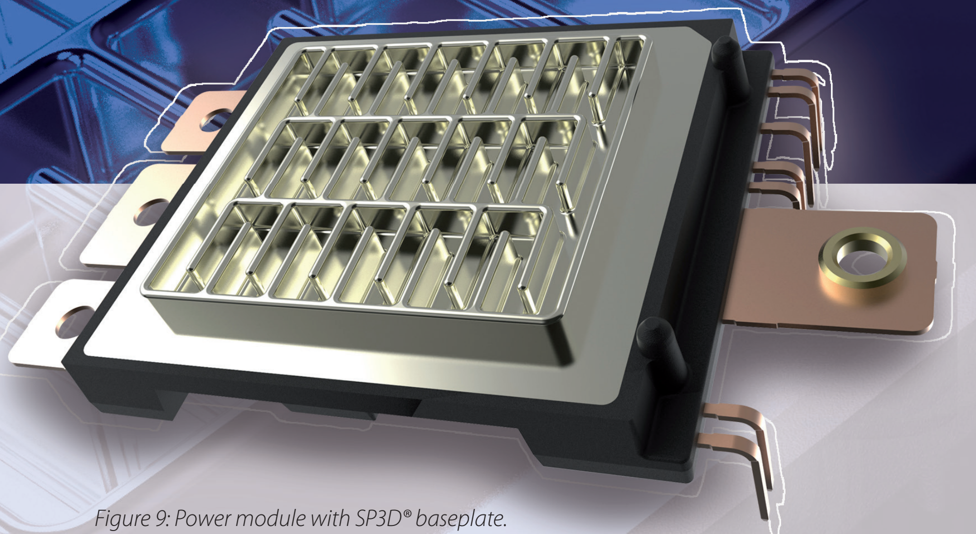


Figure 9: Power module with SP3D® baseplate.

The SP3D® concept offers several benefits compared to other liquid cooled power module e.g. pin fin coolers. The parallel cooling principle eliminates temperature gradients associated with the serial cooled pin fin concept. It also allows for tailoring the cooling e.g. focus cooling efficiency at local hot spots, a feature that is not possible for the pin fin concept due to "shadowing" effects. The walls of the SP3D® cooling channels also bring a considerably extra amount of mechanical stiffness to the module compared to the pin fin allowing for high pressures and pressure pulses in the cooling system.

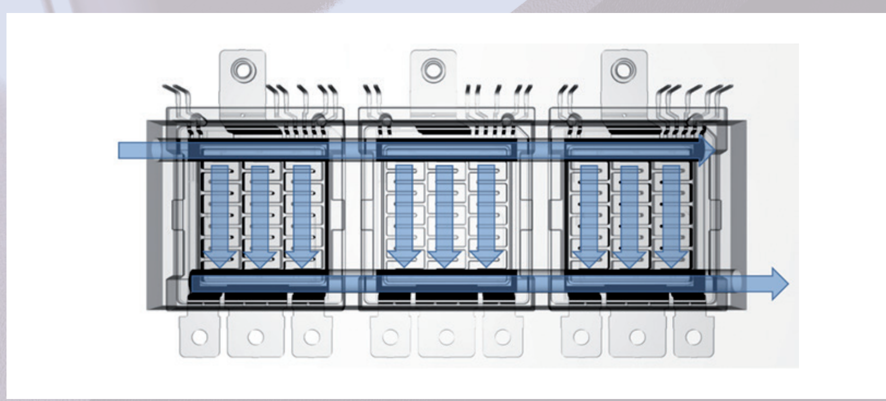


Figure 10: Transparent CAD picture visualizing the parallel flow of the coolant.

Transfer molding technology

Combining DBB® and transfer molding technologies allows for higher junction temperatures and more extreme temperature cycling than standard bonding and joining- and housing technology. Power density can be increased, and the extra power generated can be dissipated by SP3D® cooling. The bottleneck is no longer the die solder joint and the soft gel, but the chip itself. So, with DCM™1000 the scene is set for applying wide bandgap devices that allows for higher junction temperatures.

