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Special Report: Test and Measurement (pg 33)
What are the advantages of SiC-based designs and how can you implement them?

An overview of Infineon’s SiC MOSFETs and dedicated gate driver ICs

By: Giovanbattista Mattiussi, Product Marketing and Dr. Diogo Varajao, Senior System Application Engineer, Infineon Technologies

The global trends - such as digitalization and energy efficiency - that have emerged and accelerated in the past few years pose new challenges to the manufacturers as well as the semiconductor market. Developing power semiconductor devices that contribute to highly efficient power management systems is on the agenda for all of the players in the industry.

Power semiconductors as the building blocks of power systems are among the very determinant contributors to energy efficiency. Designers of power systems - from power supplies to inverters - are required to fulfill progressively challenging efficiency targets while also keeping costs under control. The cost factor plays an important role over and beyond making the bottom line of OEMs rosier. If solar inverters, high-efficiency power supplies, and electrical vehicles become cheaper, that will foster the adoption of greener infrastructure and have a positive effect on the future of our planet and hence also humankind.

The technology of choice
From a designer’s perspective, a reasonable and balanced combination of cost and efficiency is essential.

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**Figure 1: Technology positioning – Si, SiC and GaN**

- **Silicon (Si)**
  - Targeting voltages ranging from 25 V to 1.7 kV
  - The mainstream technology
  - Suitable from low to high power

- **Silicon carbide (SiC)**
  - Targeting voltages ranging from 650 V to 3.3 kV
  - High power from moderate to high switching frequency

- **Gallium nitride (GaN)**
  - Targeting voltages ranging from 80 V to 650 V
  - Medium power at highest switching frequency
In addition to the legacy silicon, recently new technologies and materials - such as silicon carbide (SiC) and gallium nitride (GaN) - have emerged with the promise of delivering higher efficiency and power density levels. Indeed, WBG semiconductors have - by the nature of the materials - a great potential to deliver pioneering performance. They enable higher breakdown voltages, higher frequency operations, more flexible thermal capability, and robustness to hard-commutation events. All these characteristics make them better-suited for new high-efficiency topologies or high-density designs than Si-based solutions.

Where is the sweet spot for each power technology?
As shown in Figure 1, Si-based products like superjunction MOSFETs or IGBTs can be used over a wide voltage range (from a few to several hundred volts) and in several power classes while SiC-based products find their ideal spot in voltage classes at and above 650 V (pushing beyond silicon limits and reaching power levels above 3 kV), and GaN-based devices are more suitable for voltage classes below 650 V. Both SiC and GaN are progressively better than Si when the operating frequency increases. Application requirements and design targets determine the technology of choice.

Looking at the three technologies and focusing on discrete FET products only, Infineon has a broad portfolio in the 600 - 650 V range (CoolMOS™ silicon superjunction MOSFETs, CoolSiC™ silicon carbide MOSFETs, and CoolGaN™ gallium nitride normally-off e-mode HEMTs). Although SJ MOSFETs fulfill most of the contemporary requirements for energy efficiency and power density in a very cost-optimized way, in case of some specific design requirements such as thermals or ultra high density SiC and GaN devices are the optimal choice. The CoolSiC™ MOSFETs demonstrate superior thermal properties thanks to their device ruggedness and CoolGaN™ HEMTs are suitable for high operating frequencies pushing the power density to very high levels.

Figure 2: The features and characteristics of Infineon’s CoolSiC™ MOSFET 650 V devices at a glance
In the future, WBG products are expected to further accelerate and replace silicon-based devices, however, these three technologies will foreseeingly still coexist for long time. The adoption of SiC is expected to be a bit faster for certain applications due to its ease of use and relatively easy transition from superjunction MOSFETs and IGBTs.

**Infineon’s CoolSiC™ MOSFETs were developed to perform** SiC technology when used in the right design approach is the best choice for applications that require high-performance. However, the area-specific on-state resistance is the major benchmark parameter for a given technology, it is still essential to find the right balance between the primary performance indicators (i.e., resistance and switching losses) and the true operating behavior. The CoolSiC™ MOSFETs and the matching EiceDRIVER™ gate drivers were developed to fully leverage the promise of SiC: deliver performance through robustness, reliability, and ease-of-use. For the available portfolio see Figure 3.

When it comes to reliability, SiC MOSFETs have a key potential failure point in the gate oxide (GOX), the layer which insulates the gate from the source. SiC crystal growth tends to inject defects into the structure and those defects that penetrate the GOX can create local thinning, ultimately increasing the electrical field beyond the dielectric breakdown and eventually destroying the device. To avoid this, the CoolSiC™ MOSFETs are based on a trench structure which provides two major benefits:

- fewer defects in the GOX, due to the orientation of the structure.
• increased GOX thickness with no compromises on performance (a thicker GOX can be chosen with no impact on $R_{\text{on}}$) thanks to increased robustness and higher achievable electrical field intensity (which allows for testing at higher voltages, increasing the effectiveness of the defect-screening).

