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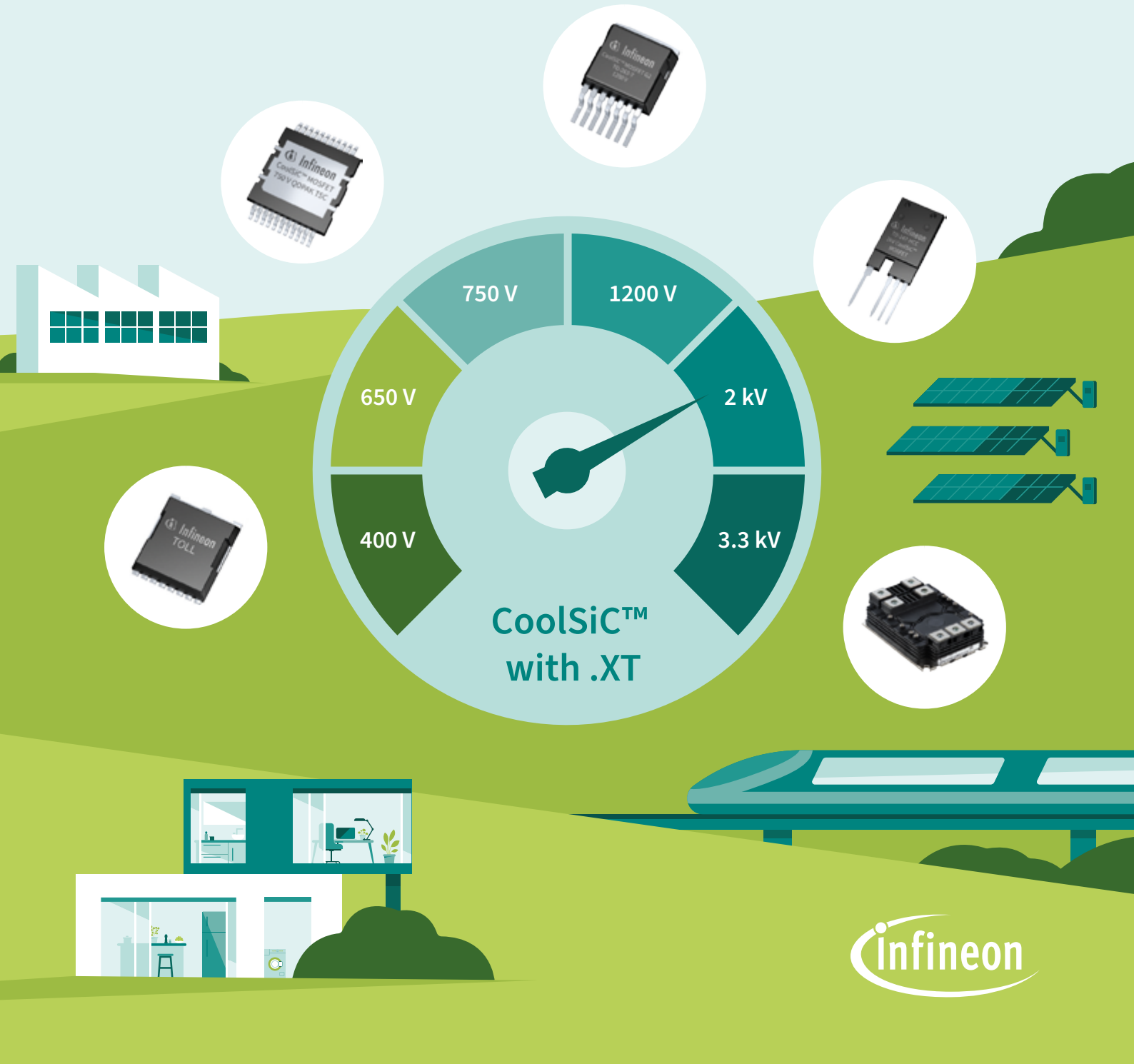
CoolSiC™ with .XT technology – Extending your Application Lifetime



SiC MOSFET and .XT – Improved Lifetime for Your Applications

Infineon takes it up a notch in 2024 with its second-generation CoolSiC™ MOSFET devices. The recently launched SiC MOSFETs in the 650 V, 1200 V and 3300 V class under the well-known CoolSiC brand are targeting high voltage industrial applications such as EV charging, industrial solar inverters, servo drives, UPS, and railway traction.