Electrical Technology

To meet future challenges with hardware and quality related topics the DCM™1000 is designed, built and certified in accordance to the LV324 automotive standard. The DCM™1000 technology platform is truly flexible since optimized to utilize Si and hybrid modules (Si IGBT's and SiC diodes) and pure SiC semiconductors, while keeping the same footprint. In Figure 11 a comparison of the output current is shown.

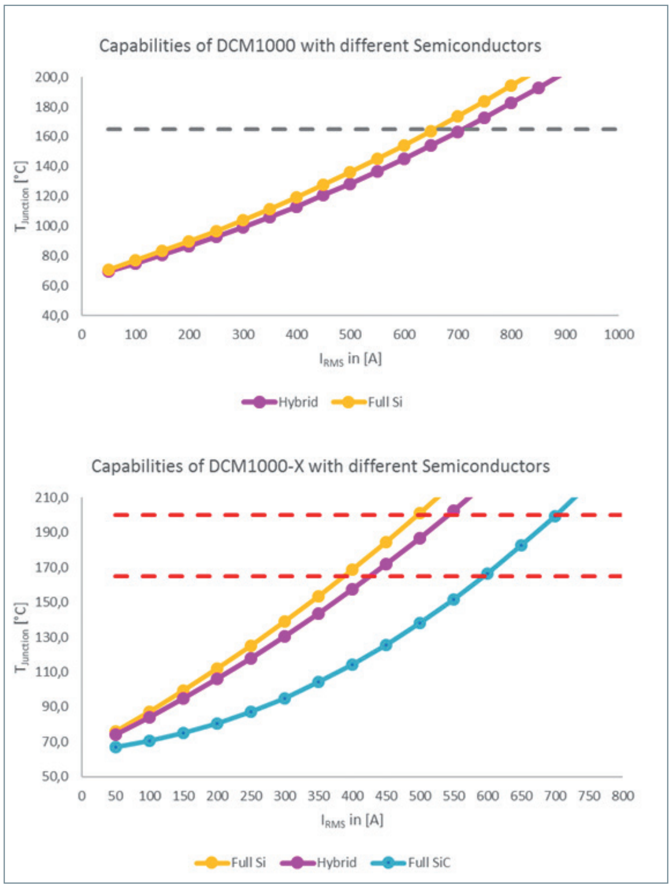


Figure 11: a comparison of the output current is shown.

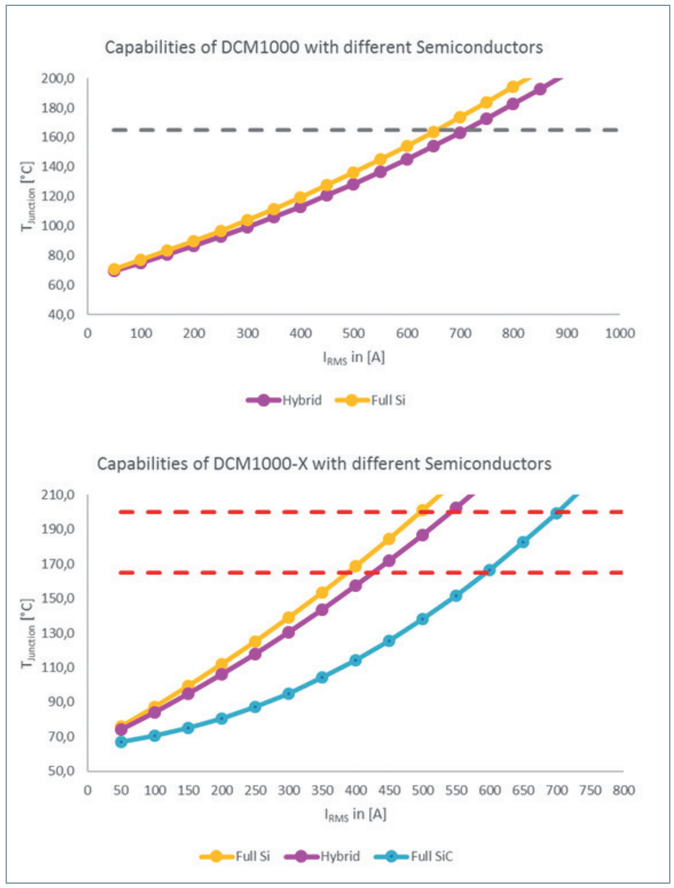


Figure 11: Impact of utilizing different semiconductor technologies.

