Solid-state battery disconnect unit demonstrator user guide

REF-SSBD800VDCJCQJ1 demonstrator

UG-2025-14

About this document

Scope and purpose

This user guide describes the setup and evaluation of the electronic battery disconnect unit (eBDU) REF-SSBD800VDCJCQJ1. It provides a brief overview of the eBDU demonstrator concept, functions, protection, and diagnosis implementations.

Intended audience

This document is primarily intended for engineers who want to operate and work with an electronic battery disconnect unit demonstrator.

Reference board/Kit

Product(s) embedded on a printed circuit board (PCB) focusing on specific applications and defined use cases that may include software. PCB and auxiliary circuits are optimized for the requirements of the target application.

Note: *Boards do not necessarily meet safety, EMI, 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

	**Warning:** *The evaluation or reference board is connected to high DC voltages during testing. Hence, high-voltage differential probes must be used when measuring voltage waveforms by oscilloscope. Failure to do so may result in board damage or personal injury.*
	**Warning:** *Remove or disconnect input power from the boards before you disconnect or reconnect wires or perform maintenance work. Failure to do so may result in personal injury or death. GUI measurements may not be an indication that supply is at safe voltage levels as communication may get interrupted during testing.*
	**Caution:** *Only personnel familiar with 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 assembly's 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 load and/or boards that are incorrectly applied or installed can lead to component damage or reduction in product lifetime. Wiring or application errors such as undersizing the load or wires, supplying an incorrect or inadequate 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.*
	**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.*

Table of contents

About this document 1
Important notice 2
Safety precautions 3
Table of contents 4
1 The demonstrator at a glance 5
1.1 Scope of supply 5
1.2 Block diagram 5
1.3 Main features 7
1.4 Board parameters and technical data 8
2 System and functional description 9
2.1 Getting started 9
2.1.1 Step-by-step startup procedure 9
2.2 Getting started - Windows® GUI 10
2.3 Description of the functional blocks 11
2.4 Hardware overview 13
2.4.1 Mounting support 18
2.4.2 Isolation coordination 19
3 eBDU schematics 20
3.1 Power supply block 20
3.2 eBDU power stage 22
3.3 Digital input and contactor output 24
4 The eBDU GUI 25
4.1 Calibrating the voltage and current scaling factors 30
4.2 The eBDU trip curve 31
5 CAN communication 32
5.1 The communication interface 32
5.2 CAN command list 33
6 eBDU performance test 38
6.1 Leakage measurement 38
6.2 Total resistance 38
6.3 Clamping measurement 39
6.4 High-energy clamping measurement 43
6.5 Current sharing 44
6.6 Fast overcurrent detection 46
6.7 Thermal measurements 49
6.7.1 Increasing current capabilities 51
6.7.2 Parasitic turn-on test 54
7 Related resources 56
References 57
Glossary 58
Revision history 61
Disclaimer 62

1 The demonstrator at a glance

This user guide gives an overview and operating instructions for the eCAV solid-state battery disconnect unit.

The solid-state battery disconnect unit (BDU) demonstrator for electric commercial construction and agricultural vehicle (eCAV) is a high-current and high-voltage disconnect unit. It provides the much-needed fast overcurrent protection in battery-powered vehicles and energy storage systems. It is designed to disconnect battery voltages up to 850 V and conduct continuous currents up to 650 A reliably when equipped with an active fan-cooled heat sink. It can handle currents up to 800 A when paired with a water-cooled heat sink.

The BDU demonstrator can conduct current in bipolar and block current in unipolar directions, and includes an inbuilt short circuit protection mechanism. It can be controlled using a Microsoft Windows® graphical user interface (GUI) software via a USB-to-CAN interface.

The top-side cooling (TSC) stack with the Q-DPAK package, and the control interface are designed at the basic isolation level as per IEC 60664-1.

The eBDU switch combines the reliable and robust switching performance of the Infineon CoolSiC™ JFET technology, IJCQ120RM25J1, with Infineon's high bandwidth XENSIV™ TMR coreless current sensor, TLE5571. The switches are controlled by Infineon isolated EiceDRIVER™ Compact, 1ED3127MU12F. The reinforced isolated supply is realized with Infineon's full-bridge transformer driver, 2EP130R. The demonstrator is controlled by Infineon's XMC4502 microcontroller. Its voltage supply is controlled by the linear voltage regulator, TLS205, and the voltage tracker, TLS115B.

For more information, please visit the application page at https://www.infineon.com/promo/super-solid-state-solutions.

1.1 Scope of supply

The demonstrator kit contains the following:

- **Demonstrator**: The eBDU power and control board with an active air-cooled heat sink and a clamping circuit
- **eBDU GUI**: The GUI and PCB design data available online
- **USB-to-CAN analyzer**: Innomaker USB-to-CAN interface (MS124)
- **24 V, 1 A wall-plug adapter**: XP Power VER24US240-YES or similar

1. *For XMC4x MCU software development, order an XMC™ Link programmer/debugger separately. See KIT_XMC_LINK_SEGGER_V1.*
2. *XMC4x firmware uses DAVE™ 4 IDE. The eBDU Demo GUI uses Visual Studio® C# for development.*

1.2 Block diagram

The top-level block diagram of the reference board is shown in Figure 1. The demonstrator consists of three different PCBs:

- The control board
- The power stage
- The clamping element

The control board consists of a galvanic isolated power supply for the gate-drive unit as well as the voltage regulators for the MCU and infrastructure, e.g., the controller area network (CAN) interface or current sensor. The demonstrator can be controlled via a CAN interface or with digital I/O pins.

The power stage PCB integrates single-ended power switches, along with a gate-drive unit and a voltage and current measurement unit. The clamping network is separated from the power stage PCB to offer complete flexibility in selecting the appropriate clamping scheme as per the requirements of the application (e.g., maximum operating voltage, clamping energy). Optionally, an additional precharge unit can be connected to the solid-state eBDU demonstrator to switch on the capacitive loads. This precharge unit is not part of this demonstrator.

Attention: Do not operate the demonstrator without attaching a clamping circuitry. This can cause damage to the power stage.

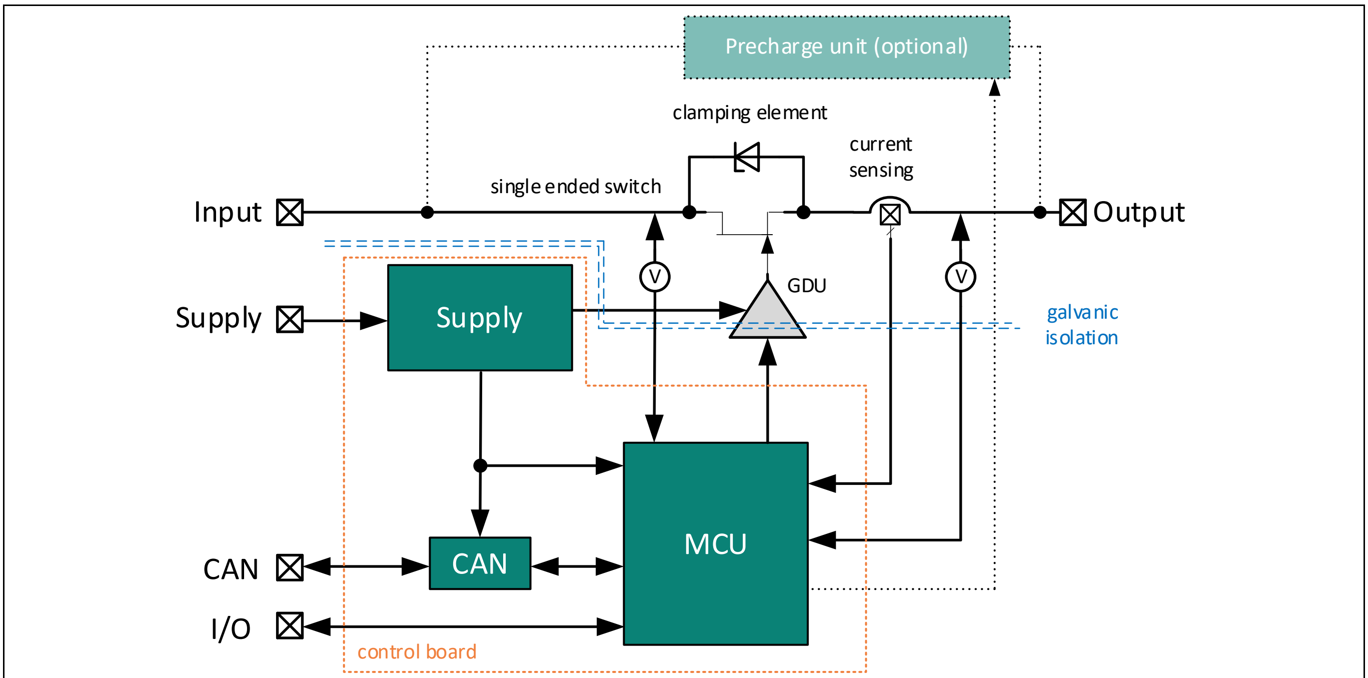

Figure 1 Block diagram

Figure 2 and Figure 3 show images of the demonstrator.

Figure 2 Demonstrator top-side view

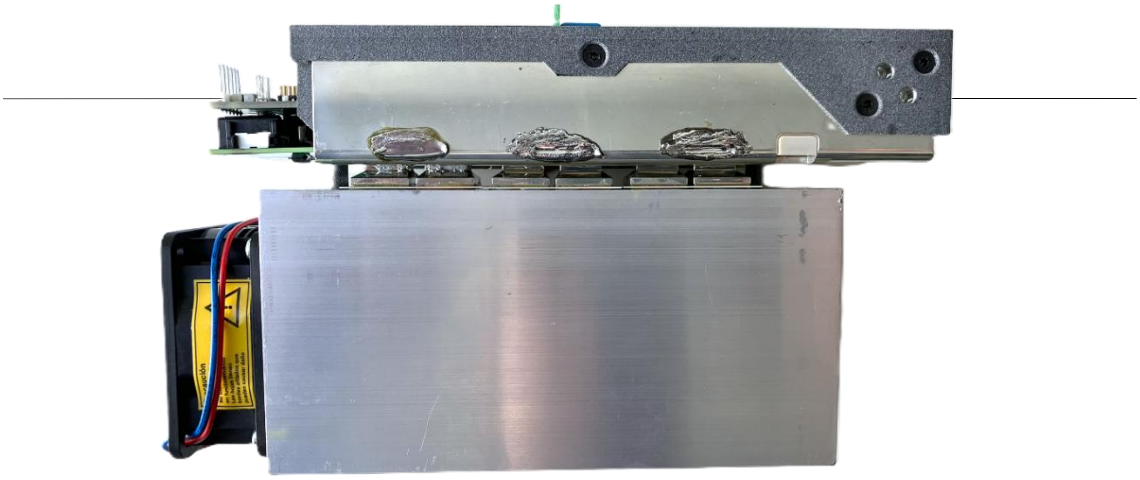

Figure 3 Demonstrator side view

1.3 Main features

The main features of the solid-state battery disconnect demonstrator include:

- Continuous current capabilities up to 800 A (with water cooling)
- Unipolar blocking capability for working voltages up to 850 V_{dc}
- Basic isolation for control and cooling interface as per IEC 60664-1
- Fast short-circuit protection (detection time < 2 µs)
- External user interface: High-speed CAN and digital I/O communication
- Active cooling with top-side cooling (TSC) concept: Copper heat spreader and a direct bonded copper (DBC) ceramic isolation soldered on power devices
- Option for precharging the block to switch the capacitive loads on safely without triggering overcurrent detection
- Clamping circuit on separate PCB to offer flexibility as per the requirements of the application
- Protection and monitoring:
  - Coreless magnetic tunnel magnetoresistive (TMR) effect -based current measurement
  - Hardware-based fast OCD
  - Isolated input and output voltage measurement
  - Isolated temperature monitoring by an NTC close to the drain potential of the power device
  - Temperature monitoring of the MCU and the power board
  - Overload (OVL), overtemperature (OVT), undervoltage (UVP), and overvoltage protection (OVP)
- Programmability and realtime monitoring with demonstrator GUI:
  - Fast OCD trip threshold
  - Overtemperature shutdown and recovery threshold
  - UVP and OVP thresholds
  - Trip chart parameters: Nominal current, fast and slow overcurrent factors, tripping integral
  - In-application programming to calibrate the channel input and output voltages and current
  - Monitoring and export of analog measurements such as V_{in}, V_{out}, I, OCD threshold references, temperatures

1.4 Board parameters and technical data

The electrical parameters of the reference board are listed in Table 1. The nominal voltage for the logic supply and control input is 24 V and the nominal battery voltage is 800 V.

The contactor control is an open-collector pin and the digital control input is active high with a maximum input voltage of 40 V.

Table 1 Key parameters

Parameter	Min.	Typ.	Max.	Unit
Battery voltage	-	800	850	V
Operating supply voltage V_{in}	6	24	32	V
Nominal supply current with V_{in} = 24 V	-	70	-	mA
Maximum 20-minute current rating (active air cooling)	-	650	-	A
Maximum 20-minute current rating (water cooling)	-	800	-	A
Fast overcurrent detection (OCD) tripping threshold, adjustable	200	-	1800	A
Absolute maximum voltage at digital input pin	-10	-	40	V
Inductive load switch-off capability	5		110	µH
Digital input pin – ON voltage	1.4	-	-	V
Maximum continuous current at contactor output (R2 shorted)	-	-	5	A
Creepage distance between the high voltage and low voltage parts	6.8	-	-	mm
Clearance distance between the high voltage and low voltage parts	2.2	-	-	mm
Rated basic isolation voltage as per IEC 60664-1	-	-	950	Vdc
Transient overvoltage clearance rating as per IEC 60664-1	-	-	2.6	kV
Altitude rating	-	-	4000	m
Pollution degree	2			
Ambient operating temperature	-40	25	65	°C
Busbar temperature continuous			110	°C

2 System and functional description

2.1 Getting started

A typical test setup for the solid-state battery disconnect unit is shown in Figure 4. One DC power supply with typically 24 V needs to be connected to the VIN and GND terminals on connector J1 or J2 as the logic supply. The demonstrator can be controlled and configured via the CAN interface on connector J1, for example, with the USB-to-CAN transceiver (Innomaker USB2CAN), included in the package, with the Windows® GUI software.

Optionally, the turn-on and turn-off functionalities can be controlled via a digital IN terminal on connector J2. The mechanical contactor to enable galvanic separation can be controlled via the OUT terminal on connector J2. Both features need to be enabled in the GUI or via the CAN interface first.

The main current path needs to be connected to the INPUT and OUTPUT busbars on the demonstrator. The high-voltage battery's negative pole-sense should be connected to P2 to enable proper voltage measurement. The demonstrator can be used as the high-side (as shown in Figure 4) or the low-side switch because of its floating gate driver supply.

Note: Infineon devices with JFET power technology are normally ON. Therefore, to prevent any unwanted current flow make sure to enable the logic power supply before V_{bat} when not using a mechanical contactor in series.

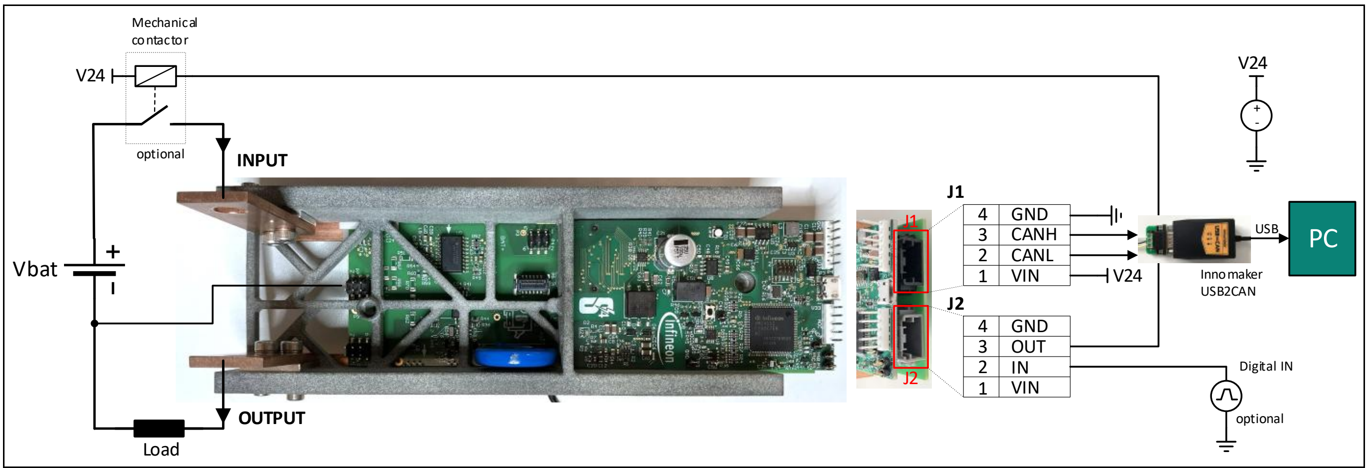

Figure 4 Getting started – Basic operation

2.1.1 Step-by-step startup procedure

1. Connect the 24 V power supply and CAN2USB transceiver to connector J1.
2. Connect the load and V_{bat} supply to the INPUT and OUTPUT terminals of the main current path (optionally, with an additional mechanical contactor).
3. Optionally, connect a digital control signal to the IN terminal of connector J2.
4. Enable a 24 Vww supply on J1.
5. Plug in the USB2CAN transceiver into the PC.
6. Open the GUI. Connect and configure the demonstrator through the GUI.
7. Enable V_{bat} supply.
8. Turn ON the battery disconnect switch via the GUI or the digital control pin.

2.2 Getting started - Windows® GUI

After the Windows® GUI software starts up, the main window, as shown in Figure 5, opens. Through this window, the demonstrator can be connected via the CAN2USB transceiver. The switch can be controlled in a static manner with the ON and OFF buttons. There is also the option to turn on the eBDU for a defined pulse length. After the demonstrator is connected or if an error occurs in the communication, messages are displayed at the bottom of the window. Generally, messages related to basic realtime monitoring, the state of the eBDU, and error notifications are shown.

> *Note: After the demonstrator is connected, to see realtime information as messages click the **Start readout** button.*

After completing the wiring and startup procedures as described in chapter 2.1.1, follow these steps (see Figure 5 for reference):

1. Open the Windows® GUI. If the CAN2USB transceiver is detected, a device indicated as "CAN x" will appear in the USB2CAN Innomaker Connect dropdown list.
2. Click the **Connect** button to connect to the demonstrator via the CAN2USB transceiver. A successful connection is indicated by a status message. The message includes the software and hardware revisions and response of the demonstrator hardware's current configuration.
3. Click **Start readout** to enable realtime readout of the measurement parameters, operational state, and error flags.
4. Click the **ON** button to turn on the demonstrator. The demonstrator can now conduct current.

