User guide for REF-CAV280KMSICINV

Reference design of a 280 kW SiC eCAV traction inverter power stage

About this document

Scope and purpose

This user guide provides an overview of the power kit REF-CAV280KMSICINV including its main features, key data, pin assignments, mechanical dimensions, and corresponding performance. The reference kit REF-CAV280KMSICINV is a traction inverter power stage for commercial vehicles with a nominal output power of 280 kW.

REF-CAV280KMSICINV includes the EconoDUAL™ 3 module FF1MR12MM1HP_B11, the current sensor TLE4973 and the EiceDRIVER™ gate driver 1ED3321MC12N together with the full-bridge transformer driver IC 2EP130R for the gate driver supply. The combination of these products helps customers to evaluate them in one design and experience the interaction between the products.

Intended audience

This user guide is intended for all technical specialists working on high-voltage traction inverters and those interested in understanding how Infineon products such as CoolSiC™ MOSFET power modules, EiceDRIVER™, and XENSIV™ current sensors work under application conditions.

Reference kit

Infineon power modules are mounted on a heatsink with a press-in PCB and the current sensors are pre-assembled on the busbar. This compact design shows a form factor similar to a commercial design.

Note: Boards do not necessarily meet safety, EMI, and quality standards (for example UL, CE) requirements.

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Safety precautions

Note: Please note the following warnings regarding the hazards associated with development systems.

Table 1 Safety precautions

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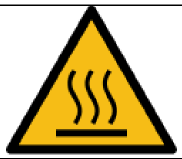
	**Warning:** *The DC link potential of this board is up to 1000 VDC. When measuring voltage waveforms by oscilloscope, high-voltage differential probes must be used. Failure to do so may result in personal injury or death.*
	**Warning**: *The evaluation or reference board contains DC bus capacitors, which take time to discharge after removal of the main supply. Before working on the drive system, wait 5 minutes for capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	**Warning:** *The evaluation or reference board is connected to the grid input during testing. Hence, high-voltage differential probes must be used when measuring voltage waveforms by an oscilloscope. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	**Warning:** *Remove or disconnect power from the drive before you disconnect or reconnect wires or perform maintenance work. Wait five minutes after removing power to discharge the bus capacitors. Do not attempt to service the drive until the bus capacitors have discharged to zero. Failure to do so may result in personal injury or death.*
	**Caution:** *The heat sink and device surfaces of the evaluation or reference board may become hot during testing. Hence, necessary precautions are required while handling the board. Failure to comply may cause injury.*
	**Caution:** *Only personnel familiar with the drive, power electronics and associated machinery should plan, install, commission and subsequently service the system. Failure to comply may result in personal injury and/or equipment damage.*
	**Caution:** *The evaluation or reference board contains parts and assemblies sensitive to electrostatic discharge (ESD). Electrostatic control precautions are required when installing, testing, servicing or repairing the assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to the applicable ESD protection handbooks and guidelines.*
	**Caution:** *A drive that is incorrectly applied or installed can lead to component damage or reduction in product lifetime. Wiring or application errors such as undersizing the motor, supplying an incorrect or inadequate AC supply, or excessive ambient temperatures may result in system malfunction.*
	**Caution:** *The evaluation or reference board is shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials that are unnecessary for system installation may result in overheating or abnormal operating conditions.*

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1 The power kit at a glance

This user guide provides information about Infineon's 280 kW power kit solution for traction applications. The power kit comprises a power conversion block with CoolSiC™ MOSFET power modules, a gate driver PCB with Infineon's latest EiceDRIVER™ gatedriver, XENSIV™ current sensors, automotive qualified DC-link capacitors, and a liquid cooling unit (Figure 1).

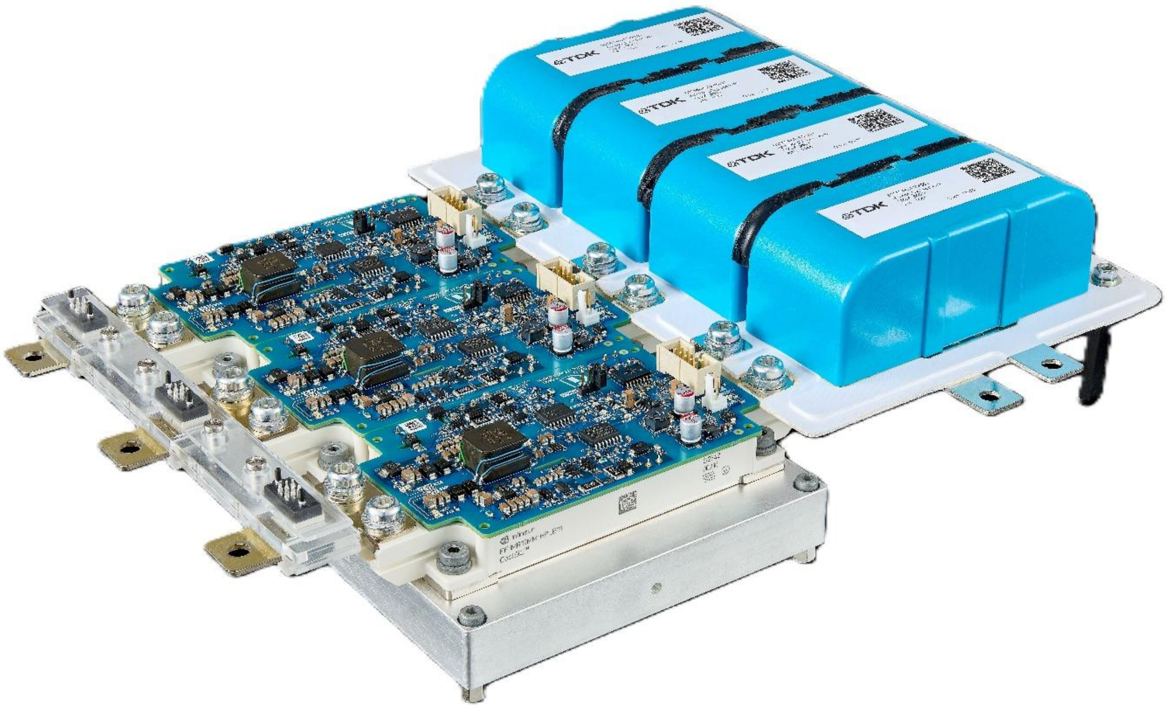

Figure 1 EconoDUAL™ 3 SiC power kit

1.1 Scope of supply

- 3x EconoDUAL™ 3 CoolSiC™ MOSFET dual modules 1200 V: FF1MR12MM1HP_B11
- 3x Gate driver boards: EVAL-FFXMR12MM1H
- 3x XENSIV™ current sensors: TLE4973
- 4x DC-link capacitors mounted on a busbar
- 1x liquid cooling unit

1.2 Block diagram

Figure 2 shows a block diagram of the components and materials. NTC, phase current measurements, and power supply for the gate driver board are isolated. The power stage including the gate driver boards can be driven with a control card/interface that does not need an isolation interface.

The power stage includes EconoDUAL™3 dual half-bridge modules with CoolSiC™ MOSFET technology inside. Each power module has an NTC to monitor the temperature inside the power device.

Based on a DC/AC 2L-B6I inverter topology, the DC stage is connected to DC-link capacitors through low stray inductive busbars. During operation, the DC link is connected to a HV supply or to a HV battery.

The power kit is cooled by an external cooling unit and a continuous coolant flow temperature of 50°C. The flow rate is 15 l/min (see Table 1).