It is evident that the module performance is enhanced while different semiconductors are utilized, Si chipset delivers great performance, especially with DBB a huge increase in life time can be achieved.
A hybrid chipset offers even more current performance because the Eon losses of the IGBTs are significantly reduced due to SiC Diode.
A SiC chipset outperforms every Si or SiC variant at comparable operating points. Furthermore, the junction temperature can be higher compared to Si, i.e. during short boost phases.
According to application need, the diverse chipset ensures maximum efficiency and cost optimal, at the different given operating point considering the stringent inverter requirements.

The module are scalable in order meet the different voltage classes, covering the different BEV/HEV inverter voltage classes ($V_{DC,Link}$ =450-900V) resulting in blocking voltages of 750 - 1200V, while having different output current classes 350-650A. The nominal output current is defined for f_{sw}=10kHz, $T_{coolant}$=65°C @ 8L/min, m=cos(phi)=1, Tj,op=165°C, note that the junction temperature is only achievable by utilizing the DBB®.
The definition of the nominal operating point is of great importance, since the boundary conditions have a great impact on the module performance.
The impact of the alternating boundary conditions on the nominal output current of the module is shown in Figure 12 - Figure 13.
The coolant can be varied with 2 parameters, the coolant temperature and coolant flow rate. The impact of coolant temperature is quantified in Figure 13.

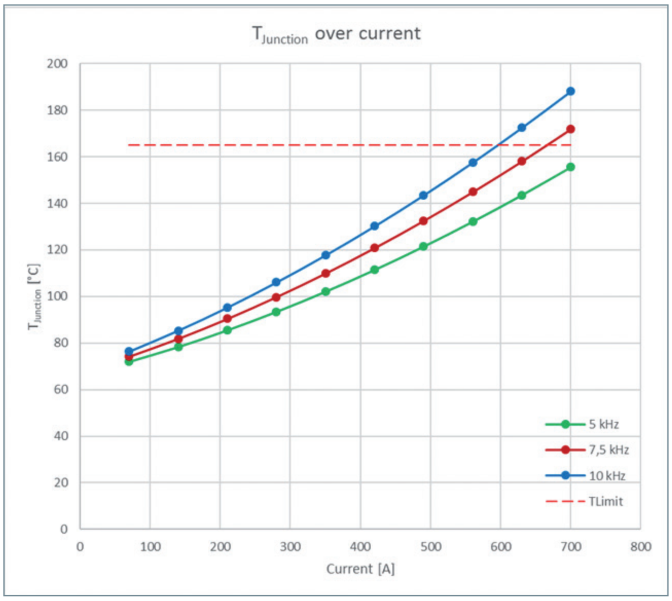


Figure 12: Impact of the switching frequency on nominal output current.

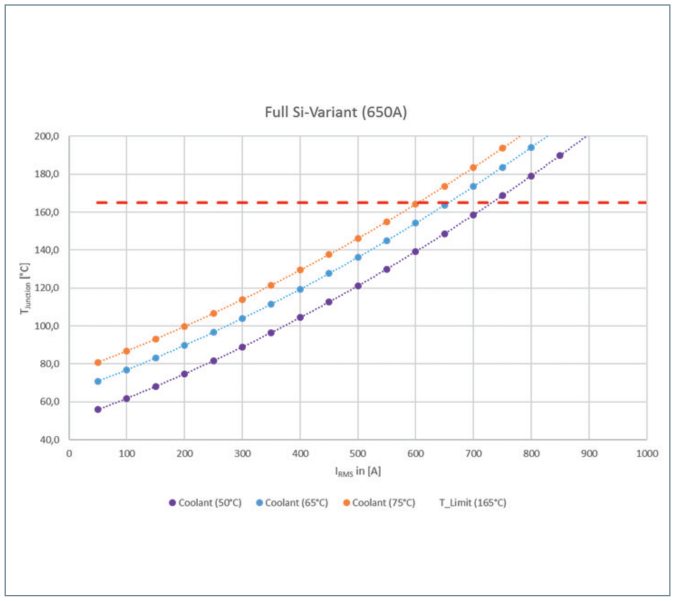


Figure 13: Impact of coolent temperature, here @ 10kHz switching frequency and 8L flow rate.