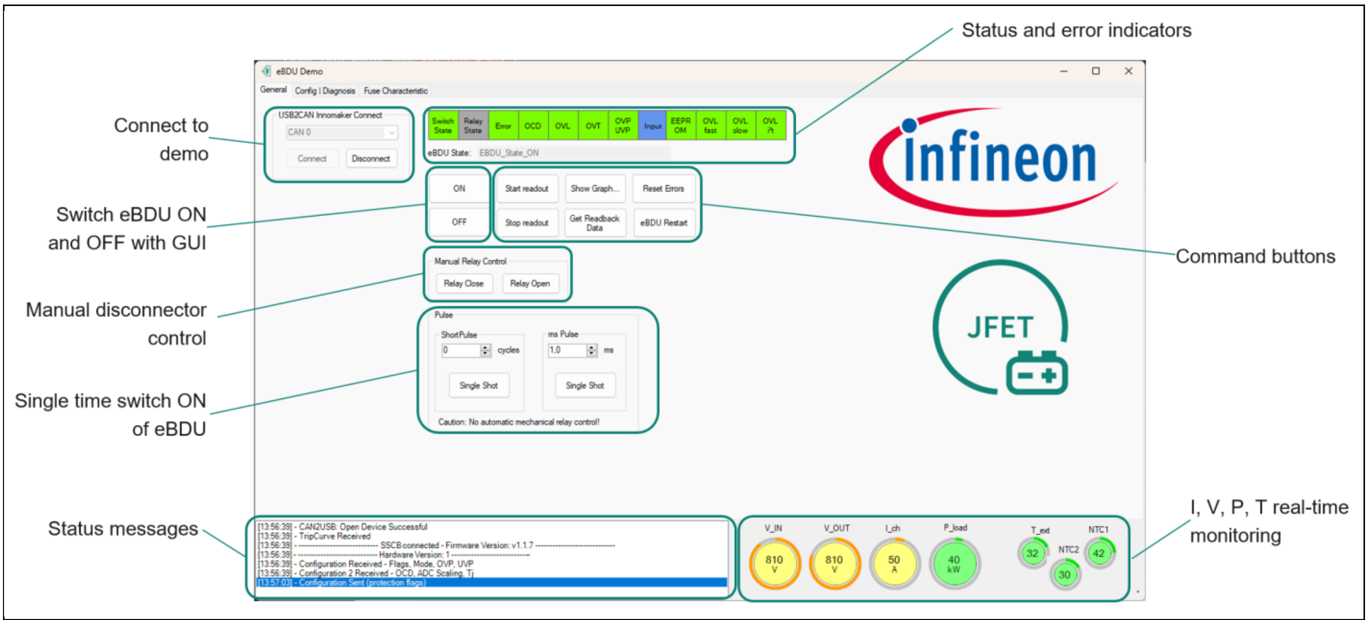

Figure 5 Main window of the eBDU GUI

2.3 Description of the functional blocks

The functional block diagram of the eBDU demonstrator if shown in Figure 6. The main functionality of the demonstrator is to control the load current between the INPUT and OUTPUT terminals and monitor the current flow through the demonstrator. If the demonstrator detects a user input or a fault condition, e.g., overcurrent in the path due to a fault in the load or a short circuit, it switches off the current quickly and safely.

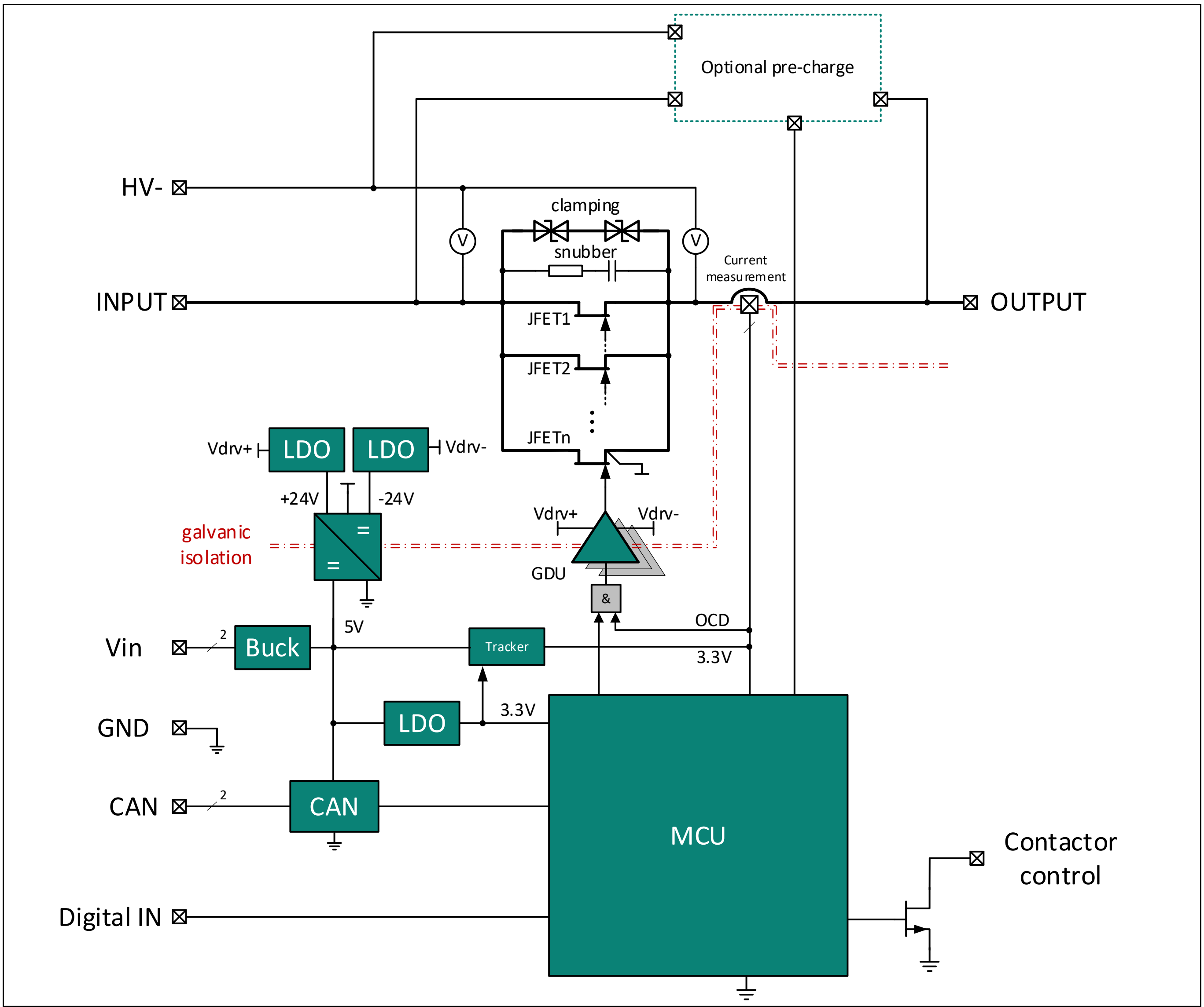

Figure 6 Functional block diagram

Main current path

The main switching element used in the demonstrator is Infineon's CoolSiC™ JFET IJCQ120RM25J1. As the power stage is designed in a unipolar configuration, the demonstrator can only prevent the current flow from INPUT to OUTPUT in the OFF state. When switching into the OFF state with an inductive load, the power device should be protected from inductive kickback voltages above the maximum allowed drain-source voltage of the power device. This is achieved by the clamping network parallel to the power stage, which is exchangeable and can be adjusted according to application requirements.

Monitoring

Voltage is measured at the INPUT and OUTPUT terminals of the battery disconnect unit. Current is measured with Infineon's coreless, open-loop TMR current sensor, TLE5571, with a sensing structure in the busbar. The fast overcurrent detection (OCD) is directly connected to the gate driver input. It switches off the power stage swiftly if an overcurrent is detected. The threshold for the OCD detection can be set in the MCU.

<u>Isolation coordination</u>
The current measurement implements a galvanic isolation from the busbar. Further isolation interfaces to the microcontroller and the logic interface are done via the voltage measurement IC, gate driver, and gate driver supply. In this case, all logic inputs and interfaces are related to the low-voltage domain as shown in Figure 7.

<u>Supply concept</u>
The auxiliary supply for controlling the JFETs as well as the microcontroller and all peripherals is provided via the low-voltage supply input. The input voltage is stepped down to 5 V using a buck converter that is used as the main input for all other linear voltage regulators or via the isolated transformer supply. The MCU and other peripherals are supplied with a 3.3 V linear regulator that works as a reference for the voltage tracker, which supplies the current and voltage measurement ICs. The secondary gate driver supply is implemented with a transformer. It is then linearly regulated, according to the positive and negative gate voltages required, by the JFET power stage.

<u>Precharge unit</u>
There is a provisioning for an optional precharge unit that can be controlled by the microcontroller. As the precharge unit is a pluggable unit, it can be implemented according to application requirements (e.g., pre-charge resistor, buck converter). For the pre-charge unit to operate properly, the software on the MCU should be adapted.

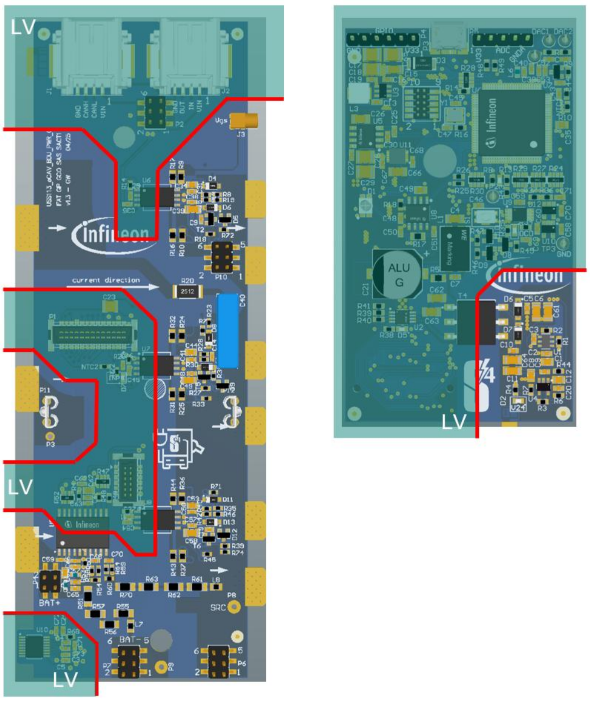

Figure 7 Isolation coordination

2.4 Hardware overview

This section provides a technical overview of the power board's hardware. Figure 8, Figure 11, and Figure 12 show images of the board with components highlighted. The layer stack of the power PCB is shown in Figure 9. The connectors are listed in Table 2 and Table 4 and the indicators in Table 3. The pinout of the main application connectors is shown in Figure 10 and the full assembly of the demonstrator in Figure 13.

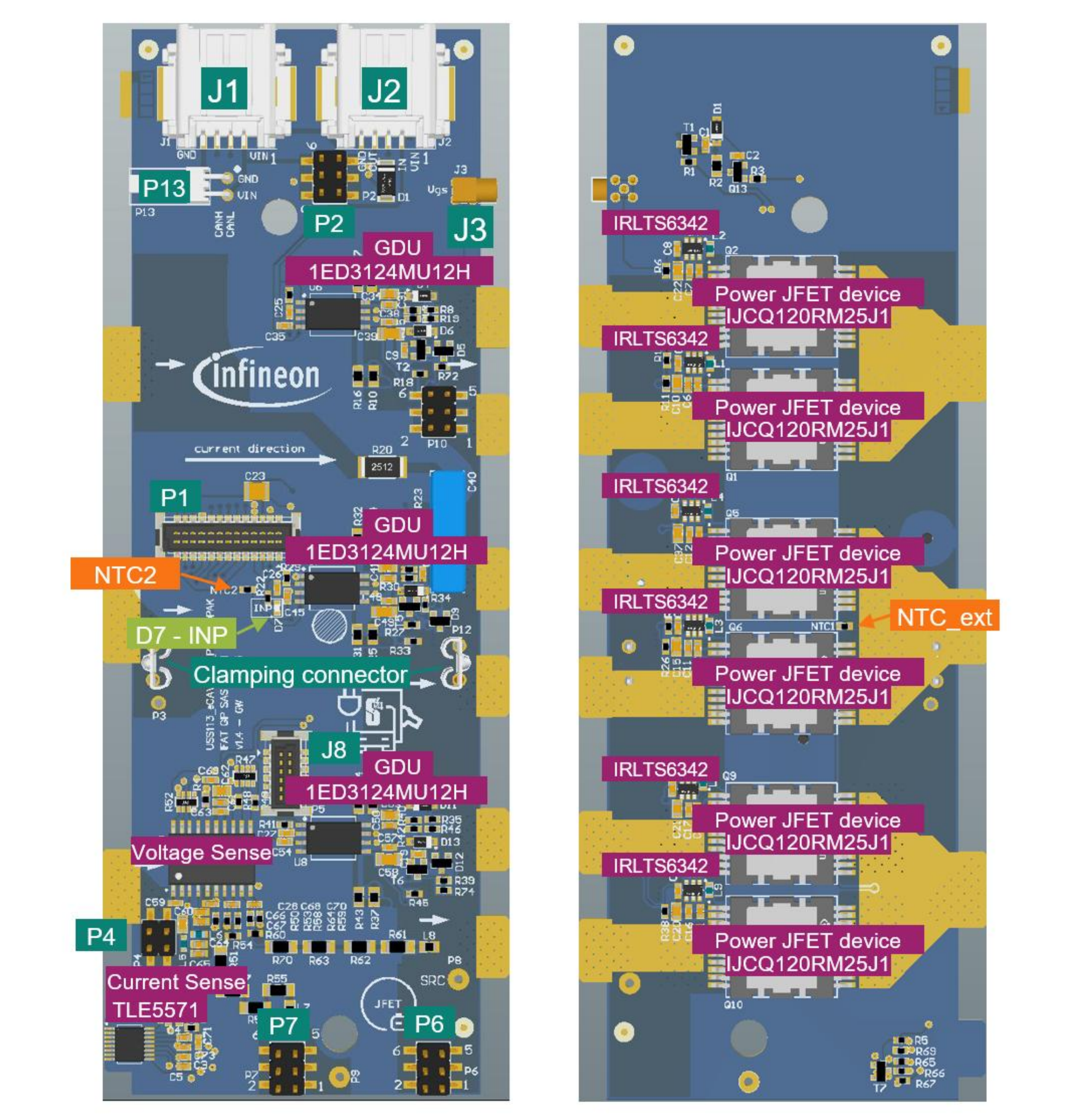

Figure 8 Overview of the power board

Note: To increase the DC capabilities of the demonstrator, the power board can be upgraded by soldering additional copper busbars directly onto the open-solder resist on its side, reducing power losses in the PCB.

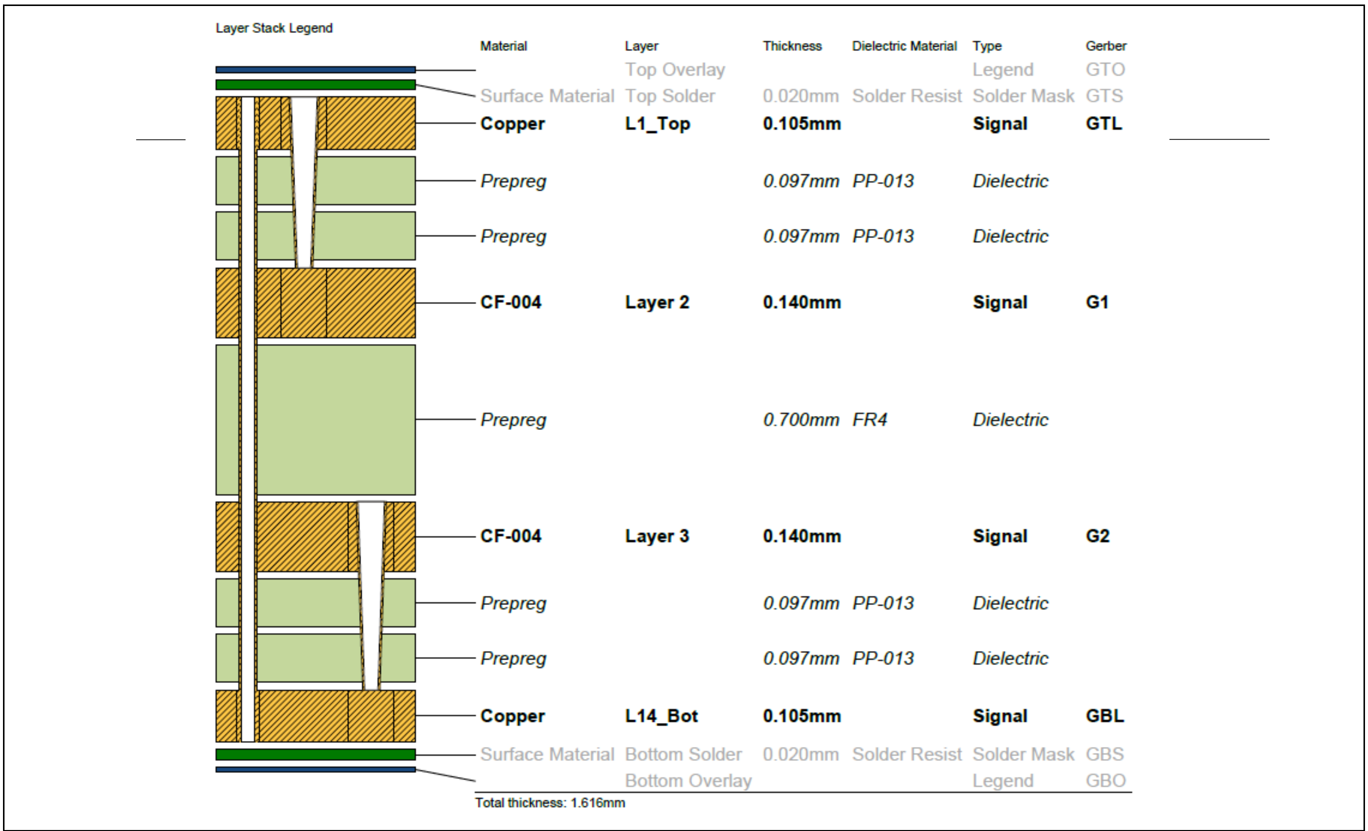

Figure 9 Power board layer stack

Table 2 Overview of power board connectors

Designator	Description	Manufacturer	Mating part
J1	Logic supply & CAN interface	MOLEX	538-34791-0140
J2	Logic supply, digital IN & contactor control	MOLEX	538-34791-0142
J8	V_{GS} measurement socket (MMCX)	WE	66046011210420
P1	Logic board signal connector	Phoenix Contact	FR 1,27/ 26-FV 9,05
P2	Logic board supply	WE	61000621121
P4	Precharge board Bat+	WE	61000421121
P6	Precharge board Out	WE	61000621121
P7/P9	Precharge board & voltage measurement Bat-	WE	61000621121
J8	Precharge board signal connector	Phoenix Contact	FR 1,27/ 12-MV 1,75
P13	Heat sink fan connector (VIN)	MOLEX	22012021

A cable harness with J1’s mating connector to connect to the CAN interface (Table 2) and supply is provided with the demonstrator kit.