By Tomislav Turščak, Product Application Engineer, Giovanbattista Mattiussi, Director of Product Management, Syeda Qurat ul ain Akbar, Product Application Engineer, and Dr. Diana Car, Principal Technical Marketing Engineer, all Infineon Technologies

For low voltage applications such as power factor correction for servers, multilevel solar topologies, and high-power drives, Infineon will soon release a 400 V SiC MOSFET with channel resistance ranging from 11 mΩ to 45 mΩ, in two different 4-pin packages – TOLL and D2PAK-7. In this article, we cover the features of these high-voltage SiC power devices built with .XT technology.

An overview of the new, industrial grade CoolSiC MOSFET 650 V discrete

Infineon's latest 650 V discrete MOSFET is based on second generation (G2) SiC trench technology. The first generation (G1) CoolSiC trench focused on providing reliable performance and implementing an industry-leading trade-off between performance and reliability – characteristics that helped develop customers' trust in the novel SiC technology. G2 builds on this by adding better performance, more usage flexibility, and advanced packaging technology, while maintaining G1's reliability and robustness with respect to the gate oxide layer (GoX). The switching behavior of Infineon's second-generation SiC MOSFETs is compelling. The figure of merits (FOM) graphs, shown in Figure 1, highlight a marked improvement over the previous generation.

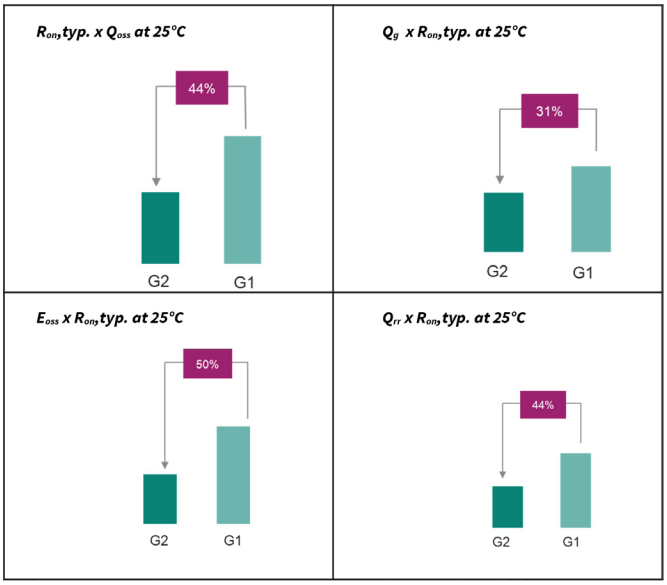


Figure 1: Figure of merits for MOSFETs of the new G2 technology compared to G1

The strong FOMs suggest that the G2 SiC MOSFETs from Infineon can successfully fit in high frequency designs, typical for soft switching topologies. Overall, they enable higher system power density. Interestingly, the improvement in switching performance in CoolSiC G2 balances the increase in thermal coefficient. Figure 2 shows the temperature dependence of R_{on}, at 25°C, in different Infineon 650 V power device technologies and generations. At 125°C, the CoolSiC G2 shows a 12 percent increase in R_{on} compared to G1. However, it stays below CoolGaN™ G1 and CoolMOS™ 7 by a minimum margin of 20 percent.