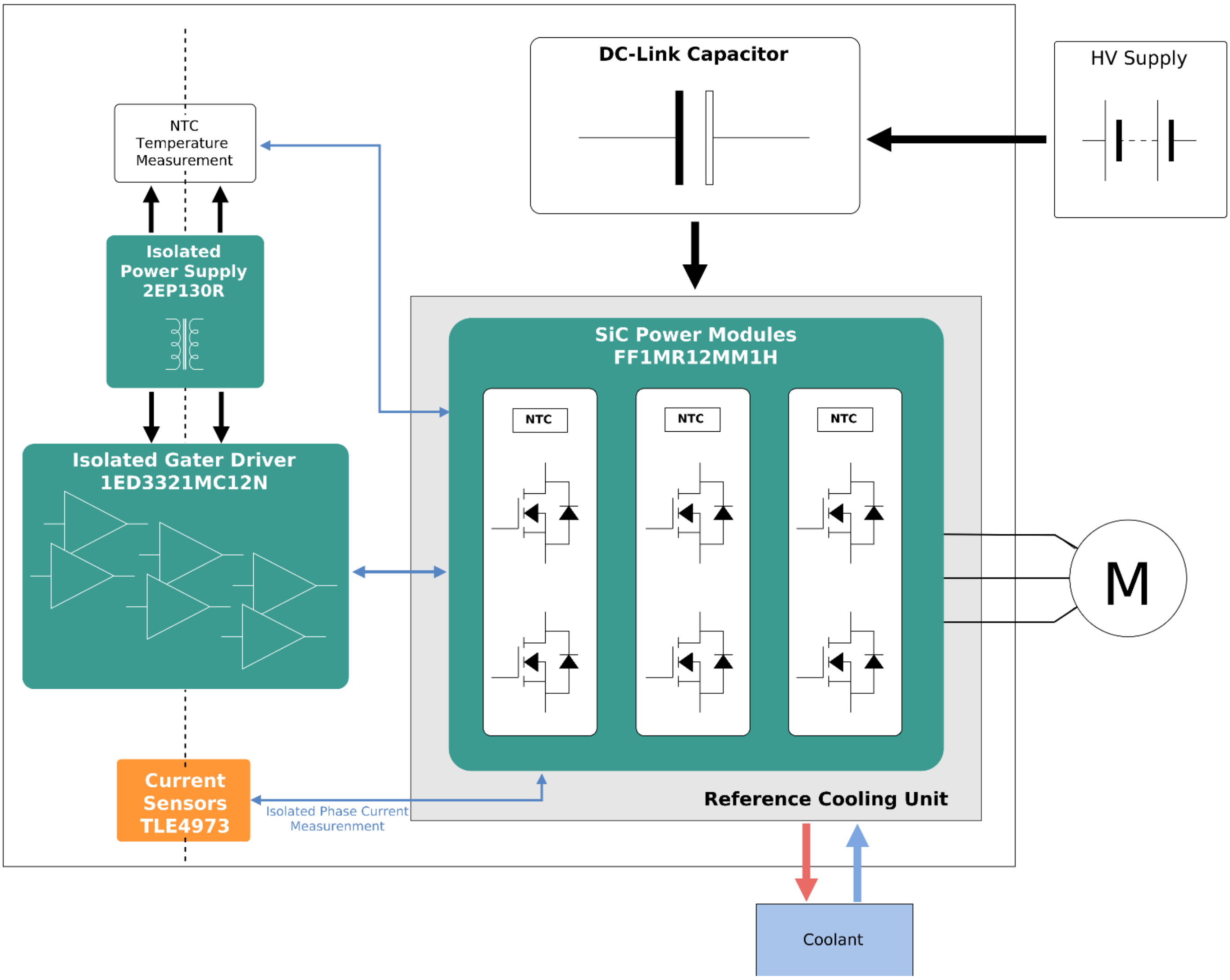

Figure 2 System level block diagram of the EconoDUAL™ SiC power kit

1.3 Main features

- Isolated gate drive units and power supply
- Isolated phase current measurement
- Isolated NTC temperature measurement
- DESAT short-circuit protection

Kit parameters and technical data

Table 1 Kit parameters

Parameter	Unit	Min. value	Nominal value	Max. value
DC-link voltage	V	750	800	850
Switching frequency	kHz	5	10	15
Inverter output current	A_{rms}	0	400	600
Output frequency	Hz	0		1000
Coolant flow temperature	°C	25	50	65
Flow rate	l/min	10	15	30

2 Driver board

This section provides an overview of the gate driver board used within the EconoDUAL™ 3 SiC power kit and describes its functional role in the overall inverter system.
The driver board ensures proper switching of the CoolSiC™ MOSFET power modules and provides the required interfaces for control, monitoring, and protection.

Figure 3 illustrates the functional architecture of the gate driver evaluation board (EVAL-FFXMR12MM1H), highlighting the main functional units and their interactions. The figure shows the partitioning into high-side and low-side gate driver stages, auxiliary power supply, gate voltage generation, temperature sensing, and interface circuitry.

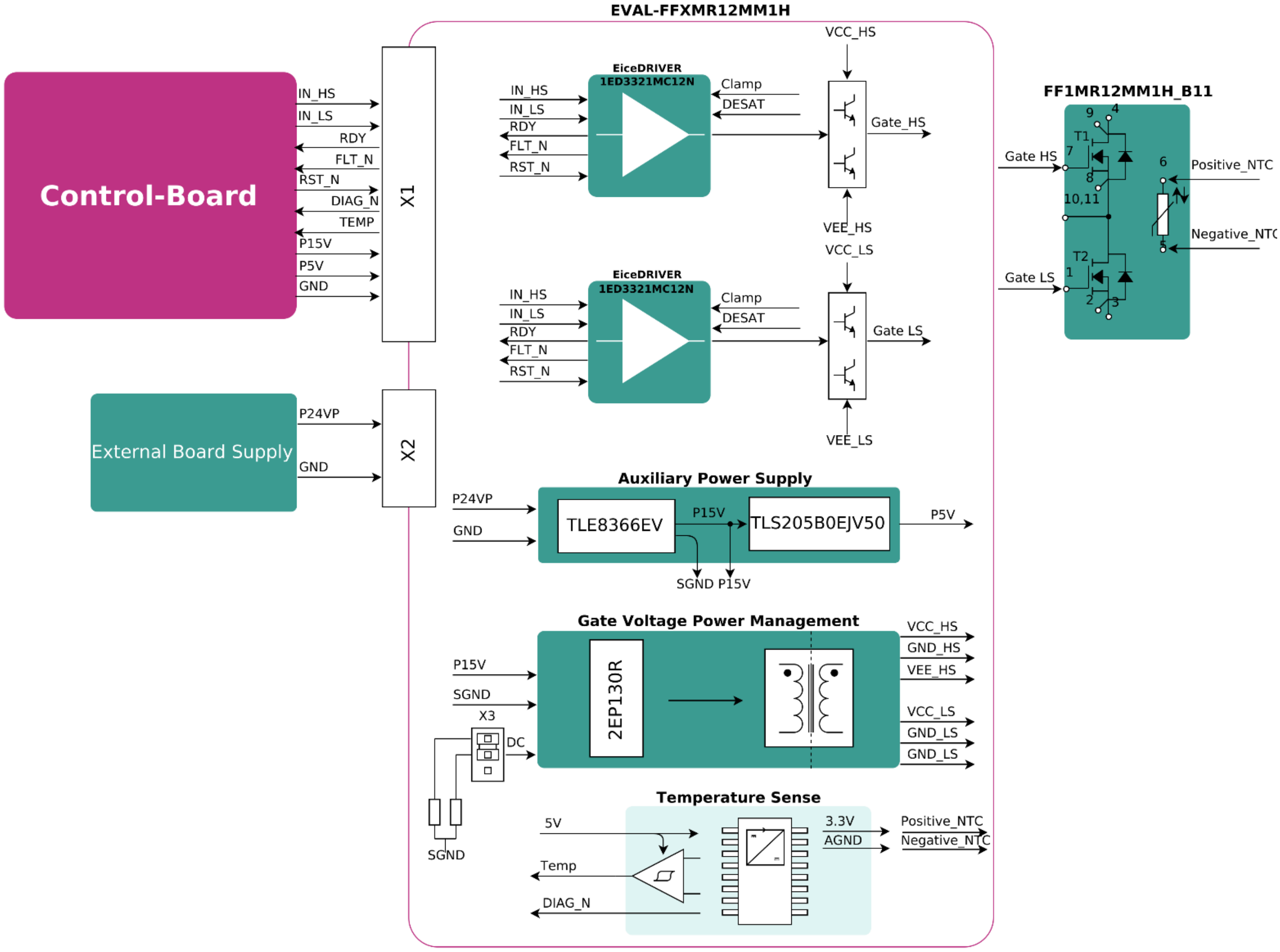

Figure 3 EVAL-FFXMR12MM1H: Overview of the driver evaluation board showing major functional units and signal interfaces

The board is supplied via an external 24 V source connected to interface X2 and is controlled through interface X1. In addition to PWM control signals, status and diagnostic signals are exchanged with the external controller, enabling monitoring of system operation and fault conditions.

2.1 Main features

The gate driver board is designed to support reliable operation of SiC MOSFET power modules under application-relevant conditions. Its main features include:

- Isolated gate driver units for high-side and low-side switching devices
- Optional booster stage for increased peak gate current capability
- Integrated auxiliary power supply for generation of 15 V and 5 V supply rails
- Isolated gate drive voltage generation with selectable output levels
- Integrated NTC-based temperature sensing
- DESAT-based short-circuit protection
- Active Miller clamping to prevent parasitic turn-on

These features enable efficient switching performance while ensuring safe and robust system operation.

2.1.1 Driver board parameters and operating conditions

The following parameters define the operating conditions of the gate driver board within the inverter system. These values shall be considered during system setup, integration with the power stage, and performance evaluation. Table 2 summarizes the key electrical characteristics relevant for operation and testing.

Table 2 Driver board operating conditions and electrical characteristics

Parameter	Unit	Min. value	Nominal value	Max. value
External power supply	V	15	24	32
PWM logical level voltages	V		5	
Negative output gate voltage V_{EE2}	V		-5 or -3	
Positive output gate voltage V_{CC2}	V		+15 or +18	
Output gate current peak I_{peak}	A	-30		40
Switching frequency	kHz		15	
Drain–Source Voltage	V			1200
Operation Temperature	°C	-40		85

2.1.2 Application-specific configuration guidelines

The gate driver board can be operated with different EconoDUAL™ 3 power modules. The required gate resistor values and configuration parameters depend on the selected module and the intended operating conditions. Table 3 provides typical configuration parameters for supported power modules.

Table 3 Recommended configuration parameters for supported power modules

Power module	Recommended $R_{G(on)}$, $R_{G(off)}$ [Ω]	Package	Note
FF1MR12MM1H_B11	3.3, 3.9	2512 / 6432	Standard assembled

In addition to the application-level parameters, certain design-related characteristics of the driver board are provided for reference. These values originate from the implemented hardware design and may support understanding of insulation coordination and layout constraints, as summarized in Table 4.