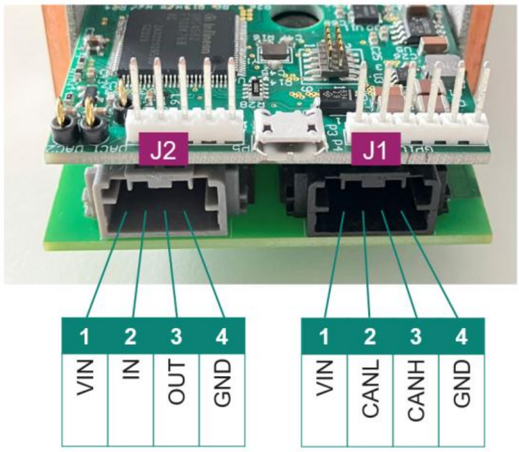

Figure 10 Main application connectors pinout

Table 3 LED indicators overview

Designator	Description	Standard color
D7-INP	Power board input (Gate driver input) state	Green
LED1	MCU running indicator	Green
D1	eBDU demonstrator state (see Table 5)	RGB
D2	Secondary gate-driver supply voltage (+24 V) status	Green
D5	2EP130R status	Green

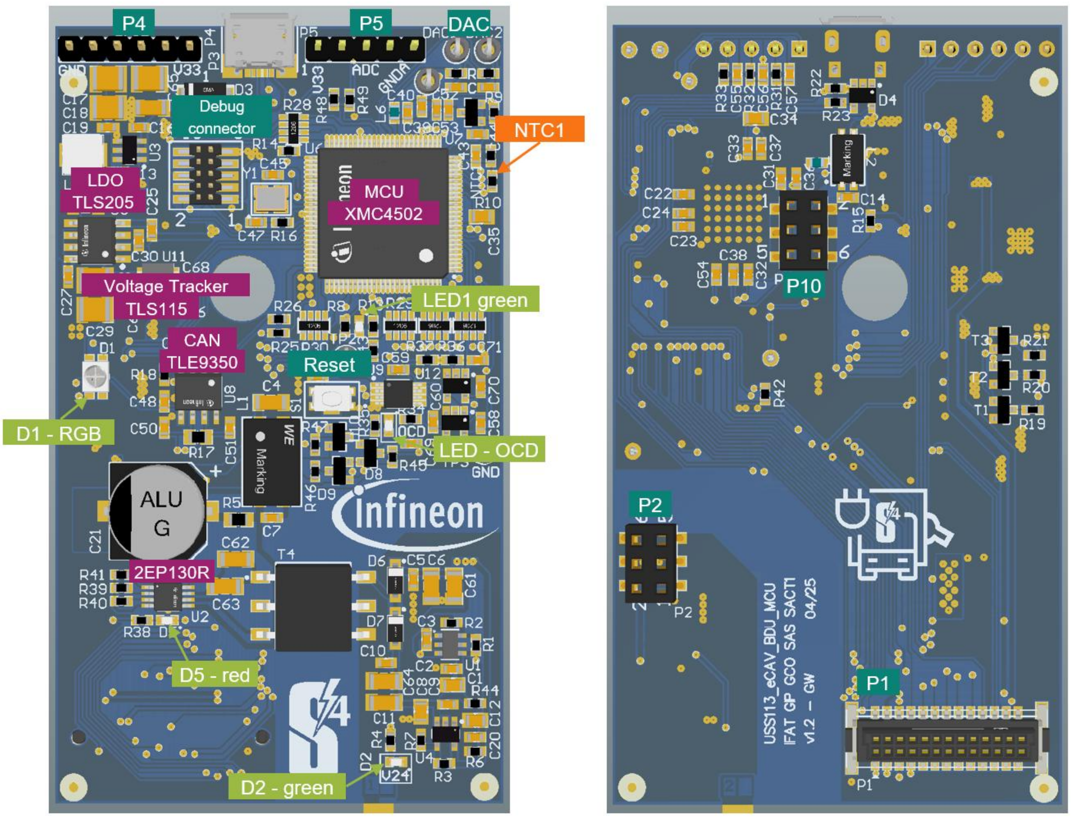

Figure 11 Overview of the MCU board

Table 4 Overview of the MCU board connectors

Designator	Description	Manufacturer	Mating part
P1	Power-board signal connector	Phoenix Contact	FR 1,27/ 26-MV 1,75
P2	Secondary gate-driver supply output	WE	61000621821
P4	Spare MCU GPIOs (not used)	WE	2.54 mm socket
P5	Spare MCU ADC inputs (not used)	WE	2.54 mm socket
P10	Logic supply input	WE	61000621821
DACx	Spare analog outputs (not used)	-	-
Debug	SWD debug connector (Infineon XMC™ Link)	Infineon	10-pin debug cable

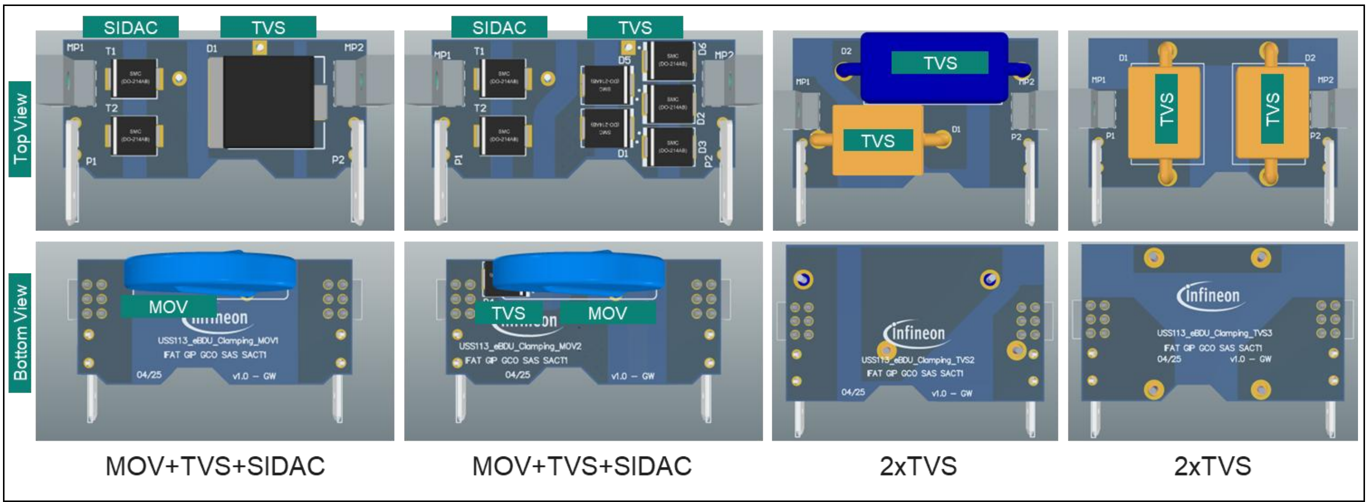

Figure 12 Clamping board options (2 x TVS is supplied with the demonstrator)

Table 5 RGB LED indicator states

LED color	eBDU state	Description
Yellow	*EBDU_State_BIST*	Inbuilt self-test
Green	*EBDU_State_IDLE*	Channel OFF – normal operation
Blue	*EBDU_State_ON*	Channel ON – normal operation
Red	*EBDU_State_ERROR*	An error occurred and the channel was switched off
Cyan	*EBDU_State_RELAY_ON* *EBDU_State_RELAY_OFF*	Automatic relay control switching, relay ON or OFF

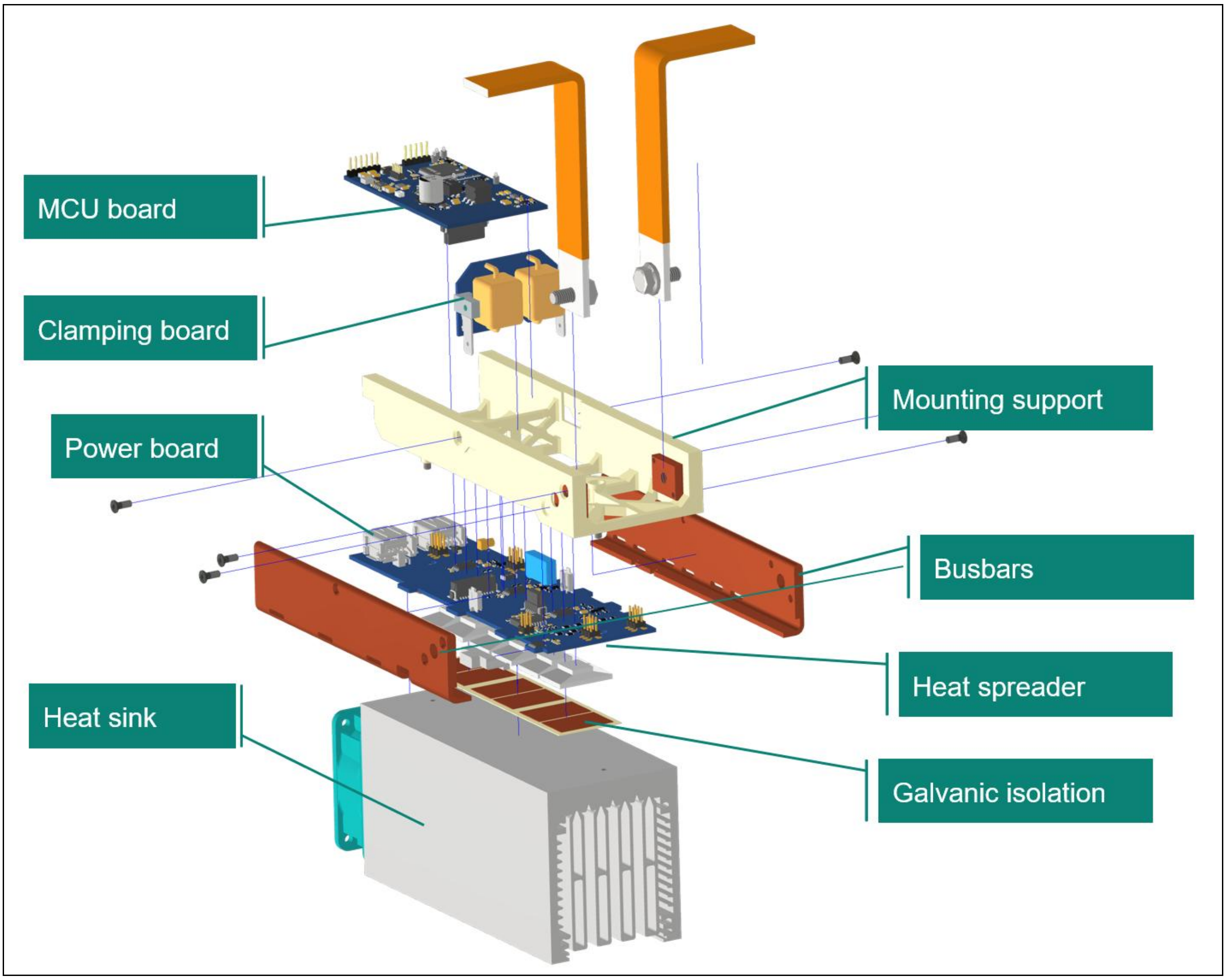

Figure 13 Full assembly (exploded view) of the eBDU demonstrator

2.4.1 Mounting support

To secure the busbars and PCBs in place, as well as to mount the cooling stack onto the heat sink, a 3D-printed mounting support is used. The design minimizes the constructed space by reducing the number of mounting points, which are limited to the screws on both sides. However, to ensure that the power components in the center remain firmly attached to the heat sink, the mounting support is engineered to apply pressure at the central position, as illustrated in Figure 14.

To evaluate the mechanical stability of the mounting support, a mechanical strain simulation was conducted. In this simulation, a force was applied at the central pressure point and the resulting displacement of the part was analyzed. The results revealed a maximum displacement of 0.074 mm when a 20 N force was applied at the center, as shown in Figure **15**.

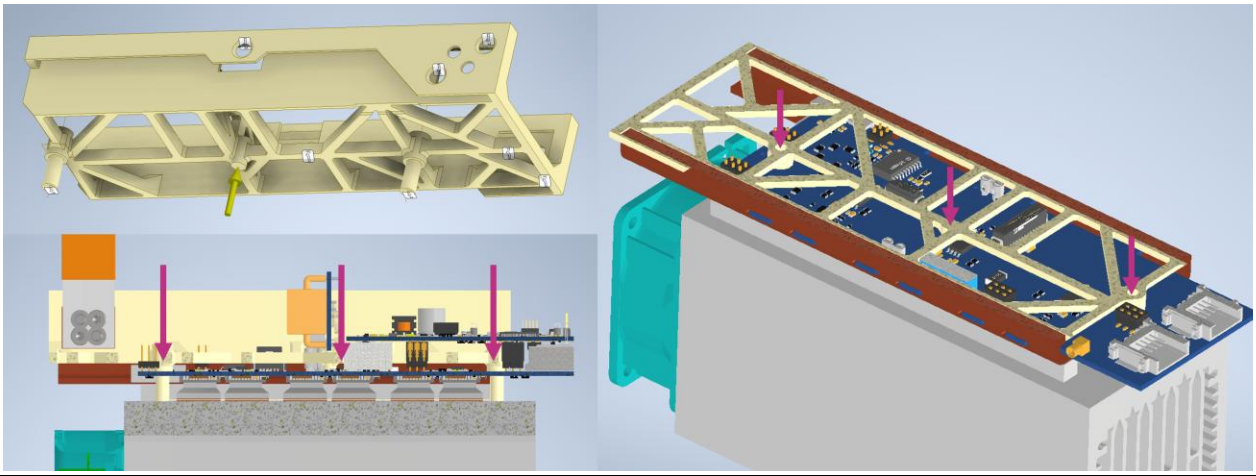

Figure 14 Mounting support for the eBDU demonstrator

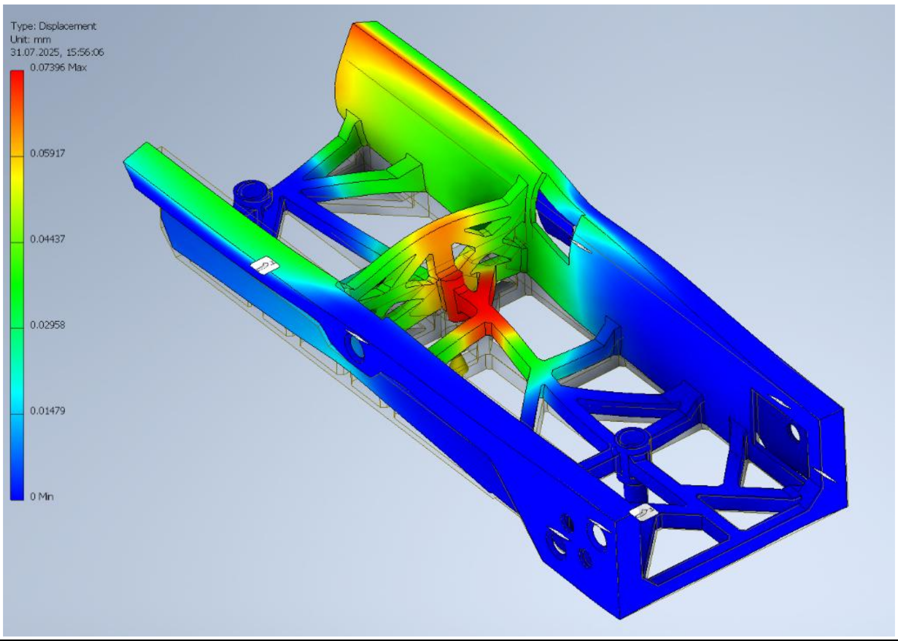

Figure 15 **Simulating mechanical strain on the eBDU demonstrator's mounting support**

The mounting support is a 3D printed part made of PA12 material. The maximum continuous operating temperature of the mounting support should not exceed 110°C (for short term up to 150°C).

2.4.2 Isolation coordination

For isolation assessment, the maximum battery voltage has been assumed to be 950 V. The required creepage distances were determined based on the IEC 60664-1 standard, considering a pollution degree of 2.
The detailed creepage parameters for the demonstrator, including the necessary distances and material properties, are listed in Table 6.

Table 6 Creepage distance according to IEC 60664-1

Parameter	Value
Maximum working voltage	950 V_{dc}
Pollution degree	2
Isolation type power device	Functional
Q-DPAK material group	I
Q-DPAK creepage distance	4.8 mm
PCB material group	II
Isolation type MCU and logic	Basic
PCB creepage distance	6.8 mm

To assess the clearance, the breakdown voltage of the semiconductor, including the clamping elements, was considered. The maximum impulse voltage considered according to the standard IEC 60664-1 is 2.6 kV. The result of the clearance assessment, detailing the minimum required distances, is summarized in Table 7. The clearance measurement of the heat spreader on the Q-DPAK package is shown in Figure 16.

Table 7 Clearance distance according to IEC 60664-1

Parameter	Value
Maximum impulse voltage	2.6 kV
Pollution degree	2
Multiplication factor for 4000 m elevation	1.29
Clearance distance	> 2 mm

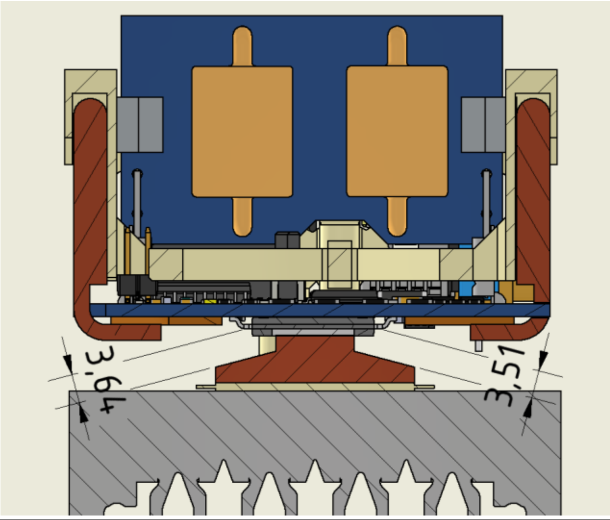

Figure 16 Clearance of the heat spreader

3 eBDU schematics

This chapter discusses specific sections of the schematic that are relevant to the design and functionality of the demonstrator. For a comprehensive overview, see the complete schematic included in the documentation package accompanying the demonstrator board.