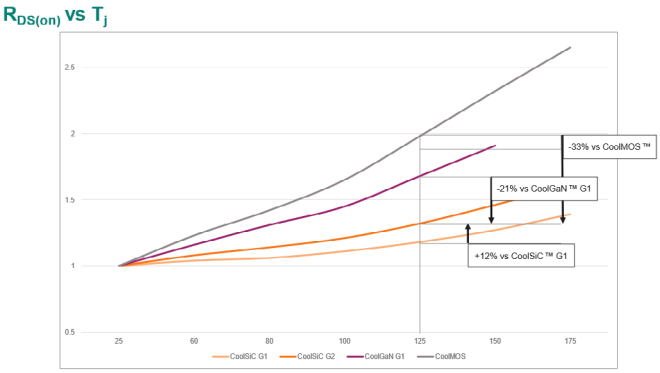


Figure 2: Temperature dependence of device resistance in different technologies

Stronger temperature dependency of device resistance does not impact the overall performance of the CoolSiC MOSFET 650 V G2, especially when assessed at the system level. System losses are generally the sum of conduction and switching losses. Conduction losses are mostly related to R_{on}, but switching losses depend on different parameters. The optimal switching behavior of the CoolSiC MOSFET G2 helps offset the more pronounced increase in R_{on} with temperature. It enables G2 to perform excellently, reaching a solid peak efficiency of 99.2 percent in the 3.3 kW continuous conduction mode totem (CCM) pole PFC measurements, as shown in Figure 3.

Apart from performance, CoolSiC G2 also makes designing easier, providing a wide range of driving voltages, from -7 V to 23 V, with excellent support for 0 V turn-off, which is possible because the parasitic turn-on effect has been reduced to negligible levels. The 0 V turn-off provides the possibility of simplifying the gate driving schema, using a unipolar design, which ensures compatibility with silicon-based super junction MOSFETs.

Another common customer pain point has been system reliability, especially in industrial applications where high availability and low maintenance costs are strong requirements. From the reliability point of view, the second-generation CoolSiC MOSFETs are best in class, leveraging the best possible gate oxide ruggedness among all SiC MOSFET alternatives in the market and an improved cosmic ray robustness.

Some distinctive aspects of the second-generation CoolSiC technology are further enhanced by advanced packaging technologies. For instance, all discrete G2 products use the .XT interconnection – a

proprietary die attach technique capable of reducing the device's thermal resistance ($R_{th,j-c}$). By mid-2024, the CoolSiC portfolio will be complemented by the top-side cooling package (TOLT).Top-side cooled SMD discrete MOSFETs combine the advantages of the TO and SMD packages – enhancing power density, reducing assembly costs, and allowing newer and more efficient designs.

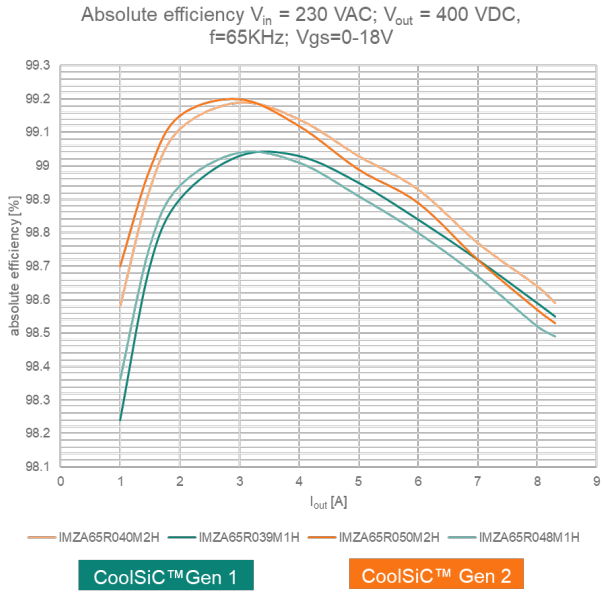


Figure 3: Comparing efficiency between G1 and G2 SiC MOSFETs

To extend the portfolio further, Infineon is also working to release the second-generation 650 V technology in a specific 8x8 package called ThinTOLL, which, while offering full compatibility with any 8x8, provides four times better thermal cycles on board (TCoB) capability than a standard 8x8.