Table 4 PCB design and insulation characteristics (reference values)

Property	Unit	Value	Note
Pollution degree		II	
Voltage	V	1200	
Minimum Creepage	mm	6	IEC 60664-1: Table F.4 [1]
Minimum Clearance	mm	0.25	IEC 60664-1: Table F.2 [1]

2.2 System design

This section describes the functional architecture of the gate driver board and its main subsystems in the context of inverter operation. The design is structured into several functional blocks that ensure proper signal processing, voltage supply generation, and safe operation of the power semiconductors.

The main functional elements include:

- Gate driver stages for high-side and low-side devices
- Control and communication interface
- Auxiliary power supply and isolated gate voltage generation
- Temperature sensing circuitry

These subsystems interact to ensure reliable switching performance and proper monitoring of system conditions.

Figure 4 shows the driver board from the top side with highlighted functional areas. The identified sections provide a visual reference for the functional blocks described in the following subsections. Test points are also indicated to support measurement and system evaluation.

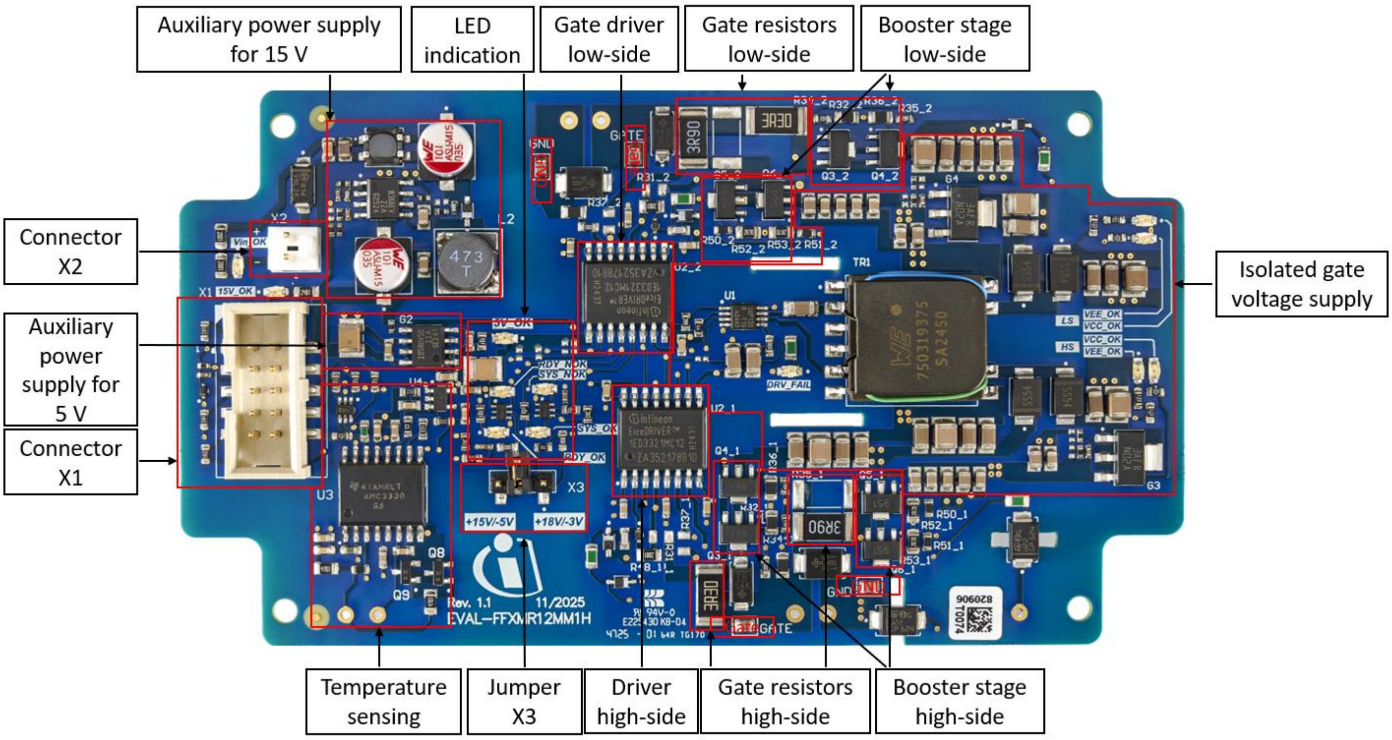

Figure 4 **Top-side view of the driver board with highlighted functional areas**

2.2.1 Gate driver high-side and low-side

The gate driver stages are responsible for driving the CoolSiC™ MOSFET devices in a half-bridge configuration. Based on the PWM input signals, the drivers generate the required gate control signals to ensure proper switching under varying operating conditions. Figure 5 shows the gate driver circuitry for the high-side and low-side stages.

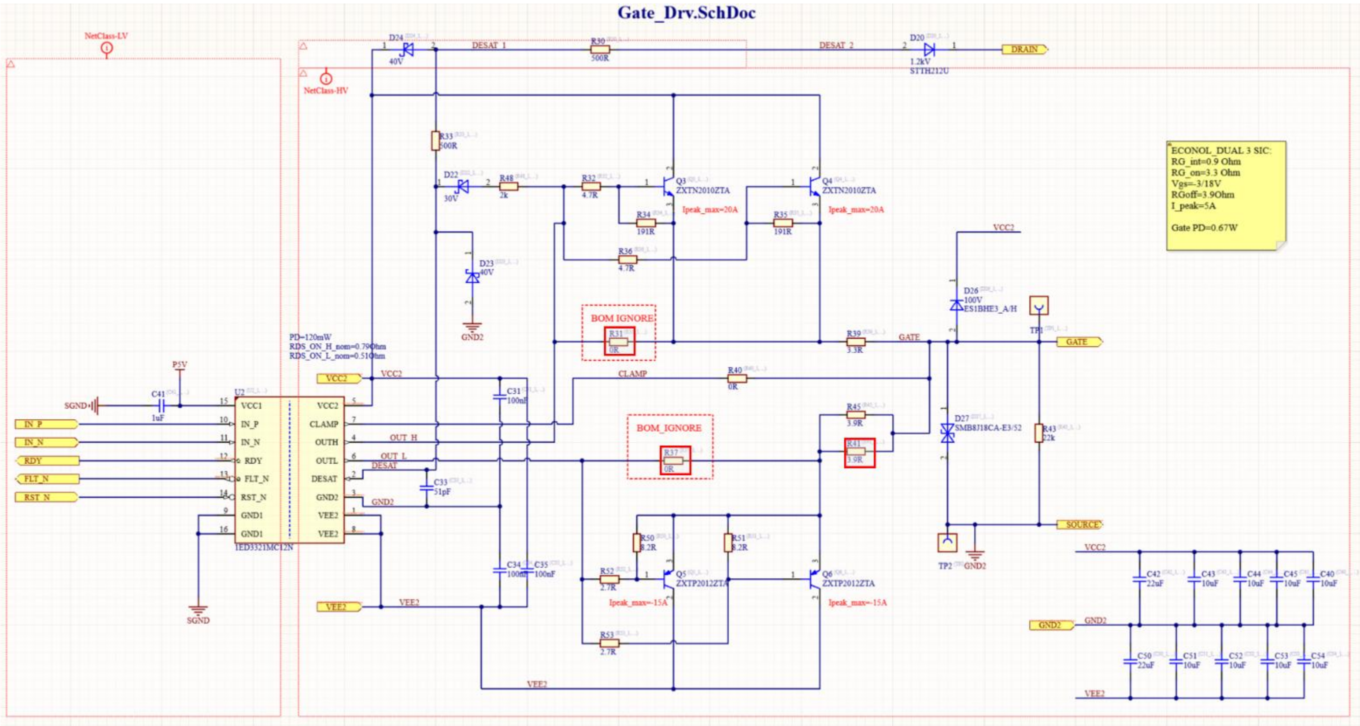

Figure 5 **Gate driver circuitry for high-side and low-side stages**

For enhanced switching performance, an optional booster stage can be used to increase the peak gate current, enabling faster turn-on and turn-off transitions. Operation without the booster stage is also possible for applications with moderate switching requirements.

To ensure safe operation, the gate driver incorporates:

- DESAT detection for short-circuit and overcurrent protection
- Controlled soft turn-off during fault conditions
- Active Miller clamping to suppress parasitic turn-on effects

In addition, status signals such as READY and FAULT are transmitted to the control interface to provide feedback on the driver state.

2.2.2 Interface, connector and indicator

The driver board provides electrical interfaces for power supply and system control through dedicated connectors.

- Interface **X2** supplies the board with an external 24 V DC voltage
- Interface **X1** connects the board to the external control system

Through interface X1, the following signals are exchanged:

- PWM control signals for high-side and low-side switching
- Reset and control signals
- Status signals such as READY and FAULT
- Temperature measurement and diagnostic signals

Figure 6 illustrates the control and interface connections of the driver board.