3.1 Power supply block

The power supply block for the demonstrator is located on the microcontroller (MCU) board. This block is responsible for generating supply voltages for both the MCU and its peripherals, as well as for generating a floating gate driver supply on the high-voltage side. On the low-voltage side, the main 5 V supply rail is generated using a step-down converter from the input voltage VIN. From this 5 V rail, the MCU's 3.3 V supply is further regulated using Infineon's linear voltage regulator, TLS205B. To ensure decoupling from the power board, the supply voltages for the voltage and current sensors are separated using Infineon's voltage tracker, TLS115B.

The 5 V supply rail is also used to generate the gate-driver supply voltage on the high-voltage side. This supply rail is galvanically isolated using a transformer (T4) to meet isolation requirements. The transformer is driven by Infineon's full-bridge transformer driver, 2EPR130R with an integrated power stage. On the secondary side of the transformer, a ±24 V supply is generated and subsequently regulated to +2 V and -18 V using low-dropout regulators (LDOs). For further decoupling within the gate driver supply, an additional diode is placed on each output. This means that the LDO output voltages have to be one diode drop higher or lower to account for the voltage drop. Both voltages can be adjusted by selecting the resistors R1, R2 and R3, R7 respectively.

The output voltage of the positive gate driver supply voltage, V_{drv+}, can be set as per:

$$V_{drv+} = \frac{0.6 \cdot (R_1 + R_2)}{R_2} = 2.63\ V$$

The negative supply rail of the gate driver supply V_{drv-} can be set according to:

$$V_{drv-} = -1.22 \cdot \left(1 + \frac{R_3}{R_7}\right) = -18.87\ V$$

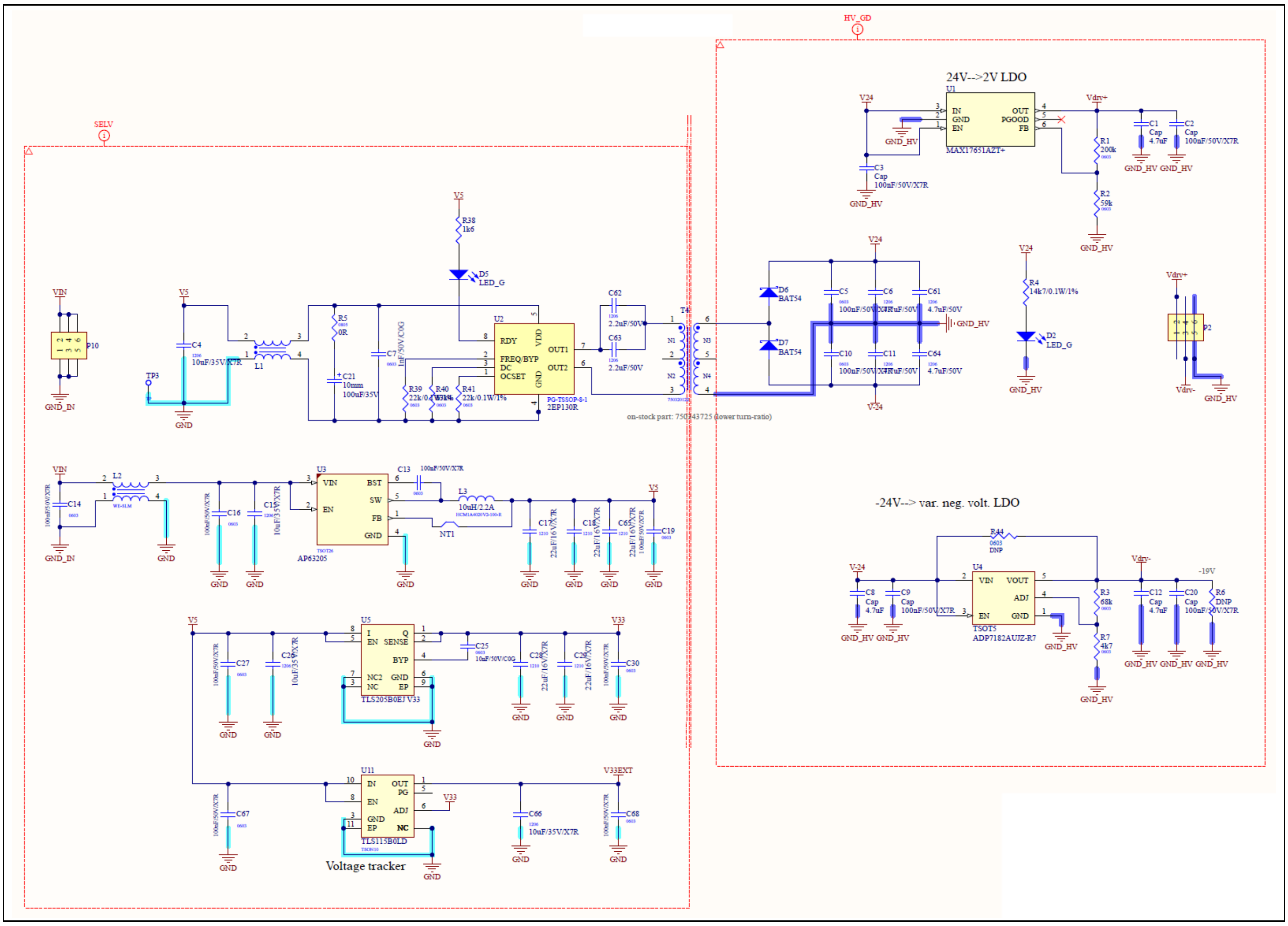

Figure 17 Schematic – Power supply block

3.2 eBDU power stage

Figure 18 provides an overview of the power stage, illustrating three parallel-connected switching blocks. One common snubber circuit, consisting of R20 and C40, is shared across all power stages. Additionally, the clamping circuit is implemented on a dedicated PCB for improved modularity and ease of design. The diagram also shows the connectors on the optional pre-charge block, which offers additional flexibility for system configuration.

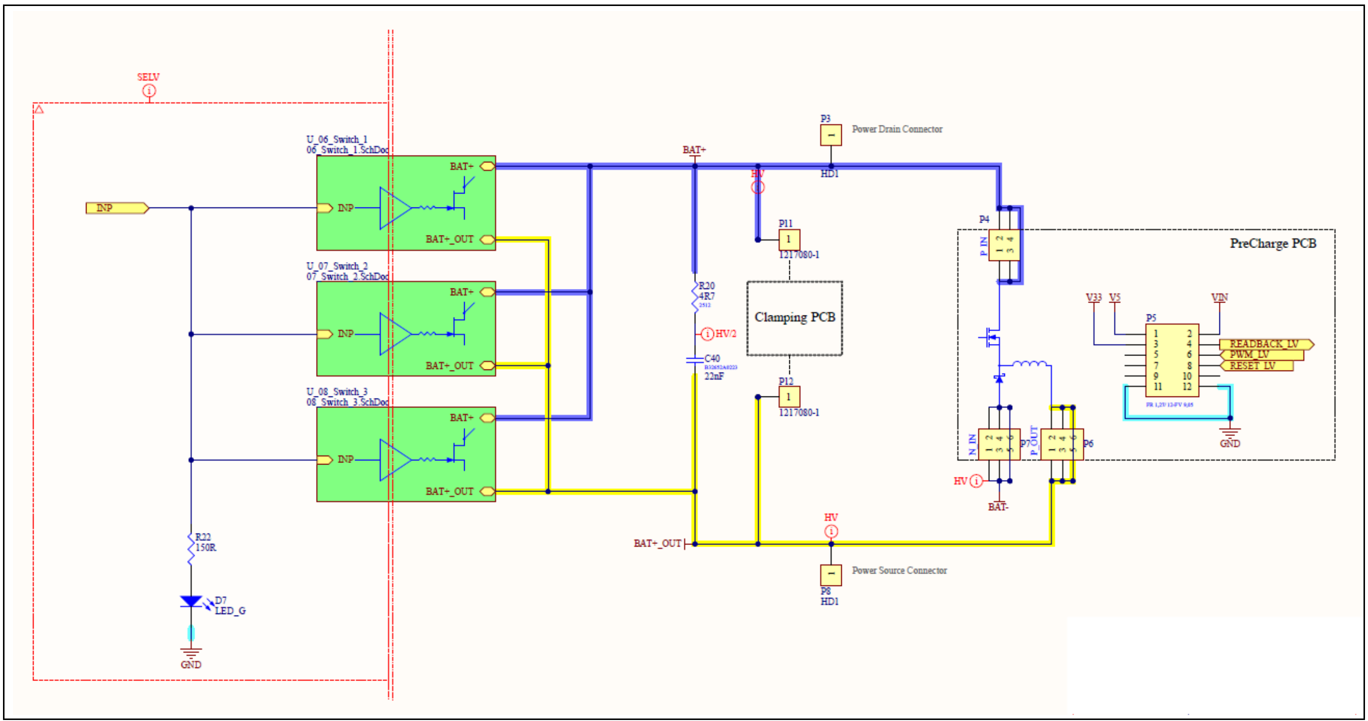

Figure 18 Schematic – eBDU power stage

The overall power stage with the respective decoupling and supply concept is shown in Figure 19. Each switching block uses two Infineon CoolSiC™ JFET power devices, IJCQ120RM25J1, and one gate driver as shown in Figure 20.

To minimize the coupling between the individual switching blocks, the gate driver's supply is decoupled using a combination of a resistor and diode connected in series on both the positive and negative supply rails. This reduces interference and maintains a proper separation between the blocks. To allow higher switching speeds, the gate driver supplies are locally buffered. The gate driver is locally referenced to the power source of each JFET couple. To optimize switching performance for both turn-on and turn-off states, each JFET is independently controlled by its own dedicated resistors, $R_{g,on}$ and $R_{g,off}$.

Due to the gate-to-drain capacitance (C_{gd}) of the JFET, a low-ohmic clamp MOSFET is used to prevent parasitic turn-on caused by fast transient voltage swings on the terminals. This event frequently occurs in the system when the mechanical contactor in the series switches ON while the eBDU remains in the OFF state. The clamp MOSFETs (Q7, Q8) are placed close to the gate and kelvin source terminals and are controlled by the same gate driver that controls the JFETs.

When the JFET is on, the gate driver U7 asserts OUT+ to +2 V, turning the JFET on and causing T5 to short the clamp MOSFET's gate to its source, which disables the clamp. When the JFET is off, U7 asserts OUT− to −18 V and drives the JFET gate to −18 V; T5 is nonconductive, so R26 pulls the clamp MOSFET's gate to the JFET source potential. With the clamp MOSFET's source referenced to the −18 V rail, this generates a positive Vgs that turns the clamp on, creating a low-ohmic path to the negative supply and bypassing Rg,off, thereby no appreciable voltage develops across $R_{g,off}$ from dV/dt-induced gate current. To minimize loop impedance, a clamp MOSFET is placed close to each JFET, with the local JFET source capacitively coupled to the clamp MOSFET (e.g., C11, C15).

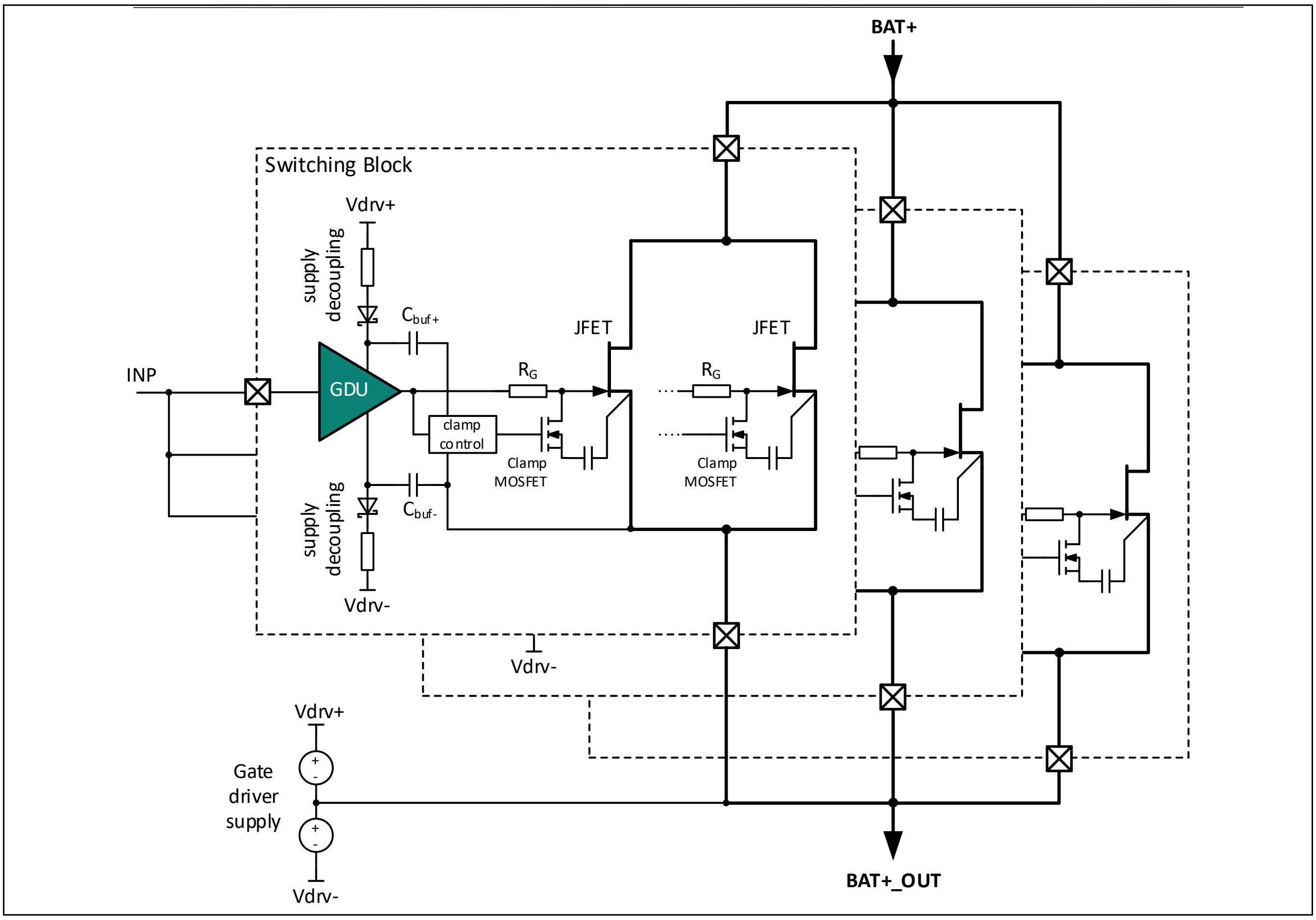

Figure 19 Schematic – Power-stage paralleling concept

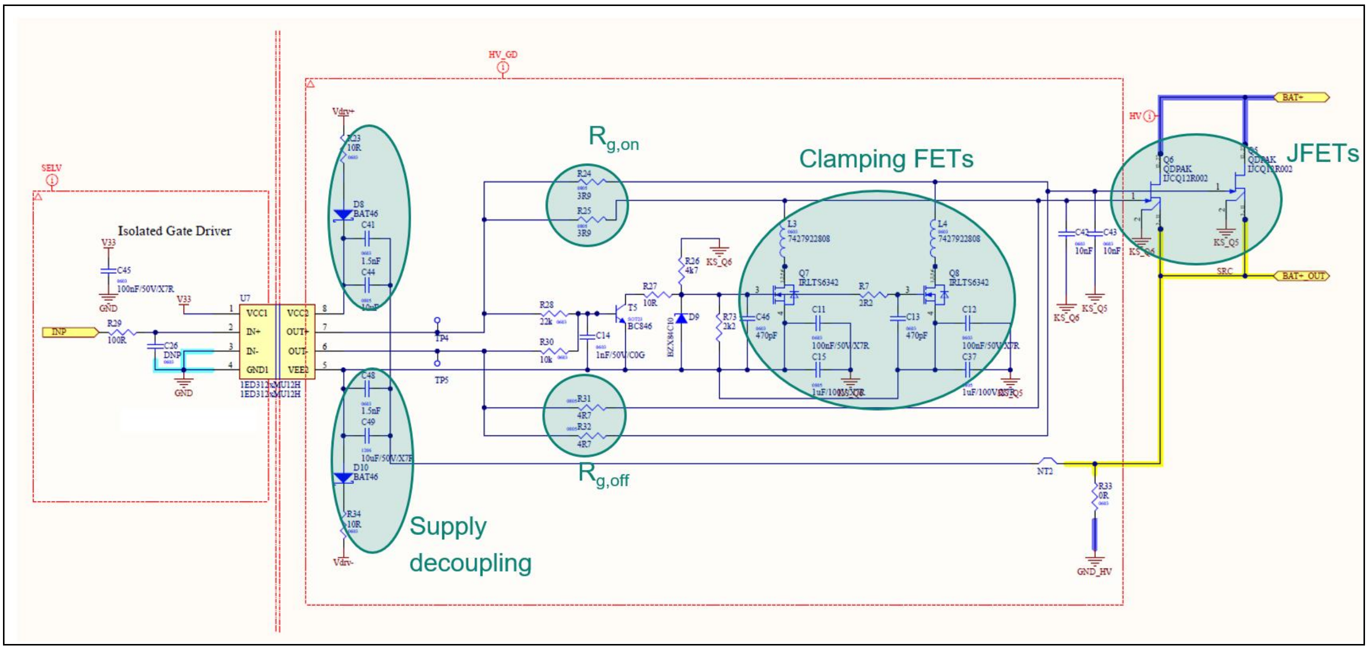

Figure 20 Schematic – Power-stage switching block

3.3 Digital input and contactor output

The digital input and contactor-control output circuitry is shown in Figure 21. The digital input is protected with the digital transistor T1. The contactor control output is driven by the MOSFET, Q13, and the current can be limited with the resistor, R2. Depending on the contactor coil current requirements, R2 should be adjusted or removed. For example, if the contactor has an integrated economizer. The diode, D1, is used for freewheeling when the contactor coil is turned off.