In summary, the new 650 V voltage class will leverage the performance, ease of use, and reliability of the second-generation CoolSiC MOSFETs through a granular and evolving product portfolio, based on advanced packaging technology that will further enhance the G2 advantages.

.XT and 200°C capability of the 1200 V MOSFET family

Infineon's .XT chip interconnection technology enables smaller form factors while providing excellent thermal performance. The new CoolSiC MOSFET 1200 V G2 with .XT provides 12 percent better junction-to-case thermal resistance due to its improved die attachment process, as shown in the Figure 4. As a result, higher output currents and a longer device lifetime can be facilitated. The .XT technology employs the diffusion soldering method to minimize connection voids and reduce the thickness of the die attach layer.

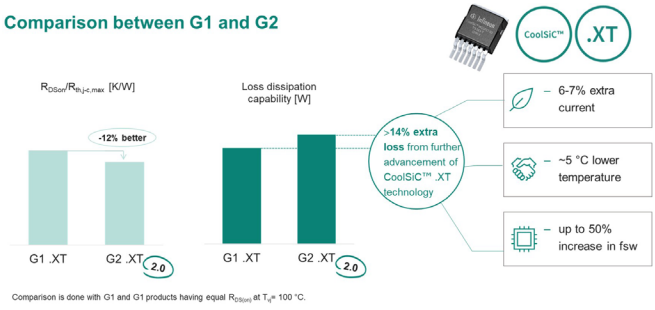


Figure 4: Reduced device thermal resistance due to improved die attachment process

SiC MOSFETs are known for their ability to operate at higher temperatures compared to traditional silicon-based MOSFETs. While the specific temperature ratings can vary between different SiC MOSFET technologies and manufacturers, most SiC MOSFETs are designed to operate reliably at junction temperatures of up to 175°C. Infineon's CoolSiC MOSFET 1200 V G2 is qualified to operate at up to 200°C for a total cumulative time of 100 hours. This device specification has been introduced to allow more reliability under overload conditions and offer engineers more freedom with system design. The ability of SiC MOSFETs to withstand short overload conditions is an important consideration in various applications. In industrial motor drives, sudden load changes, additional torque demand, or even power supply fluctuations can lead to overload conditions where the higher junction temperature margin is useful. Solar inverters and grid-tied applications are other good examples to demonstrate overload conditions because grid voltage fluctuations can impact the operation of the power converters. Voltage sags can influence the output power of the converter and temporarily increase power losses or, in severe cases, completely disconnect the system from the grid. In electric vehicle charging applications, the charger's voltage fluctuations are critical. In the case of a drop in the input voltage, the current can increase temporarily, creating additional stress for the power device. Figure 5 shows an example of the extended current capability of an 8 mΩ device due to the higher temperature limit. The gray curve represents a

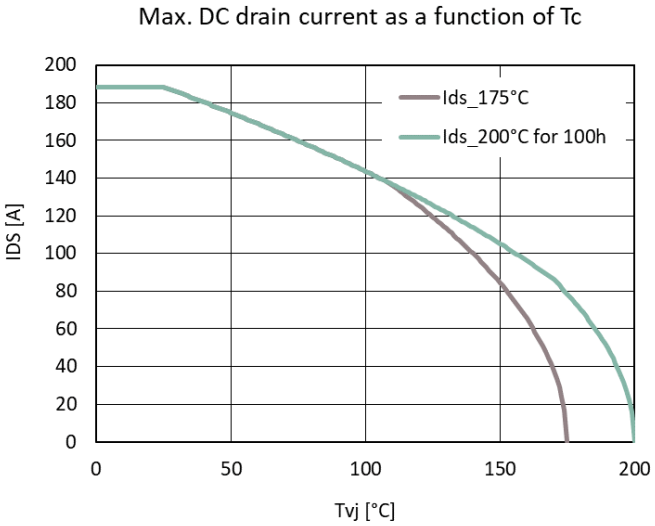


Figure 5: Device (IMBG120R008M2H) power dissipation at 200°C junction temperature

typical power semiconductor's, limited by a junction temperature of 175°C. In comparison, the green curve of CoolSiC G2 shows that more current is enabled at the same operating point, i.e., 150°C.