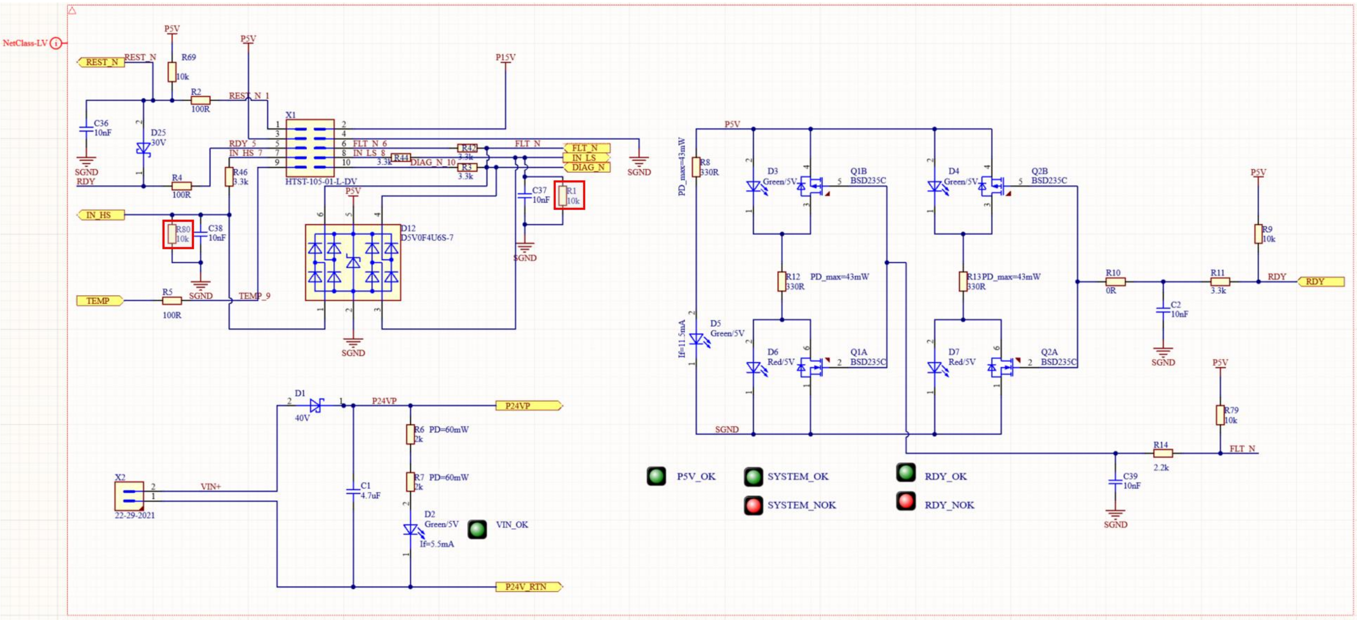

Figure 6 Control and interface connections of the driver board

Table 5 provides the pin assignment and signal description of the X1 interface.

Table 5 Control interface (X1) pin assignment and signal description

PIN	Label	Function
1	REST_N	Input signal to reset gate drive unit, low active
2	P15V	+ 15 V local supply voltage
3	P5V	+ 5 V local supply voltage
4	SGND	System Ground
5	RDY	Output Ready signal of gate drive unit
6	FLT_N	Output Fault signal of gate drive unit, low active
7	IN_HS	PWM high-side control signal
8	IN_LS	PWM low-side control signal
9	TEMP	NTC temperature measurement signal
10	DIAG_N	Temperature’s measurement status indication signal

The board is also equipped with status LEDs indicating key operating conditions such as power supply status and system readiness. These indicators support quick diagnostics and verification of correct system operation during setup and testing.

2.2.3 Auxiliary power supply and gate voltage generation

The gate driver board includes an internal auxiliary power supply that generates the required voltage levels from the external 24 V input.

- A buck converter provides the internal 15 V supply
- A linear regulator generates the 5 V logic supply

For galvanically isolated gate drive operation, a dedicated transformer-based supply is implemented, providing the isolated gate voltages required for the MOSFET devices. Figure 7 shows the auxiliary and isolated gate drive power supply architecture.

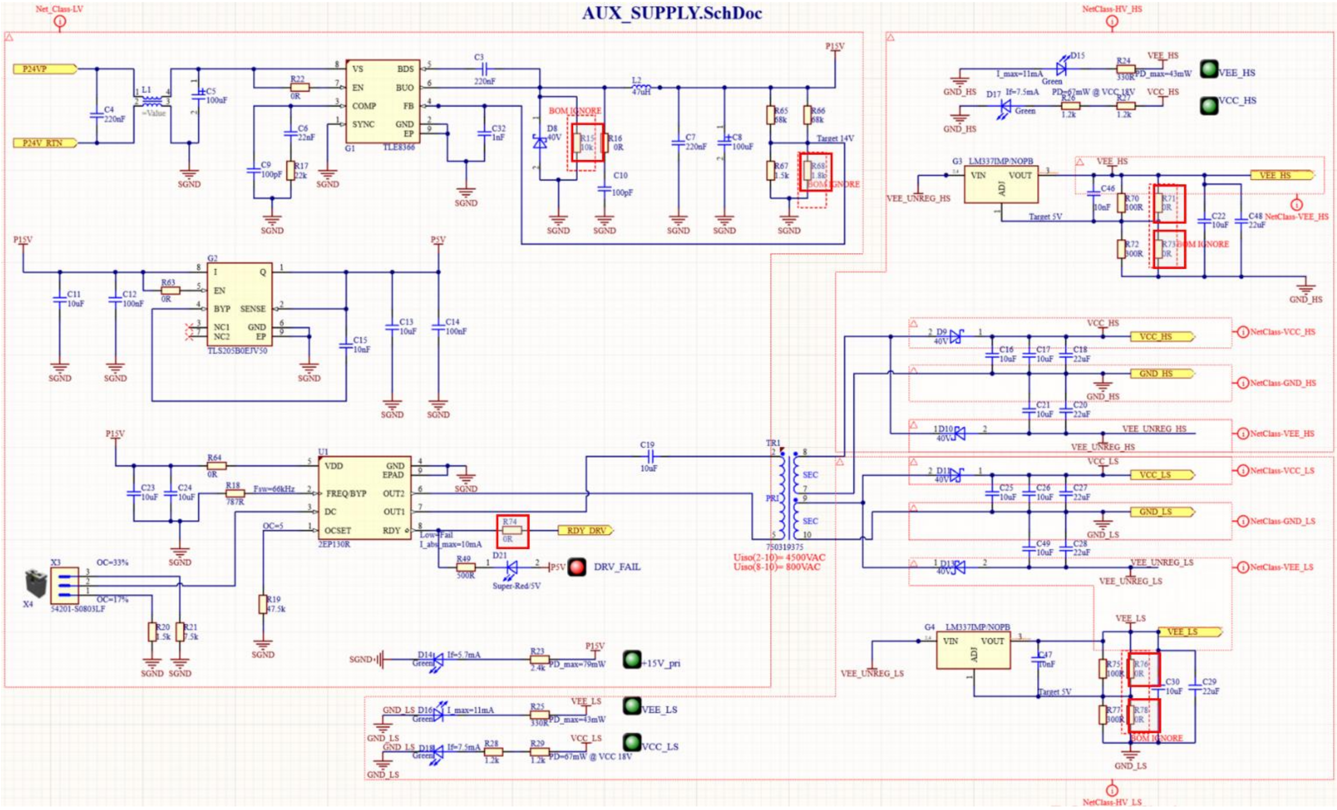

Figure 7 **Auxiliary and isolated gate drive power supply architecture**

The gate voltage levels can be configured via jumper settings, allowing selection between different operating voltage ranges (e.g., −3 / +18 V or −5 / +15 V), depending on application requirements.

2.2.4 NTC Temperature sensing

Temperature monitoring is implemented using an NTC sensor integrated into the power module. The measurement signal is processed through an isolated amplifier to ensure safe signal transmission between the high-voltage domain and the control electronics. Figure 8 shows the NTC-based temperature sensing circuit.

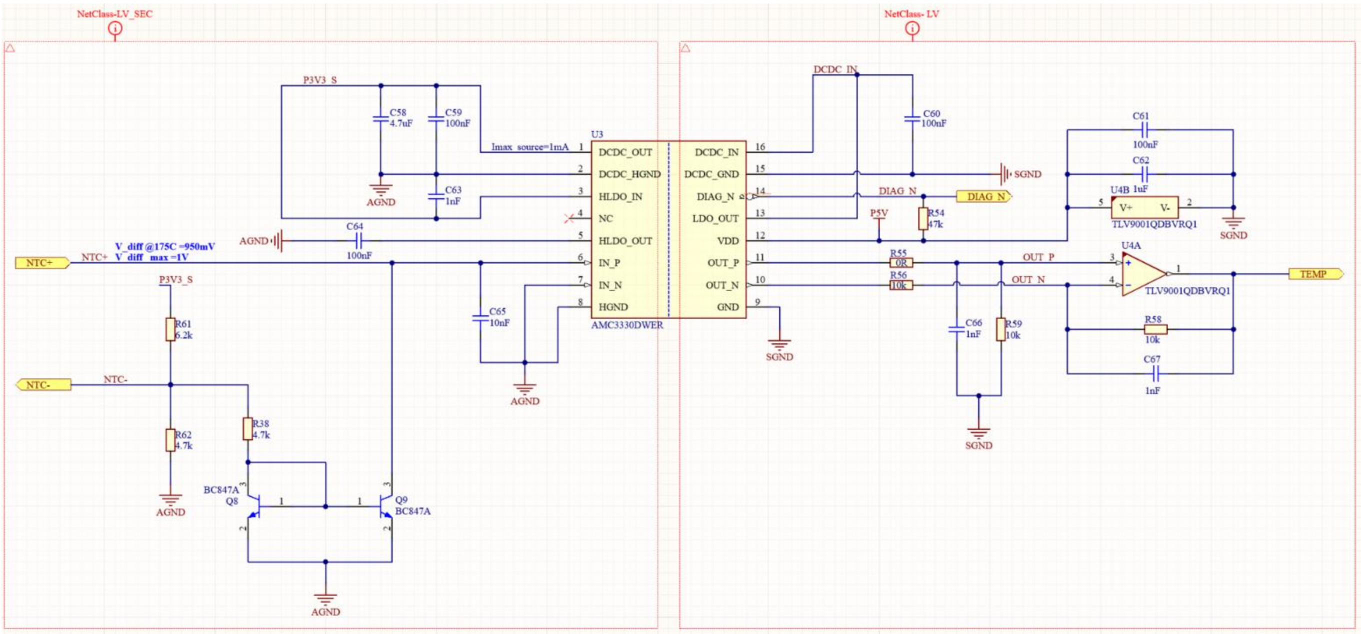

Figure 8 NTC-based temperature sensing circuit

The sensing system provides:

