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A 3-Phase 1200V/450A SiC MOSFET Intelligent Power Module for E-mobility

An increasing number of leading electrical car manufacturers are moving to Silicon Carbide (SiC) Power Transistors for traction inverters, with some relying on unconventional discrete packaging. However, very few SiC-based power modules optimized for electrical motor drive are today available. Moreover, integrating a fast switching SiC power module into an optimized inverter including gate drivers, decoupling and water cooling requires going through some learning challenges. Alternatively, fully optimized and highly integrated Intelligent Power Module solutions can save significant development time and engineering resources.

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This article introduces a new 3-Phase 1200V SiC MOSFET Intelligent Power Module (IPM) scalable platform for E-mobility. This IPM technology offers an all-in-one solution including a 3-Phase water-cooled SiC MOSFET power module with built-in gate drivers. This article presents the key electrical and thermal characteristics of the power modules and discusses its safe operating area. Finally, it explains the key characteristics of the gate driver and its functions to safely and reliably drive the SiC MOSFETs.

3-Phase water-cooled SiC Power Module

CXT-PLA3SA12450, the first product out of this scalable platform, a 3-Phase 1200V/450A SiC MOSFET IPM, features low conduction losses, with 3.25mOhms On resistance, and low switching losses, with respectively 7.8mJ turn-on and 8mJ turn-off energies at 600V/300A (see Table 1). It reduces losses by at least a factor 3 with respect to state-of-the-art IGBT power modules. The new module is water-cooled through a lightweight AlSiC pin-fin baseplate for a junction-to-fluid thermal resistance of 0.15°C/W. The power module is rated for junction temperature up to 175°C. The IPM withstands isolation voltages up to 3600V (50Hz, 1min).

Thermal robustness & Safe Operating Area

The intelligent power module has been designed for thermal robustness and is rated for a max operating junction temperature of 175°C. The gate driver itself is thermally enhanced with a max ambient operating temperature of 125°C in order to support high power density. As mentioned, the power module is cooled down through a lightweight AlSiC pin fin baseplate presenting a junction-to-fluid thermal resistance of 0.15°C/W per switch position with a flow rate of 10l/min (50% ethylene glycol, 50% water) and an inflow temperature of 75°C.
The maximum continuous drain current derating versus the case temperature of CXT-PLA3SA12450, which is calculated based on the On resistance at maximum Tj, the thermal resistance and the maximum operating junction temperature, is given in Figure 2.
If the maximum continuous drain current is a standard characteristic useful to compare the current rating of power modules, a more realistic Figure-of-Merit (FoM) is probably the RMS phase current

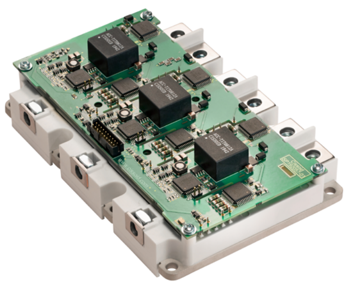

Figure 1: CXT-PLA3SA12450 3-Phase 1200V/450A SiC MOSFET Intelligent Power Module

Parameter	Conditions	Typ.	Max.
Drain to Source Voltage			1200V
Continuous Drain Current	V_{GS}=15V, T_C=25°C, Tj<175°C		450A
	V_{GS}=15V, T_C=90°C, Tj<175°C		330A
Static drain-to-source resistance	V_{GS}=15V, ID=300A, T_j=25°C	3.25mOhms	4mOhms
	V_{GS}=15V, ID=300A, T_j=175°C	5.25mOhms	
Turn-On Switching Energy	V_{DS}=600V; V_{GS}= -3/15V;	7.8mJ	
Turn-Off Switching Energy	I_{DS} = 300A; L = 50µH	8mJ	
Isolation	AC @50Hz (for 1mn), baseplate – power pins		3600VAC
Junction-to-Fluid Thermal resistance	Each switch position, Flow rate: 10l/min; 50% ethylene glycol, 50% water, 75°C inflow temperature	0.15°C/W	
Junction-to-Case Thermal resistance	Each switch position	0.13°C/W	
Operating Junction Temperature			175°C
Baseplate dimensions		104mm (W) 154mm (L)	

Table 1: CXT-PLA3SA12450 3-Phase 1200V/450A SiC MOSFET Intelligent Power Modules Main Characteristics

versus the switching frequency as shown in Figure 3 for the CXT-PLA3SA12450. It is calculated for DC bus voltage of 600V, case temperature of 90°C, junction temperature of 175°C and 50% duty cycle. This FoM is more useful to understand the applicability of the module. This Intelligent Power Module platform being scalable, Figure 3 also extrapolates (dashed line) the safe operating area of 1200V/600A module.

