Easy to Use and Compact: A Family of SiC Power Modules for Automotive Traction Inverters

eMobility is rapidly gaining market share, resulting in a growing need for power electronics such as inverters. Some of the power electronics manufacturers optimize their power modules by replacing the Si IGBTs through the SiC MOSFETs in the high-volume mainstream packages. However, it is not sufficient to just replace the semiconductors. It is necessary to develop and optimize new packages which are adjusted to the SiC demands.

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Over the last decade, Bosch has been driving electrification forward with customer-specific power modules based on IGBTs. In December 2021, Bosch introduced its first generation of SiC MOSFETs to the market. The 2nd Gen is currently in ramp-up phase, further reducing conduction and switching losses and allowing for even higher switching frequencies.

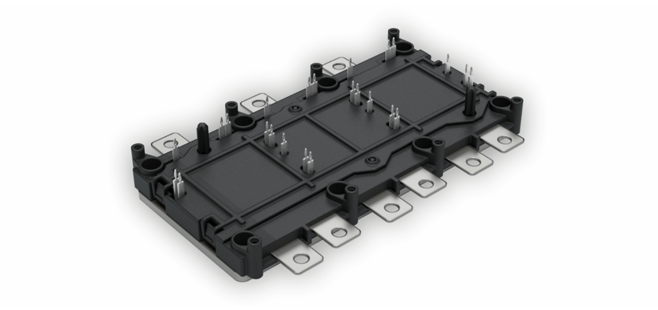

Figure 1: CSL B6 bridge with screw contacts (top view)

Combining these two areas of expertise, Bosch now presents the CSL (Compact Silicon Carbide Line) power module family for traction inverters. The CSL family is scalable for power ratings from 75 kW to 250 kW – more than 50% of the traditional ICE passenger vehicle fleet[1] falls in this range.

In comparison to commercially available gel frame solutions, CSL modules are smaller in size, allowing for cost-effective inverter designs. MOSFETs with breakdown voltages of 750 V and 1,200 V make them the ideal choice for 400 V or 800 V inverter systems.

The module DC busbars and phase contacts can be connected to the DC Link / battery / EMC filter and e-machine busbars either via screwing tabs with holes (Figure 1) or via welding contacts (tabs integrated into module body) for high volume production (Figure 2). Despite the small form factor, CSL modules are still compatible with DC link capacitors for commercially available gel frame modules with screwable contacts.

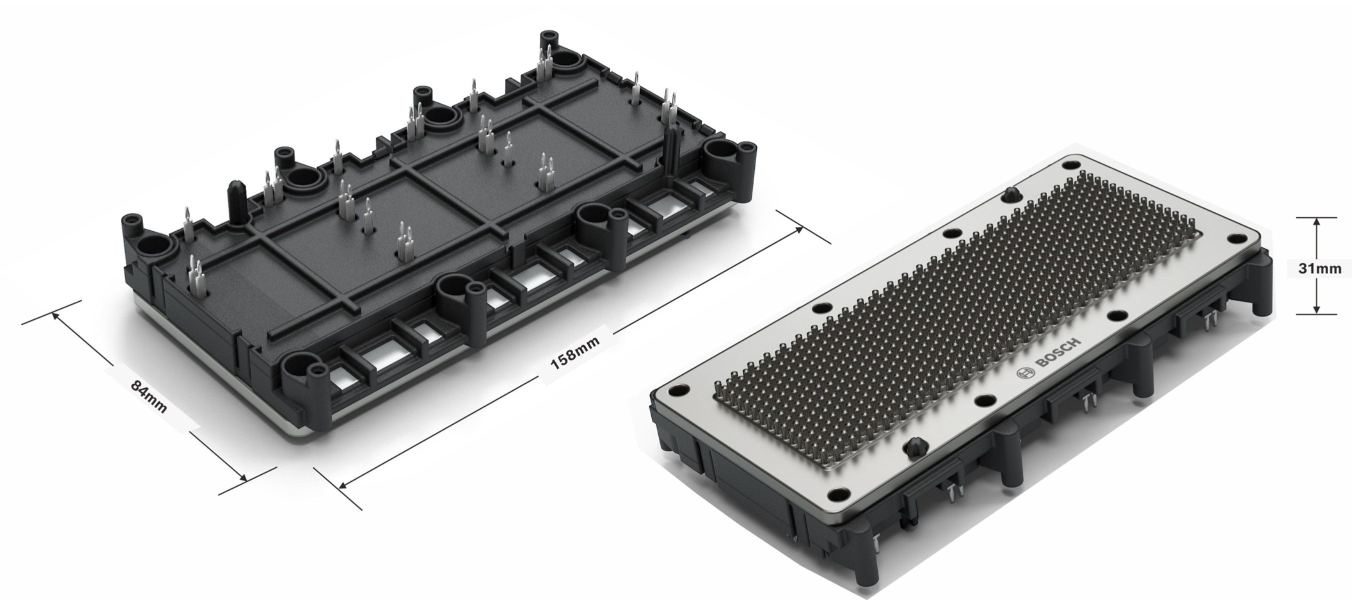

Figure 2: CSL B6 bridge, weld version (top and bottom view)

Signal pins in press fit technology connect the frame module to the gate driver printed circuit board. The use of press fit contacts effectively avoids potential solder drips on the AMB. For highest contact reliability, the press fit pins are embedded in the frame mold material.

Two cooling options are available: an industrially common PinFin cooler or an integrated closed cooler[2] .

An uppermost performance of the adjoined materials such as gel, frame, AMB with Si3N4 isolation, baseplate, double-sided sintering of the SiC die with die top system Cu termination and Cu thick wire bonding allows operation at a steady state temperature of 175°C.