- Continuous monitoring of the module temperature
- Signal conditioning and amplification
- Diagnostic feedback indicating sensor status

The processed temperature signal is transmitted to the external controller via the interface, enabling system-level thermal monitoring and protection.

2.3 Mechanics

This section describes the mechanical integration of the gate driver board onto the EconoDUAL™ 3 power module by using press-fit technology.

The electrical and mechanical connection between the driver board and the power module is realized via press-fit pins. This mounting approach enables a reliable and low-inductance connection while supporting a compact system design.

Figure 9 illustrates the force–path characteristic during the press-in process. The curve represents the force required as a function of insertion depth, including the initial contact and the final seating of the board.

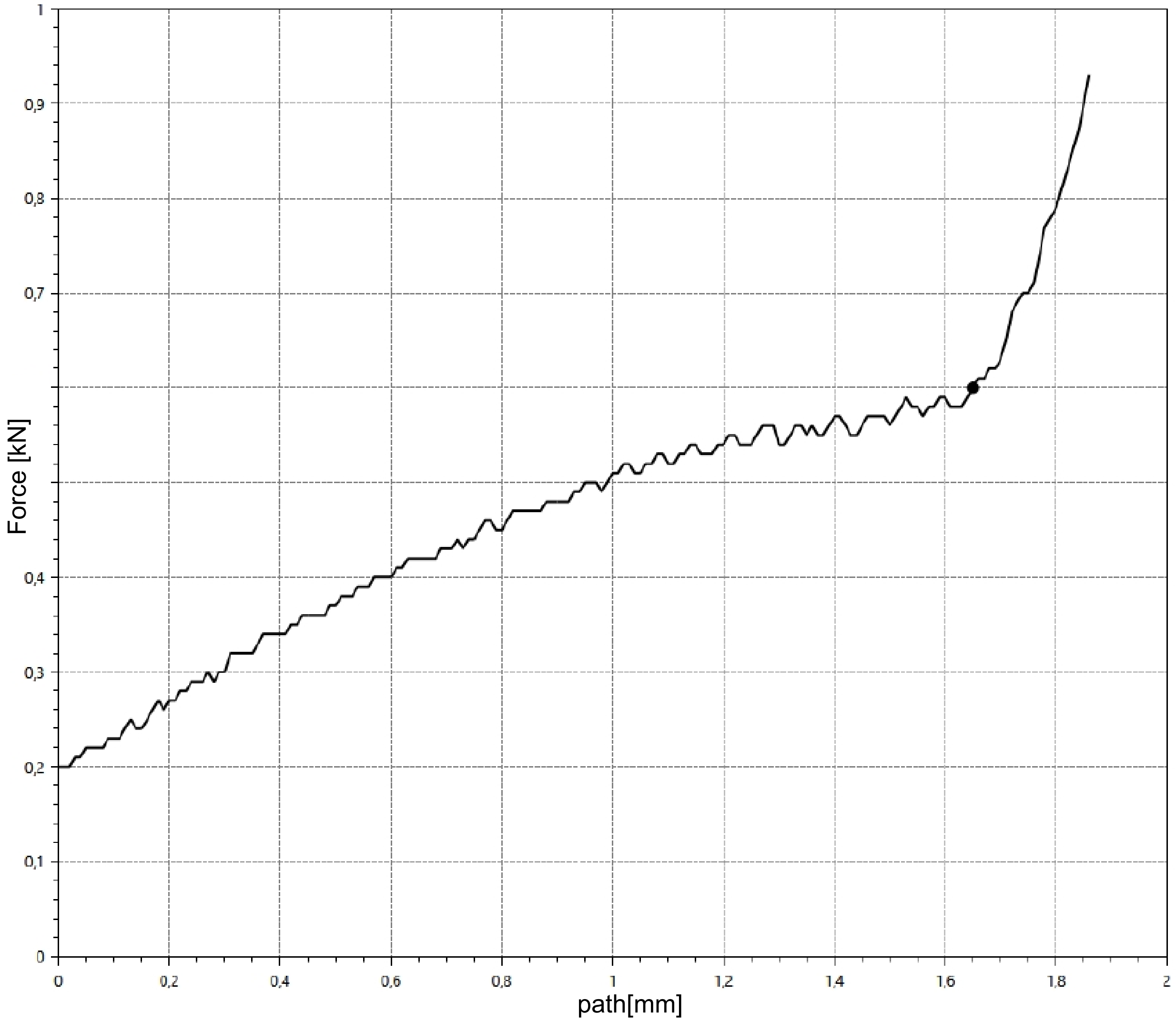

Figure 9 **Press-fit insertion force versus path characteristic**

During assembly, the contact between the PCB and the module frame is reached at approximately 600 N. The press-fit connection fulfills the mechanical requirements specified for EconoDUAL™ 3 modules [2], including the minimum required insertion force of 770 N.

3 Inverter system testing and functional description

This section describes the procedures and conditions used to validate the operational behavior of the EconoDUAL™ 3 SiC power kit. The focus is on verifying the switching performance of the power modules as well as the functionality of the gate driver board under application-relevant conditions.

The evaluation process starts with double-pulse testing to assess dynamic switching behavior and determine suitable operating parameters such as dead time. Subsequently, the inverter system is operated in PWM mode to evaluate performance under steady-state conditions.

3.1 Starting the inverter system

Before applying high-voltage operation, several preparation steps shall be performed to ensure safe and reliable system operation.

A visual inspection of the system is recommended prior to commissioning. All components and connections should be checked for completeness, correct mounting, and absence of visible damage. Attention should be paid to connector alignment and the mechanical stability of the assembled setup.

The gate driver board must be supplied with an external 24 V DC source, and proper voltage levels for all internal supply rails should be verified. In addition, all control and interface connections between the gate driver board and the external control system should be confirmed.

Before applying high voltage to the DC link, the correct switching behavior of the gate drivers should be validated. For this purpose, PWM signals can be applied and the corresponding gate signals should be monitored using appropriate measurement equipment.

Only after verifying correct low-voltage operation should the system be connected to a high-voltage supply. During operation, appropriate safety measures must be ensured, including the use of suitable measurement probes and properly rated loads.

3.2 Double-pulse tests

Double-pulse testing is used to evaluate the dynamic switching behavior of the CoolSiC™ MOSFET devices and to determine suitable operating parameters under application-relevant conditions.

The test is performed under defined electrical and thermal conditions, including DC-link voltage, load current, gate resistance, and junction temperature. These parameters influence switching characteristics such as voltage overshoot, current slopes, and switching losses.

The double-pulse tests are performed under the following conditions: DC-link voltage V_{DC} = 800 V, load current I_D = 500 A, junction temperature T_j = 175 °C, and a dead time of t_{dead} = 500 ns. Variations in gate resistance values are indicated in the respective figure captions.

The measured waveforms illustrate the turn-on and turn-off behavior of the devices for different gate voltage configurations.