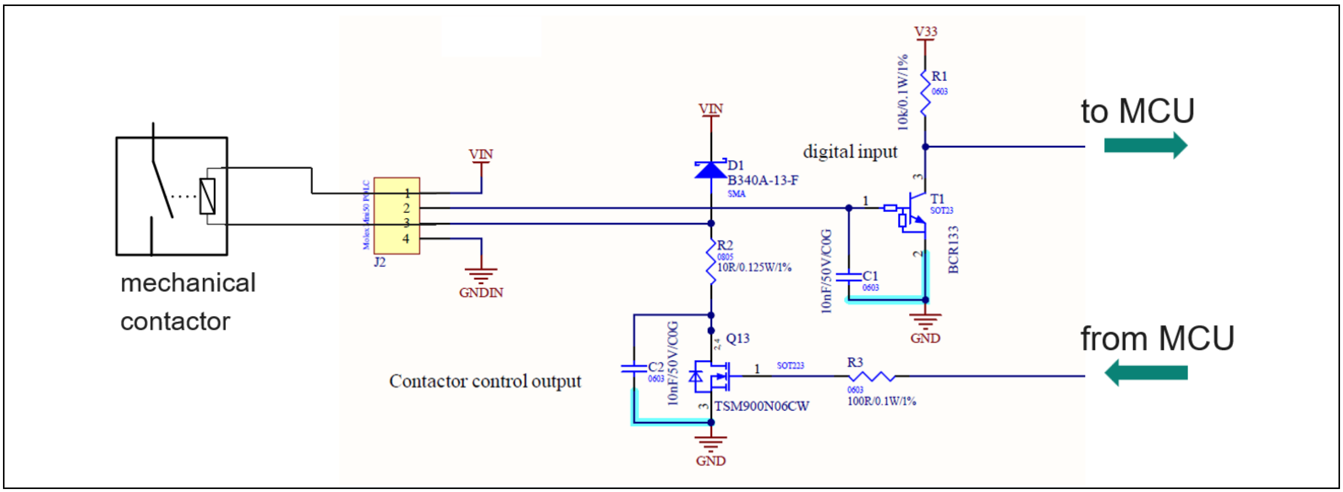

Figure 21 Schematic – Digital input and contactor output

4 The eBDU GUI

The eBDU Demo GUI is used for communicating with the demo board over CAN communication. This GUI is divided into three distinct windows and provides different monitoring and programmability options.

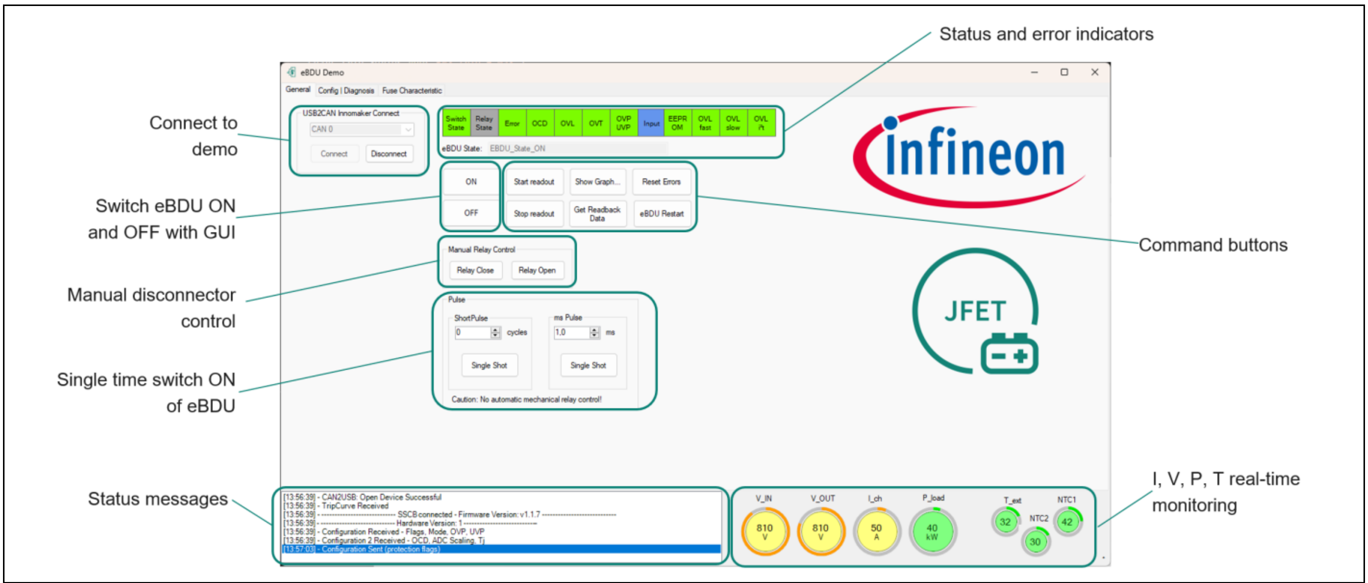

Figure 22 **Main window of the eBDU GUI**

Table 8 Description of the main window's functions

Function/Button	Description
Connect/Disconnect	To establish the communication with the GUI via the Innomaker USB-to-CAN device. After successful connection, a status message with the hardware and software revisions is displayed in the status message area.
ON/OFF	To turn the eBDU channel ON or OFF from the GUI.
Start readout/Stop readout	To start or stop the periodic readout of the status flags and analog measurements.
Show Graph	To show the realtime data graph (see Figure 25).
Reset Errors	To reset error flags, if possible.
Get Readback Data	To get one-time status flags and analog measurements readback
eBDU Restart	To restart the eBDU from the eBDU_Down state (Redo startup and BIST routines).
Manual Relay control	To switch the mechanical disconnector ON or OFF manually if the automatic relay control is disabled in the configuration
Pulse	To activate the channel for a single pulse with a defined pulse length. Setting delays in milliseconds and short pulses in µs range is possible. Automatic relay control is not available for these pulses.
Status and error indicators	These show the status, error flags (Refer to Table 9), and the present operating state of the eBDU.
Status messages	The space where status messages are displayed.
V, I, P, T realtime monitoring	Shows channel input, output voltage, and current along with the temperature of all the NTCs on the PCB.

Table 9 Description of the status and error indicators

Indicator	Description	Indication
Switch State	Current state of the channel	Green: ON Grey: OFF
Relay State	Current state of the mechanical disconnector	Green: Relay closed Grey: Relay open
Error	Any fault/error condition	Red: Error Green: Normal operation
OCD	Fast detection of overcurrent in the hardware (latched)	Red: Error Green: Normal operation
OVL	Overload condition: Channel current is above nominal current from trip characteristic or after an overload cooldown	Red: Overload Green: Normal operation Yellow: Cooldown
OVT	Overtemperature condition in any NTC	Red: Overtemperature Green: Normal operation
OVP/UVP	Overvoltage or undervoltage condition	Red: Overvoltage Green: Normal operation
Input	State of the digital input	Blue: Active - ON Green: OFF
EEPROM	EEPROM read error – Readout of saved values from EEPROM failed	Red: Error Green: Normal operation
OVL fast	Software trip: Fast overload current exceeded (latched)	Red: Error Green: Normal operation
OVL slow	Software trip: Slow overload current exceeded (latched)	Red: Error Green: Normal operation
OVL i^2t	Software trip: i^2t integral exceeded (latched)	Red: Error Green: Normal operation

Table 10 Description of the eBDU states

Indicator	Description
EBDU_State_DOWN	Initial state after power down; initializing all variables
EBDU_State_BIST	Inbuilt self-test during startup; wait for the voltage measurements to be ready
EBDU_State_STARTUP	Transmits current configuration to the GUI
EBDU_State_IDLE	Channel OFF state – monitoring of the temperature and voltages is active
EBDU_State_ON	Channel ON state
EBDU_State_ERROR	Error state – An error occurred during the ON state
EBDU_State_RELAY_ON	Transition to the ON state and activate relay (only if the automatic relay control is active)
EBDU_State_RELAY_OFF	Transition to the OFF state and deactivate relay (only if the automatic relay control is active)

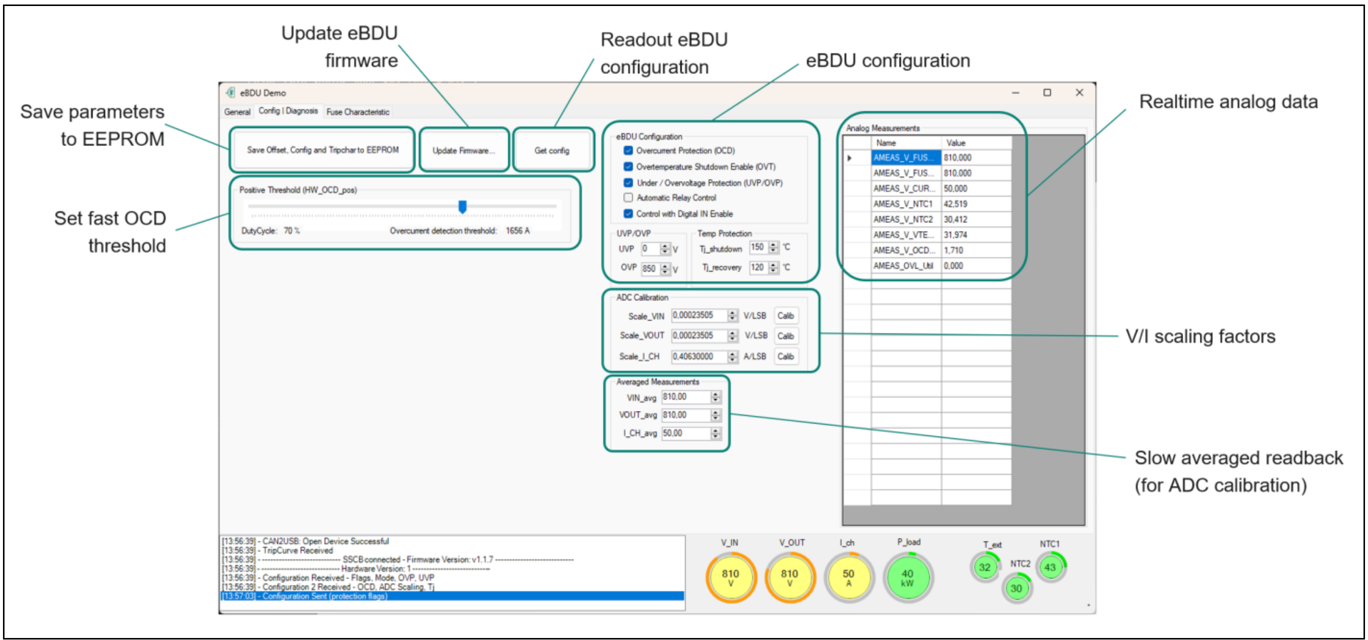

Figure 23 The configuration window of the eBDU GUI

Table 11 Description of the configuration window's functions

Function/Button	Description
Save Offset, Config and Tripchar to EEPROM	To save current configuration and trip curve to the eBDU EEPROM memory
Update Firmware	To update the firmware of the MCU via CAN from a *.hex file
Get config	To readback the current eBDU configuration from the hardware
eBDU Configuration	To enable or disable different functions: - Fast hardware overcurrent detection - Overtemperature shutdown - Undervoltage or overvoltage protection - Automatic relay control when channel turns ON or OFF - Enable hardware digital input pin control Set overtemperature limit and hysteresis or the overvoltage and undervoltage limits.
Positive Threshold (HW_OCD_pos)	To set the fast hardware-overcurrent detection threshold (with a click on the label the exact values can be entered directly)
Analog measurements	Shows the latest, realtime analog readback values from the eBDU
ADC Calibration	Shows the scaling factors for voltage and current measurements (refer to section 4.1)
Averaged Measurements	Shows highly averaged analog readback values using a moving average filter – used for calibrating scaling factors

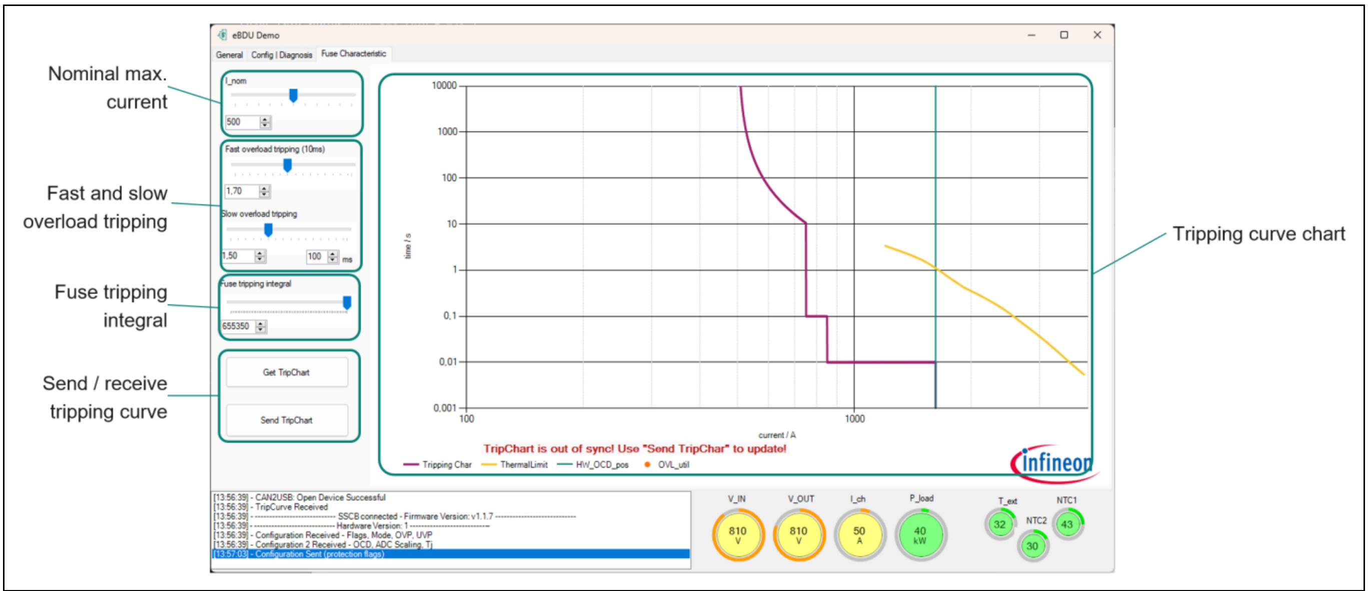

Figure 24 The trip-curve window of the eBDU GUI

Table 12 Description of the trip-curve window's functions

Function/Button	Description
I_nom	To set the maximum nominal current used for the trip curve. No overload occurs till this current value
Fast overload tripping (10ms)	To set the software-based fast trip limit – fixed value (overcurrent must be present for over 10 milliseconds till eBDU trips)
Slow overload trip current	To set the software-based slow trip limit – fixed value (overcurrent must be present at least in the configured timeframe)
Fuse tripping integral	To set the melting-fuse like trip characteristic i^2t value
Get Tripchart/Send Tripchart	To send or receive the trip curve from the eBDU
Tripping curve chart	Graphical representation of the configured trip curve. Hardware-based fast overcurrent detection and thermal limit of the eBDU is shown as well. Under overload conditions, the present i^2t utilization is shown with a dot named OVL_util.

Note: For a detailed explanation of the tripping curve functionality, refer to section 4.2.

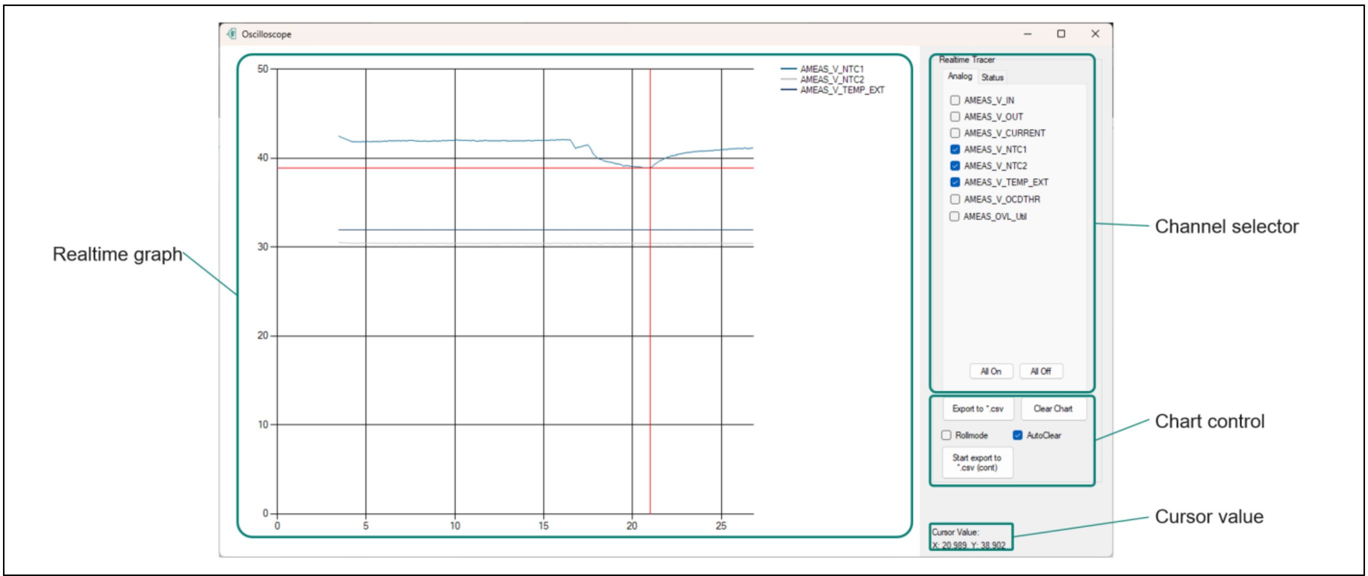

Figure 25 Realtime graph window of the eBDU GUI

Table 13 Description of the realtime graph's functions

Function/Button	Description
Realtime graph	Realtime graph visualization of selected analog values or status flags
Realtime Tracer	To select analog channel or status bits
Chart control	Shows different options to control the chart: - Export to *.csv: Export the currently displayed data to a .csv file (could take a long time depending on the amount of data displayed) - Clear Chart: Clear the contents of the graph - Rollmode: Rolling mode for displaying data in the graph - AutoClear: To automatically clear data after 100 seconds to prevent memory overflow - Start export to *.csv (cont): To create a file and continuously export data to that file
Cursor value	Shows the X and Y values of the cursor on the graph (when clicked on a chart area)

Table 14 Description of the analog measurements

Parameter	Description	Unit
AMEAS_V_FUSE_IN	Voltage measurement on the IN pin (Note: The BAT-terminal has to be connected)	V
AMEAS_V_FUSE_OUT	Voltage measurement on the OUT pin (Note: The BAT-terminal has to be connected)	V
AMEAS_V_CURRENT	Channel current measurement	A
AMEAS_V_NTC1	Temperature of NTC1	°C
AMEAS_V_NTC2	Temperature of NTC2	°C
AMEAS_VTEMP_EXT	Temperature of the NTC connected to the drain potential	°C
AMEAS_V_OCDTHR	Readback of the hardware OCD threshold	V

AMEAS_OVL_Util	Overload percentage of i²t budget at the current load level. The eBDU will trip at 100%	%

4.1 Calibrating the voltage and current scaling factors

The scaling factors for current and voltage measurements can be adjusted in the configuration window of the GUI. The corrected factor can be calculated manually or using the integrated calibration calculator tool after clicking the button **Calib**.