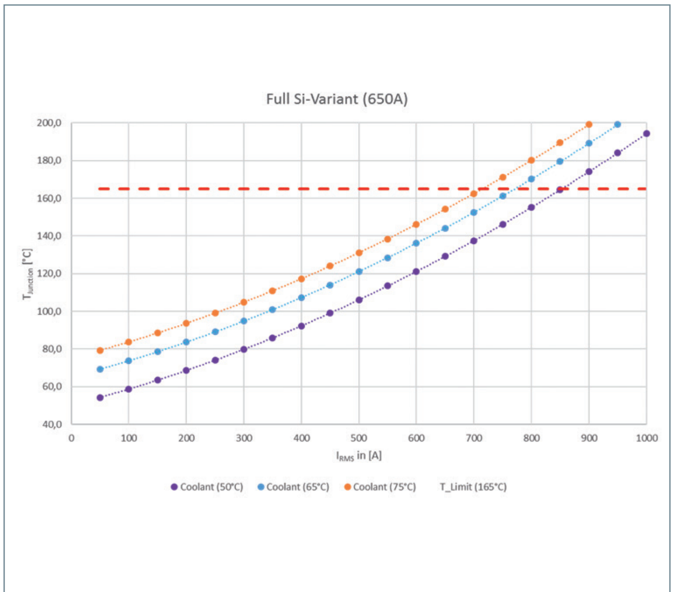


Figure 14: Impact of coolant temperature, here @ 6kHz switching frequency and 10L flow rate.

Any customization of the DCM™1000 technology platform, like different semiconductor brand or type, different connector to fit the exact customer needs of the different traction inverters is an option on request.

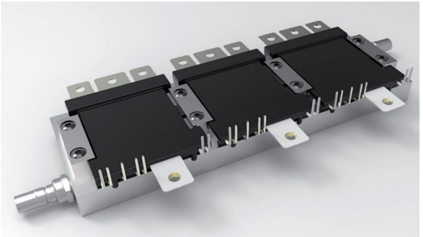


Figure 15: Planar configuration

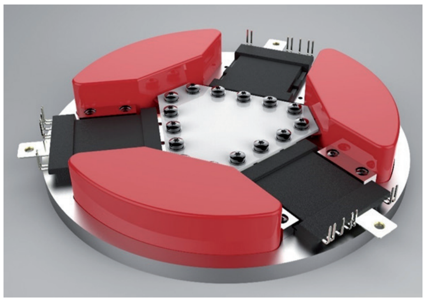


Figure 16: Circular configuration

Easy integration

DCM™1000's compact form factor makes system integration easy and offers a range of mechanical designs to optimize the inverter design. Possible configurations range from simple planar assemblies to advanced 3D setups - a few examples are shown below.
The standard planar configuration with three modules placed in a row. The cooler is a laboratory design, placement of flow inlet and outlet is flexible.

The circular configuration offers the opportunity for easy integration of the DC-link capacitors for low stray inductance and high symmetry in switching. A laminated busbar, shown in Figure 16, connects the power modules to the capacitors.

The three modules are assembled on a triangular cooler on top of the DC-link capacitor in Figure 17.

For larger motors the modules can be coupled in parallel; the example below shows six modules placed on the inside of the stator of the motor.

Figure 17: Triangular configuration

Danfoss' DCM™1000 is the next generation technology platform for automotive traction inverters.

The technology platform is well-defined, based on known and proven technologies, and yet open enough to be scalable and customized to meet specific requirements. In addition, the technology platform is versatile in application and performance as a consequence of combining materials and technologies in the best possible way. Qualification tests according to LV 324 and openness to any automotive qualified semiconductor reduce risk of failure and allocation.