When it comes to performance, the CoolSiC™ MOSFETs are characterized by very low switching- and conduction losses improved by a relatively flat dependency of the $R_{\text{DS(on)}}$ with temperature. In particular, the robustness against parasitic turn-on has not only a positive effect on the switching losses but is also significant in terms of ease-of-use. Thanks to the low tendency to parasitic turn-on behavior, the CoolSiC™ MOSFETs are the only devices in the market that can authentically be switched off at 0 V, without the need of using negative voltages (although the device can be used that way too). Resultantly, the driving schema can be kept simple and is fully compatible with superjunction MOSFET driving solutions.

With regards to the driving voltage range, some voltage margin between the upper limit of the $V_{\text{GS}}$ range and the maximum tolerated voltage ($V_{\text{GS,max}}$; specified in the datasheet) is needed. This margin guarantees the buffer to protect against the overshoots that may stress and damage the gate oxide. This is an additional token that the CoolSiC™ technology pays to reliability.

**EiceDRIVER™ ICs make the solution complete**

Six dedicated gate driver ICs have been developed in order to optimally drive and protect Infineon’s CoolSiC™ MOSFET 650 V devices. As shown in Figure 4, they are available in four different packages to allow...
an easy adaptation to different
design requirements in terms of
power density, PCB space, and
isolation rating [1].

The single-channel non-isolated
EiceDRIVER™ ICs 1EDN9550B
and 1EDN6550B are available in
the SOT-23 6-pin package and
can be used to drive the low-
side switch of a SiC half-bridge
(HB) [2]. Due to their truly
differential inputs (TDI) they are
particularly well suited to drive
4-pin MOSFETs with Kelvin-
source connection. The unique
differential driving concept can
safely prevent false triggering due
to resistive or inductive voltage
drops between controller and
driver IC reference potentials even
for very fast switching transients
[3]. As a result, the TDI gate driver
ICs provide a compact and robust
solution for the highly efficient
operation of SiC MOSFETs.

The isolated EiceDRIVER™ ICs
1EDB9275F and 1EDB6275F
are offered in a DSO-8 150mil
package, featuring 3 kVrms
isolation voltage rating according
to UL 1577 (certification pending)
[4]. In combination with the
TDI driver, a hybrid gate driving
configuration can be obtained
to drive SiC HB in totem-pole
PFC or resonant LLC topologies.
The increased layout flexibility,
obtained by employing single-
channel gate driver ICs, allows
optimizing the driver IC
placement on the PCB in order to
minimize the gate loop parasitic
inductances. Furthermore, this
hybrid gate driving configuration
results in a 28% PCB area saving
(compared with a dual-channel
gate driver IC) and it comes with a
competitive bill of materials
(BOM).

The alternative gate driving
solutions are enabled by utilizing
Infineon’s dedicated dual-
channel isolated gate driver ICs.
The EiceDRIVER™ 2EDF9275F,
available in a DSO-16 150mil
package, is a perfect fit for the
totem-pole PFC topology [5].
And if the PWM signals have to
cross the safe isolation barrier,
such as in the resonant LLC
with secondary-side control,
the 2EDS9265H with reinforced
isolation is the right choice.
Furthermore, this driver comes in
a DSO-16 300mil package
and is compliant with the safety
requirements of the VDE 0884-10
and UL 1577 standards [6].

Table 1: Gate driver ICs for Infineon’s CoolSiC™ MOSFETs 650 V

<table>
<thead>
<tr>
<th>Product</th>
<th>Package</th>
<th>Input-to-output isolation</th>
<th>UHLO (typ.)</th>
<th>Output peak source/sink current</th>
<th>CMTI (min.)</th>
<th>Propagation delay (typ.)</th>
<th>Propagation delay accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1EDN9550B*</td>
<td>SOT-23 6</td>
<td>Non-isolated</td>
<td>22.2 V / 11.5 V</td>
<td>5.4 A / -9.8 A</td>
<td>14.9 V / 14.4 V</td>
<td>45 ns</td>
<td>-7 / +10 ns</td>
</tr>
<tr>
<td>1EDN6550B*</td>
<td>SOT-23 6</td>
<td>Non-isolated</td>
<td>22.2 V / 11.5 V</td>
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<td>14.9 V / 14.4 V</td>
<td>45 ns</td>
<td>-7 / +10 ns</td>
</tr>
<tr>
<td>1EDB9275F</td>
<td>DSO-8 150mil</td>
<td>Single protection</td>
<td>13.7 V / 12.9 V</td>
<td>37 ns</td>
<td>-5 / +7 ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1EDB6275F</td>
<td>DSO-8 150mil</td>
<td>Single protection</td>
<td>13.7 V / 12.9 V</td>
<td>37 ns</td>
<td>-5 / +7 ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2EDF9275F</td>
<td>DSO-16 150mil</td>
<td>Functional</td>
<td>13.7 V / 12.9 V</td>
<td>37 ns</td>
<td>-5 / +7 ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2EDS9265H</td>
<td>DSO-16 300mil</td>
<td>Reinforced</td>
<td>13.7 V / 12.9 V</td>
<td>37 ns</td>
<td>-5 / +7 ns</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Coming soon; 1 VDDO = 15 V, VOUT = 0 V, Tamb = 25°C

