CoolSiC™ MOSFET - a Revolution to Rely on

Silicon Carbide (SiC) switches are increasingly popular for power converters and other power-related applications. The latest technologies deliver higher efficiency, faster switching frequencies, reduced heat dissipation and space savings – benefits that, in turn, also lead to overall lower costs.

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Launched at PCIM in May 2016 under the banner of ‘A revolution to rely on’, Infineon’s latest CoolSIC™ MOSFETs offer designers unsurpassed power density and performance. Here we look at this technology and introduce an integrated CoolSIC-based reference design.

CoolSiC applications now and in the future

Certain application segments will always be early adopters of any new technology. Depending on a number of factors, including the system value, others will follow when the cost/performance ratio is attractive enough to migrate to a new technology.

SiC Schottky diodes are already used extensively in high-end power supplies. Looking forward, Infineon believes solar inverters and boost circuits will gain the most from MOSFET technology, quickly followed by Uninterruptible Power Supplies (UPS) and chargers. Traditional segments such as motor drives, traction and, on a longer time scale, automotive applications are expected to embrace a large scale migration to the new semiconductor technology in the future.

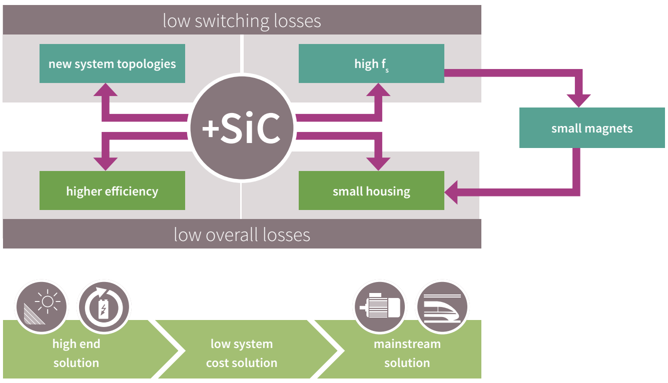

Figure 1: SiC benefits and target applications

The most significant trend in solar inverter designs is the increasing power density based on the reduction of switching losses, thereby enabling smaller heatsinks. Associated with this are the higher operation frequencies that enable smaller magnetic components.

CoolSiC MOSFET solutions

CoolSiC MOSFET devices with an on-resistance ($R_{DS(ON)}$) of 45 mΩ are an important step for SiC in power semiconductors. However, electrical performance is only part of the story. For fast switching IGBTs and SiC transistors, the design of the package is equally as important. That’s why Infineon has developed a broad portfolio of packages.

By using the 4-Pin TO-247 (IMZ120R045M1) instead of the standard 3-pin TO-247 device (IMW120R045M1) it is possible to have a dedicated Kelvin source pin for the gate emitter connection. As a result, the gate control voltage is not impeded by the load current flowing in the power source pin. This improves turn on losses by up to 40%.

These discrete leaded products are ideal for fast switching applications and are expected to be implemented very quickly with the earliest applications being photovoltaic (PV) string inverters, chargers and UPS equipment.

Alongside discrete packages, the popular and flexible Easy1B power module is used to implement a half bridge configuration and booster solutions optimized for PV. These booster modules include 1200 V CoolSiC Schottky diodes and low VF silicon diodes for bypass and inverse-polarity protection. The flexible pin grid of Easy modules makes PCB layout easy and offers <10 nH stray inductance. This is a factor-of-five improvement over previous solutions and represents a valuable step in power module design. The booster module is the size of a matchbox and is designed to be used in MPP tracker systems up to 20 kW.

Lead products

Schematic	Type	R_{DSON}	V_{DS}	Package
Single switch	IMW120R045M1	45 mOhm	1200 V	TO247-3pin
Single switch	IMZ120R045M1	45 mOhm	1200 V	TO247-4pin
Half bridge with NTC	FF11mR12W1M1_B11	11 mOhm	1200 V	Easy1B PressFIT
	FF23mR12W1M1_B11	23 mOhm	1200 V	
Booster with NTC	DF11mR12W1M1_B11	11 mOhm	1200 V	
	DF23mR12W1M1_B11	23 mOhm	1200 V	

Selectively sampling on request.

Figure 2: CoolSiC MOSFET lead product overview

Efficiency, power density and cost are all key drivers behind the use of alternative semiconductor materials for power diodes and transistors. Hybrid power modules using silicon IGBTs and SiC Schottky diodes have become mainstream in power converters with high switching frequencies (>10 kHz) such as solar string inverters and UPS systems. Infineon addresses these requirements with a broad portfolio of CoolSiC Schottky Diodes in various discrete packages and several hybrid power modules using EasyPACK™ and EconoPACK™

The next big step towards higher switching frequencies and conversion efficiencies can be achieved by the use of full SiC solutions that combine SiC diodes with transistors.

