CoolSiC™ Automotive MOSFET 750 V G2

The latest generation of Silicon Carbide (SiC) MOSFET

About this document

Scope and purpose

This application note introduces the new generation trench-based CoolSiC™ 750 V G2 MOSFET and describes the differences between the earlier generation of CoolSiC™ 750 V MOSFETs and the latest CoolSiC™ 750 V G2 Silicon Carbide (SiC) MOSFET from Infineon. This application note includes technology parameters, figure of merits, target applications, and topologies and describes the latest and most important additional benefits for designers.

The purpose of this document is to explain the features of this new family of products. Important application topics are covered to help in designing systems with maximum performance and reliability.

Intended audience

This application note is intended for design engineers, technicians, and developers of electronic systems.

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1 Introduction

CoolSiC™ 750 V G2 MOSFETs are designed to meet the increasing demand of modern automotive power electronics applications (refer to Section 1.2 for target applications). CoolSiC™ 750 V G2 MOSFETs are completely compatible with any system incorporating the predecessor technology (CoolSiC™ 750 V G1).

Key features of CoolSiC™ 750 V G2 MOSFETs are:

- **Higher switching speeds:** CoolSiC™ 750 V G2 MOSFETs can switch faster than previous generation by approx. 25%, leading to lower switching losses thus enabling switching at higher frequencies and in turn smaller and lighter passive components (e.g., inductors and capacitors) in power converters
- **Reduced parasitic capacitance (C_{oss}, C_{iss}, C_{rss}):** Lower Parasitic capacitances minimizes switching losses, particularly at high voltages and frequencies
- **Reduced gate charge (Q_g):** Lower gate charge allows for faster switching and reduces gate drive losses, making them more efficient in high-frequency applications
- **Improved body diode performance:** The intrinsic body diode in CoolSiC™ 750 V G2 MOSFETs has better reverse recovery characteristics compared to CoolSiC™ 750 V G1 MOSFETs, reducing reverse recovery losses in bridge configurations
- **Extended negative gate driving voltage:** CoolSiC™ 750 V G2 MOSFETs allows for extended gate driving capabilities, supporting static gate voltages of up to –7 V and transient gate voltages of up to –11 V, a notable improvement over the previous CoolSiC™ 750 V G1 MOSFETs, that were limited to –5 V static and –10 V transient respectively. This enhanced voltage tolerance provides engineers with greater design margins and enables multi-source compatibility with other vendors
- **Enhanced thermal performance:** CoolSiC™ 750 V G2 MOSFETs can operate at higher junction temperatures (up to 200°C for <100 hours, up to 7500 temperature cycles, where the maximum delta T limited to 100K), improving thermal management and reliability and ideal for surge events in the applications

These characteristics make CoolSiC™ 750 V G2 MOSFETs ideal for use in electric vehicles (EVs) and hybrid electric vehicles (HEVs), where efficiency and performance are critical. One of the key benefits is reduced energy loss during power conversion processes, that enhances overall vehicle efficiency and extends battery life. Additionally, the higher switching frequencies operation, the SiC MOSFETs allow for smaller and lighter components, contributing to the reduction of vehicle weight and improvement in fuel economy. Furthermore, their robustness and reliability under harsh conditions ensure better long-term performance and lower maintenance costs.

The integration of SiC MOSFETs in automotive systems thus supports the development of more efficient, powerful, and reliable electric drivetrains, ultimately advancing the progress towards greener and more sustainable transportation solutions.

1.1 Portfolio

Table 1 CoolSiC™ 750 V G2 MOSFETs portfolio

$R_{DS\,(on)}$, typ, 25°C [mΩ]	Q-DPAK	D^2 PAK-7	TO-247-4
			
60	AIMDQ75R060M2H	AIMBG75R060M2H	AIMZA75R060M2H
50	AIMDQ75R050M2H	AIMBG75R050M2H	AIMZA75R050M2H
40	AIMDQ75R040M2H	AIMBG75R040M2H	AIMZA75R040M2H
33	AIMDQ75R033M2H	AIMBG75R033M2H	AIMZA75R033M2H
25	AIMDQ75R025M2H	AIMBG75R025M2H	AIMZA75R025M2H
20	AIMDQ75R020M2H	AIMBG75R020M2H	AIMZA75R020M2H
16	AIMDQ75R016M2H	AIMBG75R016M2H	AIMZA75R016M2H
11	AIMDQ75R011M2H	AIMBG75R011M2H	AIMZA75R011M2H
7	AIMDQ75R007M2H	AIMBG75R007M2H	AIMZA75R007M2H
4	AIMDQ75R004M2H		

Table 1 shows the first part of the product roadmap that will continue over the next few years with different packages and further $R_{DS\,(on)}$ granularity.

As part of the CoolSiC™ 750 V G2 MOSFETs family, equivalent industrial-grade variants will be available following the same package and $R_{DS\,(on)}$ combination listed in the Table 1, with a sales code 'IMxx75RxxxM2H'.

1.2 Target applications

In automotive power electronics, Silicon Carbide (SiC) MOSFETs perform key role in applications such as:

- On-board charger
- HV-LV DC-DC converter
- Battery disconnect switch
- Auxiliary drives

The increasing demand for higher power classes and greater power density in on-board chargers (up to 22 kW) and HV-LV DC-DC converters (up to 7 kW), with power density targets advancing from 2 kW/l to 6 kW/l, necessitates the adoption of highly efficient power semiconductor devices. Silicon Carbide (SiC) MOSFETs have emerged as a critical enabler in addressing these requirements, offering superior efficiency and enhanced performance compared to traditional silicon-based solutions. Their ability to operate at higher switching frequencies with minimal losses not only supports the achievement of higher power densities but also facilitates more compact and lightweight designs. These attributes make SiC MOSFETs an ideal choice for meeting the evolving demands of modern power electronics systems, ensuring optimal performance while maintaining energy efficiency.

Infineon latest generation CoolSiC™ 750 V G2 MOSFETs power devices are characterized by enhanced switching performance and significantly faster switching speeds, serves as a key enabler for achieving higher power density in modern power electronics systems. By enabling higher frequency operation and more compact designs, the new generation of Infineon CoolSiC™ devices further supports the development of smaller, lighter, and more energy-efficient systems.

Best-in-class low ohmic devices of CoolSiC™ 750 V G2 MOSFETs, such as the AIMDQ75R004M2H (4 mΩ) and AIMDQ75R007M2H (7 mΩ), provide designers with highly efficient and reliable solutions for top-side cooling applications in e-fuse and battery disconnect switches. These advanced components are specifically engineered to meet the rigorous demands of battery electric vehicles (BEVs), and hybrid electric vehicles (HEVs) e-fuse and battery disconnects, offering exceptional thermal performance and reduced power losses. By leveraging their ultra-low on-resistance and superior thermal management capabilities, these devices enable more compact, energy-efficient, and thermally optimized designs. This makes them an ideal choice for enhancing the performance and reliability of critical power management systems in next-generation electric and hybrid vehicles.

1.3 Target topologies

This new-generation technology is ideal for various applications, and the following sections introduce the applications that provide usage scenarios without limits for designers.

1.3.1 Bridgeless totem-pole PFC rectifier

Figure 1 shows, the totem-pole power factor correction (PFC) rectifier topology. Its main benefit compared to the classic boost PFC rectifier is that it is a bridgeless circuit, meaning that it doesn't include a rectifier diode bridge at its input. Therefore, the associated rectifier bridge losses are eliminated, leading to higher efficiency and power density.

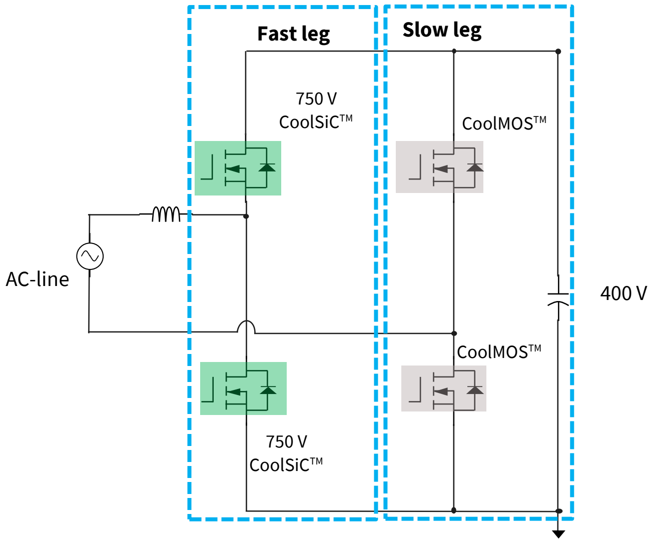
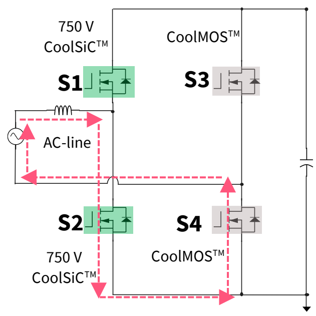


Figure 1 Structure for totem-pole PFC rectifier power stage

Figure 2 shows the operational modes of the totem pole during the positive and negative halves of the AC-line cycle. Two switches (fast leg) run at high switching frequency with the function of the boost switch and rectifier switch, while the other two switches (slow leg) run at line frequency with the function of line rectifier.

Positive AC voltage half line	Negative AC voltage half line
S1: Switching as synchronous switch	S1: Switching as control switch
S2: Switching as control switch	S2: Switching as synchronous switch
S3: Off	S3: On
S4: On	S4: Off



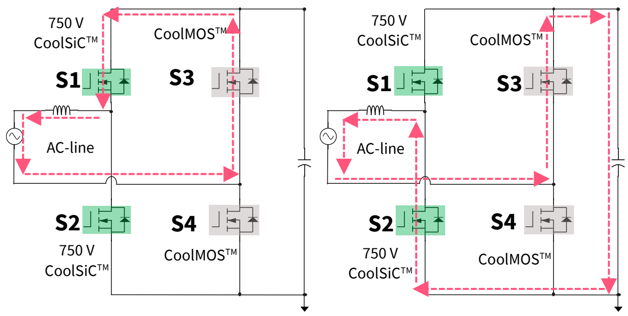


Figure 2 **Operational totem-pole rectifier modes during positive and negative halves of the AC-line cycle [4]**

1.3.2 LLC converter

Figure 3 shows the full-bridge LLC topology. Its main benefits are high efficiency, wide input voltage range, low EMI, and high-power density makes it a preferred choice for many automotive applications. For example, DC-DC stage in an on-board charger. By leveraging the advantages of LLC converters, designers can create compact, efficient, and cost-effective power solutions for the future.

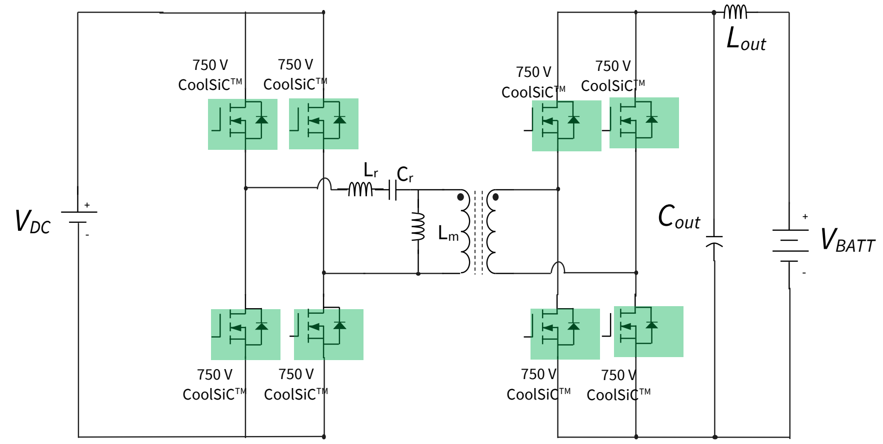


Figure 3 **Structure for LLC converter power stage**

Figure 4 shows the operational modes of the LLC converter during the positive and negative halves of the AC-line cycle.

Principle of operation

S1, S4: Switching as control switch

S2, S3: turned off

S5, S8: Switching as synchronous rectifier

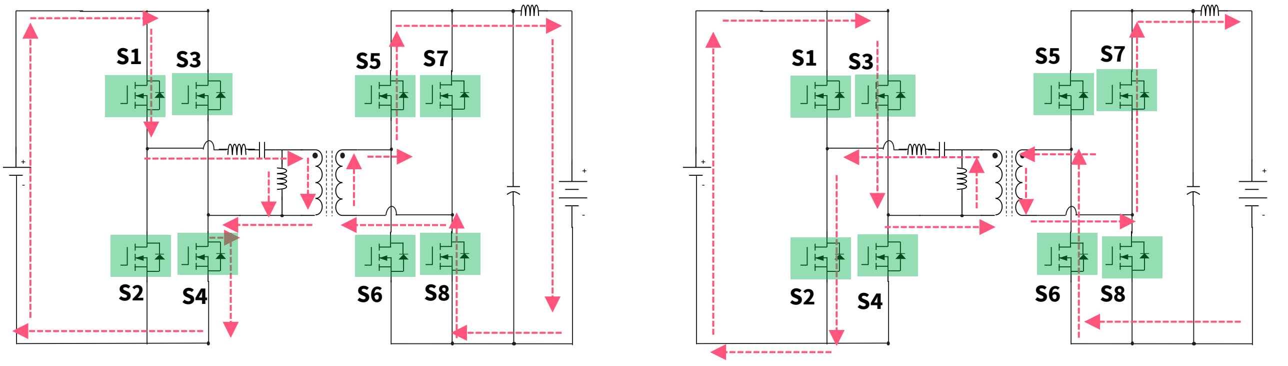
S6, S7: turned off

S2, S3: Switching as control switch

S1, S4: turned off

S6, S7: Switching as synchronous rectifier

S5, S8: turned off



a) b)

S1, S4: Switching as control switch

S2, S3: turned off

S5, S8: turned off

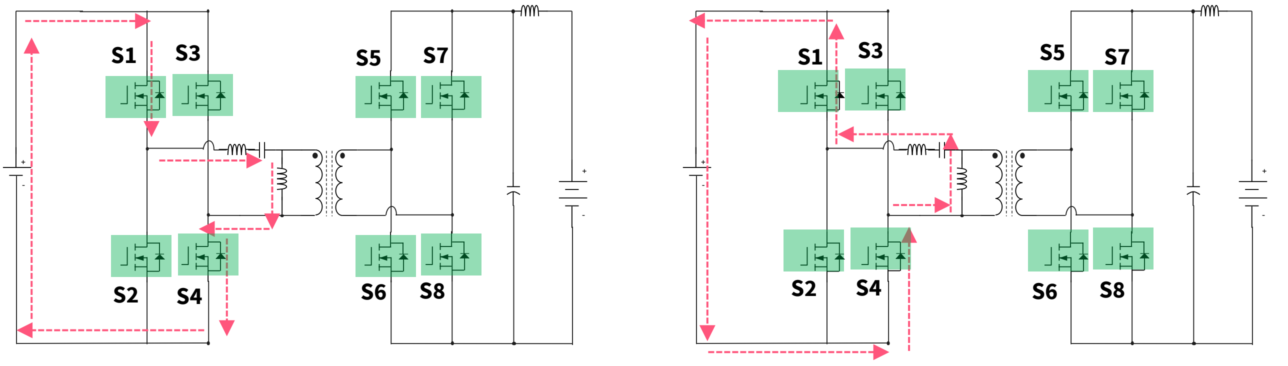
S6, S7: turned off

S2, S3: Switching as control switch

S1, S4: turned off

S6, S7: turned off

S5, S8: turned off



c) d)

Figure 4 Operational modes of LLC converter

As shown in Figure 4, (a) Mode1-magnetizing phase during first half of switching cycle (b) Mode2-demagnetizing phase during second half of switching cycle (c) Mode3- freewheeling operation during first half of switching cycle (d) Mode4- freewheeling operation during second half of switching cycle [7].