Table 1 shows the main
specifications of the dedicated
gate driver ICs for Infineon’s
CoolSiC™ MOSFET 650 V
devices. Despite the different
packages and input-to-output
isolation classes, ratings, and
certifications, these gate drivers
are based on the same rail-to-
rail driver output stage. It is
realized with complementary
MOS transistors that can provide
a typical 5.4 A sourcing and 9.8
A sinking current for fast turn-
on and turn-off to minimize
switching losses. With an RON
of 0.85 Ω for the sourcing pMOS
and 0.35 Ω for the sinking
nMOS transistor, the driver can
be considered as a nearly ideal switch, enabling it to run cooler due to less power dissipation in the IC.

The common-mode transient immunity (CMTI) is crucial to ensure that no signal corruption occurs during fast transients applied between the input and output reference potentials (grounds) of the galvanically isolated gate driver IC. Since SiC MOSFETs can generate fast voltage transients exceeding 100 V/ns, CMTI is a key parameter to be considered for gate driver selection. 1EDB6275F and 1EDB9275F ensure a minimum 300 V/ns CMTI robustness, while the 2EDF9275F and 2EDS9265H feature a minimum 150 V/ns, which by far exceeds the requirements for the majority of fast-switching SiC applications.

The timing performance of the driver is also of particular importance in order to exploit the full potential of SiC MOSFETs. The low input-to-output propagation delay combined with high accuracy over both temperature and production variations allows for using a short dead-time period between the two PWM signals of the half-bridge; this improves efficiency by increasing the effective power transfer period.

Figure 5 depicts a typical use case for Infineon’s CoolSiC™ MOSFETs 650 V in a totem-pole PFC. It consists of a 48 mΩ SiC half-bridge driven by the EiceDRIVER™ 1EDB9275F and 1EDN9550B in the hybrid gate driving configuration; the diode functions indicated in the power path are usually realized with low-RDS(on) MOSFETs operating as synchronous rectifiers. As a result, this power stage can handle up to 3.3 kW with an efficiency above 99% [7].

One of the benefits of Infineon’s wide-bandgap (WBG) technology is the possibility of using standard gate drivers, since driving voltages of 0 V and 18 V, respectively, are recommended. As demonstrated in [8], an 18 V gate drive voltage reduces the RDS(on) by around 18% compared with a 15 V drive. Anyway, considering the portfolio listed in Table 1, the customer has plenty of options in terms of under-voltage lockout (UVLO) levels to choose the best-suited gate drive voltage. The UVLO feature ensures that in case the output-side supply voltage VDDO drops to a level that would cause the power switch to operate in its linear mode, the gate driver IC will keep the transistor “off” and within its safe operating area (SOA), thereby avoiding any excessive power dissipation.
With a typical UVLO_{off} of 11.5 V, 1EDN6550B and 1EDB6275F are the right choice for 15 V gate driving. For applications with a higher gate driving voltage (e.g., 18 V), 1EDN9550B, 1EDB9275F, 2EDF9275F, or 2EDS9265H have to be selected since they feature a higher UVLO_{off} level. Additionally, and as represented in Figure 5, it is recommended to connect a Schottky diode between gate and Kelvin-source to clamp switching induced undershoots on the gate terminal which may cause a potential drift of the gate threshold voltage V_{GS(th)} over the lifetime.

Since the 1EDB9275F, 1EDB6275F, 1EDN9550B and 1EDN6550B have inverting (IN-) and non-inverting (IN+) inputs, shoot-through protection can be implemented by routing both PWM signals to each gate driver IC, as depicted in Figure 5; any undesired overlap of low-side and high-side PWM signals is not propagated to the gate of the transistors. In case this additional protection feature is not required, it can simply be disabled by connecting IN- to GNDI.

To summarize, the 1-channel and 2-channel galvanically isolated gate driver ICs of the EiceDRIVER™ family are the best choice to operate Infineon’s CoolSiC™ MOSFET 650 V devices to achieve the optimum combination of efficiency, power density, and robustness in high-performance power conversion applications.

Infineon Technologies AG
www.infineon.com

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[3] Infineon Technologies AG, “Applications of 1EDNx550 single-channel low-side EiceDRIVER™ with truly differential inputs,” Application Note AN_1803_PL52_1804_112257, 2018