With the introduction of DCM™1000 technology platform, Danfoss Silicon Power further strengthens it's customized power module offering. The DCM™1000 will be on display at APEC. Visit the Danfoss Silicon Power booth for a first impression and introduction.

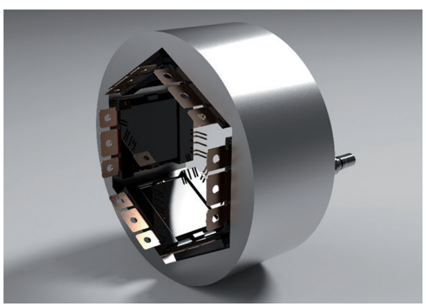


Figure 18: Motor configuration, the modules

References:

1. Paris to ban all petrol cars from the city by 2030 in pollution crackdown, http://www.telegraph.co.uk/news/2017/10/12/paris-ban-petrol-cars-city-2030-pollution-crackdown/
2. China to ban petrol and diesel cars, state media reports, http://www.independent.co.uk/news/world/asia/china-petrol-diesel-car-ban-gasoline-production-sales-electric-cabinet-official-state-media-a7938726.html
3. California Considers Following China With Combustion-Engine Car Ban, https://www.bloomberg.com/news/articles/2017-09-26/california-mulls-following-china-with-combustion-engine-car-ban
4. Reducing CO2 emissions from passenger cars, https://ec.europa.eu/clima/policies/transport/vehicles/cars_en
5. Tesla mega-battery in Australia activated. http://www.bbc.com/news/world-australia-42190358
6. Electric Vehicle Outlook 2017, https://about.bnef.com/electric-vehicle-outlook
7. R. Eisele, D. Migdalek, T. Rabsch, J. Rudzki; Reliable Chip Contact Joining, PCIM Conference Europe, 2009
8. J. Rudzki; Reliability of Ag Sintering vs. Soldering, ECPE Workshop Paris 2009

The **future power** of performance is **electric**

OPTIMISE PERFORMANCE

Danfoss Silicon Power modules are used in a wide range of automotive applications:

- *Electric Traction (Hybrid and battery electric drive train)*
- *Medium voltage high power electronics / 48 V electronics*
- *Electric Power Steering*
- *Power management: DC/DC converter, body electronics, auxiliary drives*
- *Thermal Management with ShowerPower®*

CORE COMPETENCES

- *Power module design*
- *Advanced bonding and joining technologies*
- *Prototyping and qualification*
- *High-volume manufacturing*
- *Semiconductor independence*

MANUFACTURING AND QUALITY MANAGEMENT

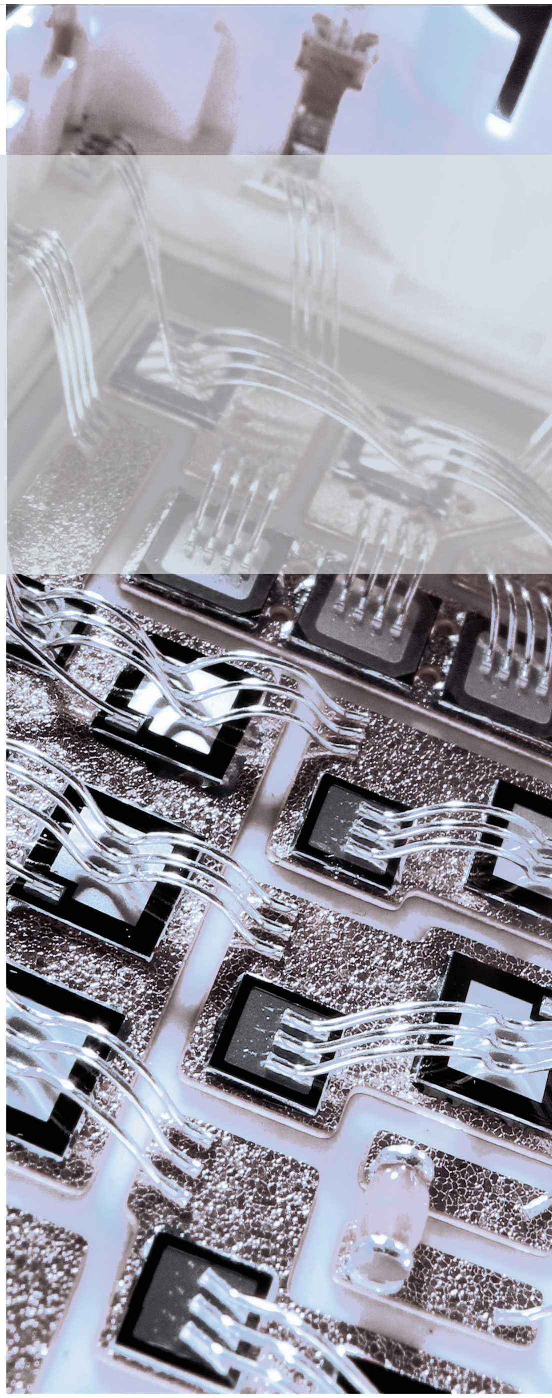
- *ISO/TS 16949*
- *ISO 14001*
- *ISO 9001*
- *ISO 50001*
- *OHSAS 18001*