For better calibration results, the GUI shows a moving average of the last 100 samples sent by the eBDU.

With an external measurement, the new scaling factor can be calculated as:

$$Scale\_X_{new} = Scale\_X_{current} \cdot \frac{X_{measured}}{X_{GUI}}$$

Or the GUI feature for calibration can be used, which will do the calculation automatically:

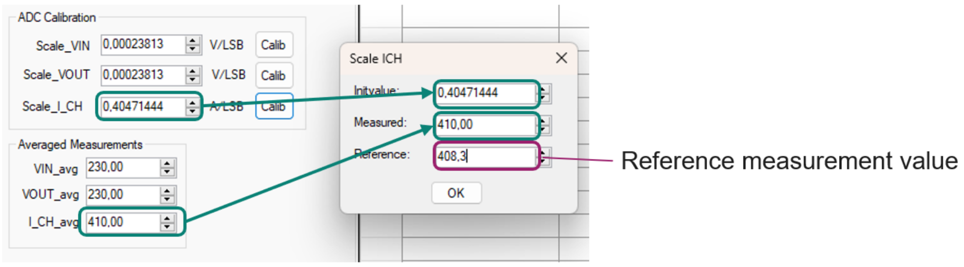

Figure 26 Calibration feature of the eBDU GUI for voltage and current measurement

4.2 The eBDU trip curve

The eBDU trip curve that can be configured in the GUI is shown in Figure 27. Besides the actual thermal limit curve of the eBDU demonstrator, it also shows the configurable tripping characteristic and the current overload utilization. The tripping curve comprises four different sections that are configured individually:

i^2t trip integral:
This part replicates the traditional melting fuse trip characteristic. It is defined by the i^2t value and is calculated when the current exceeds the nominal value. The current i^2t value is calculated as:

$$i^2t_{current} = \begin{cases} \iint (I_{current} - I_{nom})^2 \; dt \;, & I_{current} > I_{nom} \\ 0, & otherwise \end{cases}$$

To discharge the I^2t integral once the current no longer exceeds the nominal level, the integrator decays linearly at 40.000 A^2/s, equivalent to the charging rate for a constant 200 A overcurrent

The time until the eBDU trips with a constant current can be calculated as:

$$t_{trip,i^2t} = \frac{i^2t_{trip}}{(I_{current} - I_{nom})^2}$$

Software-based slow overcurrent:
The first linear part of the tripping curve uses a configurable trip time. The eBDU will trip when this current level is exceeded for the configurable time.

Software-based fast overcurrent:
This part is the fastest software-based tripping detection. It will be triggered if the current exceeds its limit for 10 milliseconds.

Hardware-based fast overcurrent:
The hardware-based OCD works within microseconds and is used as a software-independent tripping unit. The threshold level can be configured in the GUI. An integrated comparator in the current sensor, TLE5571, is used.

In the event of an overload, or after an overload condition, the current level of OVL i^2t utilization is shown in the chart with an orange dot. As soon as this dot reaches the i^2t curve, the eBDU will trip and switch off the channel. In case the current decreases after an overload event, the dot slowly decays with a fixed cooldown i^2t value equivalent to a 200 A overload.

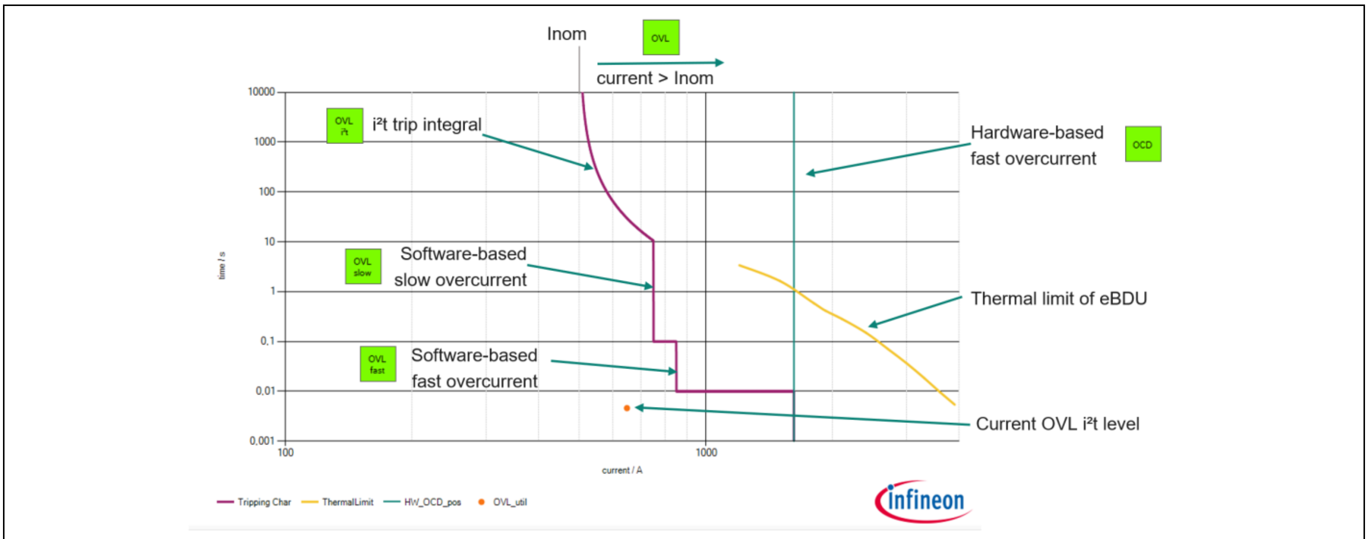

Figure 27 eBDU GUI trip curve

5 CAN communication

5.1 The communication interface

The eBDU demonstrator uses a CAN interface to communicate with the PC GUI. The specifications for the CAN interface are listed in Table 15 and Figure 28.

Table 15 SPI configuration of the mainboard

Setting	Value
Identifier	Standard 11 bit
RX Identifier Address	$0x321_h$
TX Identifier Address	$0x321_h$
Data length (RX & TX)	8 bytes
Baud rate	500 Kbps

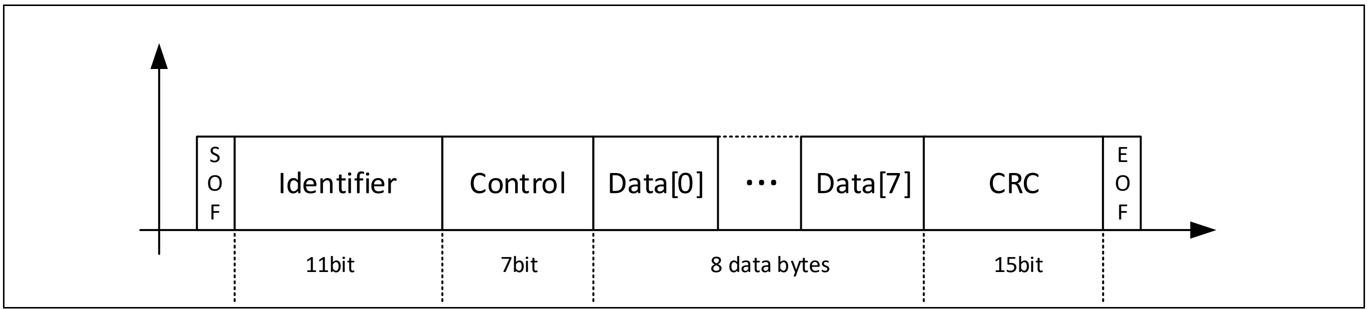

Figure 28 The CAN frame structure for communication

5.2 CAN command list

The return data for each command is returned with the CAN commands listed in Table 16. The width of each CAN frame is 8 bytes.

Table 16 CAN RX – Receive data

Command	Byte number	Data	Description
SWITCH_ON	0	$0x01_h$	Turn the eBDU switch on
SWITCH_OFF	0	$0x02_h$	Turn the eBDU switch off
START_READOUT	0	$0x06_h$	Initiate status feedback from the eBDU (all status frames)
EEPROM_WRITE	0	$0x0C_h$	Write the configuration and current offset values into EEPROM
SWITCH_RESET	0	$0x0D_h$	BDU reset errors
BDU_RESTART	0	$0x1C_h$	BDU reset and restart without an MCU reset
SET_OCD_LVL	0	$0x0E_h$	Set OCD threshold
	1	*<var>*	OCD threshold output PWM duty cycle high byte
	2	*<var>*	OCD threshold output PWM duty cycle low byte
SHORT_PULSE	0	$0x1D_h$	Switch ON the eBDU for several µs (not accurate) – Single pulse
	1	*<var>*	Switch ON time high byte
	2	*<var>*	Switch ON time low byte
PULSE_MS	0	$0x1E_h$	Switch ON the eBDU for ms/10 – Single pulse
	1	*<var>*	Switch ON time high byte
	2	*<var>*	Switch ON time low byte
SET_TRIP_CURVE	0	$0x0F_h$	Set eBDU trip curve
	1–2	*<var>*	param_TRIP_INOM
	3	*<var>*	param_TRIP_OVL_FAST
	4	*<var>*	param_TRIP_OVL_SLOW
	5	*<var>*	param_TRIP_OVL_SLOW_DELAY
	6–7	*<var>*	param_TRIP_OVL_INTEG
GET_TRIP_CURVE	0	$0x13_h$	Initiate trip curve readback
SET_CONFIG	0	$0x10_h$	Set eBDU configuration 1
	1	*<var>*	eBDU config flags (See 0)
SET_CONFIG2	0	$0x11_h$	Set eBDU configuration 2
	1	*<var>*	SCALE_VIN – byte 0 (float)
	2	*<var>*	SCALE_VIN – byte 1 (float)
	3	*<var>*	SCALE_VIN – byte 2 (float)
	4	*<var>*	SCALE_VIN – byte 3 (float)

	5	*<var>*	TJ_SHUTDOWN
	6	*<var>*	TJ_RECOVERY
	7	*<var>*	SCALE_VOUT – byte 0 (float)
SET_CONFIG3	0	*0x12$_h$*	Set eBDU configuration 3
	1	*<var>*	SCALE_CURR – byte 0 (float)
	2	*<var>*	SCALE_ CURR – byte 1 (float)
	3	*<var>*	SCALE_ CURR – byte 2 (float)
	4	*<var>*	SCALE_ CURR – byte 3 (float)
	5	*<var>*	SCALE_VOUT – byte 1 (float)
	6	*<var>*	SCALE_VOUT – byte 2 (float)
	7	*<var>*	SCALE_VOUT – byte 3 (float)
SET_CONFIG4	0	*0x19$_h$*	Set eBDU configuration 4
	1	*<var>*	Undervoltage protection limit high byte
	2	*<var>*	Undervoltage protection limit low byte
	3	*<var>*	Overvoltage protection limit high byte
	4	*<var>*	Overvoltage protection limit low byte
RELAY_CLOSE	0	*0x09$_h$*	Close contactor
RELAY_OPEN	0	*0x08$_h$*	Open contactor
GET_CONFIG	0	*0x14$_h$*	Initiate config readout from the eBDU (version frame + all config frames)
BLD_INIT	0	*0x1A$_h$*	Reset the MCU in the bootloader mode via CAN for firmware update

Table 17 CAN TX – transmit data

Command	Byte number	Data	Description
ADC_DATA	0	*0x04$_h$*	Status feedback frame
	1	*0x00$_h$*	Frame number
	2–3	*<var>*	Status bytes 0 – 1 (see Table 19)
	4–5	*0*	Reserved
	6–7	*<var>*	V_OCD_thr
ADC_DATA	0	*0x04$_h$*	Status feedback frame
	1	*0x01$_h$*	Frame number
	2–3	*<var>*	V_CURRENT
	4–5	*<var>*	V_IN
	6–7	*<var>*	V_OUT
ADC_DATA	0	*0x04$_h$*	Status feedback frame
	1	*0x02$_h$*	Frame number
	2–3	*<var>*	TEMP_EXT
	4–5	*<var>*	TEMP_NTC1

	6–7	*<var>*	TEMP_NTC2
ADC_DATA	0	*0x04*$_h$	Status feedback frame
	1	*0x03*$_h$	Frame number
	2–3	*<var>*	OVL_utilization
	6–7	*0*	reserved
GET_CONFIG	0	*0x14*$_h$	Get eBDU configuration 1
	1	*<var>*	SSCB config flags (See 0)
	2	*<var>*	Undervoltage Protection limit low byte
	3	*<var>*	Undervoltage Protection limit high byte
	4	*<var>*	Overvoltage Protection limit low byte
	5	*<var>*	Overvoltage Protection limit high byte
GET_CONFIG2	0	*0x15*$_h$	Get eBDU configuration 2
	1	*<var>*	SCALE_VIN – byte 0 (float)
	2	*<var>*	SCALE_VIN – byte 1 (float)
	3	*<var>*	SCALE_VIN – byte 2 (float)
	4	*<var>*	SCALE_VIN – byte 3 (float)
	5	*<var>*	TJ_SHUTDOWN
	6	*<var>*	TJ_RECOVERY
	7	*<var>*	SCALE_VOUT – byte 0 (float)
GET_CONFIG3	0	*0x16*$_h$	Get eBDU configuration 3
	1	*<var>*	SCALE_CURR – byte 0 (float)
	2	*<var>*	SCALE_ CURR – byte 1 (float)
	3	*<var>*	SCALE_ CURR – byte 2 (float)
	4	*<var>*	SCALE_ CURR – byte 3 (float)
	5	*<var>*	SCALE_VOUT – byte 1 (float)
	6	*<var>*	SCALE_VOUT – byte 2 (float)
	7	*<var>*	SCALE_VOUT – byte 3 (float)
GET_CONFIG4	0	*0x18*$_h$	Get eBDU configuration 4
	1	*<var>*	OCD threshold level low byte
	2	*<var>*	OCD threshold level high byte
GET_VERSION	0	*0x17*$_h$	Get the eBDU version
	1	*<var>*	SW VERSION
	2	*<var>*	SW MAINVERSION
	3	*<var>*	SW SUBVERSION
	4	*<var>*	HW_REVISION

Table 18 Description of the eBDU configuration flags

Bit number	Name	Description
0	OCD_en	Enable hardware OCD
1	OVT_en	Enable overtemperature protection
2	OVP_UVP_en	Enable overvoltage/undervoltage protection
3	RELAY_en_auto	Enable automatic relay control
4	DIGITAL_IN_en	Enable control via digital IN

Table 19 Description of the SSCB status feedback flags

Bit number	Name	Description
0–4	SSCB State	SSCB operating states: *0 … DOWN* *1 … BIST* *2 … STARTUP* *3 … IDLE* *4 … ON* *5 … ERROR* *6 … EBDU_State_RELAY_ON* *7 … EBDU_State_RELAY_OFF*
5	SwitchState	MOSFET switch state
6	MSwitchState	Relay state
7	Error	Error indication
8	OCD	OCD error flag
9	OVL	Overload error flag
10	OVT	Overtemperature error flag
11	OVP_UVP	Overvoltage or undervoltage error flag
12	InputState	External input state
13	EEPROM_Error	EEPROM readout error
14	OVL_fast	Overload fast trip
15	OVL_slow	Overload slow trip
16	OVL_integ	Overload i^2t-based trip

Table 20 Analog values conversion factors

Parameter ADC value	Factor
General	$V_{ADC} = ADC_{Value} * \frac{3.3}{4096}$
NTC, TEMPEXT measurement	As per the NTC lookup table
OCD duty cycle values	$DC[\%] = \frac{DC\_val}{100}$
Short ms pulse	$Pulse\ duration[ms] = \frac{Reg\_val}{10}$
Undervoltage/overvoltage protection limit	$Limit[V] = \frac{Reg\_val}{100}$
AMEAS_V_FUSE_IN	$V_{in}[V] = \frac{AMEAS\_V\_FUSE\_IN}{10}$
AMEAS_V_FUSE_OUT	$V_{out}[V] = \frac{AMEAS\_V\_FUSE\_OUT}{10}$
AMEAS_V_CURRENT	$I_{out}[A] = \frac{AMEAS\_V\_CURRENT}{10}$
AMEAS_V_OCD_thr	$V_{OCD,thr}[V] = AMEAS\_V\_OCD\_thr \cdot \frac{3.3\ V}{4096}$
param_TRIP_INOM	I_{nom} = param_TRIP_INOM
param_TRIP_OVL_FAST	$I_{trip,fast} = I_{nom} \cdot \frac{param\_TRIP\_OVL\_FAST}{100}$
param_TRIP_OVL_SLOW	$I_{trip,slow} = I_{nom} \cdot \frac{param\_TRIP\_OVL\_SLOW}{100}$
param_TRIP_OVL_SLOW_DELAY	$t_{trip,slow} = param\_TRIP\_OVL\_SLOW\_DELAY \cdot 0.2$
param_TRIP_OVL_INTEG	$i^2 t_{trip} = param\_TRIP\_OVL\_INTEG \cdot 10$

6 eBDU performance test

6.1 Leakage measurement

The leakage current of the demonstrator supplied and power stage in OFF condition is shown in Figure 29.

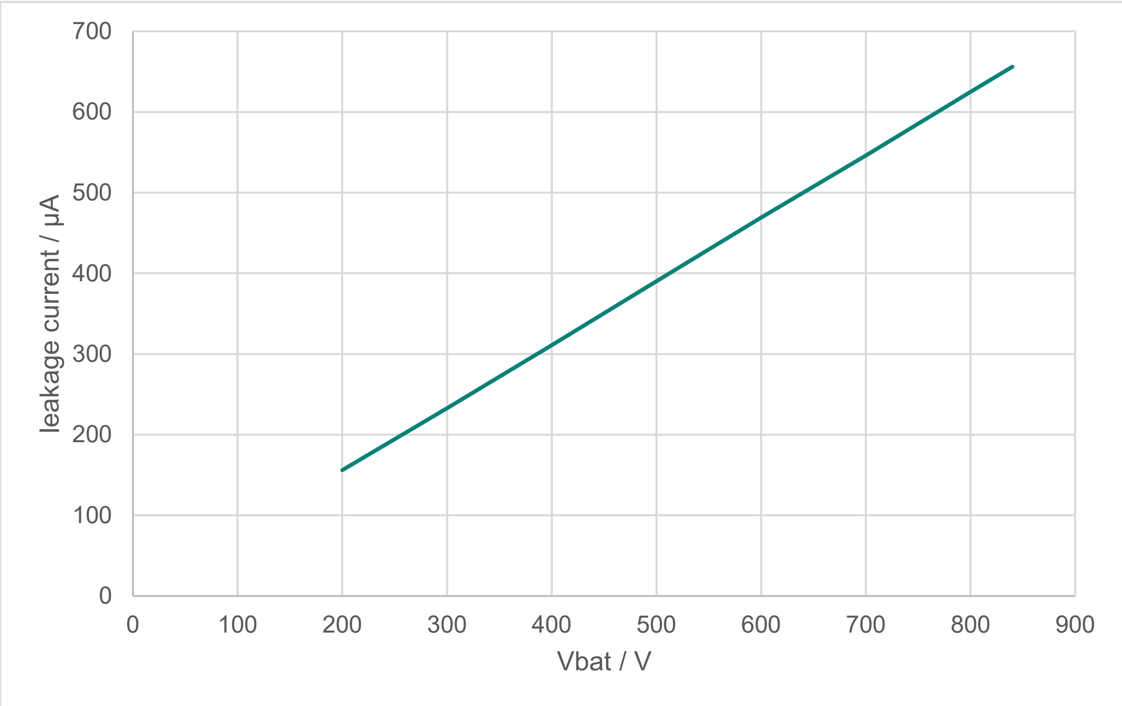

Figure 29 Leakage measurement of the overall demonstrator

6.2 Total resistance

The overall resistance of the eBDU is measured from the input to the output current rail, as shown in Figure 30. With a test current of 300 A (pulsed) the measured voltage drop resulted in a total resistance of 497 µΩ at room temperature. A graphical representation of power losses at room temperature for different load currents is shown in Figure 31.