1.3.3 Single-phase single-stage matrix converter

Figure 5 shows the single-phase matrix converter also called as single-stage AC-DC converter. Its main benefit compared to the classic two-stage converters (for example, PFC rectifier+LLC converter), is that it directly converts AC voltage to an isolated DC voltage at the output therefore it has minimal energy storage requirements, that allows to get rid of bulky and lifetime-limited energy-storing capacitors, additionally this topology can be modulated in a way that both primary and secondary stages are soft switched. Therefore, the associated second stage losses are eliminated, leading to higher efficiency and power density.

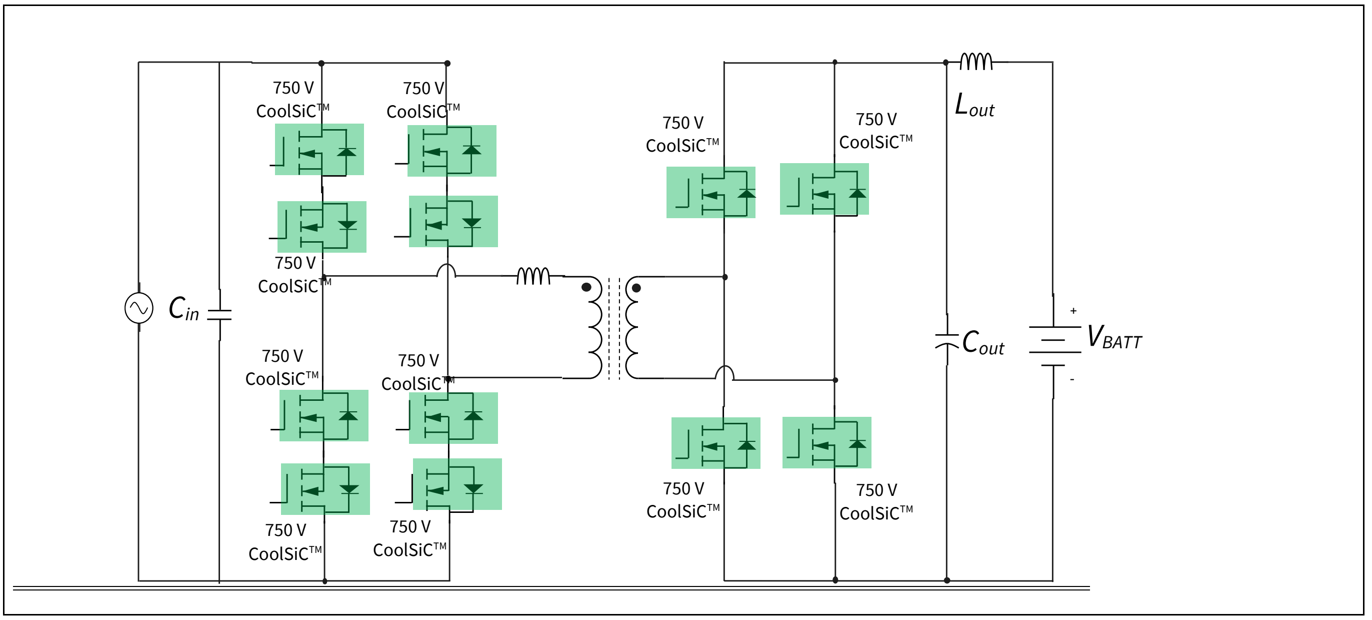


Figure 5 Structure for single phase matrix converter for an on-board charger

The converter transforms the low frequency grid line voltage to high frequency AC at primary side of isolating transformer. It is then rectified in the secondary side to generate the dc voltage. It can control the power flow in both directions i.e. from grid to vehicle and vehicle to grid hence also meeting the requirements of upcoming marketing trends of bidirectional charging in EV space.

Typically, the primary AC side includes 8x SiC MOSFETs and 4x SiC MOSFETs on the secondary side. On the primary side (as illustrated in Figure 3), this type of arrangement is suitable for single phase grid interfaces where the grid voltage varies up to 277 V (RMS) and secondary side for 400 V battery system where battery voltage can reach up to 525V when fully charged. Infineon CoolSiC™ 750 V G2 offers high efficiency and possibility to switch faster helps hence reduced passive size therefore increasing the power density of overall on-board charger. Due to low Q_{oss} in CoolSiC™ 750 V G2, an optimized dead time helps to reduce the resonant current hence increased efficiency.

In three phase matrix converters the primary side MOSFETs shall be replaced with higher breakdown voltage ratings ≥ 900 V however for same battery voltage system, i.e. 400 V, Infineon CoolSiC™ 750 V MOSFETs are best fit for secondary side of this application.

1.3.4 Battery disconnect switch and e-fuse

With the growing emphasis on vehicle safety in automotive electric vehicle (EV) applications, coupled with the need for fast reaction time requirements, high-voltage automotive discrete solid-state solution have become an increasingly popular choice among engineers for critical functions such as battery disconnect and e-fuse systems.

A key configuration for these applications is the bidirectional current handling capability, that allows for the interruption or flow of current in both directions. A bidirectional battery disconnect switch plays a vital role in enhancing safety by enabling the high-voltage battery to be swiftly and securely isolated from the rest of the vehicle's electrical system in the event of a short circuit, collision, or other fault conditions. This capability is crucial for mitigating risks such as electrical hazards, thermal runaway, or potential fires, thereby safeguarding both the vehicle and its occupants.

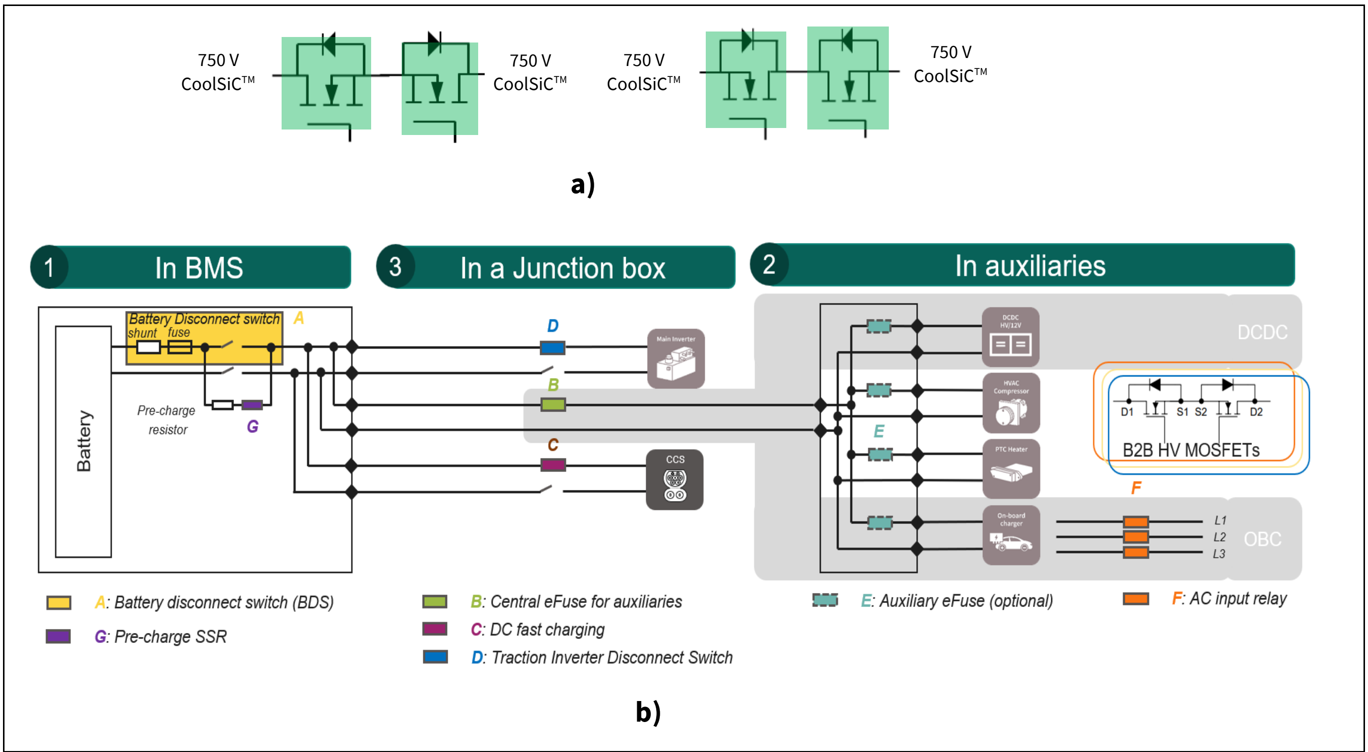


Figure 6 (a) Typical common source and common drain arrangement for BDS and e-fuse (b) e-fuse /e-disconnect and solid-state switches on automotive high voltage board net [5]

For safe and reliable operation, battery disconnect and e-fuses applications has tough requirements such as:

- Continuous current conduction
- High-current handling capabilities (mostly system $R_{DS\,(on)}$ < 10 mΩ, needs paralleling)
- High-current avalanche capabilities
- Uncontrolled and higher di/dt need fast reaction time

To meet these requirements, CoolSiC™ 750 V G2 MOSFETs offers best in class 4 mΩ (AIMDQ75R004M2H) and 7 mΩ (AIMDQ75R007M2H) in top-side cooling Q-DPAK that enables lower on state losses and better thermal dissipation.

2 Technology parameters

This section describes the most important technology parameters and provides general recommendations for the usage of CoolSiC™ 750 V G2 MOSFETs. The comparison is represented for AIMDQ75R060M2H against AIMDQ75R060M1H as both products represent the same $R_{DS\,(on)}$ typ.

'M2' in AIMDQ75R060M2H represent the CoolSiC™ 750 V G2 and 'M1' in AIMDQ75R060M1H represent the CoolSiC™ 750 V G1. For more details on the device nomenclature, see Infineon Power MOSFET product webpage.

2.1 Figure of merits

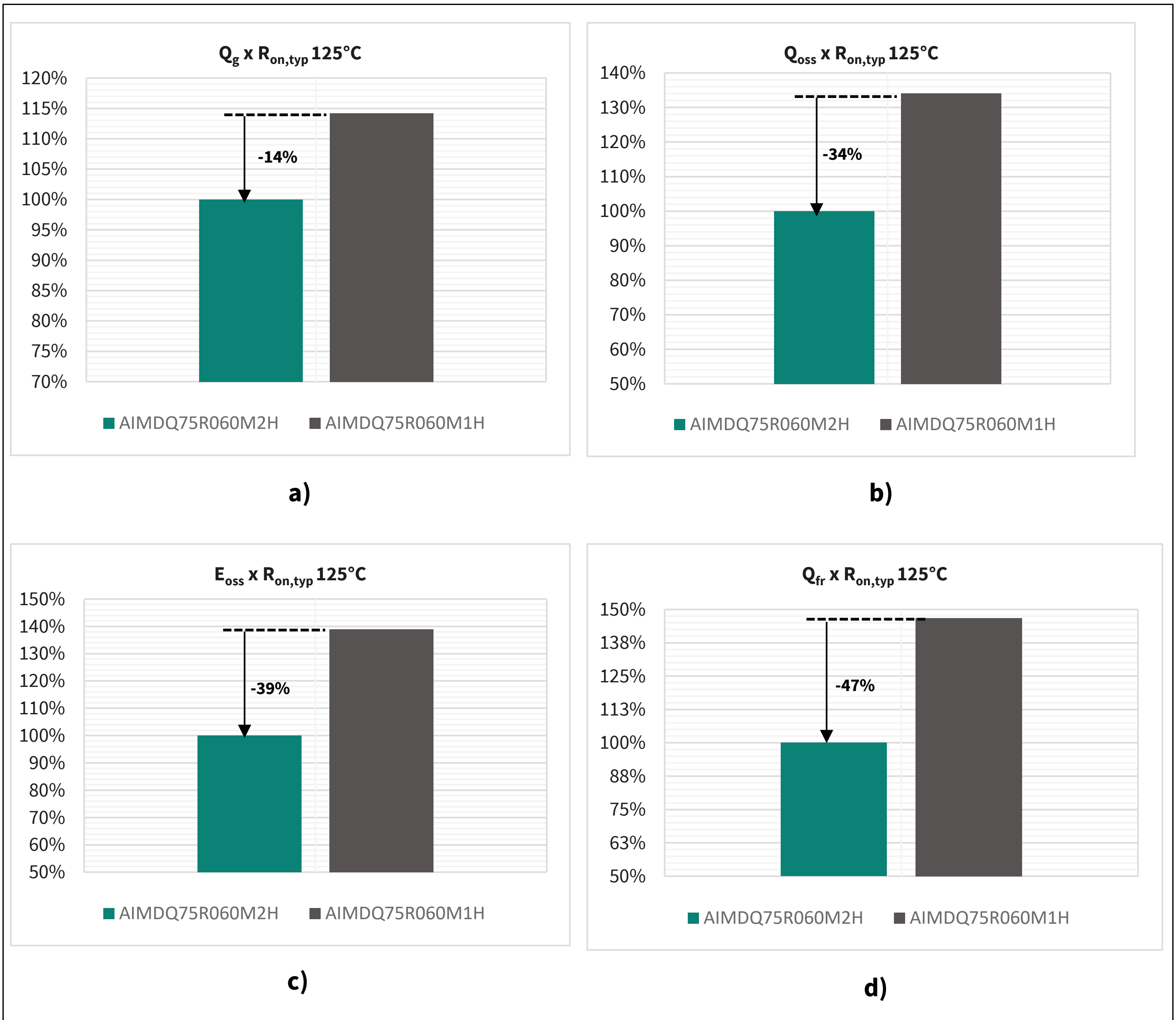


Figure 7 **SiC MOSFET figures of merit (a) Total gate charge × On-state resistance at 125°C (b) Output capacitance charge × On-state resistance at 125°C (c) Output capacitance energy × On-state resistance at 125°C (d) MOSFET forward recovery charge × On-state resistance at 125°C**

As shown in Figure 7, CoolSiC™ 750 V G2 shows improved figures of merit (FoMs) compared to CoolSiC™ 750 V G1. These figure of merits in applications can be translated to application relevant benefits such as faster switching speeds, smaller system deadtime, and lower switching losses. By optimizing these FoMs, MOSFETs can be tailored to meet the specific requirements of different applications, balancing performance, power efficiency, and cost.