A detailed loss comparison of an G2 device, IMBG120R026M2H, and a G1 device, IMBG120R030M1H, under the same operating conditions, showed that the G2 device had 0.7 W (~3.5 percent) less conduction losses and 5.75 W (~23 percent) less total switching losses. Its overall operating junction temperature was also lower due to the combination of reduced losses and better $R_{th,j-c}$. [1]

Enabling shorter deadtimes for additional benefits

Today's MOSFETs are capable of switching in the range of tens of nanoseconds (ns). The switching energy curves available in the datasheets show that it is possible to achieve a significant reduction in device recovery losses and turn-on losses by reducing the deadtime of the driving voltage in the 3rd quadrant operation (time for the body diode to conduct before the channel is turned on). The recommended deadtime range is between 150 ns to 300 ns. By implementing the recommended values, turn-on losses can be reduced by 20 percent and recovery losses by 40 percent compared to nominal device values.

The deadtime limit depends on multiple factors such as the parasitics in the device and circuit, the speed of the gate driver, and the switched current level. Replacing a CoolSiC MOSFET G1 with the best matching G2 device allows for a 30 percent reduction in the required deadtime due to improved parasitic capacitance of the switch. This provides a wider margin for designing even in the case of a simple plug-and-play MOSFET replacement.

System benefits of a 2 kV discrete CoolSiC MOSFET

The new 2 kV discrete CoolSiC MOSFET enables the development of more efficient, cost-effective, and simplified designs for energy storage and photovoltaic systems – addressing the growing need for higher DC link voltage in these applications.

To increase power levels, photovoltaic systems are transitioning towards higher system voltages – 1500 V_{DC} being increasingly popular. This shift aims at reducing both power loss and system costs, making renewable energy more affordable.

Two options are available while designing a solar inverter with 1500 V at the DC link. The first option involves using a 3-level booster for the DC-DC maximum power point tracking (MPPT) stage and a 3-level topology, such as active neutral-point clamped (ANPC), for the DC-AC stage. 1200 V class devices are used in both these stages to ensure a safe and reliable system design. However, this approach is comparatively more complex, and has a higher component count. The second option involves using a simplified 2-level topology with higher voltage class devices. This approach can, potentially, be more efficient depending on the performance of the semiconductor devices used. Designers generally choose discrete devices to optimize system costs, improve design flexibility, and to lower the overall cost of ownership.

The most commonly available discrete semiconductor devices in the highest voltage class, so far, are 1700 V devices. Although using 1700 V class MOSFETs in 1500 V solar inverter systems with a simplified 2-level topology may seem like a viable option, it is essential to consider the impact of cosmic radiation-induced failures. These failures increase drastically at blocking voltages exceeding 80 percent of the rated voltage [2]. Therefore, using 1700 V class MOSFETs in 1500 V solar inverter systems with 2-level topology can significantly increase their failure rate.

2 kV CoolSiC MOSFET

The design challenges and reliability concerns can be mitigated by Infineon's new CoolSiC MOSFET 2 kV in a discrete package. The performance and bill of materials of a solar inverter using 2 kV CoolSiC MOSFET and diode was compared with that of inverter designs that implemented 1200 V devices. System-level simulation results showed that a 2-level booster stage with a CoolSiC 2 kV had 20 percent lower losses than a 3-level booster stage implemented with 1200 V MOSFETs. Similarly, the 2-level DC-AC stage with CoolSiC 2 kV had 15 percent lower power loss than the 3-level ANPC stage implemented with 1200 V devices. A detailed analysis of simulation and measurement data will be presented in the paper "Performance Evaluation of CoolSiC 2 kV SiC MOSFET Discrete in 1500 V DC Link Systems" at PCIM 2024.