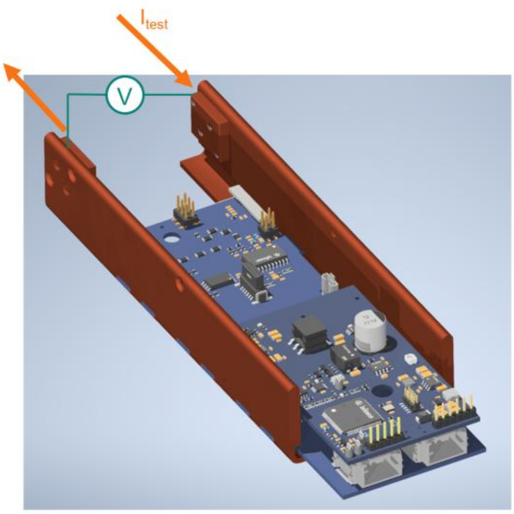

Figure 30 Measuring the overall resistance

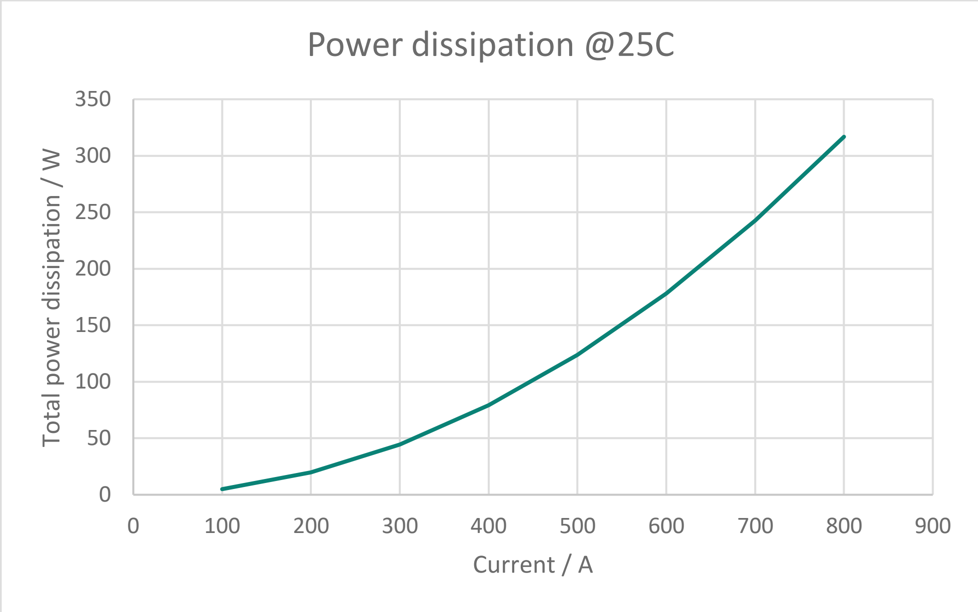

Figure 31 The overall power dissipated from the eBDU demonstrator at room temperature

6.3 Clamping measurement

The clamping measurement circuit is shown in Figure 32. The results with a 5 µH inductor and the AK10-530C + AK10-430C clamping options are shown in Figure 33 and Figure 34. The results of the 2 x PTVS10-470C clamping option are shown in Figure 35 and Figure 36.

A high-current shutdown without an additional inductor at a shutdown current of 2.4 kA is shown in Figure 37.

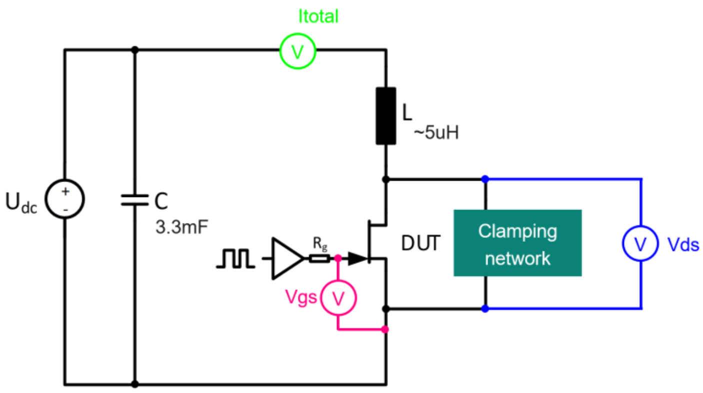

Figure 32 Measurement setup for the clamping test

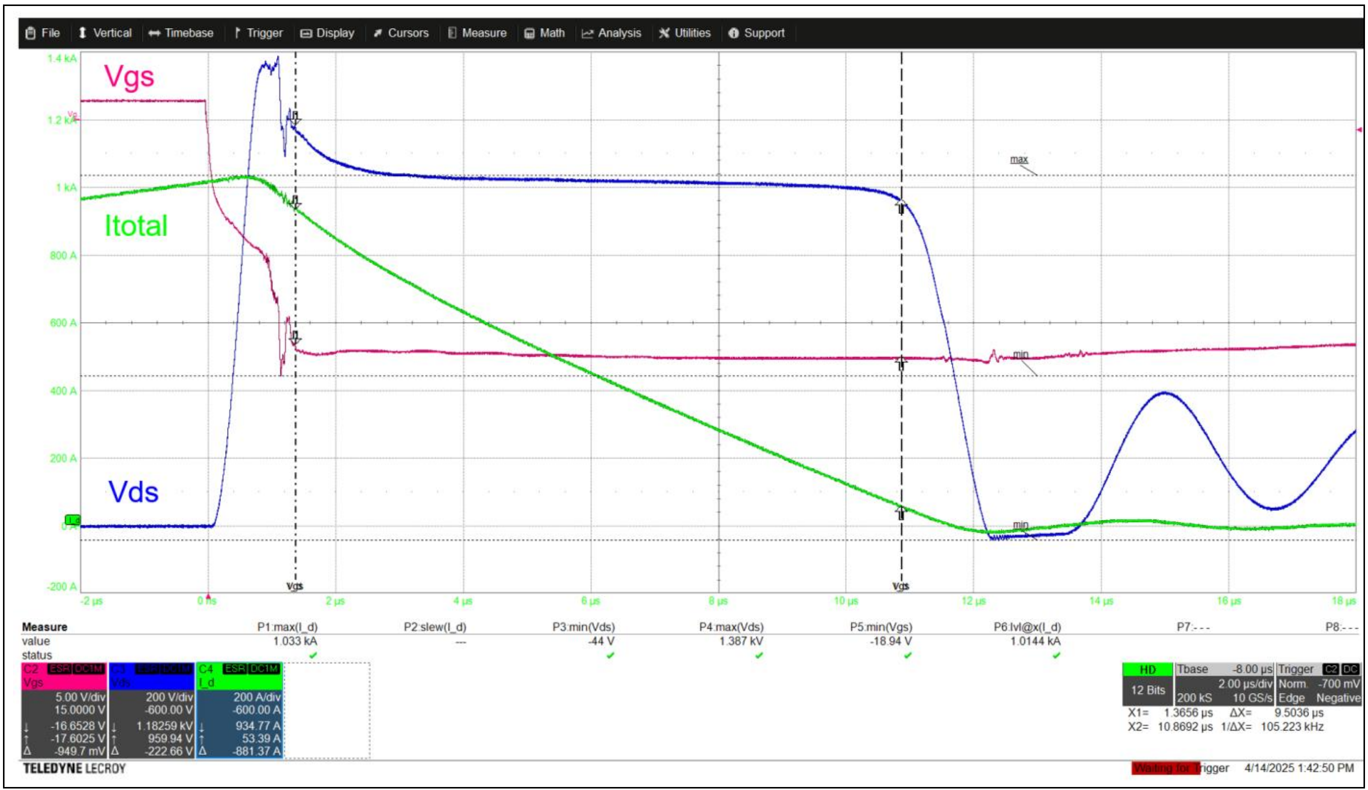

Figure 33 Clamping measurement: AK10-530C + AK10-430C – V_{bat} = 200 V, $I_{shutdown}$ = 1 kA

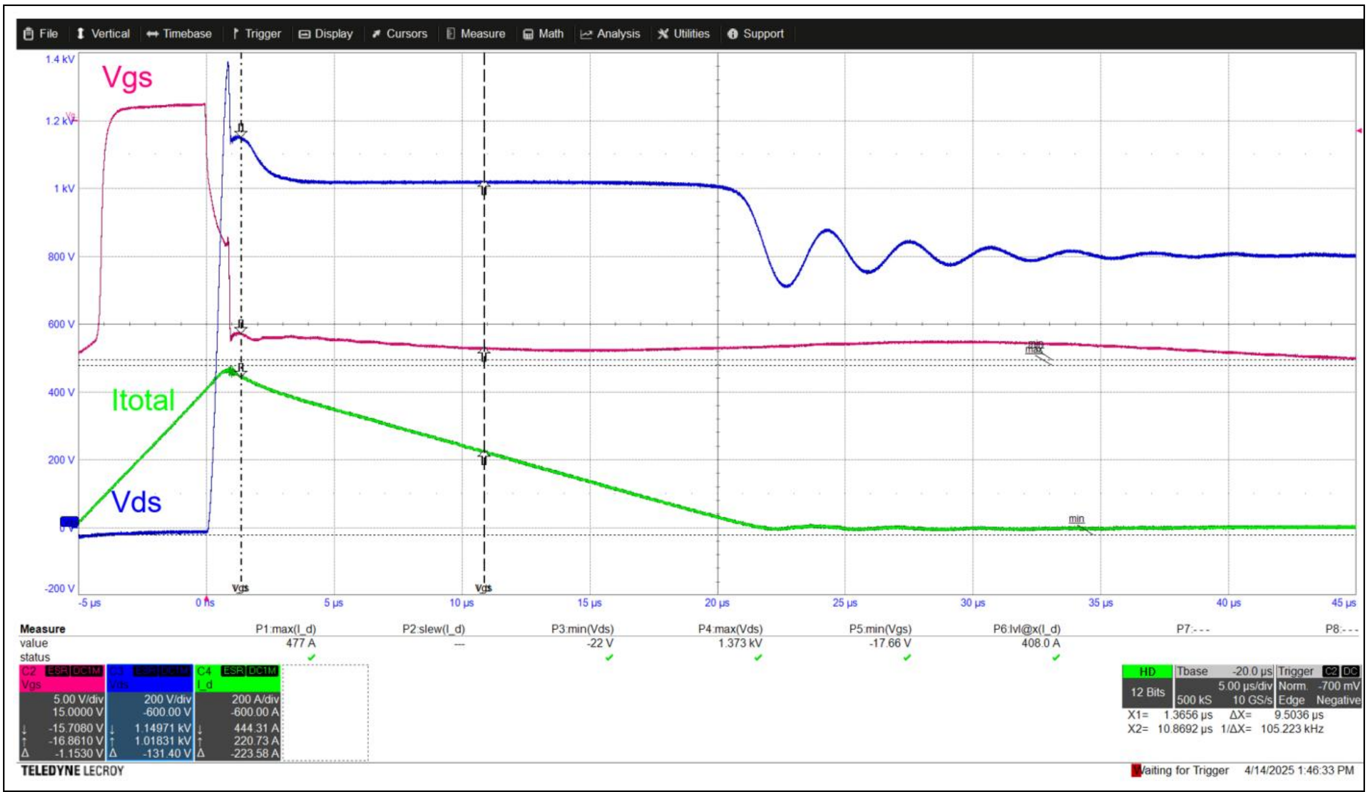

Figure 34 Clamping measurement: AK10-530C + AK10-430C – V_{bat} = 800 V, $I_{shutdown}$ = 480 A

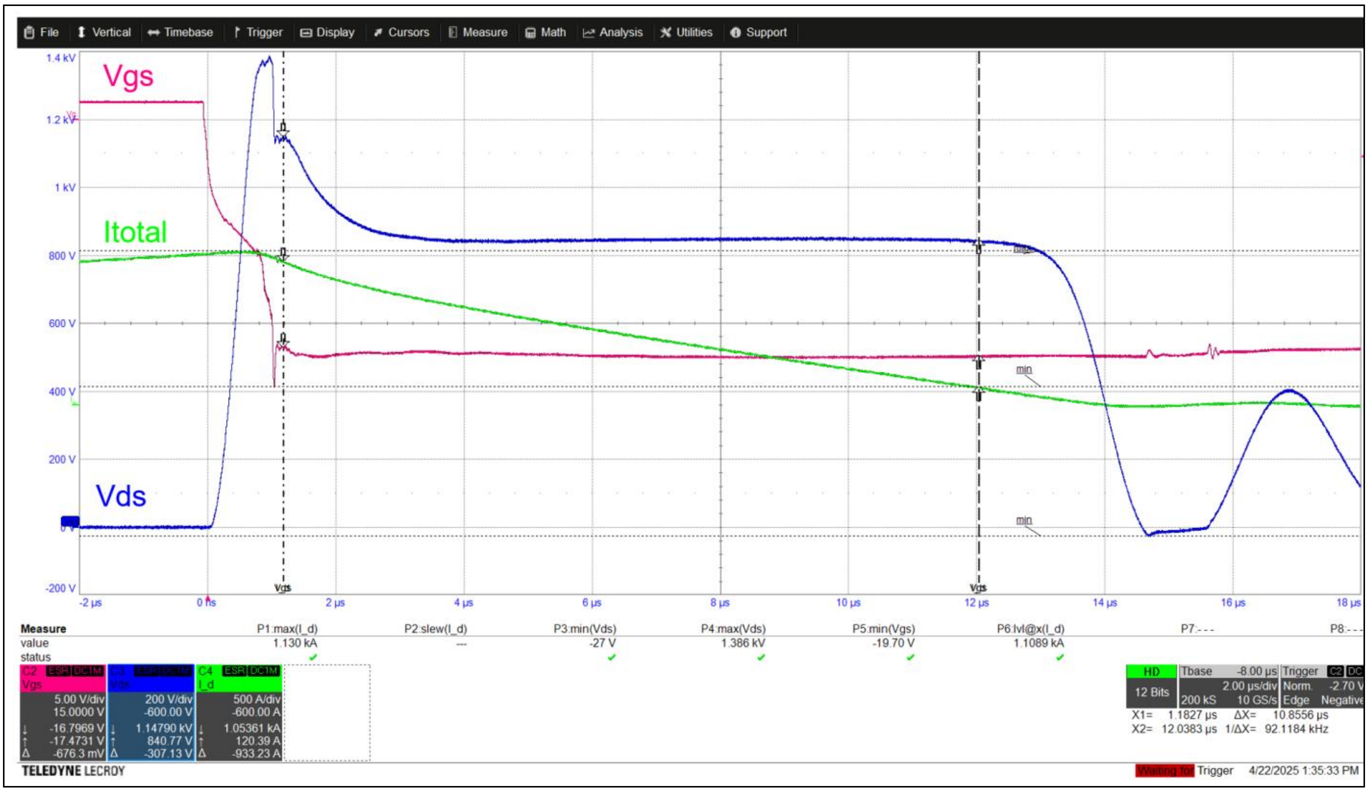

Figure 35 Clamping measurement: 2 x PTVS10-470C – V_{bat} = 200 V, $I_{shutdown}$ = 1 kA

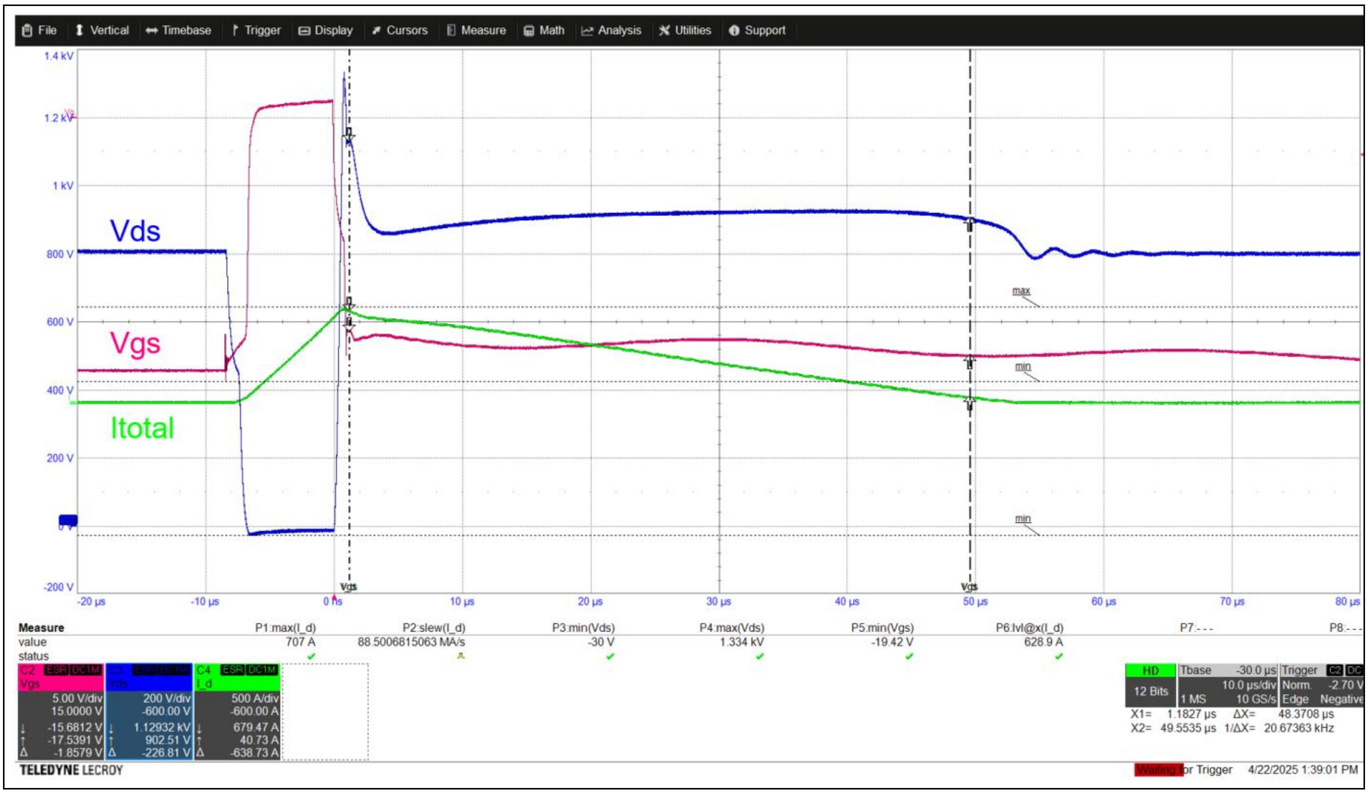

Figure 36 Clamping measurement: 2 x PTVS10-470C – V_{bat} = 800 V, $I_{shutdown}$ = 700 A

Figure 37 High-current shutdown: V_{bat} = 200 V, $I_{shutdown}$ = 2.4 kA

6.4 High-energy clamping measurement

To demonstrate the high-energy clamping capability of the demonstrator, a test was performed using a 116 µH load inductor with a 1 kA switch-off current. Figure 40 shows the measurement setup, comprising the buffer capacitor, the load inductor, and the demonstrator. Figure 39 shows the measured total current, the V_{ds} and V_{gs} of the power device, and the energy in the system.