2.2 $R_{DS\,(on)}$ over junction temperature

The thermal coefficient of MOSFETs is a vital parameter in the design and operation of automotive power converters (e.g. OBC, DC-DC converters, etc.). It influences temperature stability, thermal management, reliability, design considerations, safety, and energy efficiency. Properly managing this parameter ensures that the power converter can operate reliably and efficiently in the demanding conditions typical of automotive environments.

The $R_{DS\,(on)}$ shows a positive temperature coefficient which results in an increased $R_{DS\,(on)}$ value at higher temperatures. Therefore, it is mandatory to know the $R_{DS\,(on)}$ value at higher temperatures that are relevant for application conditions such as at 125°C (automotive applications mostly operate in the range of 100°C-125°C).

As shown in Figure 8 the X-axis is the junction temperature (T_j) and the Y-axis is the normalized $R_{DS\,(on)}$ value. It is

Shown such that at 25°C the $R_{DS\,(on)}$ is the same for CoolSiC™ 750 V G1 and G2 MOSFETs.

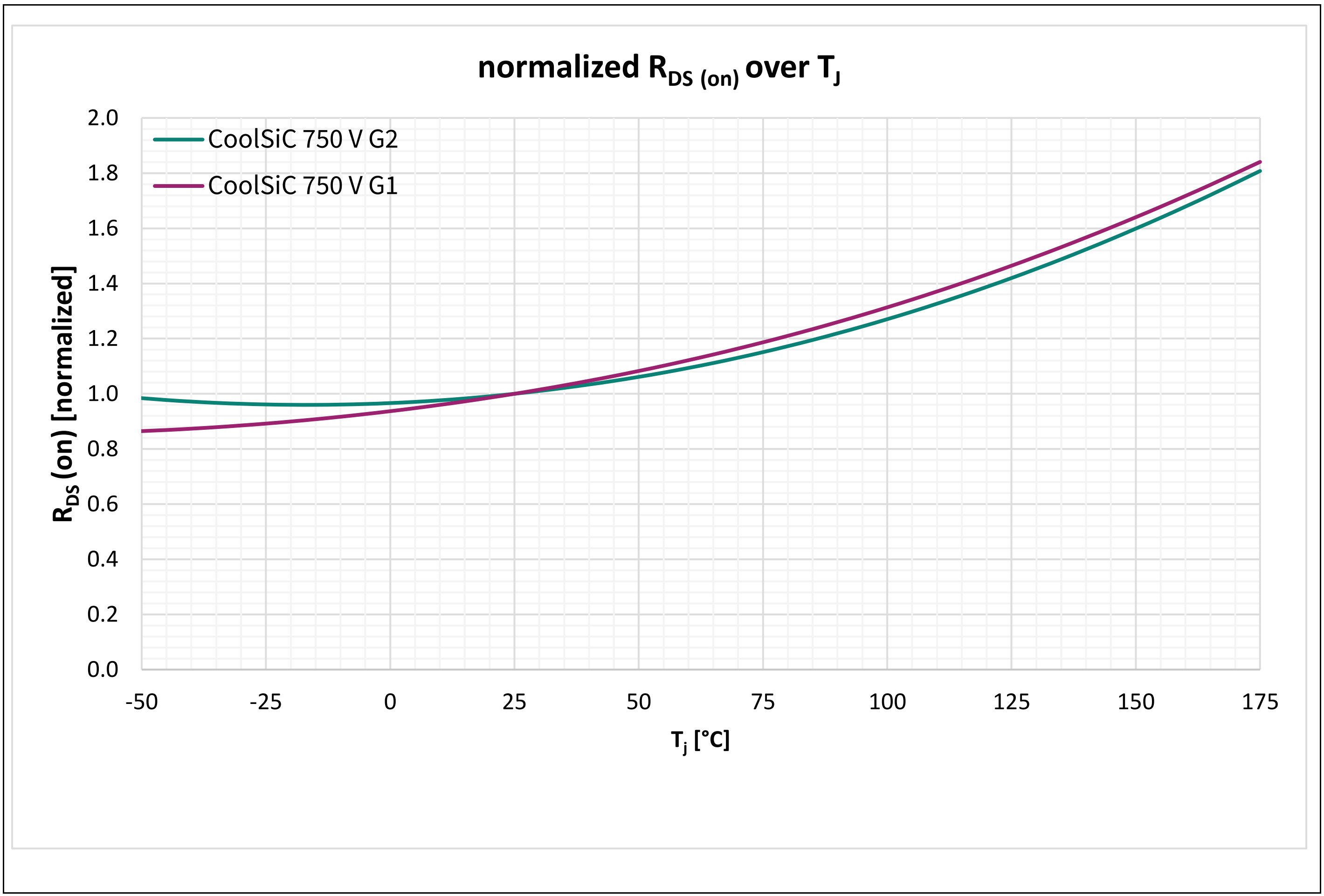
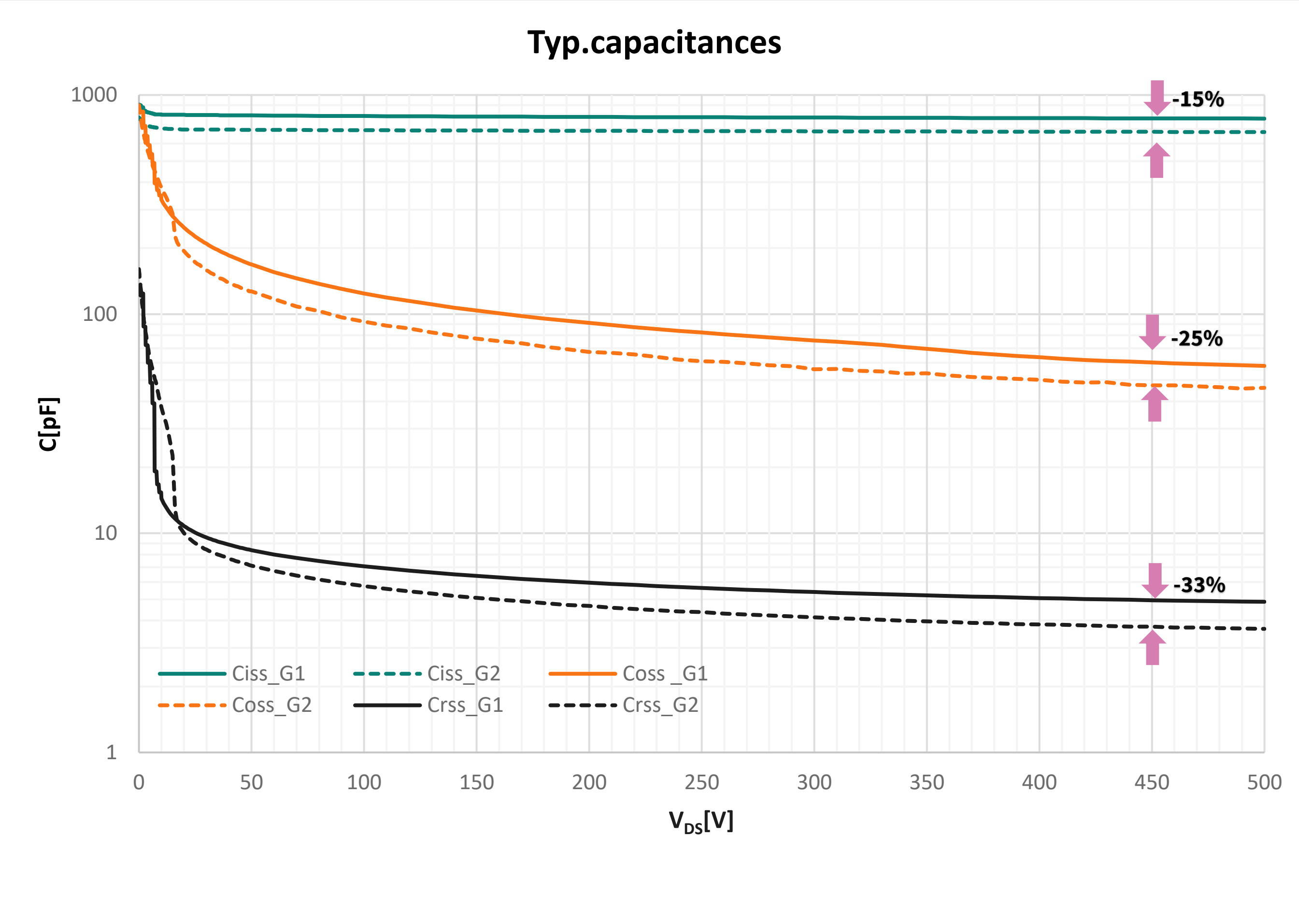


Figure 8 Thermal coefficient comparison CoolSiC™ 750 V G2 vs G1

It has been seen from Figure 8, CoolSiC™ 750 V G2 MOSFETs have a slightly better behaviour than CoolSiC™ 750 V G1 MOSFETs at higher temperatures. Furthermore, this behaviour is the result of a channel and drift region improvement, resulting in an increased process stability leading to a reduction of the required typical to maximum $R_{DS\ (on)}$ margin in the final datasheets for CoolSiC™ 750 V G2 MOSFETs.

2.3 Typical capacitances

Lower parasitic capacitances are an indicator of faster switching speed hence lower switching losses. Specifically, lower output capacitance in CoolSiC™ 750 V G2 (approx. 25%) leads to lower Q_{oss} and E_{oss}, this enables faster switching and lower switching losses compared to CoolSiC™ 750 V G1.



$C=f(V_{DS})$, $V_{GS}=0$ V, f=250 kHz

Figure 9 Capacitances comparison CoolSiC™ 750 V G2 (AIMDQ75R060M2H) vs G1(AIMDQ75R060M1H)

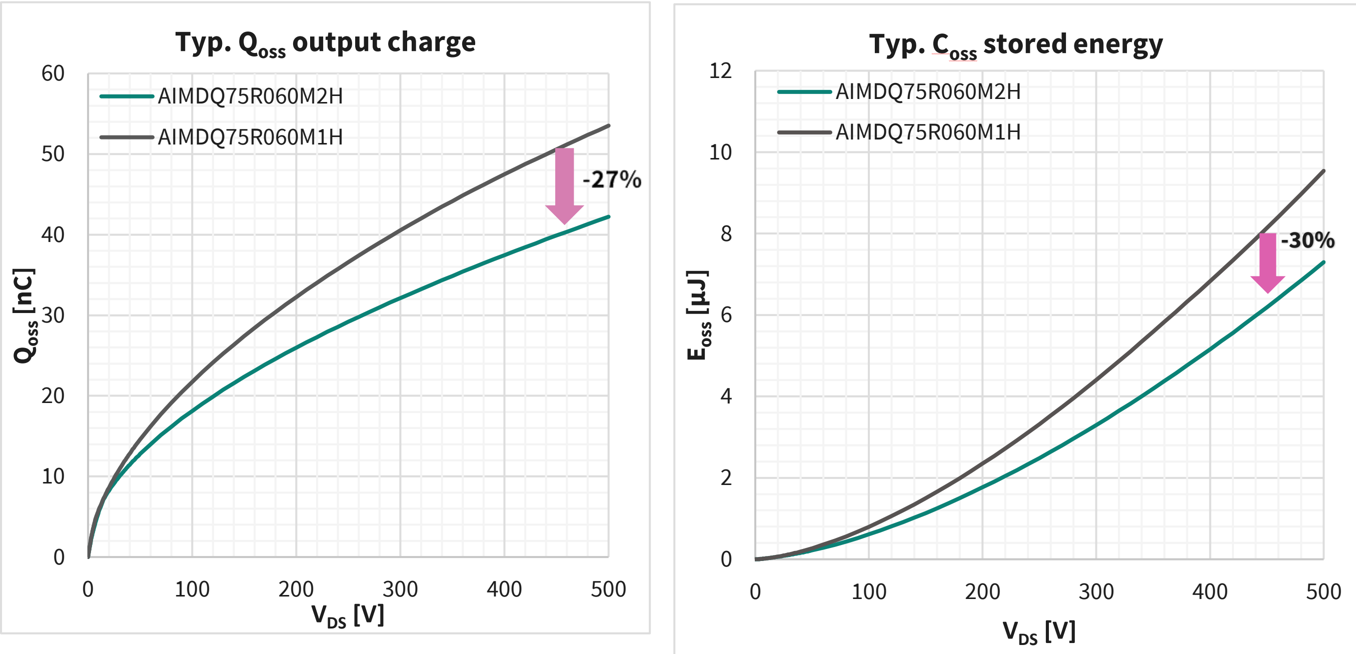
The benefit of the lower C_{oss} over the whole V_{DS} voltage range of CoolSiC™ 750 V G2 MOSFETs is that E_{oss} and Q_{oss} shows the same behavior with a reduction of 25 – 30% in comparison to CoolSiC™ 750 V G1 MOSFETs as shown in Figure 10.

As the Q_{oss} and the E_{oss} are derived by the C_{oss} according to the following two equations (up to V_{DS} =500 V):

$$Q_{oss} = \int_0^{500} \mathrm{Coss}\,(\mathrm{v}).\,dv$$

$$E_{oss} = \int_0^{500} \mathrm{Coss}\,(\mathrm{v}).\,\mathrm{v}\,.\,dv$$

Equation 1 Calculation of E_{oss} and Q_{oss}



$Q_{oss}=f(V_{DS})$

a)

$E_{oss} =f(V_{DS})$

b)

Figure 10 (a) Q_{oss} comparison CoolSiC™ 750 V G2 (AIMDQ75R060M2H) vs. G1(AIMDQ75R060M1H) (b) E_{oss} comparison CoolSiC™ 750 V G2 (AIMDQ75R060M2H) vs. G1(AIMDQ75R060M1

2.4 Q_G–gate charge

The gate charge is an indicator of how fast a device can be turned on and off. Furthermore, it describes the charge needed to fully activate the device and provides an indicator for switching losses.