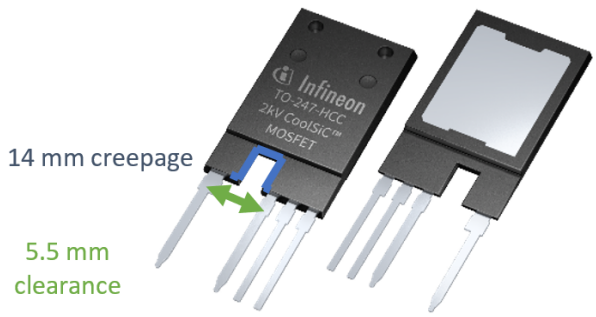


Figure 6: The new TO-247PLUS-4-HCC package

The new CoolSiC 2 kV comes in a new discrete TO-247PLUS-4-HCC high creepage and clearance package, shown in Figure 6, that ensures high-voltage insulation robustness and reliable operation. The product portfolio includes CoolSiC MOSFETs 2 kV [2] and Schottky diodes 2 kV with optimized switching performance and high blocking voltage, making it ideal for 1500 V_{DC} systems. These features of the new 2 kV MOSFET enable the development of simplified and reliable designs, making it an attractive solution for applications that demand high efficiency, low part count, and smaller system size and weight.

XHP™ 2 CoolSiC MOSFET 3.3 kV with .XT: Infineon's new high-power silicon carbide modules

Infineon is raising the bar in the field of power and technology with its two new 3.3 kV-rated silicon carbide (SiC) modules with robust .XT interconnection technology. These modules are designed to deliver high power (~1.5 MW) to applications with demanding mission profiles and challenging cycling requirements. The modules are:

- FF2000UXTR33T2M1: Room temperature on-state resistance of 1.9 mΩ and nominal current rating of 1000 A
- FF2600UXTR33T2M1: Room temperature on-state resistance of 2.5 mΩ and nominal current rating of 750 A

The 3.3 kV-rated CoolSiC MOSFET is optimized for fast switching with low oscillation tendency, which results in low total dynamic losses. The total dynamic loss at 150°C can be further reduced by ~ 30 percent by using XHP™ 2 CoolSiC MOSFET in the synchronous rectification mode and by optimizing deadtime. This means, reducing the time at the beginning and end of the freewheeling phase during which the load current is conducted through the integrated body diode [3]. The CoolSiC MOSFET 3.3 kV comes in the symmetrically designed and low-inductive (L_s = 10 nH) XHP 2 package to utilize fully the potential of fast-switching SiC MOSFETs in high-voltage and high-current applications.

To highlight the increased power density that the new SiC power module can deliver to traction converters, its performance was compared with the performance of the 3.3 kV IGBT IHV, which is still in use in many railway traction converters. Specifically, the performance of the 2-level, 3-phase motor inverter based on the 3.3 kV IGBT IHV solution (FZ2400R33H34) was compared with the performance of the 2-level, 3-phase motor inverter based on the new 3.3 kV SiC XHP 2 modules (two FF2000UXTR33T2M1 in parallel).

The comparison was done under the following conditions: 1800 V DC link voltage (VDC), power factor (pf) 0.9, modulation index (m) 0.9, and 60°C coolant temperature (Ta) of a water-cooled heatsink. In addition to an almost 50 percent lower footprint, the SiC-based solution provided 50 percent lower total losses, resulting in 50 percent more output current at the same switching frequency (1.5 kHz), or the same output current at a four times higher switching frequency (6 kHz instead of 1.5 kHz) [4].