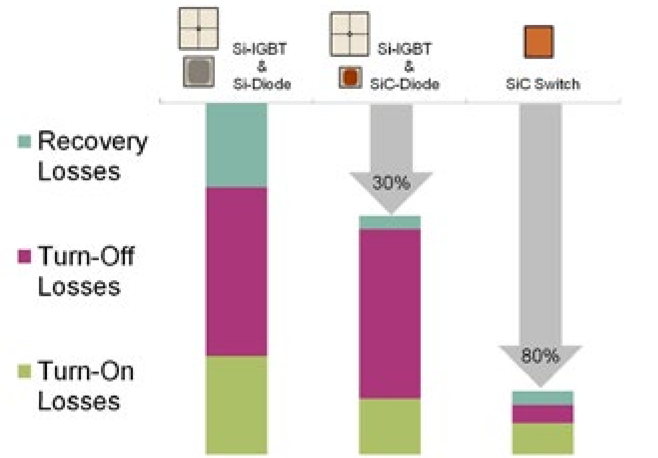

Figure 3: Evolution of loss reduction by the use of SiC power devices

The additional loss reduction of about 50 % resulting from the transition to full SiC is the result of lower turn-off and on-state losses.

Many of the currently available SiC MOSFETs require special drivers in combination with non-standard driving voltages, leading to low market adoption. The new Infineon CoolSiC MOSFET uses standard IGBT driving voltages (e.g. -5 V/15 V or -0 V/15 V). This allows the use of standard gate driver IC's such as the EiceDRIVER™ Compact and enables wide spread adoption of SiC MOSFETs into power electronic systems.

Switching behavior

The switching behavior of the new devices has been investigated by testing a 45 mΩ CoolSiC MOSFET in a TO-247 4-pin package driven with -5 V/15 V. The device exhibits very clean switching with almost no oscillations during switch on. This benign behavior allows easy and fast implementation of the CoolSiC into existing systems using standard EiceDRIVER IGBT drivers.

For the evaluation of the switching behavior at the system level, a DC/DC converter using a CoolSiC half-bridge module and an EiceDRIVER Compact with 6A output (1EDI60H12AH) was built. The module is configured in a bidirectional buck-boost converter topology and has an ohmic resistance ($R_{DS(ON)}$) of 23 mΩ at room temperature (FF23MR12W1M1_B11).

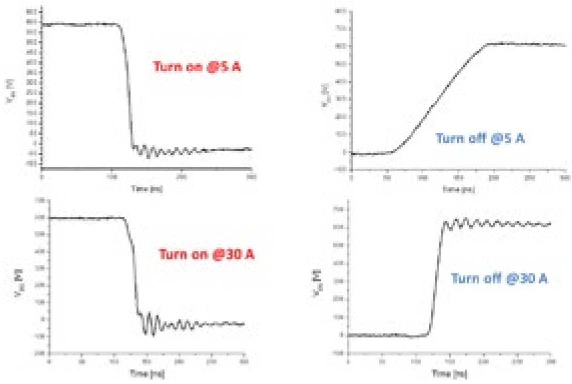

Figure 4: Turn on and turn off of the CoolSiC module within a DC/DC converter at 5 A and 30 A

Double pulse measurements were performed to measure the dv/dt at a gate resistance of 1 Ohm and different drain currents. The upper charts in Figure 4 illustrate the switching at 5 A where the turn on and turn off behavior shows only slight oscillations. The dv/dt at turn-off has a relatively low value of 5 kV/µs. The lower charts show the switching of the CoolSiC MOSFET module at 600 V and 30 A.

The dv/dt at turn-off is 34 kV/µs, which is much higher than for 5 A. The strong dependence of the switching behavior on the drain current is a result of the large output capacitance of the SiC MOSFET. Large displacement currents in the output capacitance of the device accelerate the turn-off by a dynamic increase of the turn-off voltage.

Further measurements of dv/dt and the peak voltage are shown in Table 1.

Current [A]	dv_{on}/dt [kV/µs]	$\Delta V_{DS,\ on}$ [V]	dv_{off}/dt [kV/µs]	$\Delta V_{DS,\ off}$ [V]
5	40	-71	5	+24
10	52	-79	11	+33
20	50	-89	22	+40
30	55	-97	34	+52

Table 1: dv/dt and V_{peak} of V_{DS} at different currents

Controllability

A further advantage of the CoolSiC MOSFET is the controllability of dv/dt and di/dt by the adjustment of external gate resistors. The results of testing an FF45mR12W1M1_B11 CoolSiC Easy1B half-bridge module can be seen below.