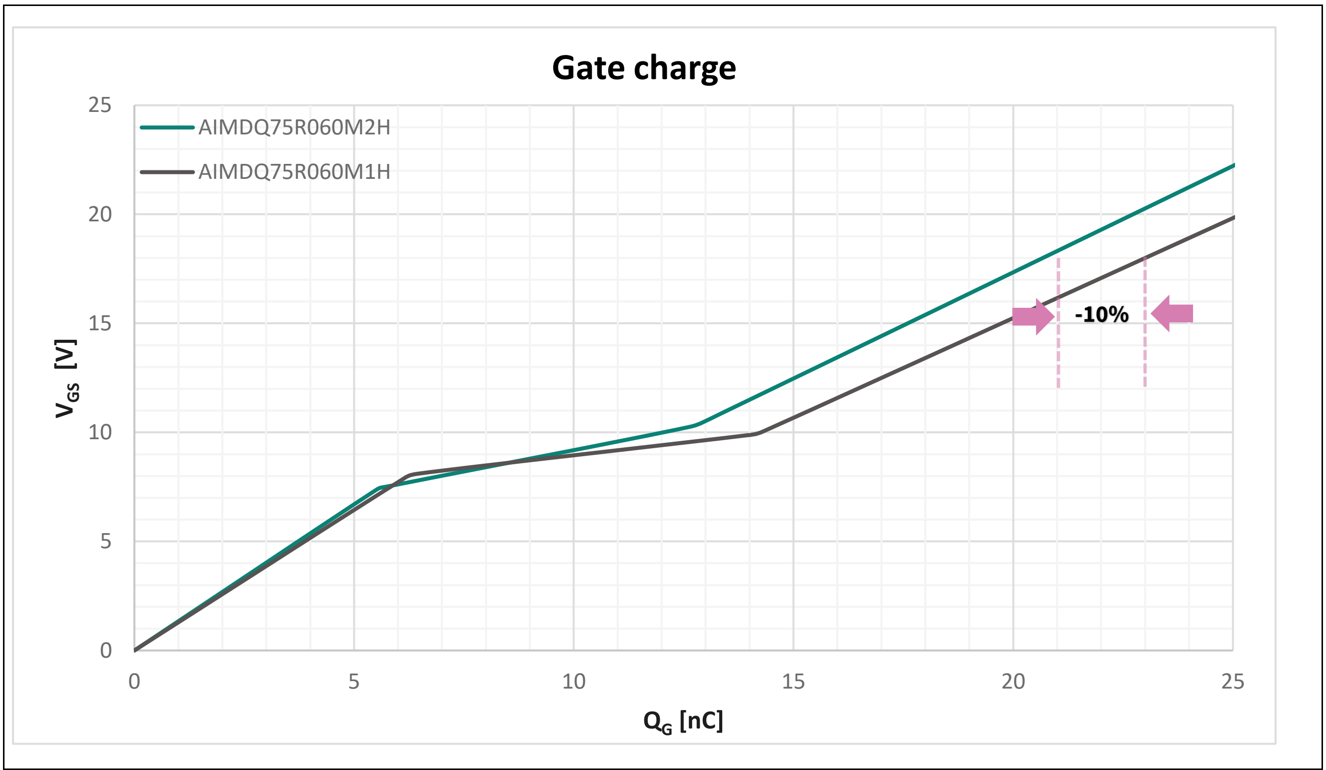


Figure 11 Q_G comparison: CoolSiC™ 750V G2 (AIMDQ75R060M2H) vs G1(AIMDQ75R060M1H)

As shown in Figure 11, reduced gate charge in CoolSiC™ 750 V G2 compared to G1 will help to reduce gate drive losses, making them more efficient in high-frequency application.

2.5 Body diode reverse recovery

The reverse recovery characteristic of MOSFETs, is a critical factor in the design and performance of power converters, practically in hard-switching applications. It directly impacts efficiency, switching losses, thermal management, and overall system reliability. Below is a detailed explanation of its importance in power converters:

Reverse recovery is a critical factor in automotive high-power applications (e.g. OBC and DC-DC converters) as it requires high efficiency while operating at a very high switching frequency. It directly impacts:

- **Efficiency:** Lower reverse-recovery losses improve converter efficiency due to lower switching losses
- **Switching performance:** Fast reverse-recovery enables higher frequency operation
- **Thermal management:** Reduced losses lower heat generation

Figure 12 shows at practically the same test condition, CoolSiC™ 750 V G2 MOSFETs have approximately 28% lower Q_{fr} than CoolSiC™ 750 V G1 MOSFETs.

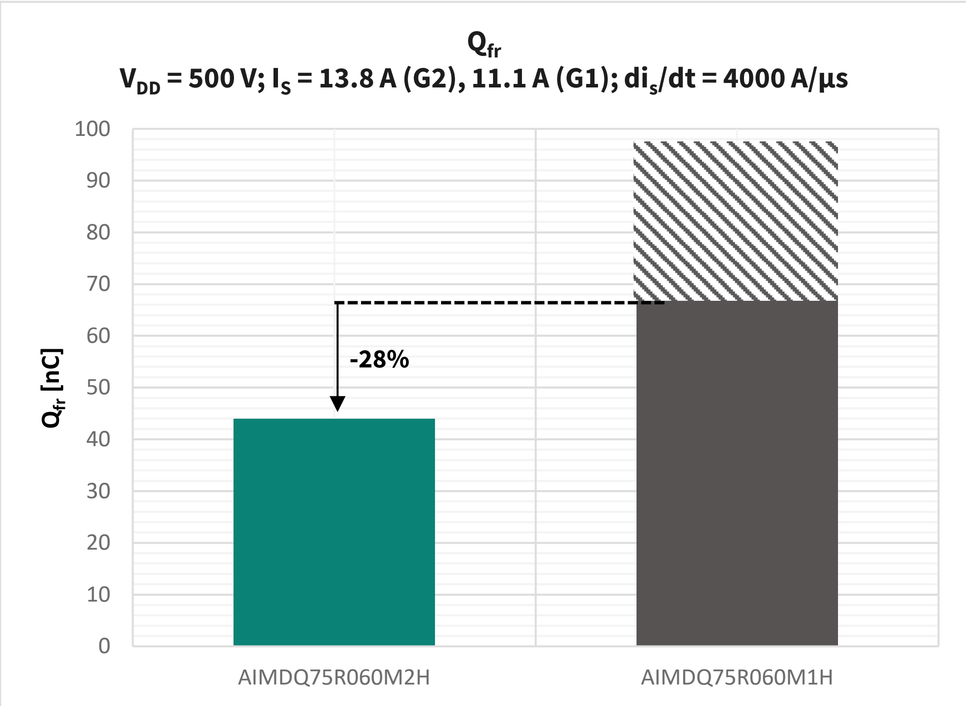
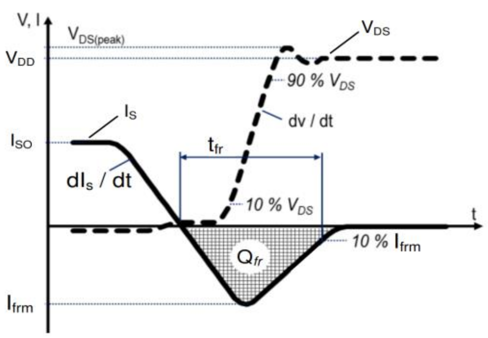


Figure 12 Q_{fr} **comparison: CoolSiC™ 750 V G2 vs. G1 MOSFETs**

Note that CoolSiC™ 750 V G2 MOSFETs use a different and more accurate nomenclature for the body diode recovery parameters from CoolSiC™ 750 V G1 MOSFETs. The old nomenclature of Q_{fr} included the parasitic charge of the test setup (PCB, probes, inductor, etc.). Parasitic's in switching cells play an important role while measuring the switching parameters, and it has higher impact to high ohmic devices, have smaller die sizes and hence smaller output capacitors. Note that CoolSiC™ 750 V G2 MOSFETs gives more accurate values by eliminating the charge of parasitic capacitance from switching cells.

The shaded portion in Figure 12 is the measured parasitic charge in the switching test setup that was included in AIMDQ75R060M1H Q_{fr} definition in CoolSiC™ 750 V G1 datasheets, to have a realistic comparison this parasitic charge has been neglected while comparing it with CoolSiC™ 750 V G2 AIMDQ75R060M2H.

Figure 13 shows an example reverse recovery waveform and its definition in CoolSiC™ 750 V G2 MOSFETs.



Note :

- Q_{fr} includes Q_{oss}
- Q_{fr} excludes measured parasitic charge Q_{par} (PCB, probes, inductor, etc.) .

Figure 13 **Body diode reverse recovery waveform**

3 Extended junction temperature of operation

Silicon Carbide (SiC) MOSFETs are advanced power semiconductor devices that offer significant advantages over traditional Silicon-based MOSFETs, particularly in high-temperature and high-power applications. Operating a SiC MOSFET at 200°C in theory feasible due to the material's inherent properties. Infineon CoolSiC™ 750 V G2 MOSFET is qualified to operate up to 200°C for a total cumulative time of 100 hours up to 7500 temperature cycles, where the maximum delta T to reach 200°C is limited to 100K. This device specification has been introduced to allow more reliability under overload conditions and offer engineers more freedom with their system design. In automotive OBC, the primary side of OBC is tied to grid, grid voltage fluctuations and also load behaviour in case of vehicle to home/grid can impact the operation of on-board charger.

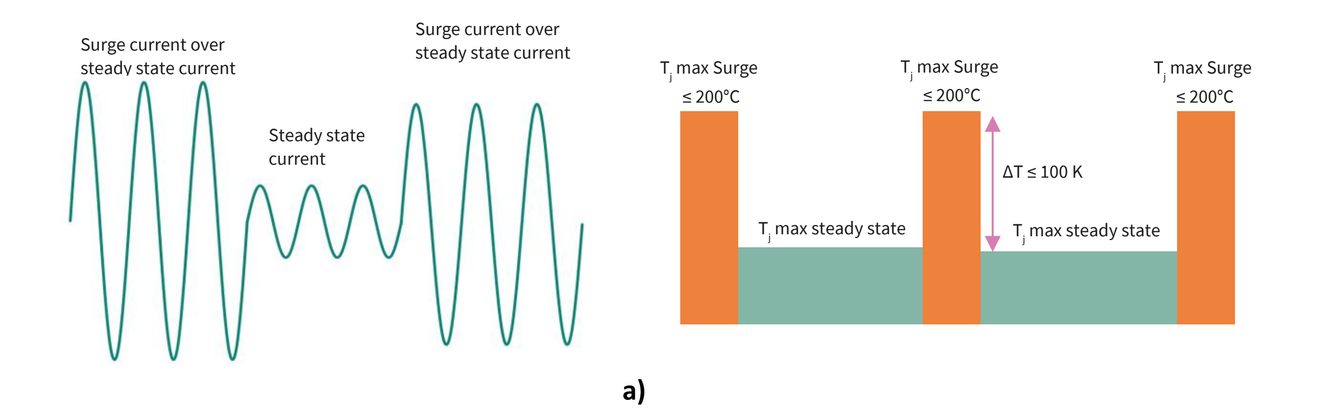


Figure 14 **(a) Example of load current variation and corresponding junction temperature due to repetitive surge events**

Figure 15 shows an example of the extended power dissipation capability of CoolSiC™ 750 V G2 AIMDQ75R060M2H device due to the higher temperature limit. The solid curve represents a typical semiconductor power limited by a case temperature of 175°C. In comparison, the dashed curve of CoolSiC™ G2 shows that 33% more current is enabled at the same operating point.

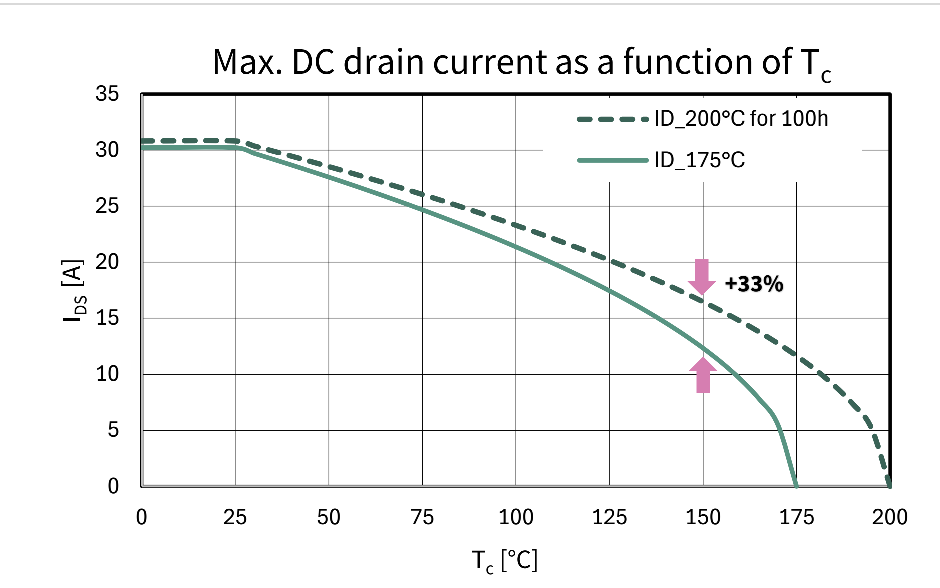


Figure 15 **Device (AIMDQ75R060M2H) max. DC drain-current as a function of case temperature**

4 Worst-case $R_{DS\,(on)}$ drift at the end of the mission profile

Infineon CoolSiC™ MOSFETs do not requires negative gate drive voltage because the parasitic turn on (PTO) factor is very low (refer Section 6.3) and show the best behavior with respect to re-turn-on on the market. However, due to second source possibility, CoolSiC™ 750 V G2 MOSFETs have an improved gate oxide, allowing a higher (–7 V static) negative gate source voltage as the continuous turn-off voltage. Because a lot of SiC MOSFETs on the market can only perform at VGS = –5 V without PTO, this new gate oxide is introduced. This results in an even easier-to-use and easier-to-drive for CoolSiC™ 750 V G2 MOSFETs.