The key features of XHP 2 CoolSiC MOSFET — lower losses, higher switching frequency, and higher power density — can be directly translated to multiple system benefits. Lower losses help save ~10 percent energy at the system level [5] and can enable simplified, quieter cooling systems. For example, by using passive motion cooling instead of forced air cooling. Operating the converters at higher switching frequencies results in lesser noise from the motor and allows for smaller size and lesser weight of the magnetic components. Higher power density helps reduce the converter volume by approximately 10 to 25 percent [6]. Reduction in system volume and weight is important, particularly in the case of hybrid-propulsion trains. Here, the additional space and reduced weight can be used to increase the size and, thus, capacity of the onboard traction batteries. Additionally, lower system weight and higher efficiency will allow better utilization of the available energy and help achieve the required driving ranges. Alternatively, if the required range is already achieved, lower system weight and higher efficiency will

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help in optimizing and reducing the cost of the installed traction battery, which is still very cost intensive.

Apart from high output power, many applications such as railway traction and wind power generation also require strong power cycling performance and longer device lifetimes. Due to the smaller chip sizes and specific material properties of silicon carbide (e.g., higher Young's modulus compared to silicon), it is more challenging to enable silicon carbide for such applications. Under cycling conditions, these factors result in greater thermomechanical stress on adjoining interconnecting layers, which can reduce the power cycling capability of the module [7].

Infineon's .XT technology can compensate for this effect by increasing the robustness of the interconnecting layers. XHP 2 CoolSiC MOSFET 3.3 kV with .XT has robust copper bond wires on the copper front-side metallization of the SiC chip, sintered chip on the substrate, and a highly reliable system solder. This boosts the cycling capability and the lifetime of the product, taking the SiC power cycling performance to the next level [8].

To illustrate the power of .XT, a lifetime simulation based on the exemplary mission profile of a line-converter in a regional hybrid-propulsion train was performed for SiC with standard joining technology (Al bond-wires, Al front-side metallization of the chip, chip solder, system solder) and SiC with .XT.

The simulation results showed that .XT extended the lifetime of the product by an order of magnitude — from ~4 years in the case of SiC with standard joining technology to ~40 years in the case of SiC with .XT. This demonstrates that .XT is crucial for enabling the full utilization of silicon carbide at higher junction temperatures. To achieve the required lifetime of 30 years in the case of SiC with standard joining technology, the maximum junction temperature during operation would have to be significantly reduced.

This means, a more cost intensive chip area would be needed to achieve the required output current. Due to the requirement for paralleling at the module level, this would also lead to increased complexity and costs.

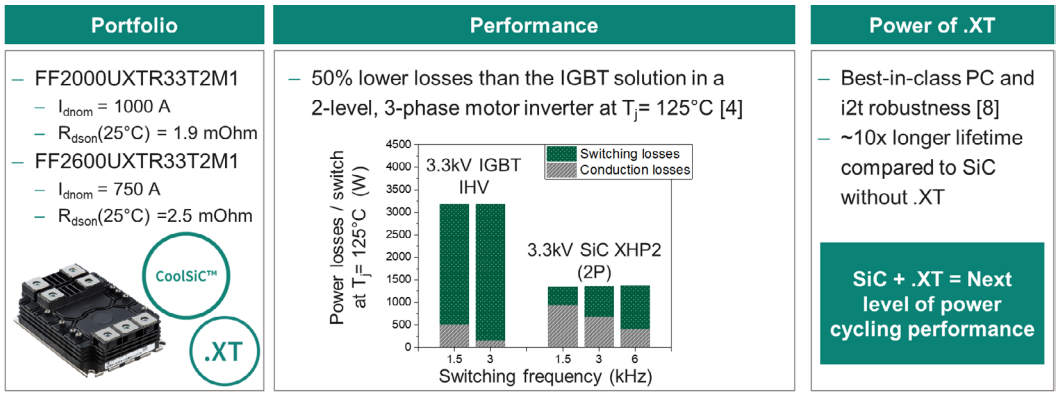

Figure 7: XHP™ 2 CoolSiC™ MOSFET 3.3 kV with .XT: Infineon's new high power silicon carbide power modules

In addition to providing the best-in-class cycling capability, benefits of .XT for XHP 2 CoolSiC MOSFET include high surge current robustness and short circuit withstand time [8]. This gives system designers more freedom in handling failure cases.

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