9. J. Rudzki, L. Jensen, M. Poech, L. Schmidt, F. Osterwald; Quality evaluation for silver sintering layers in power electronic modules, CIPS Conference Nuremberg 2012
10. J. Rudzki, F. Osterwald, M. Becker, R. Eisele; Novel Cu-bond contacts on sintered metal buffer for power module with extended capabilities, PCIM Conference 2012
11. M. Becker, J. Rudzki, R. Eisele; Improved thermo-mechanical properties of a new bonding and joining technology lead to highly reliable modules for advanced power electronic applications; Microtherm 2013, Warsaw
12. Guido Mannmeusel, Marco Bäßler, Henning Ströbel-Maier, Martin Becker, Frank Osterwald; Influence of Danfoss Bond Buffer and Cu-Wire Bonds on the Electrical Switching Behaviour of IGBTs, PCIM Europe 2014, 20 – 22 May 2014, Nuremberg, Germany
13. http://www.mentor.com/products/mechanical/engineering-edge/volume4/issue1/showerpower-turbulator-keeps-igbts-cool
14. http://www.oxbowriver.com/Web_Pages/Stream_Ecology_Pages/Ecology_Aquatic/Ecology_Helical.html
15. Klaus Olesen, Rüdiger Bredtmann, Ronald Eisele; "ShowerPower" New Cooling Concept for Automotive Applications, SIA, International Conference Automotive Power Electronics, Paris, 21-22.06.2006
16. Klaus Olesen; Innovative Cooling Concept for Power Modules, Bodo's Power Systems, July 2006
17. Klaus Olesen; Dr. Rüdiger Bredtmann, Prof. Dr. Ronald Eisele, Dr. Frank Osterwald; "Power under the hood" Increasing power density of inverters with a novel 3D-approach, SIA, International Conference Automotive Power Electronics, Paris, 2009.03.26-27
18. Klaus Olesen, Ryan Drabek, Dr. Frank Osterwald, Dr.-Ing. Michael Tønnes, Prof. Dr. Ronald Eisele; „Designing for reliability, liquid cooled power stack for the wind industry", European Wind Energy Conference - EWEC 2010, 20-23 April 2010, Warsaw, Poland
19. Klaus Olesen, Ryan Drabek, Dr. Frank Osterwald, Dr.-Ing. Michael Tønnes, Prof. Dr. Ronald Eisele; Direct liquid cooling of power modules in converters for the wind industry, PCIM Europe 2010, Nuremberg, 4-6 May 2010
20. Klaus Olesen, Dr. Rüdiger Bredtmann; Dr. Florian Söhnchen, Prof. Dr. Ronald Eisele, Under the Hood High density IGBT module tuned to automotive mission profile, APE, SIA 2011, Paris
21. Siegbert Haumann, Klaus Olesen, Jørgen Holst; Custom Power Module Solutions for Automotive Traction Inverters - the basis for lower cost, higher power density and improved reliability, EVS26, Los Angeles, California, May 6-9 2012, poster presentation
22. Siegbert Haumann, Klaus Olesen, Jørgen Holst; Advanced Thermal Management Solutions in Power Electronics -the basis for lower cost, higher power density and improved reliability-, APEC 2012 conference, Orlando FL, February 2012
23. Rüdiger Bredtmann, Ole Muhlfeld, Klaus Olesen; IGBT-Power Module – How to make the most out of silicon? EEHE 2014: "Electrics/Electronics in Hybrid and Electric Vehicles and Electrical Energy Management", Bamberg, May, 6th-7th, 2014
24. Klaus Olesen; Designing innovative cooling solutions for high power modules using CFD, NAFEMS seminar „CFD-Methoden zur Simulation des Wärmeübertragungsverhaltens" 22. - 23. November 2017, Neuendettelsau