However, it cannot be neglected that there is still a V_{th} drift over lifetime and therefore a corresponding $R_{DS\,(on)}$ drift over the lifetime, as with all SiC MOSFETs that are available on the market. Figure 16 shows drift values under worst-case conditions and are valid if the devices do not exceed the limits given in the datasheets. With the help of these diagrams, the design engineers can choose any parameter set inside the datasheet framework that fits their application best without spending much effort on considering the drift impact, and parasitic overshoots and undershoots in the gate signal. Products belonging to this family can be identified using the following part number structure:

- AIMxx75yyyM2H (automotive grade)

Where:

- xx is the package identifier: 'BG' (D2PAK-7), 'DQ' (QDPAK TSC), 'ZA' (TO247-4)
- yyy is the typical $R_{DS\,(on)}$ in mΩ

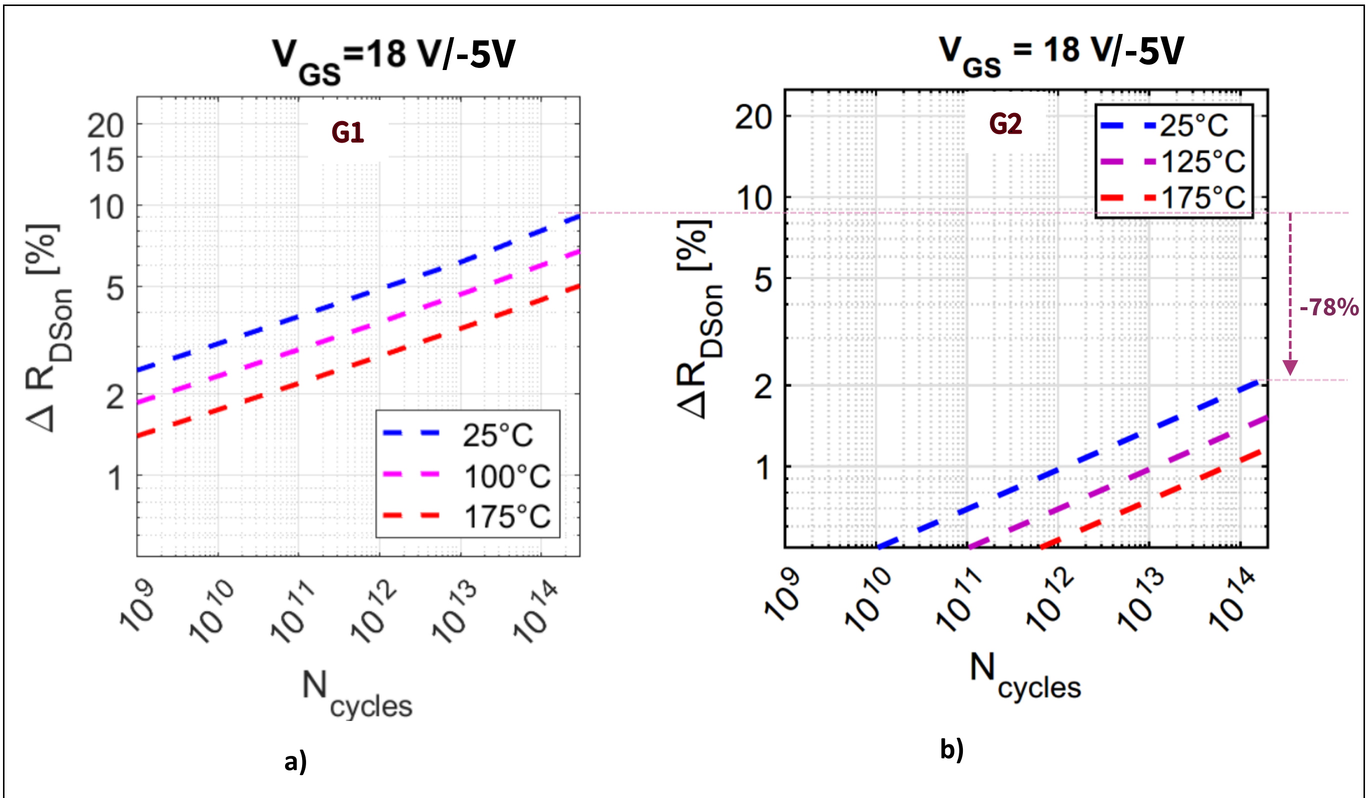


Figure 16 Relative end of lifetime $R_{DS\,(on)}$ drift for:

(a) $V_{GS\,(on)}$ = 18 V, $V_{GS\,(off)}$ =-5V, T_{jop}= 25°C, 100°C, and 175°C CoolSiC™ 750 V G1 [6]

(b) $V_{GS\,(on)}$ = 18 V, $V_{GS\,(off)}$ =-5V, T_{jop}= 25°C, 125°C, and 175°C CoolSiC™ 750 V G2

Worst-case RDS (on) drift at the end of the mission profile

CoolSiC™ 750 V G2 MOSFET technology comes with an improved gate oxide and shows a significant improvement with regard to bipolar AC stress, also referred to as gate switching instability (GSI).

CoolSiC™ 750 V G2 MOSFET shows, a reduction of ~6% (absolute),78% (relative) in $R_{DS\,(on)}$ drift at 25°C and ~4% (absolute) ,78% (relative) at 175°C respectively can be expected, as shown in Figure 16 compared to CoolSiC™ MOSFET 750 V G1.

The following example explains how to use this information:

- Targeted lifetime: 20 years
- Real operation time: 10 years (assuming 50% duty cycle)
- Real operating time [s]: 315,360,000 s (10 years)
- Switching frequency: 48 kHz
- Cycle duration: 1/switching frequency = 0.0000208 s
- Number of cycles at end of life: operating time/cycle duration = ~1.52E+13 cycles

5 Switching behavior of CoolSiC™ 750 V G2 MOSFET

Switching losses are a key consideration in the design and operation of automotive power converters. They affect efficiency, thermal performance, reliability, EMI, system cost, and overall vehicle performance. By minimizing switching losses through wide bandgap semiconductor technologies (e.g. SiC), optimized control strategies, and effective thermal management, automotive power converters can achieve higher efficiency, higher power density, and better performance, that are essential for the demanding requirements of modern vehicles.

With CoolSiC™ 750 V G2 MOSFETs lower switching losses are achievable compared to the previous generation. CoolSiC™ 750 V G2 MOSFETs technology introduces improvements to the device's capacitive nature. As listed in Table 2, a significant reduction in the input and output capacitance, of 22% and 28% respectively, has been achieved.

Table 2 Parasitic capacitances and charges of G1 and G2 devices value at V_{DS}=500V

Parameter	Symbol	Value	
		AIMDQ75R060M1H	AIMDQ75R060M2H
Input capacitance	C_{iss}	779 pF	638 pF
Output capacitance	C_{oss}	60 pF	47 pF
Reverse transfer capacitance	C_{rss}	4.8 pF	4.0 pF
Output charge	Q_{oss}	54 nC	42 nC
Gate charge	Q_g	23 nC	21 nC

The switching behavior of a SiC MOSFET depends on several factors such as the operating temperature, the current conducted by the device etc. This section provides the switching measurement results comparison of CoolSiC™ 750 V G2 MOSFET (AIMDQ75R060M2H), CoolSiC™ 750 V MOSFET G1 (AIMDQ75R060M1H) and 60 mΩ vendor 1 all in top side cooling package at 25°C and 150°C (heating the device with external hot plate to precisely maintain the case temperature of the devices under test at T_C=150°C)

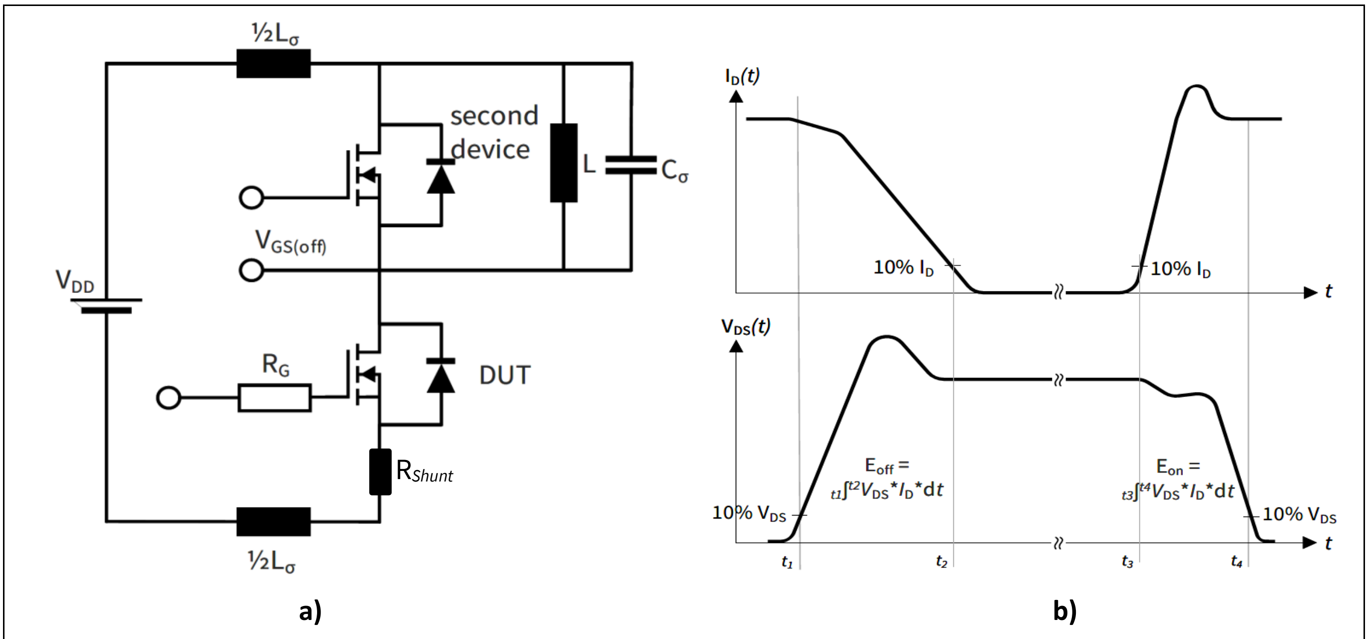


Figure 17 (a)Test schematic for double pulse test (b)Representative waveform of the switching loss setup

Equipment used:

- Programmable DC power source-Chroma 62024P-600-8
- Tektronix oscilloscope MSO56B
- High-voltage probe PMK PHV 1000–V_{DS} measurement
- Optical isolated probes PMK FF-1500–V_{GS_LS} and V_{GS_HS} measurements
- 10X passive probe TPP0100–I_{DS} measurements across shunt

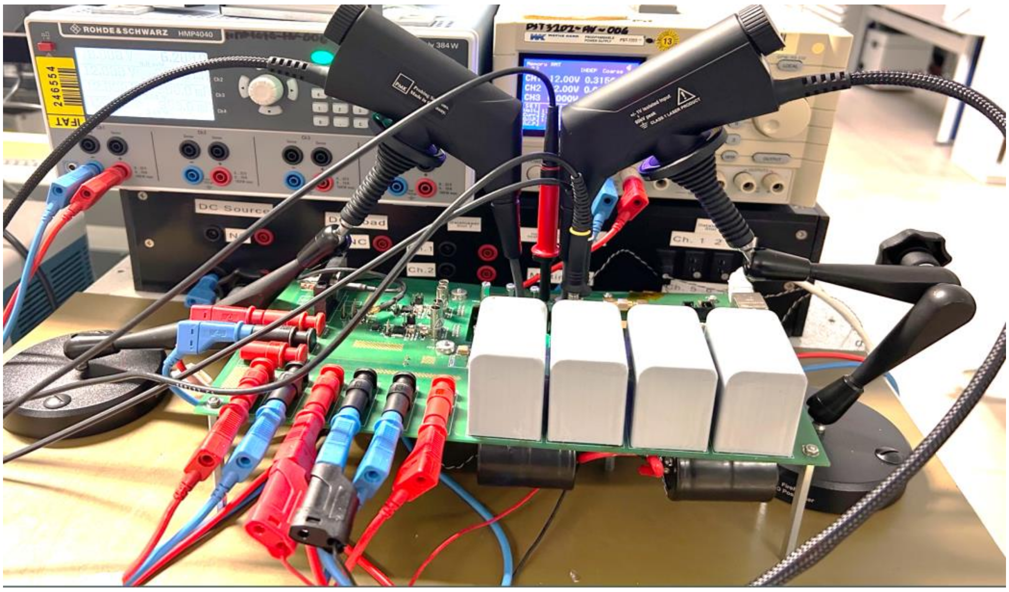


Figure 18 Test setup for switching losses measurement (double pulse test)

Parasitic elements can significantly influence switching loss measurements by distorting voltage and current waveforms, causing more oscillations, and increasing overlap losses. To accurately measure the losses and switching behavior of the devices, an optimized test board shown in Figure 18 has been chosen in which the measured loop inductance L_σ from oscillation frequency f_{osc} (Figure 20 a.) can be calculated as:

$$f_{osc} = \frac{1}{2\pi\sqrt{L_\sigma C_\sigma}}$$

$$f_{osc} = 200 \text{ MHz (measured -refer Figure 20a)}$$

$$C_\sigma \approx C_{oss} \text{ at } 400\text{ V} = 55\text{pF max } (C_{pcb} \text{ ignored})$$

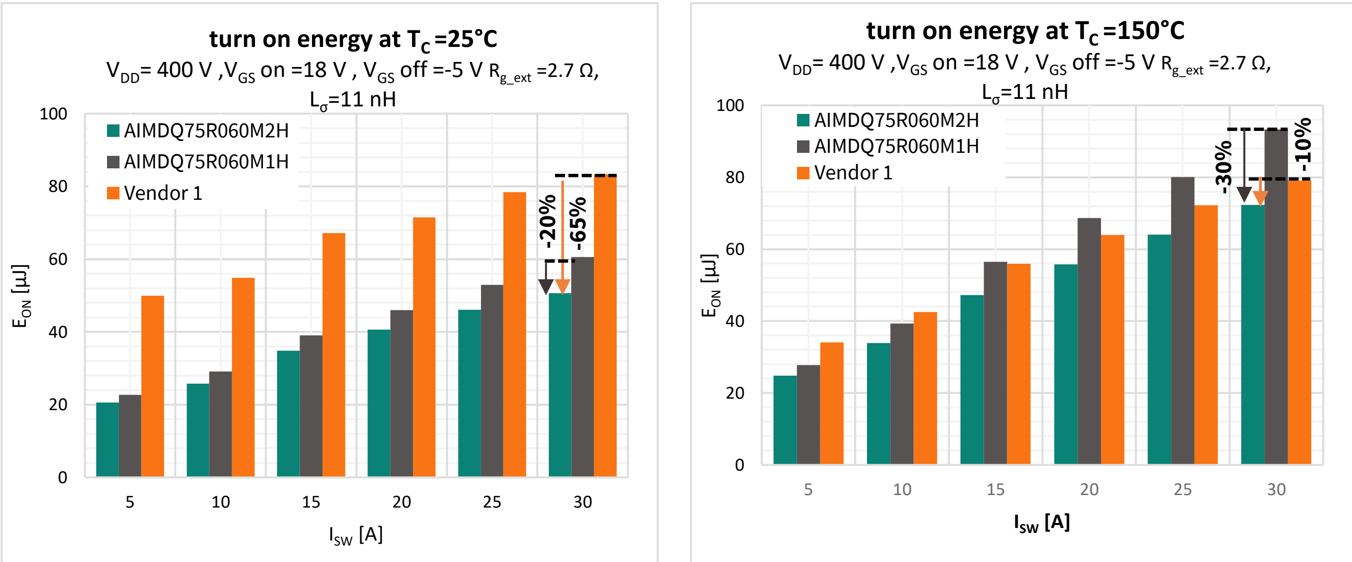
$$L_\sigma \approx 11 \text{ nH (measured)}$$