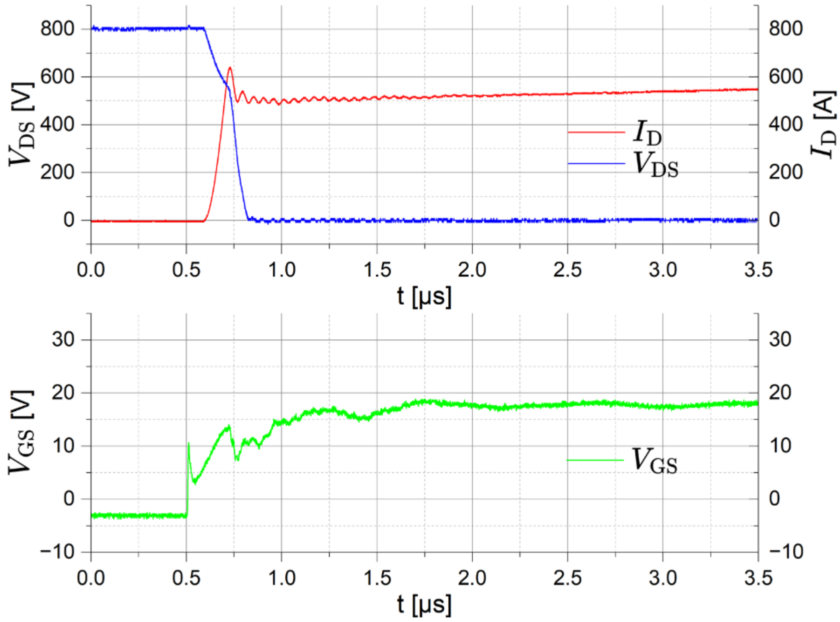

Figure 10 Double-pulse test: turn-on behavior ($R_{G(on)}$ = 3.3 Ω, V_{GS} = −3 / +18 V)

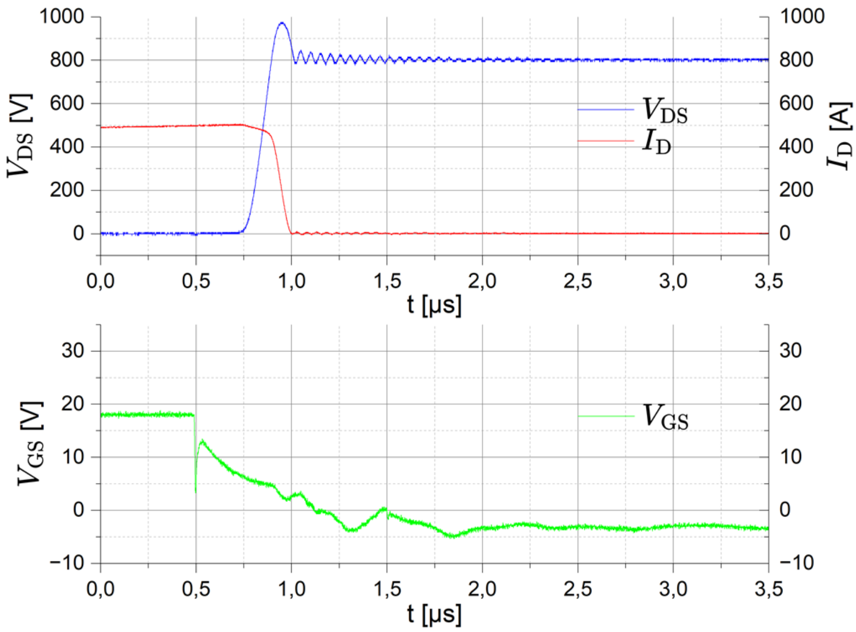

Figure 11 Double-pulse test: turn-off behavior ($R_{G(off)}$ = 3.9 Ω, V_{GS} = −3 / +18 V)

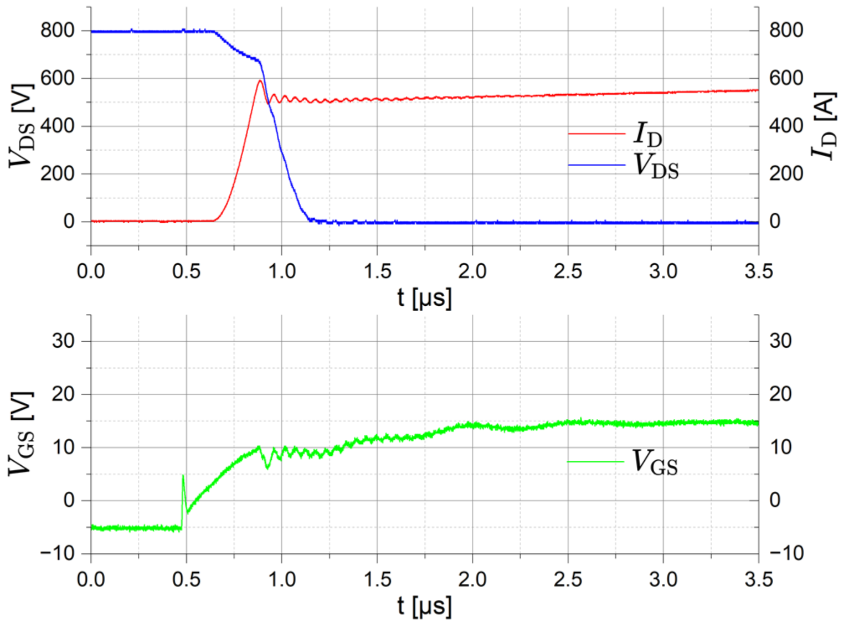

Figure 12 Double-pulse test: turn-on behavior ($R_{G(on)}$ = 6.8 Ω, V_{GS} = −5 / +15 V)

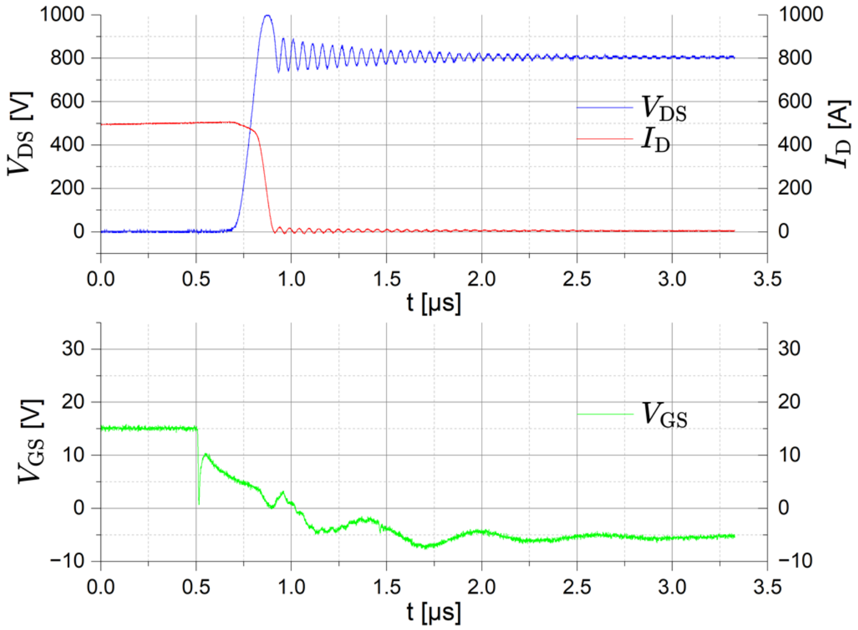

Figure 13 Double-pulse test: turn-off behavior ($R_{G(off)}$ = 3.9 Ω, V_{GS} = −5 / +15 V)

The results demonstrate the switching behavior of the MOSFET devices under representative operating conditions. The applied dead time of t_{dead} = 500 ns was confirmed to provide reliable operation of the half-bridge configuration while minimizing the risk of shoot-through and limiting switching losses.

3.3 Reverse recovery testing

Reverse recovery testing is performed to analyze the commutation behavior of the body diode during switching transients.

The test conditions are comparable to those used for double-pulse measurements, ensuring consistency in the evaluation of switching behavior. In particular, the tests are conducted at V_{DC} = 800 V, I_D = 500 A, T_j = 175 °C, V_{GS} = -3 / +18 V and t_{dead} = 500 ns.

Figure 14 illustrates the reverse recovery current and voltage during diode commutation.

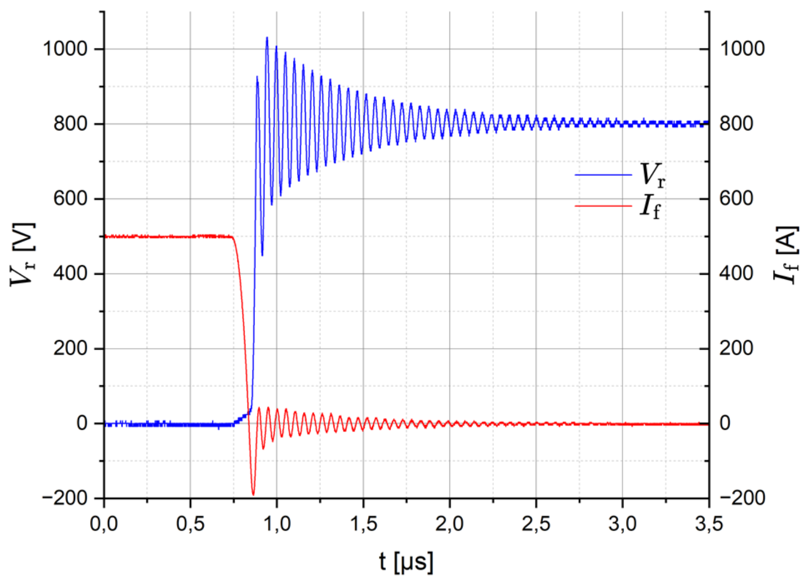

Figure 14 Reverse recovery behavior of the low-side MOSFET body diode

The results demonstrate the reverse recovery characteristics of the diode under application-relevant conditions, including high current and elevated temperature.

The measurements confirm a controlled reverse recovery of the diode, supporting stable and reliable inverter operation during commutation events.

3.4 Short-circuit protection via DESAT detection

Short-circuit protection of the inverter system is implemented using DESAT detection integrated in the gate driver circuitry. This function detects overcurrent or short-circuit conditions and initiates a controlled shutdown of the MOSFET devices.