ENGINEERING
TOMORROW

Danfoss Silicon Power

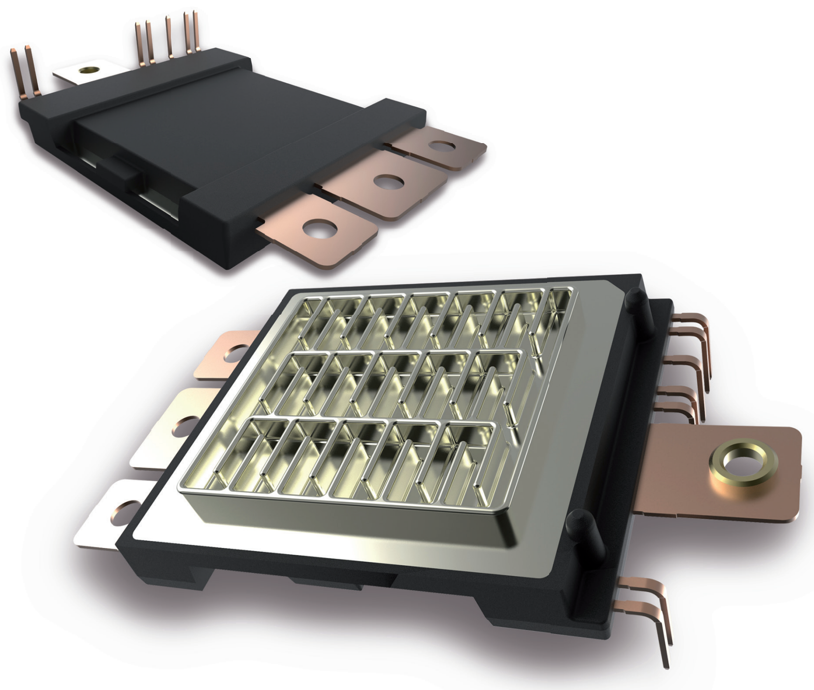
Based in Flensburg, Germany, Danfoss Silicon Power is a leading developer of customer specific IGBT and MOSFET modules and power stacks for power intensive applications.



Our power modules and power stacks are a preferred choice in demanding automotive and wind power applications and a wide variety of industrial applications.

Our 35,000 m^2 research, development and production facility is certified according ISO 9001, ISO/TS 16949, ISO 14001, ISO 50001 and OHSAS 18001. This enables us to quickly transfer development projects to high volume production that can be integrated seamlessly into our customers' supply chain with full focus on quality.

Danfoss Silicon Power is a subsidiary of the Danfoss Group, the largest industrial company in Denmark. Danfoss employs more than 24,000 people in 100 countries within development, production, sales and support.



Danfoss Silicon Power GmbH, Husumer Strasse 251, 24941 Flensburg, Germany, Tel. +49 461 4301-40, Fax +49 461 4301-4310
www.siliconpower.danfoss.com, E-mail: dsp-sales@danfoss.com

DKSP.PB.434.A1.02 Produced for DSP 2018/02