Equation 2 Calculation of power loop inductance L_σ

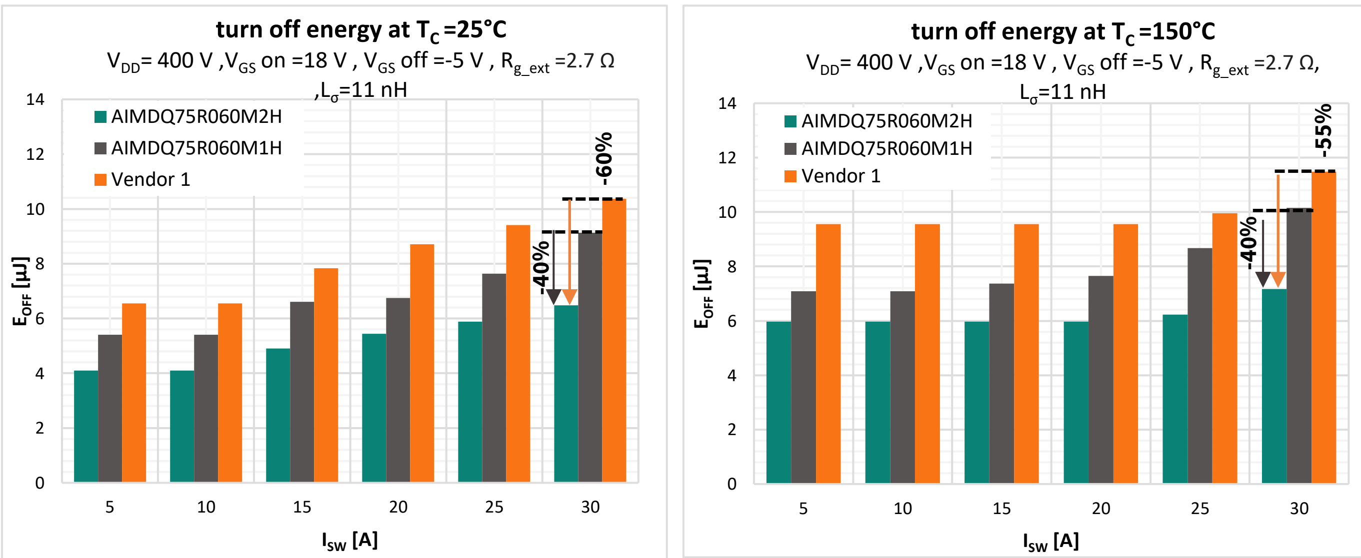
Figure 19 shows the measured switching losses comparison of AIMDQ75R060M2H, AIMDQ75R060M1H and 60mΩ vendor 1 and their dependencies on case temperature 25°C and 150°C.

- CoolSiC™ MOSFET 750 V G2 device switches faster by 25% to 30% (refer to Figure 20a) and shows lower switching losses than previous generation by 30% to 40% (refer to Figure 19)
- Both CoolSiC™ MOSFET 750 V G2 and G1 perform better then vendor 1 by 65% and 37%, respectively at T_c=25°C however at T_c=150°C CoolSiC™ MOSFET 750 V G2 performs better than G1 and vendor 1

- Body diode reverse recovery charge of CoolSiC™ MOSFET 750 V G2 and G1 are comparable at same load current (refer Figure 20b and Figure 20c at T_c=25°C and T_c=150°C)
- Vendor 1 shows substantially high reverse recovery charge compared to CoolSiC™ MOSFET 750 V G2 and G1 which is also been reflected in the turn on energies (refer Figure 20b and Figure 20c) for case temperature of T_c=25°C and T_c=150°C)
- Strong signs of parasitic turn on have been seen in vendor 1 device at T_C=150°C and, partially at T_c=25°C even at $V_{GS\ off}$ =-5 V, measured switching losses of vendor 1 at T_C=150°C were lower than at T_C=25°C



a)



b)

Note:

- turn off energy includes the E_{OSS}
- turn on energy does not include the E_{OSS}

Figure 19 **a) E_{on} losses vs switching current comparison CoolSiC™ 750 V G2 (AIMDQ75R060M2H) vs G1(AIMDQ75R060M1H) vs vendor 1 at T_c=25°C and 150°C respectively (b) E_{off} losses including E_{OSS} vs switching current comparison CoolSiC™ 750 V G2 vs G1(AIMDQ75R060M1H) vs vendor 1 at T_c=25°C and 150°C respectively**

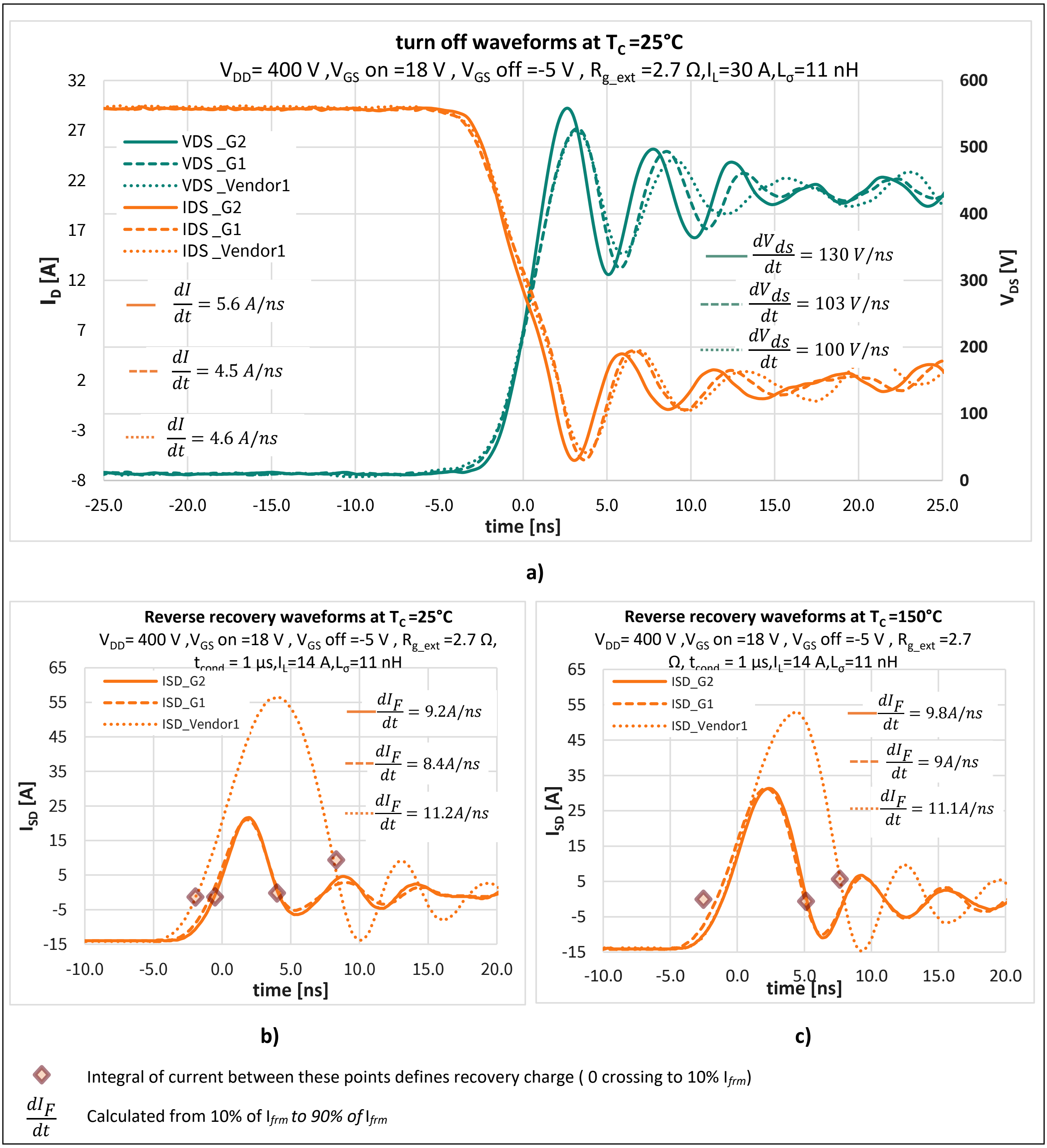


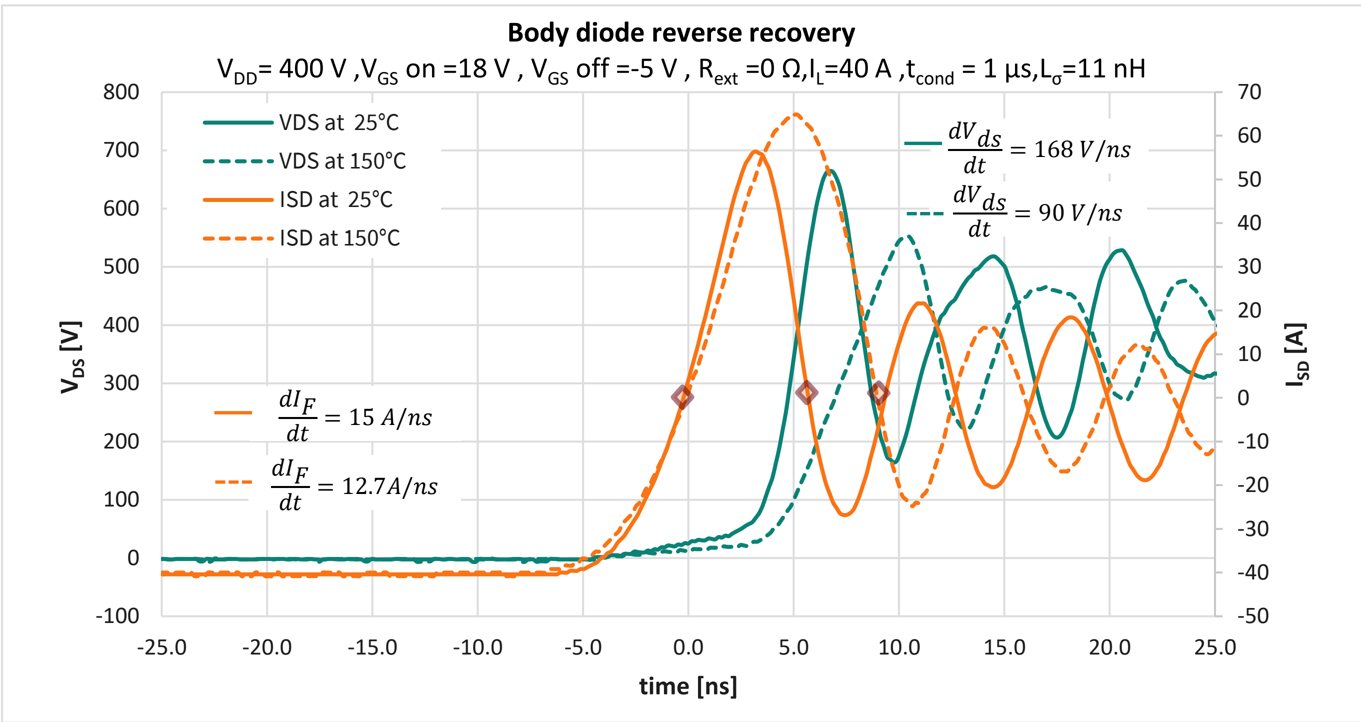
Figure 20 **a) Turn off comparison CoolSiC™ 750 V G2 (AIMDQ75R060M2H) vs G1(AIMDQ75R060M1H) vs vendor 1 at T_c=25°C (b)Reverse recovery comparison CoolSiC™ 750 V G2 vs G1(AIMDQ75R060M1H) vs vendor 1 at T_c=25°C**

6 Body diode reverse recovery of CoolSiC™ MOSFET 750 V G2

6.1 Temperature dependency

The reverse recovery characteristics of a MOSFET's body diode are strongly temperature-dependent, with higher temperatures leading to increased reverse recovery time, charge, and peak current. This can result in higher switching losses, hence higher temperature in hard switching application.

This section will show experimental results of body diode reverse recovery of the CoolSiC™ 750V G2 and discuss the recommended driving strategy to minimize its losses.



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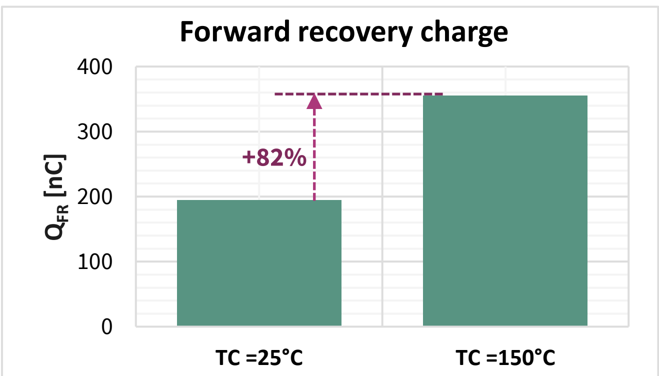

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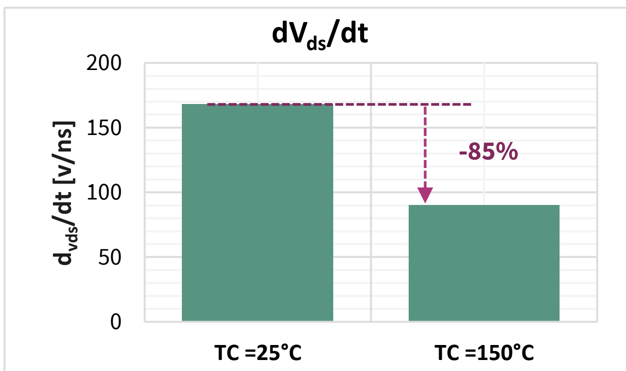


C)

Integral of current between these points defines recovery charge (0 crossing to 10% I_{frm})

$\frac{dI_F}{dt}$ Calculated from 10% of I_{frm} *to 90% of* I_{frm}

$\frac{dV_{ds}}{dt}$ Calculated from 20% of V_{DS} *to 90% of* V_{DD}

Figure 21 **a) Body diode reverse recovery waveform of CoolSiC™ 750 V G2 (AIMDQ75R016M2H) at T_c=25°C and 150°C respectively (b) Body diode reverse recovery comparison of CoolSiC™ 750 V G2 (AIMDQ75R016M2H) at T_c=25°C and 150°C respectively (c) dV_{ds}/dt comparison of CoolSiC™ 750 V G2 (AIMDQ75R016M2H) at T_c=25°C and 150°C respectively**