The DESAT protection operates by monitoring the drain-source voltage of the MOSFET during conduction. In the event of a fault condition, such as a short-circuit event, the drain-source voltage rises above a predefined threshold, triggering the protection mechanism.

The test is carried out under defined operating conditions ($R_{G(on)}$ = 3.3 Ω, $R_{G(off)}$ = 3.9 Ω, V_{DC} = 800 V, V_{GS} = -5 / +15 V) to evaluate the response of the system in the event of a short-circuit fault and to verify the effectiveness of the protection concept. Figure 15 shows the short-circuit response with DESAT detection and soft turn-off.

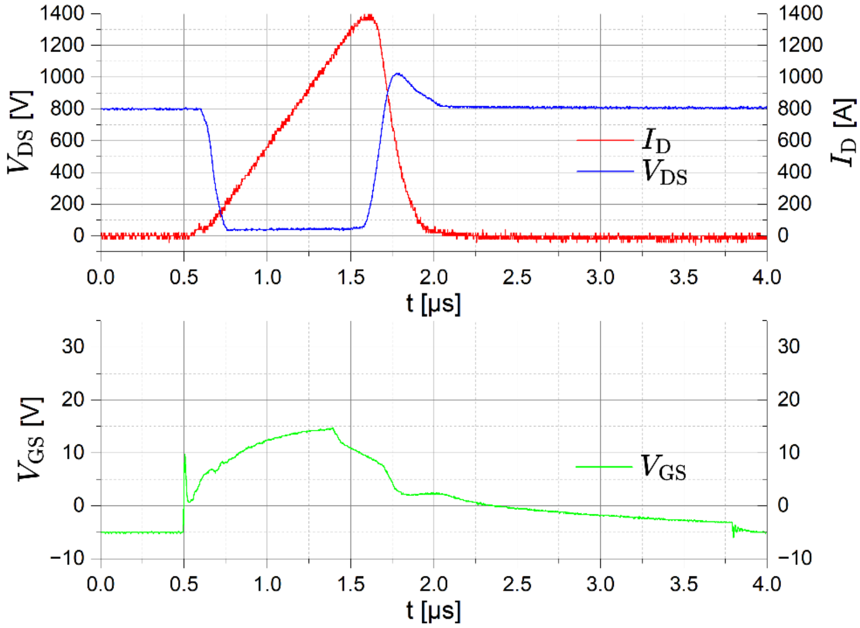

Figure 15 Short-circuit response with DESAT detection and soft turn-off at Tj = 25°C

Upon detection of a short-circuit condition, the gate driver initiates a soft turn-off of the MOSFET. This feature ensures a controlled reduction of the drain current, thereby limiting voltage overshoot across the device.

As shown in Figure 15, the drain-source voltage remains below the maximum rated value of the power module ($V_{DS,max}$ = 1200 V) and reaches approximately 1032 V during the fault event. This demonstrates the effectiveness of the soft turn-off mechanism in preventing excessive voltage stress on the MOSFET.

The timing of the protection response can be observed from the gate-source voltage waveform, where the initiation of the soft turn-off following the short-circuit event is clearly visible. The corresponding reaction time of approximately 0.9 µs confirms proper activation of the protection mechanism.

This controlled turn-off behavior ensures that electrical stress remains within safe limits and contributes to robust and reliable inverter operation under short-circuit conditions.

3.5 Stationary PWM inverter operation system tests

The inverter system is operated in stationary PWM mode to validate its performance under application-relevant operating conditions. This test evaluates the interaction between the power stage and the gate driver during continuous operation and verifies compliance with the defined system requirements.

The operating conditions and performance targets considered for the PWM inverter operation are summarized in Table 6.

Table 6 Technical Requirements for PWM inverter operations

Parameter	Symbol	Unit	Value
DC Link Voltage	V_{DC}	V	800
Output Current at nominal load	$I_{N,rms}$	Arms	400
Output Current at high load	$I_{HL,rms}$	Arms	600
Maximum Output current peaks	$I_{max,rms}$	Arms	800
Voltage slopes	du/dt	V/ns	<15
Switching frequency	f_{sw}	kHz	10-15
Throttled frequency	$f_{sw,d}$	kHz	8
Flow Rate of Coolant	V	l/min	15
Coolant Temperature	T_{inlet}	°C	40
Maximum Terminal Temperature	$T_{term,max}$	°C	90

Typical operating conditions for traction applications are considered, including a DC-link voltage of approximately V_{DC} = 800 V and output currents representative of nominal and high-load operation. The switching frequency is selected in the range of 10 kHz to 15 kHz, with the possibility of reduction at elevated thermal load conditions.

Key evaluation criteria include:

- Achievable output current under defined thermal conditions
- Voltage overshoot across the MOSFET devices
- Influence of dead time on system performance
- Compliance with voltage slope requirements (dV/dt)

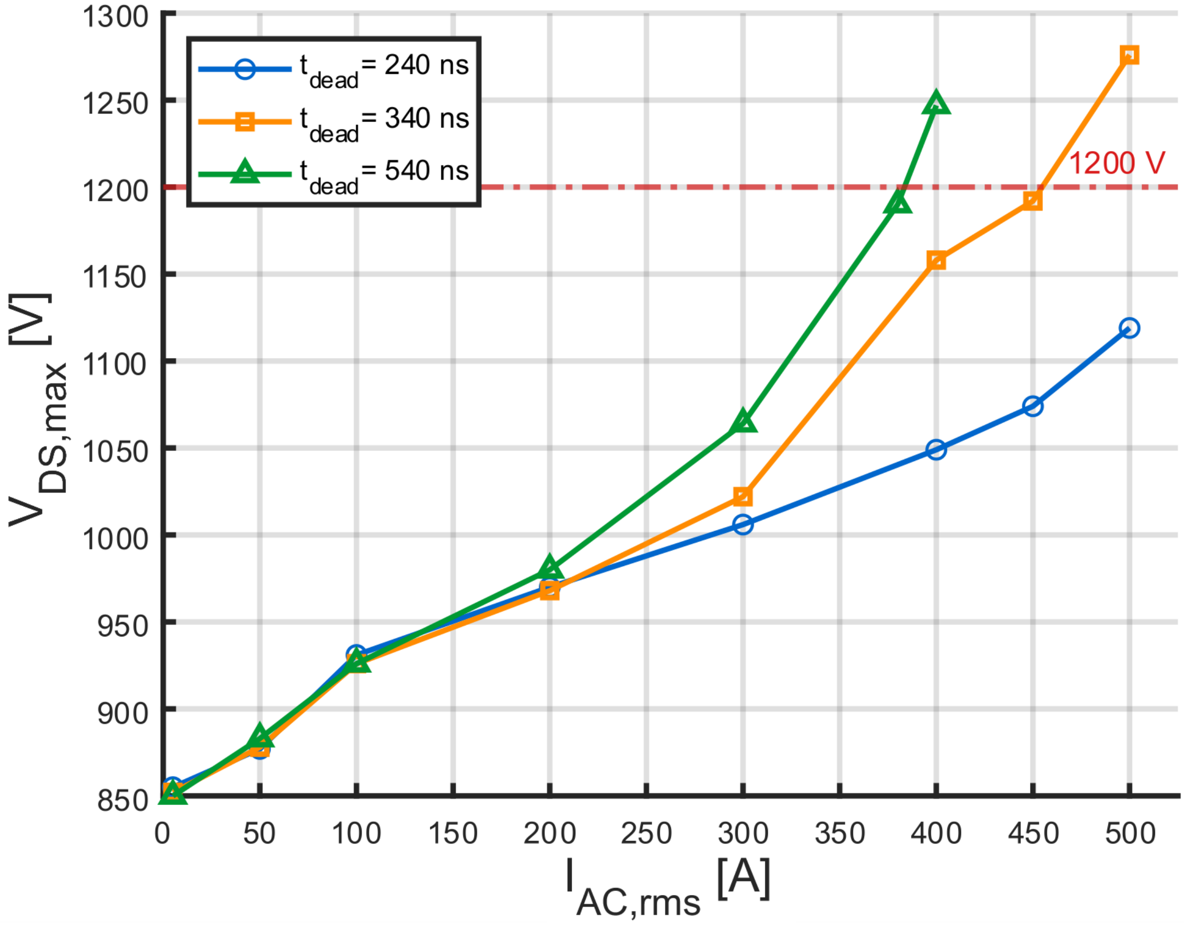

Figure 16 Maximum drain-source voltage as a function of output current for different dead times

$R_{G(on)}$ = 3.3 Ω, $R_{G(off)}$ = 3.9 Ω, V_{DC} = 800 V, V_{GS} = −5 / +15 V, f_{sw} = 15 kHz, f_{out} = 50 Hz

The results shown in Figure 16 illustrate the dependence of the maximum drain-source voltage on the output current for different dead times. This behavior highlights the significant impact of the applied dead time on the voltage stress of the MOSFET devices. A reduction of the dead time improves conduction behavior but may increase the risk of voltage overshoot. Increasing the dead time, on the other hand, reduces switching overlap but may lead to higher voltage peaks due to commutation of the MOSFET body diode.

Under the investigated conditions, a dead time of t_{dead} = 240 ns enables operation at an output current of up to approximately 500 A, while maintaining the drain-source voltage within the specified limit of 1200 V.