For efficient cooling, the module features an optimized thermal path. The SiC MOSFETs are sintered on a Si_3N_4 AMB, the AMB is soldered on the cooler for lowest thermal resistance R_{th}.

To exploit the full potential of the MOSFETs, special attention was paid to a symmetrical layout and to the placement of the SiC MOSFETs.

Every phase incorporates a separate NTC for MOSFET temperature measurement. For accurate temperature reading, the NTCs are located in the high side path, as close as possible to the MOSFET dies.

The CSL complies with AQG 324 and is RoHS compatible, all plastic components are UL94 V-0 compliant and therefore flame-retardant.

The compact design also contributes to reduced leakage inductances, enabling high switching dynamics. For the screw variant, the internal stray inductance is typically less than 10 nH. For the weld variant, internal stray inductance is typically less than 6 nH.

With outline dimensions of 158 x 84 x 31 mm (see Figure 2), the weld version is 35% smaller in volume than other commercially available frame modules for automotive traction inverters.

In addition, the high dynamics of the weld variant enables efficient partial load operation. The efficiency is further increased by fast transients and low R_{DSon}.

Figure 3 shows the current waveform of four MOSFETs switched in parallel. The start junction temperature in this operation point is 175 °C at 920 A. The current mismatch between the MOSFETs is 5 % max.

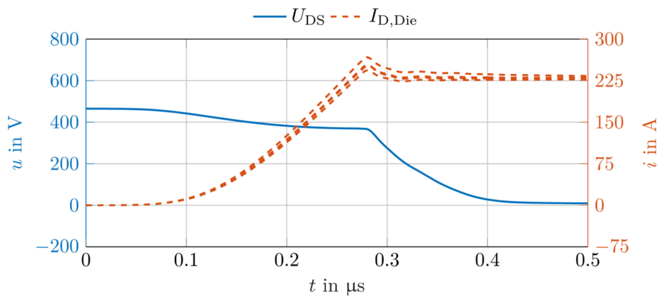

Figure 3: Dynamic Switching of 750 V CSL module at Tj =175 °C and 920 A

The low mismatch leads to an optimal utilization of the SiC MOSFETs. Ringing between the MOSFETs is minimized, asymmetrical stress and aging is reduced. The symmetrical current distribution also results in an improved short-circuit robustness.

Short-circuit capability is further increased by a current feedback, helping to reduce the peak short-circuit current $\hat{I}_{SC}$.

Figure 4 shows the current waveform for a short-circuit type 1. The start temperature of the event is 175 °C with an applied DC link voltage of 460 V.

The interaction of layout and chip design increases the critical short-circuit time, while at the same time R_{DSon} is kept low at typically 1.4 mΩ.

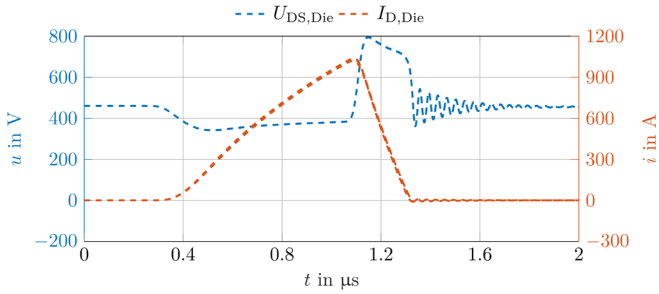

Figure 4: Short-circuit type 1 of 750 V CSL module at Tj =175 °C and 460 V

The selected interconnection technology enables high pulse loads during operation and a high current carrying capacity - even at high temperatures in the safe state of the traction inverter.

For a comfortable validation of the module's performance and capabilities, Bosch collaborated with NXP Semiconductors to develop a custom gate driver evaluation board, using advanced high-voltage isolated gate drivers (GD3160). The result is the FRDMG-D3160CSLEVM, a half-bridge evaluation kit, implemented using two GD3160 ICs, a KL25Z microcontroller to interface to a PC, and free FlexGUI interface software. The software allows users to perform dynamic SiC switching measurements (e.g., double pulse and short-circuit type 1,2 tests) on all CSL module B2 bridges. Figure 5 shows the evaluation board attached to the module.

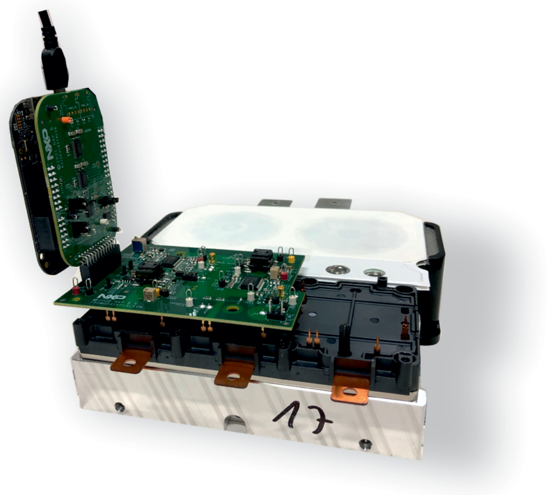

Figure 5: FRDMGD3160CSLEVM half-bridge evaluation kit from NXP for dynamical measurements on CSL modules For more information, visit NXP's website (https://nxp.com/FRDMGD3160CSLEVM)

Summary

The CSL (Compact SiC Line) B6 bridge family addresses the requirements of mainstream automotive traction inverters. Using the 2nd Gen of Bosch SiC MOSFETs allows for lowest switching and conduction losses and a smooth dynamic behavior. With its symmetrical AMB design, the CSL family provides high performance during normal and special operating conditions.

References

1. Exawatt, Silicon Carbide in Electric Vehicles: Market Outlook, Edition of July 2022.
2. Bosch Website: https://www.bosch-semiconductors.com/power-semiconductors/

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