In Figure 21, the reverse recovery diode behaviour at T_c = 25°C and 150°C of AIMDQ75R016M2H G2 shows:

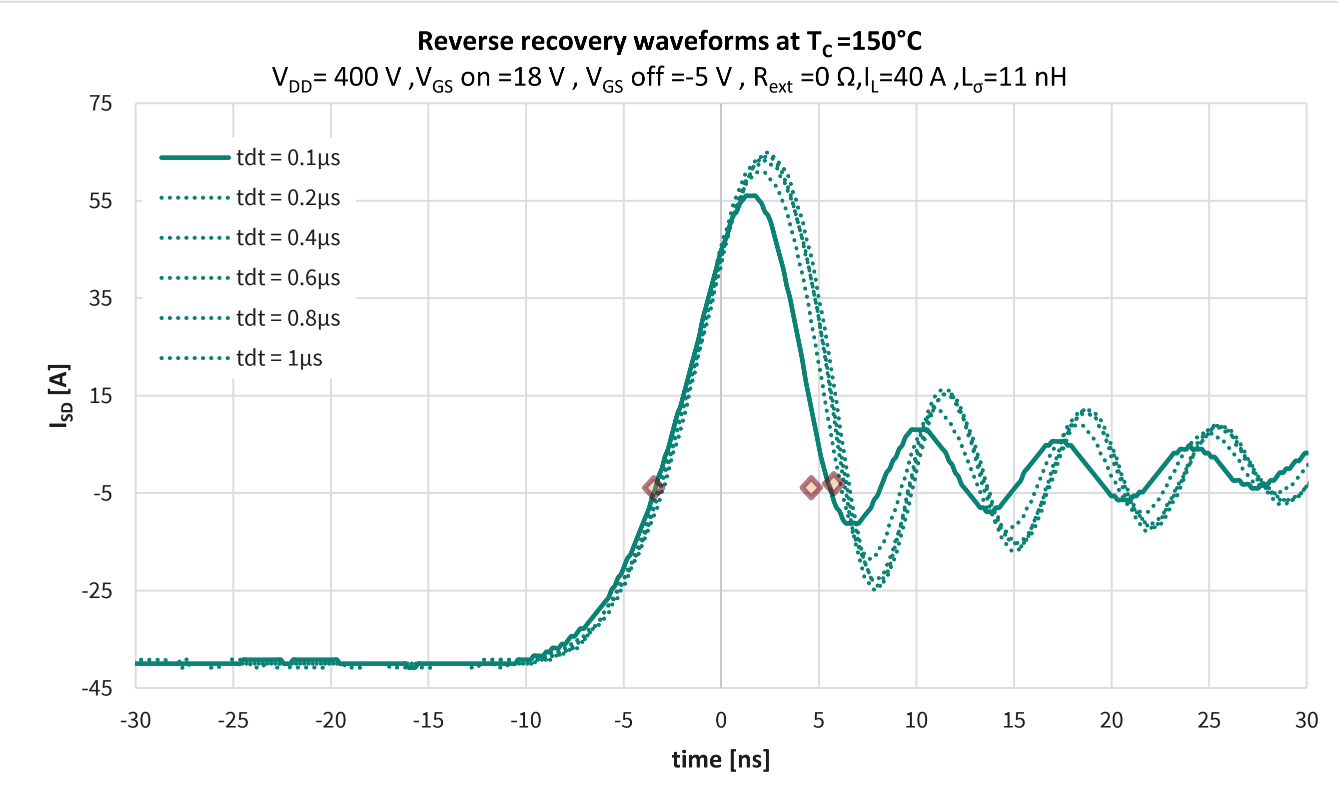
- Reverse recovery charge at T_c=150°C increased by 82% compared to T_c = 25°C
- $\frac{dV_{ds}}{dt}$ at T_c=150°C reduced by 85% and V_{DS} overshoots reduced by approx. 100 V compared to T_c = 25°C

6.2 Optimum dead time for best energy efficiency

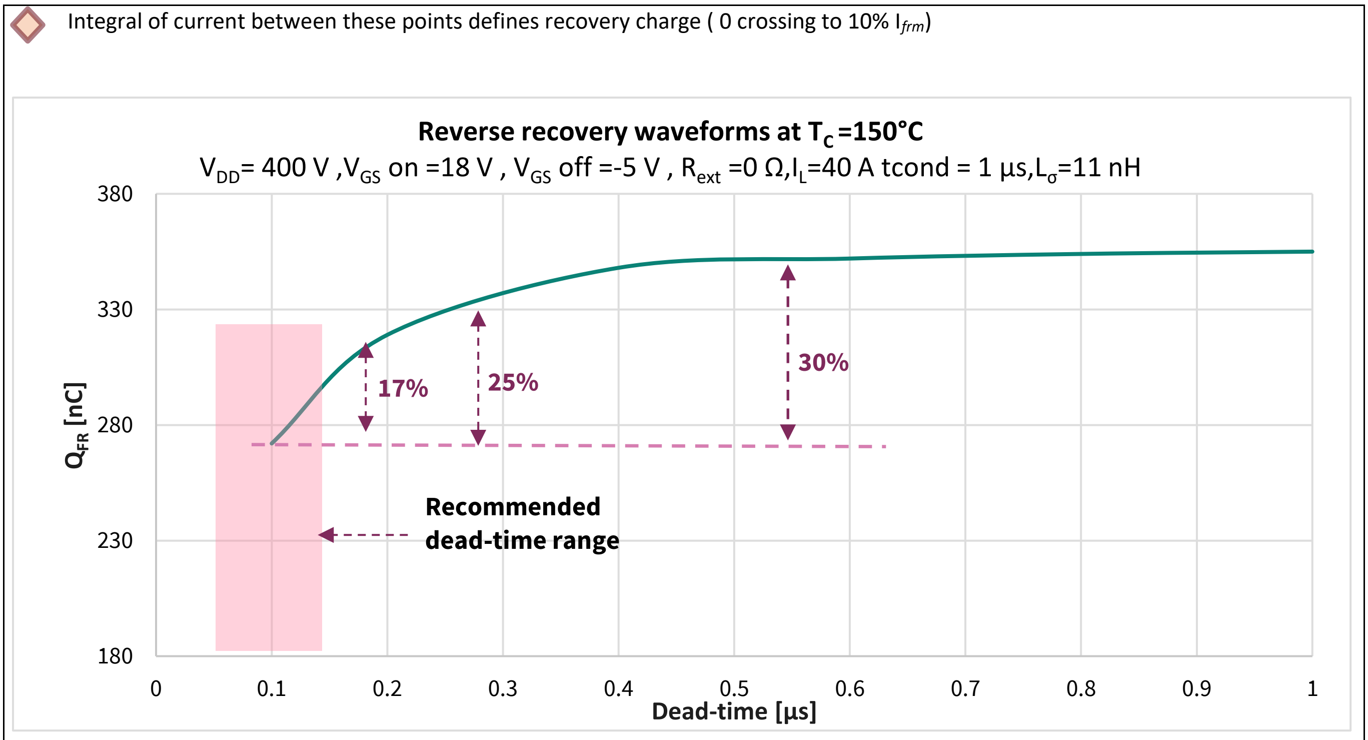
Dead-time settings in application boards are closely dependent on the reverse recovery charge (Q_{rr}) of the MOSFET's body diode. Proper dead-time management is essential to minimize switching losses, avoid shoot-through, and ensure efficient operation. Factors like temperature, load current, switching frequency, and MOSFET characteristics must be considered when setting dead-time. By optimizing dead-time—either through fixed values or dynamic adjustment—designers can improve the performance and reliability of power electronics systems.

In Figure 22, the reverse recovery diode behaviour at T_c = 150°C of the CoolSiC™ 750 V G2 AIMDQ75R016M2H for different dead time (t_{dt}) settings shows:

- Reverse recovery charge increases with increase in diode conduction time (dead-time in application), the optimum dead-time for CoolSiC™ 750 V G2 MOSFETs is between 50 ns to 150 ns (as shown in Figure 22b)



a)



b)

Figure 22 **a) Body diode reverse recovery current waveforms of CoolSiC™ 750 V G2 (AIMDQ75R016M2H) at T_c = 150°C vs variable dead-time(b) Body diode reverse recovery charge of CoolSiC™ 750 V G2 (AIMDQ75R016M2H) at T_c = 150°C vs variable dead-time**

6.3 Unipolar driving and parasitic turn on factor

Parasitic turn-on is a well-known issue in SiC MOSFETs if not driven properly in hard switching applications, primarily caused by the miller effect, high dv/dt, and parasitic inductance. It can lead to shoot-through currents, increased losses, and device failure. By implementing strategies such as negative gate-source biasing, Miller clamp circuits, optimized PCB layout, and advanced gate drivers. Out of these the most popular way to bias more and more negative during turn off.

CoolSiC™ MOSFETs from Infineon do not need negative gate drive voltage because the PTO factor is very low and show the best behavior with respect to re-turn-on on the market, however CoolSiC™ 750 V G2 MOSFETs allows for static gate voltages of up to -7V and transient gate voltages of up to -11V. This enhanced voltage tolerance provides engineers with greater design margins, and compatible with other vendors.

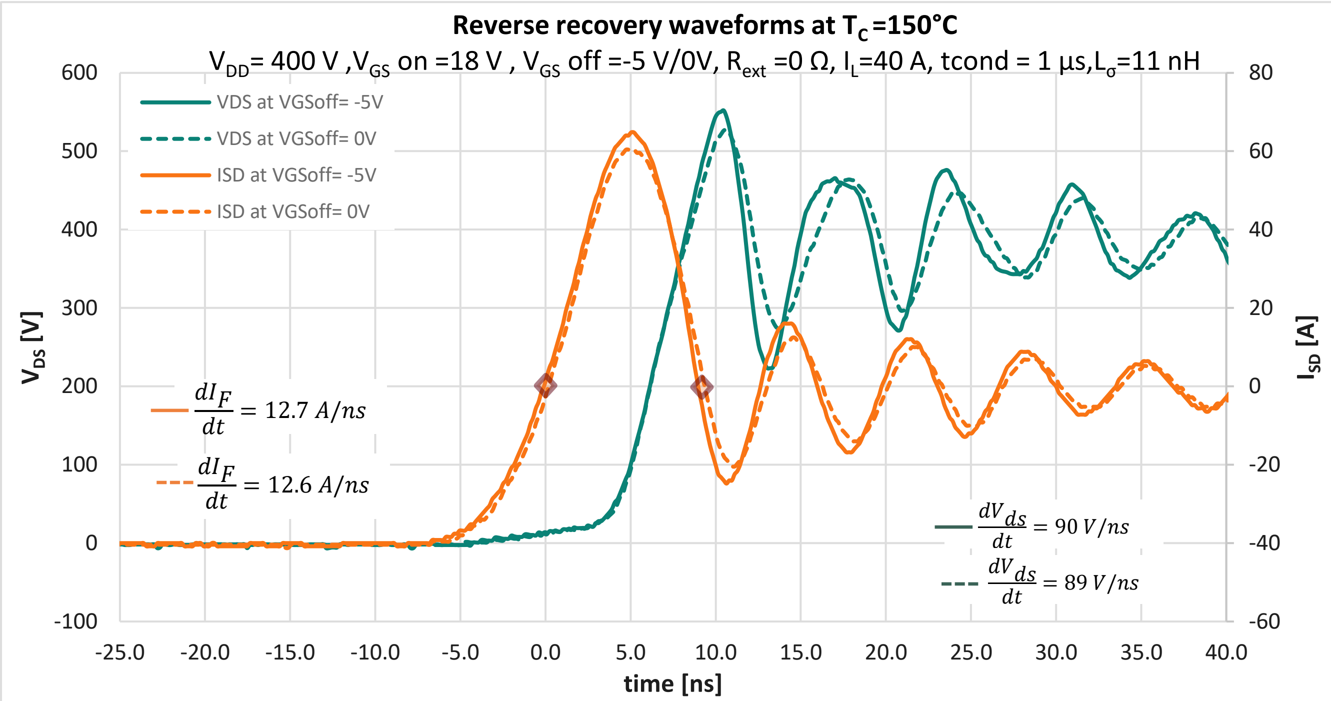
This parasitic turn-on (PTO) factor can be calculated based on datasheet values according to the following formula:

$$PTO\ Factor = \frac{Q_{GD}\ at\ 500\ V}{Q_{GS}\ at\ V_{th}}$$

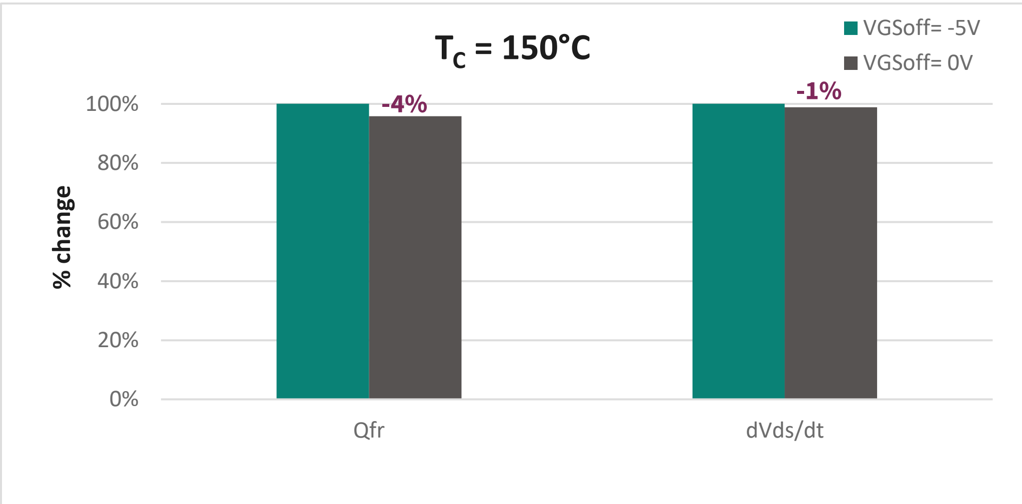
Equation 3 **Parasitic turn on factor**

The PTO factor (ratio Q_{GD} 500 V to Q_{GS} @ V_{th}) of AIMDQ75R016M2H G2 is < 1 which is sufficient condition for full immunity to capacitive induced spurious turn on.