Increasing the value of the external gate resistors can reduce the dv/dt and di/dt of the MOSFET. This is a simple way to reduce electromagnetic noise, if necessary, or to fulfill application specific requirements.

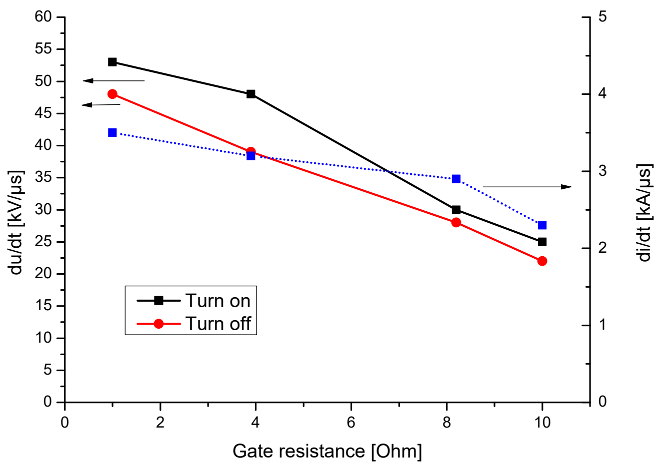

Figure 5: Controllability of the CoolSiC MOSFET via external gate resistors and the corresponding di/dt and du/dt levels

This simple dv/dt control allows the device switching performance to be tailored to match the requirements of a specific application. A common example relates to the restrictions regarding dv/dt limits for motor winding insulation (e.g. 5 kV/µs). With the right choice of gate resistors these restrictions are easy to meet with the CoolSiC MOSFET.

The key challenge for the gate driver PCB layout is to maintain a very low inductance around the gate source loop between the driver IC, the module gate and the auxiliary source pins. This can be achieved through the principle of a "strip line" design by using planes, and wide traces arranged in parallel paths. This enables a significant electromagnetic noise reduction especially in the context of hard switching with R_g=1 Ω.

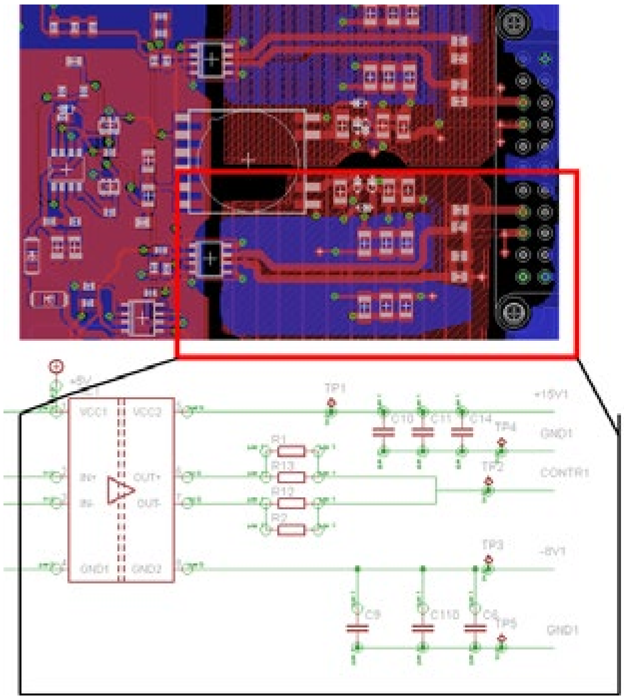

Figure 6: Example of a simple driver circuit for the CoolSiC MOSFET using Infineon's new compact driver 1EDI60H12AH

To obtain maximum performance from CoolSiC MOSFETs it is critical to pay special attention to the PCB layout, especially minimizing inductive loops. The demonstration driver circuit is part of an evaluation system, designed to measure the performance of the CoolSiC module. This system has been run at operating frequencies up to 500 kHz.

Summary and Conclusion

Full access to the additional switching performance available when using Infineon SiC MOSFETs can be obtained with standard components and topologies.
Due to the standard IGBT driver voltages and the benign switching behavior, Infineon CoolSiC MOSFETs enable very low design effort, especially with respect to driver development. Coupled with easy controllability of the dv/dt through the use of external gate resistors (simplifying EMI management and ensuring excellent switching performance), the result is a lower cost of development for high-performance power converters based on CoolSiC devices.
With the introduction of the CoolSiC MOSFET technology the beginning of a new era of power electronics in terms of power conversion efficiency and power density has begun. The new CoolSiC MOSFET enables engineers to develop smaller and more efficient PV inverters, UPS and charger systems that use higher switching frequencies and smaller heatsinks resulting in up to 80 % lower switching losses compared to silicon IGBT based solutions.

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