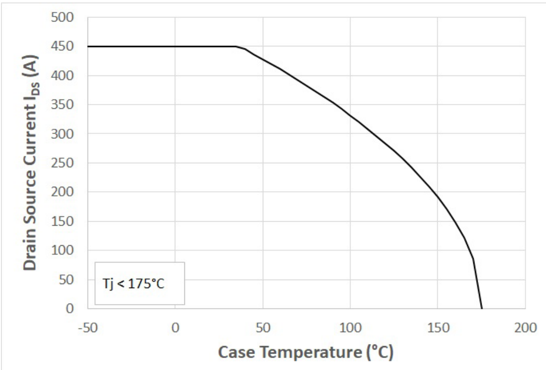

Figure 2: CXT-PLA3SA12450 maximum Continuous Drain Current versus the case temperature

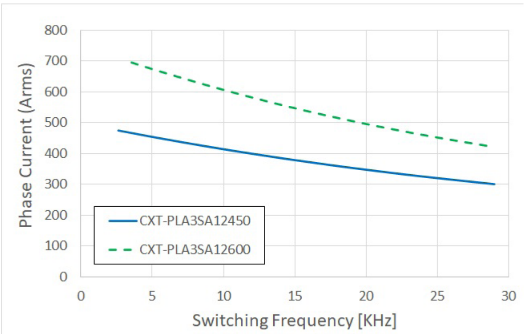

Figure 3: Phase current (Arms) versus switching frequency (Conditions: VDC=600V, Tc=90°C, Tj<175°C, D=50%) for 1200V/450A SiC power module (CXT-PLA3SA12450) and extrapolation for future 1200V/600A module (CXT-PLA3SA12600, in development)

3-Phase SiC Gate Driver

CXT-PLA3SA12450 3-phase gate driver is originated from CMT-TIT8243 [1, 2] and CMT-TIT0697 [3] single phase gate driver boards respectively designed for 62mm 1200V/300A and fast-switching XM3 1200V/450A SiC MOSFET power modules (see Figure 4).
The 3-phase gate driver has been optimized to fit on top of CXT-PLA3SA12450 power module thanks to a more compact transformer module or slightly reduced creepage distances. CXT-PLA3SA12450 gate driver also includes a DC bus voltage monitoring function.
As for CMT-TIT8243 and CMT-TIT0697, the gate driver board has been designed for maximum ambient operating temperature of 125°C. All the components have been carefully selected and sized to warranty the operation at this temperature. It also relies on CISSOID's high temperature gate driver chipset [4, 5] and a power transformer module optimized for low parasitic capacitance (10pF typically) in order to minimize common mode currents at high dV/dt and for high operating temperature.
CXT-PLA3SA12450 gate driver still has headroom to support the power module scalability. The module has a total gate charge of 910nC. At 25KHz, the average gate current is equal to 22.75mA. This is well below the 95mA maximum current capability of the on-board isolated DC-DC converter. The current capability and gate charge of the power module can thus be increased, without gate driver board modifications.

With the populated gate resistors, the actual max dV/dt is in the range of 10 to 20 KV/µs. The gate driver has been designed to be immune to dV/dt up to 50KV/µs, offering margin in terms of dV/dt robustness.

Figure 4: CMT-TIT0697 Gate Driver Board for fast-switching XM3 1200V/450A SiC MOSFET Power Module

Gate Driver Protection functions

Gate Driver protection functions are critical to guarantee the safe operation of the power module. This is particularly true when driving fast-switching SiC transistors. CXT-PLA3SA12450 gate driver offers the following protection functions:

- **Undervoltage Lockout (UVLO):** CXT-PLA3SA12450 Gate Driver monitors primary & secondary voltages and reports a fault when below a programmed voltage.
- **Anti-overlap:** avoids simultaneous turn-on of both high-side and low-side to prevent short circuit of the power half bridge.
- **Protection against any short-circuit at secondary:** isolated DC-DC converter cycle-by-cycle current limitation protect the gate driver against any short-circuit (e.g. gate-source short-circuit).
- **Glitch filter:** suppresses glitches on incoming PWM signals which might be due to common mode currents.
- **Active Miller Clamping (AMC):** implements a bypassing of the negative gate resistor after turn-off to protect the power MOSFETs against parasitic turn-on.
- **Desaturation detection:** at turn-on, checks after blanking time that the power MOSFET drain-source voltage is below a threshold.
- **Soft Shut-down:** in case of fault, a slow turn-off of the power transistor is implemented to minimize overshoots due to high dI/dt.

Conclusion

A new 3-Phase 1200V/450A SiC MOSFET intelligent Power Module is now available on the market. Co-optimizing the electrical, mechanical and thermal design of the power module and its proximity control, this new scalable platform will improve time-to-market for Electric Car OEMs and electric motor manufacturers willing to rapidly adopt SiC-based inverters for more efficient and compact motor drives.

References

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[5] High Temperature Gate Driver -Secondary Side IC Datasheet: Driver & Protection Functions http://www.cissoid.com/files/files/products/titan CMT-HADES2S-High-temperature-Gate-Driver-Secondary-side.pdf

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