In Figure 23, reverse recovery diode behaviour of AIMDQ75R016M2H G2 has been discussed at V_{gs} off = -5 V and 0 V at T_c = 150°C.



a)



b)

◇ Integral of current between these points defines recovery charge (0 crossing to 10% I_{frm})

$\frac{dI_F}{dt}$ Calculated from 10% of I_{frm} *to 90% of* I_{frm}

$\frac{dV_{ds}}{dt}$ Calculated from 20% of V_{DS} *to 90% of* V_{DD}

Figure 23 **(a) Body diode reverse recovery current waveforms of CoolSiC™ 750 V G2 (AIMDQ75R016M2H) at T_c = 150°C with V_{GS} off = -5 V and 0V respectively (b) Body diode reverse recovery and switching speed comparison of CoolSiC™ 750 V G2 (AIMDQ75R016M2H) at T_c = 150°C with V_{GS} off = -5 V and 0 V respectively**

In Figure 23, the reverse recovery diode behavior at T_c = 150°C at V_{gs} off = 0 V AIMDQ75R016M2H G2 shows:

- Similar or slightly lower forward recovery charge compared to V_{gs} off =-5 V
- Slightly softer diode recovery behavior compared to V_{gs} off =-5 V
- No sign of parasitic turn on compared to V_{gs} off =-5 V
- Similar dV_{ds}/dt compared to V_{gs} off =-5 V

Figure 24 shows the CoolSiC™ 750 V G2 typ. gate threshold voltage as a function of junction temperature

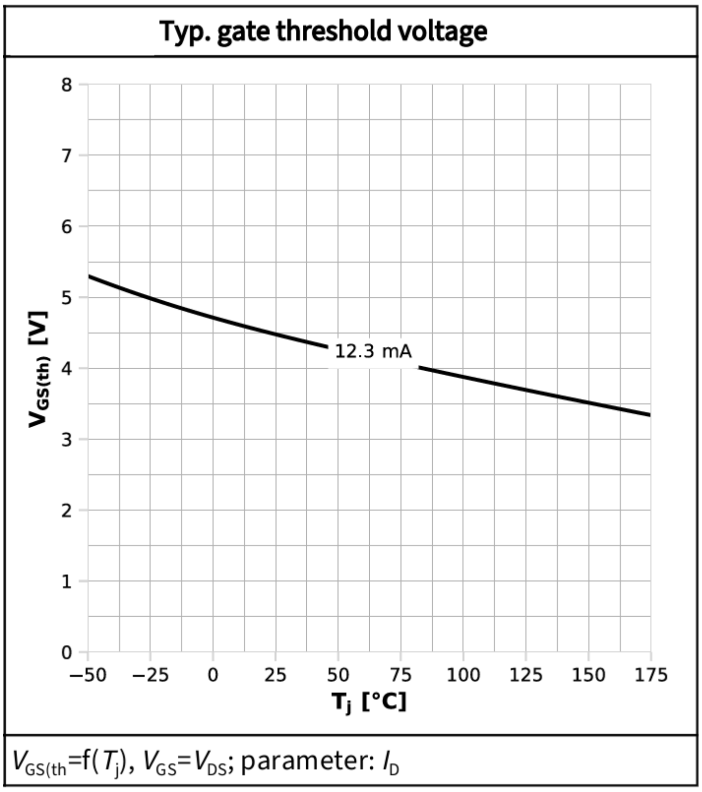


Figure 24 Typ. gate threshold voltage as a function of junction temperature

With higher $V_{GS\,(th)}$, CoolSiC™ 750 V G2 MOSFETs are fully immune to parasitic turn on with very good safety margins among other vendors, as temperature increases safety margin further increases as the dV_{ds}/dt goes lower.

7 Efficiency analysis relative to switching frequency

This section provides the efficiency analysis and comparison of CoolSiC™ 750 V G2 and G1 MOSFETs vs Vendor 1 considering the measured switching losses (illustrated in Section 5, Figure 19).

7.1 Hard switching topology: 3.5 kW totem pole PFC rectifier

In hard-switching applications, such as totem pole PFC rectifier, the relationship between efficiency and switching frequency is inherently inverse. Higher switching frequencies allow for smaller passive components (inductors, capacitors), reducing system size. However, each switching transition incurs energy loss due to voltage-current overlap during turn-on/turn-off events. As frequency increases, these losses accumulate proportionally, significantly reducing overall efficiency. While lower frequencies minimize switching losses, they necessitate bulkier components.

Design engineers must thus balance efficiency, thermal management, and system size, often optimizing frequency to meet application-specific priorities, such as minimizing losses in high-power scenarios or prioritizing compactness in portable devices.

In Figure 25, a relative efficiency comparison has been shown considering the measured switching losses (E_{on}+E_{off}) as illustrated in Section 5, Figure 19 for worst case grid input voltage V_{in}=176 V as the switching current will be maximum at minimum input voltage to keep the output power constant.

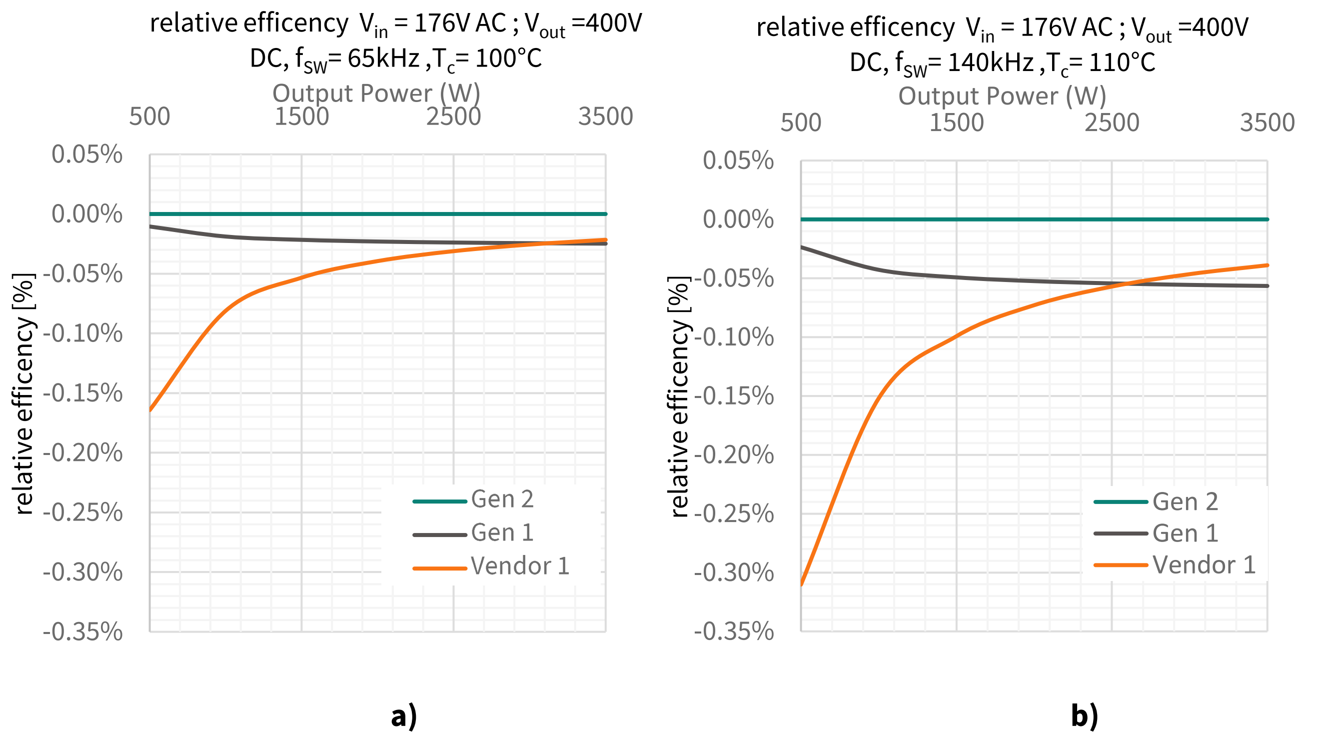


Figure 25 a) Relative efficiency comparison at V_{in} = 170 V at f_{SW} = 65kHz (b) Relative efficiency comparison at V_{in} = 170 V at f_{SW} = 140 kHz

It shows that the CoolSiC™ 750 V G2 MOSFET outperforms relatively compared to

- CoolSiC™ 750 V G1 MOSFET by approx. 0.035 to 0.06% at f_{sw} =65 kHz and f_{sw} =140 kHz respectively
- Vendor 1 by approx. 0.15 to 0.30% at f_{sw}=65 kHz and f_{sw}=140 kHz respectively

The advantage from CoolSiC™ 750V G2 MOSFETs can be translated into achieving high power density by increasing the switching frequency and/or improving the efficiency even further.

7.2 Soft-switching topology: 3.5 kW LLC converter

In soft-switching applications, such as LLC converter the impact on efficiency versus switching frequency is generally more favorable compared to hard switching applications. Soft-switching techniques, such as zero-voltage switching (ZVS) and zero-current switching (ZCS), significantly reduce the overlap between voltage and current during transitions, thereby minimizing switching losses. As the switching frequency increases, the efficiency remains relatively higher compared to hard switching because the energy dissipated during each transition is lower (only in the form of turn of losses). Nonetheless, in soft-switching applications, the ability to maintain higher efficiency at elevated switching frequencies makes them particularly advantageous for high-performance power electronics systems.

In Figure 26, a relative efficiency comparison has been shown considering the measured switching losses (E_{off} only) as illustrated in Section 5, Figure 19 for f_{sw} =200 kHz and 400 kHz.

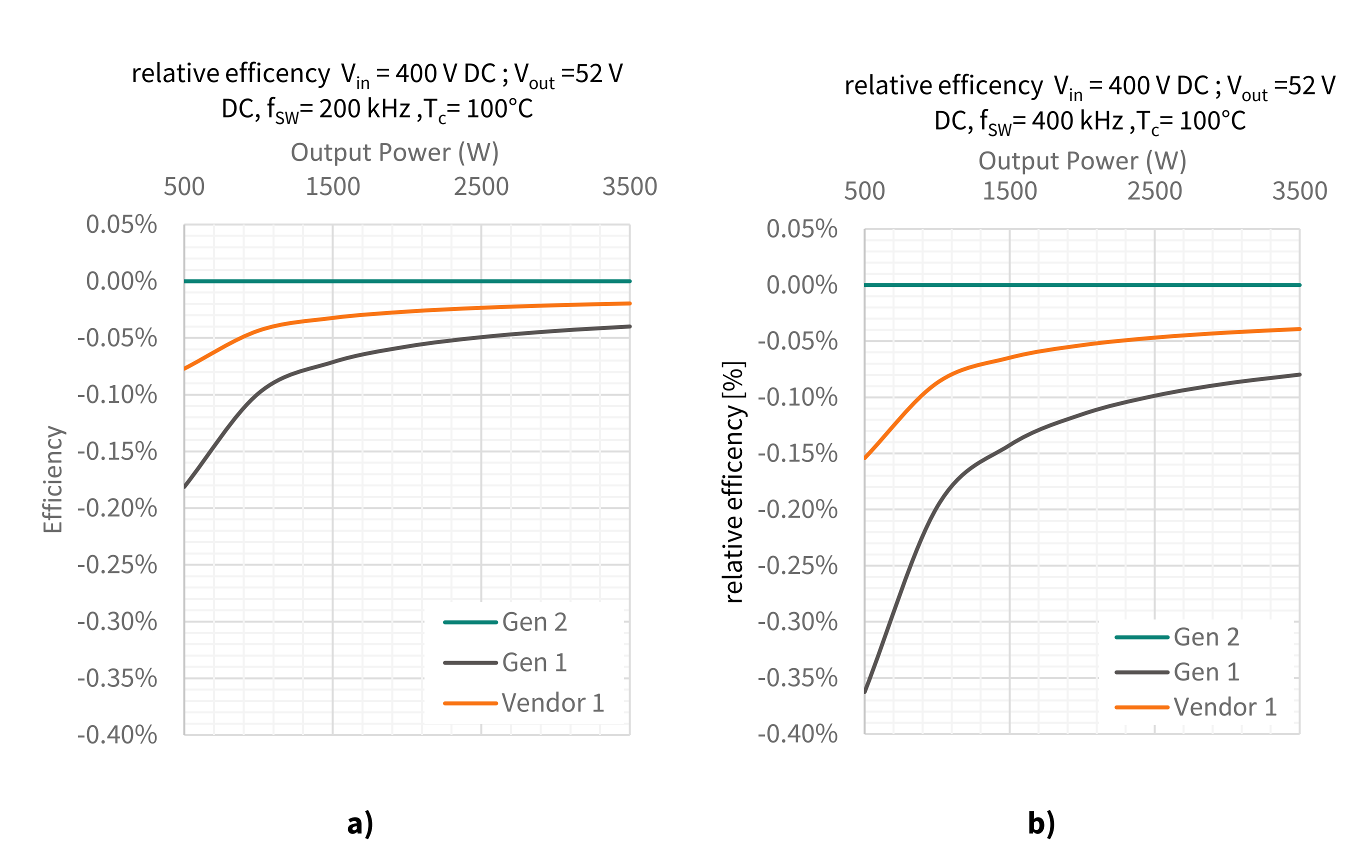


Figure 26 a) Relative efficiency comparison at V_{in} = 400 V DC at f_{sw} = 200 kHz (b) Relative efficiency comparison at V_{in} = 400 V at at f_{sw} = 400 kHz

It shows that the CoolSiC™ 750 V G2 MOSFET outperforms relatively compared to:

- CoolSiC™ 750 V G1 MOSFET by approx. 0.08 to 0.15% at f_{sw} =200 kHz and f_{sw} =400 kHz respectively
- Vendor 1 by approx. 0.18 to 0.35% at f_{sw} =200 kHz and f_{sw} =400 kHz respectively

The advantage from CoolSiC™ 750 V G2 MOSFETs can be translated into achieving high-power density by increasing the switching frequency and/or improving the efficiency even further.

References

Note: Contact Infineon support to obtain the documents that are not publicly available.

[1] Infineon Technologies AG: CoolSiC™ MOSFET 1200 V G2 in a TO263-7 (D^2PAK) package application note; Available online

[2] Infineon Technologies AG: CoolSiC™ 650 V G2 MOSFET application note (AN112138); Available online

[3] Spurious Turn-On Investigation for SiC MOSFETs In hard-switched half-bridges; Available online

[4] Infineon Technologies AG: CoolSiC™ totem-pole PFC design guide and power loss modelling application note (AN_2212_PL52_2301_194003); Available online

[5] Infineon Technologies AG: Automotive high-voltage electronic fuse demonstrator Application note (UM_2211_PL52_2212_165057); Available online

[6] Infineon Technologies AG: Guidelines for CoolSiC™ MOSFET gate drive voltage windowapplication note; Available online

[7] Infineon Technologies AG: Resonant LLC Converter: Operation and Design application note; Available online

[8] Infineon Technologies AG: 3300 W CCM bi-directional totem pole with 650 V CoolSiC™ and XMC™

[9] application note (AN_1911_PL52_1912_141352); Available online

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