The following waveforms are grouped according to the applied switching frequency and allow direct comparison of inverter behavior at identical or comparable operating conditions.

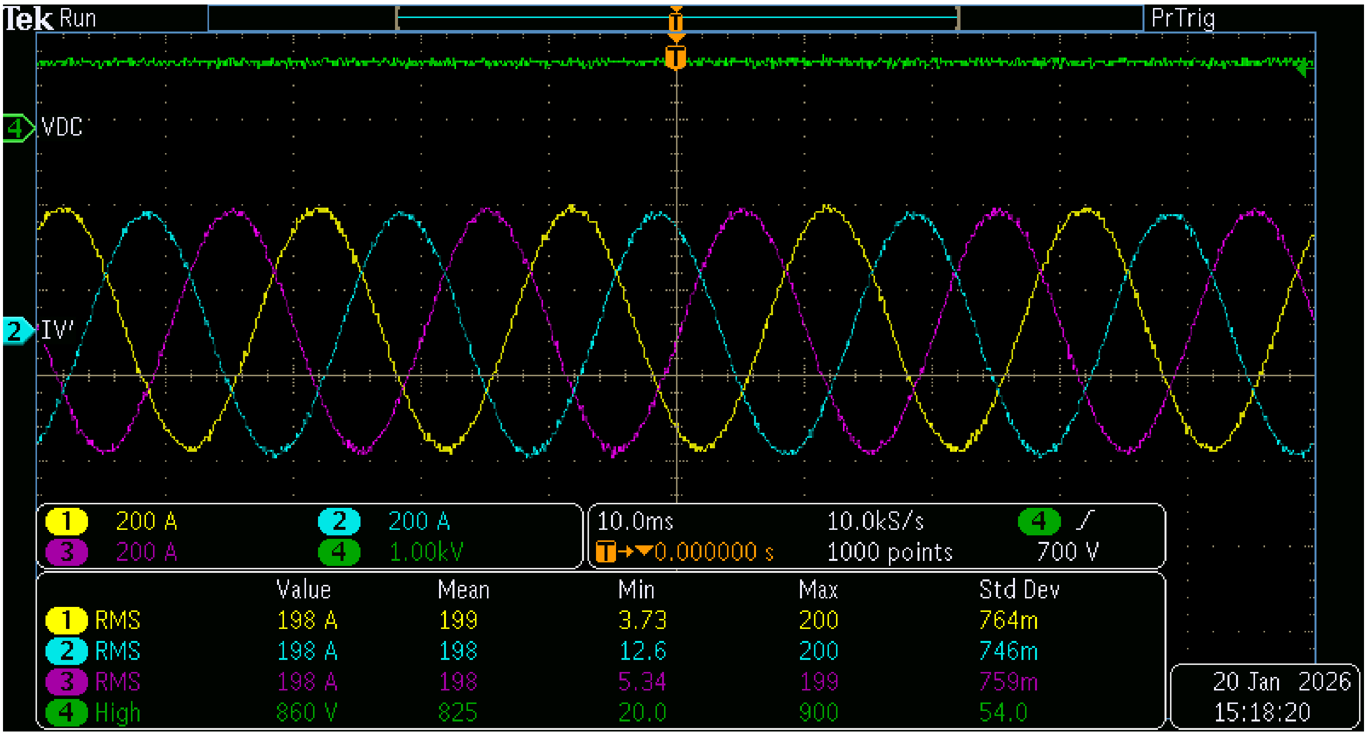

Figure 17 Stationary PWM inverter operation at $I_{AC,rms}$ = 200 A and f_{sw} = 10 kHz

T_J = 40°C, $R_{G(on)}$ = 3.3 Ω, $R_{G(off)}$ = 3.9 Ω, V_{DC} = 800 V, V_{GS} = -5 / +15 V, t_{dead} = 240 ns

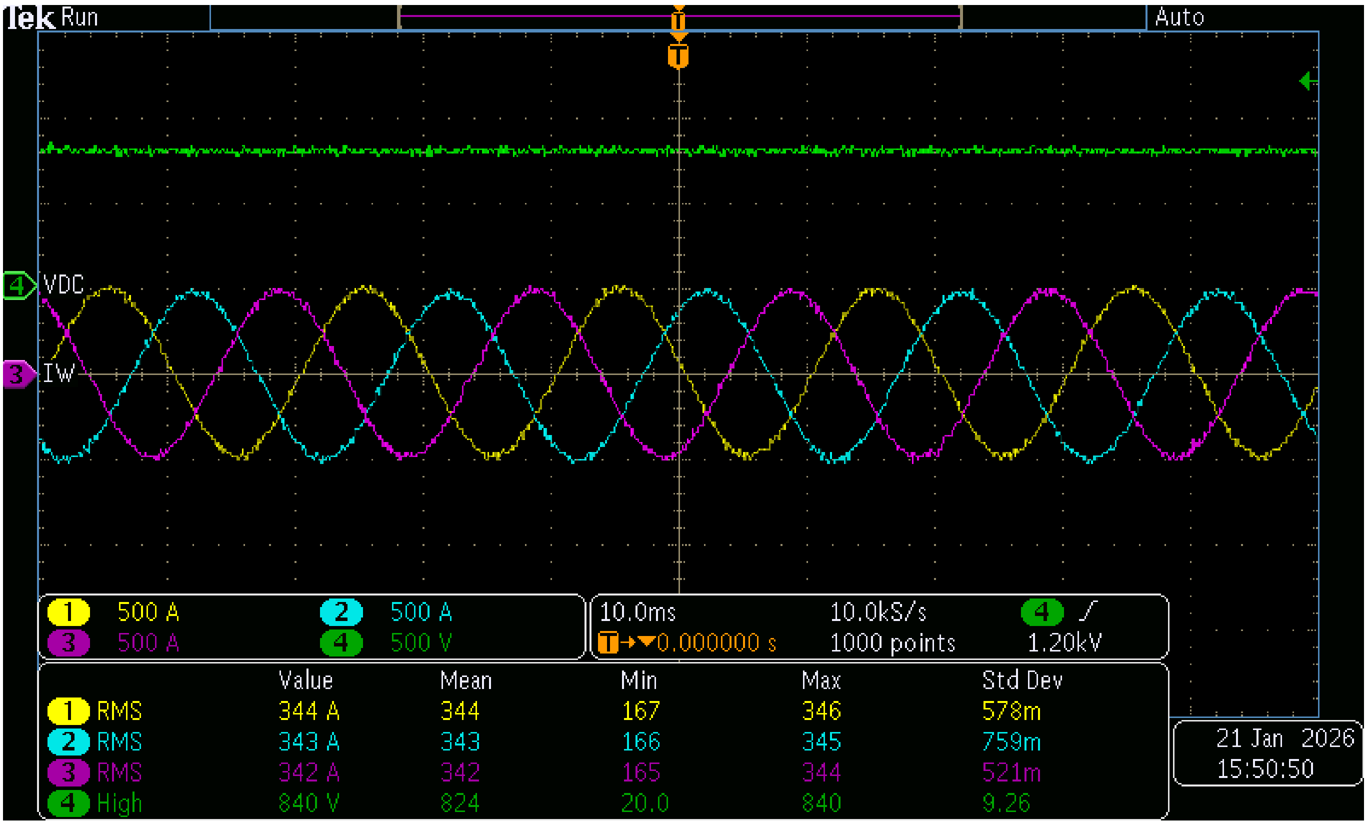

Figure 18 Stationary PWM inverter operation at $I_{AC,rms}$ = 350 A and f_{sw} = 10 kHz

T_J = 40°C, $R_{G(on)}$ = 3.3 Ω, $R_{G(off)}$ = 3.9 Ω, V_{DC} = 800 V, V_{GS} = -5 / +15 V, t_{dead} = 340 ns

Figure 19 Stationary PWM inverter operation at $I_{AC,rms}$ = 200 A and f_{sw} = 15 kHz

T_J = 40°C, $R_{G(on)}$ = 3.3 Ω, $R_{G(off)}$ = 3.9 Ω, V_{DC} = 800 V, V_{GS} = -5 / +15 V, t_{dead} = 240 ns

Figure 20 Stationary PWM inverter operation at $I_{AC,rms}$ = 400 A and f_{sw} = 15 kHz

T_J = 40°C, $R_{G(on)}$ = 3.3 Ω, $R_{G(off)}$ = 3.9 Ω, V_{DC} = 800 V, V_{GS} = -5 / +15 V, t_{dead} = 340 ns

The presented waveforms demonstrate stable and consistent inverter operation across the investigated load range and switching frequencies at a constant DC-link voltage of 800 V.

A direct comparison between the 10 kHz and 15 kHz operating points shows similar switching behavior at identical load conditions, confirming consistent performance across the investigated frequency range.

The results confirm that the inverter system fulfills the defined performance targets, including high current capability, controlled voltage slopes, and reliable operation within the specified thermal limits.

References

[1] EUROPEAN STANDARD. Insulation coordination for equipment within low-voltage supply systems - Part 1: Principles, requirements and tests. Brussels : CEN_CENELEC, 4/12/2020. EN IEC 60664-1:2020/AC2020-12.

[2] Infineon Technologies AG. EconoDUAL™3 Mounting instructions. AN 2006-05. 2006.

Revision history

Document revision	Date	Description of changes
1.0	2026-xx-xx	Initial version

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