When the power device turns off, the energy stored in the inductor reaches 64 J. Based on the measured waveforms, the clamping elements dissipate 36 J, while the remaining energy is dissipated in the wiring harness's ohmic resistance. The measurement setup exhibits higher resistive losses than the target application, so the clamping elements experience lower stress in laboratory tests. For more information, refer to the application note on the solid-state battery disconnect unit with Infineon's CoolSiC™ JFET technology [1].

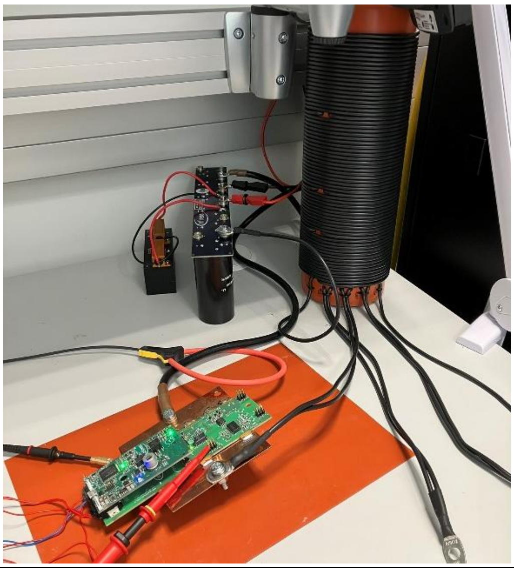

Figure 38 Setup for high-energy clamping measurement

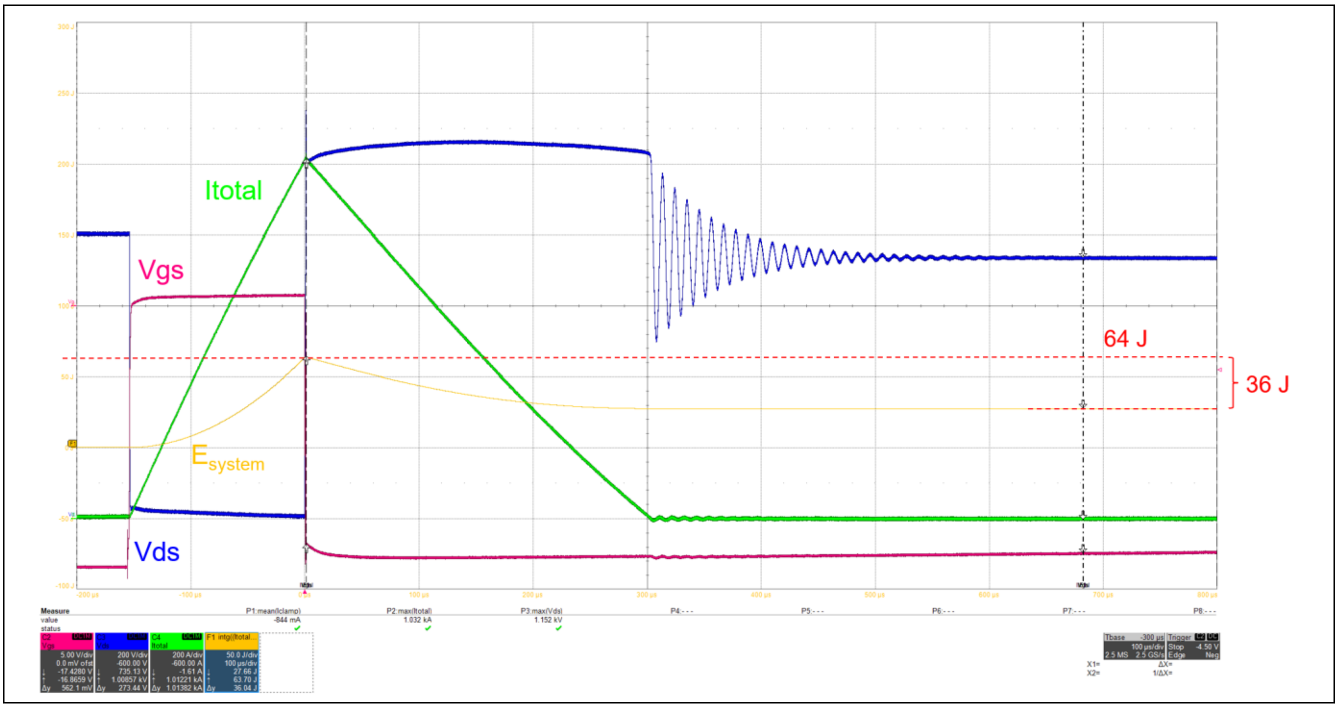

Figure 39 Results of high-energy clamping measurement (116 µH, 1 kA, V_{bat} = 800 V)

6.5 Current sharing

To measure the current sharing of individual paralleled power stages, a special assembly with flat busbars was used, as shown in Figure 40.

The results after the demonstrator switches ON is shown in Figure 41. The initial current sharing depends on the distance of the devices to the current infeed. The closest device takes over approximately double the current in the beginning while the middle and furthest power stages carry a similar current range. This causes the closest devices to heat up first and as their temperature rises, their on-resistance increases, shifting current into the other branches and intrinsically equalizing the current share. With this behavior the system is thermally stable and after ~250 µs, all currents are symmetriced and all three power stages are conducting the same current.

Figure 42 shows the switch-off and clamping of the demonstrator. All power stages conduct approximately the same current. The power stage located closest to the clamping element shows a negative current due to inductive kickback. In this test, the clamping element was placed outside the demonstrator to avoid measurement artifacts that could occur if the clamp took over the current.

To reduce the current mismatch, a fully symmetric design from the input and output would be beneficial. Due to $R_{DS(on)}$ and Vth mismatch of the power devices, a certain current mismatch cannot be compensated with mechanical symmetry. In this case adding additional parasitic source inductance via splitted source paths of the individual devices would help to ensure symmetric switching when paralleling power devices. Furthermore, each power device must remain within its datasheet limits throughout switching transients and the design shall consider for transient current imbalance between the branches.

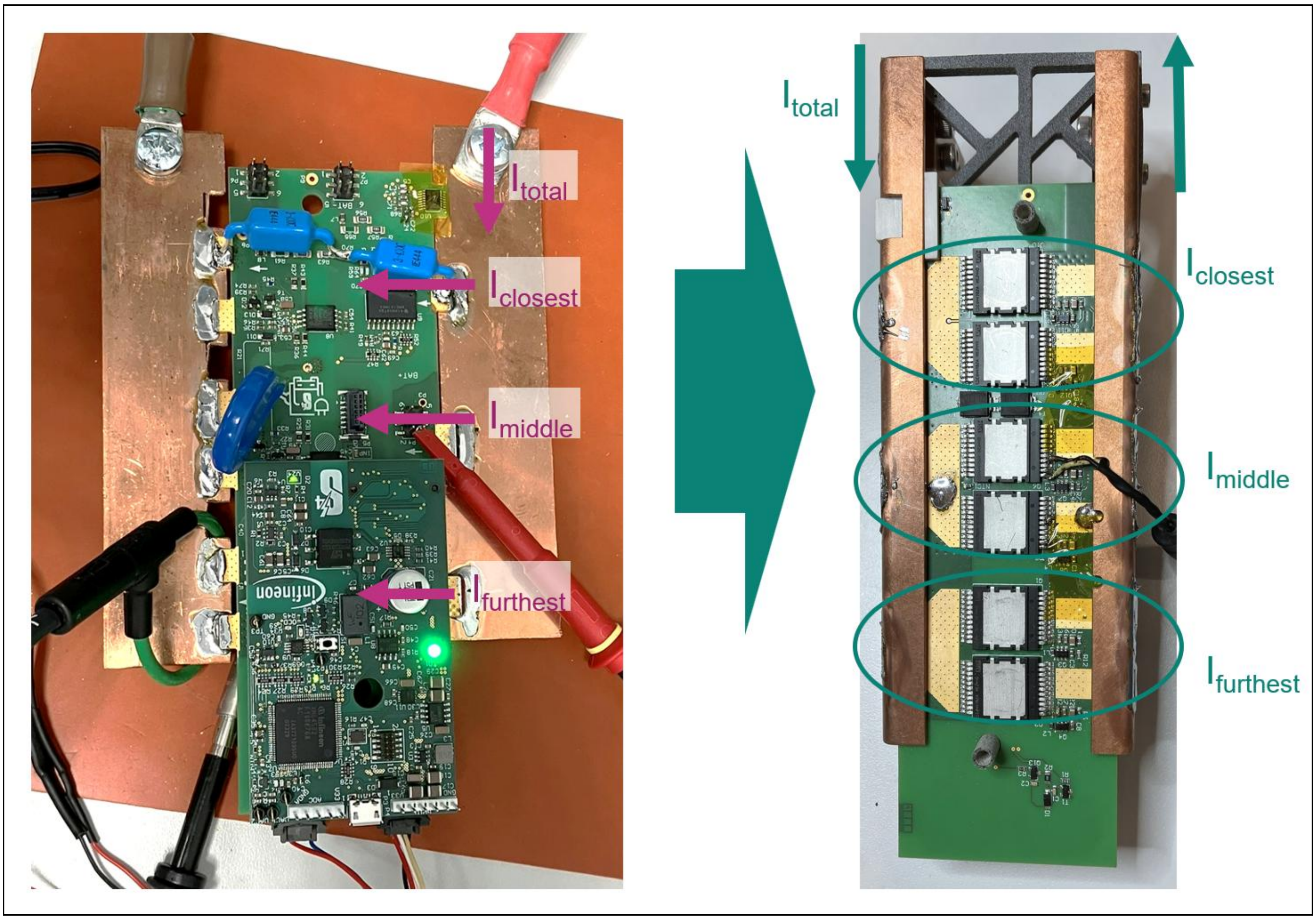

Figure 40 Setup with special assembly for current sharing measurement

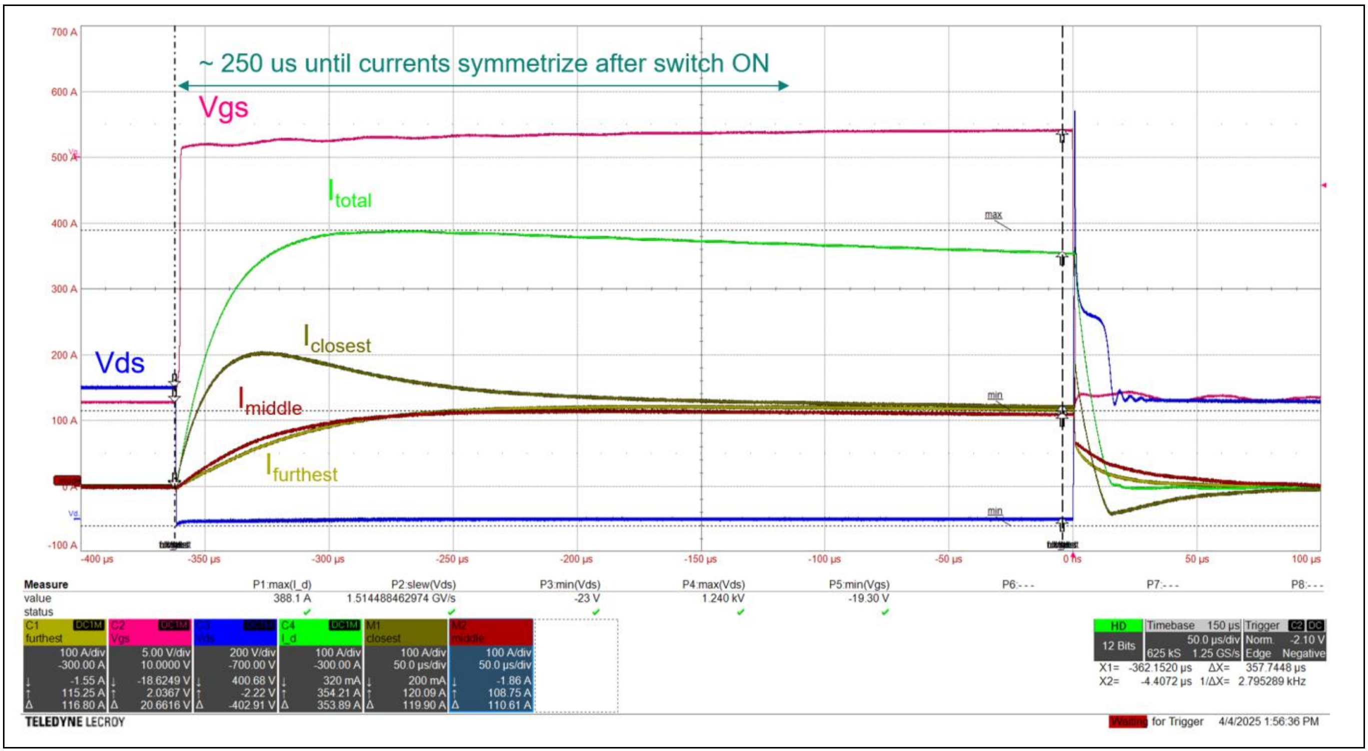

Figure 41 Current-sharing measurement result after switch ON

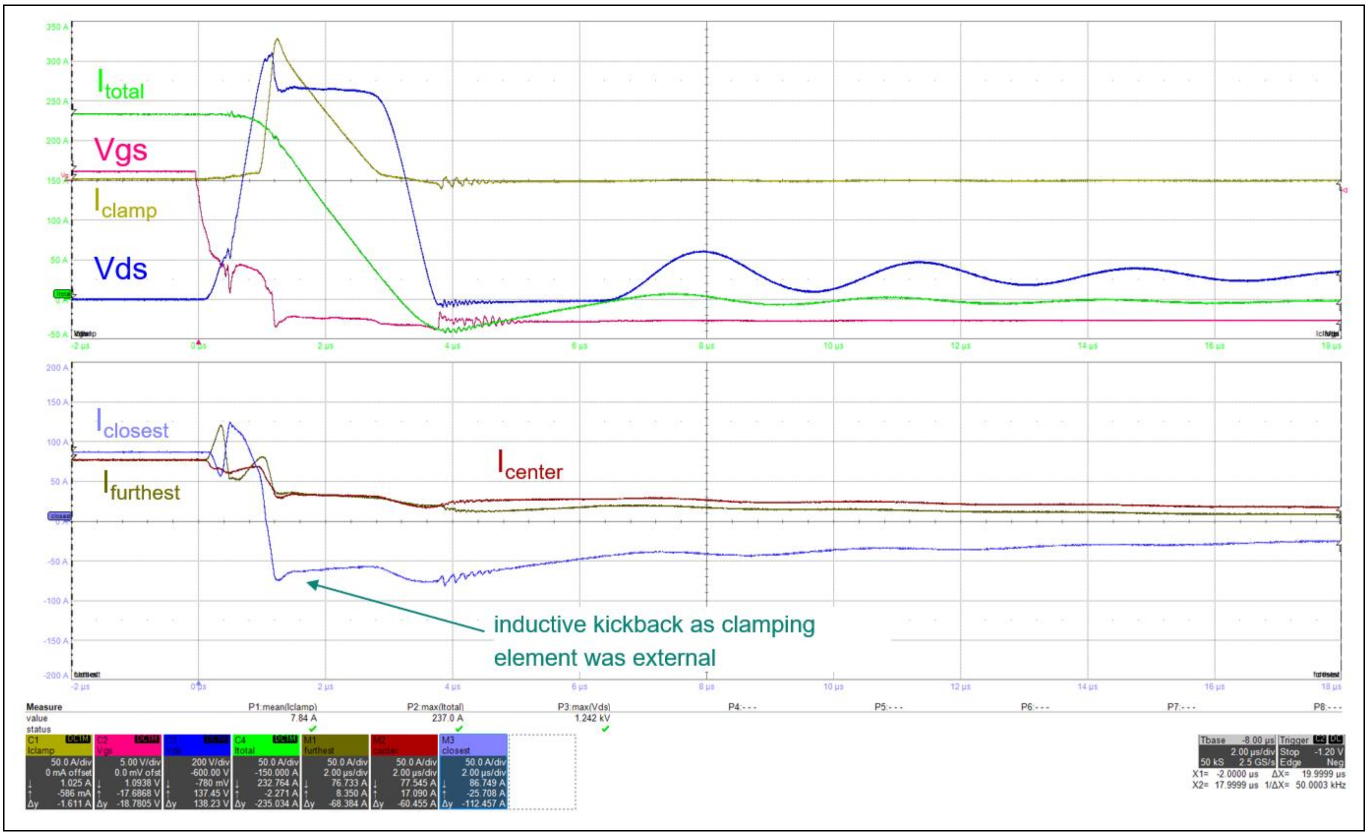

Figure 42 Current-sharing measurement result after switch OFF

6.6 Fast overcurrent detection

A typical shutdown event with overcurrent detection is shown in Figure 43. In the test, the demonstrator was on when the V_{DS} voltage started decaying and the current started rising. After reaching the overcurrent threshold voltage, the power device is switched off directly via the gate driver input. As the propagation delay of the gate driver is maximum 50 ns, the current level at which the gate voltage starts decaying is used as the overcurrent detection threshold, as shown in Figure 44.

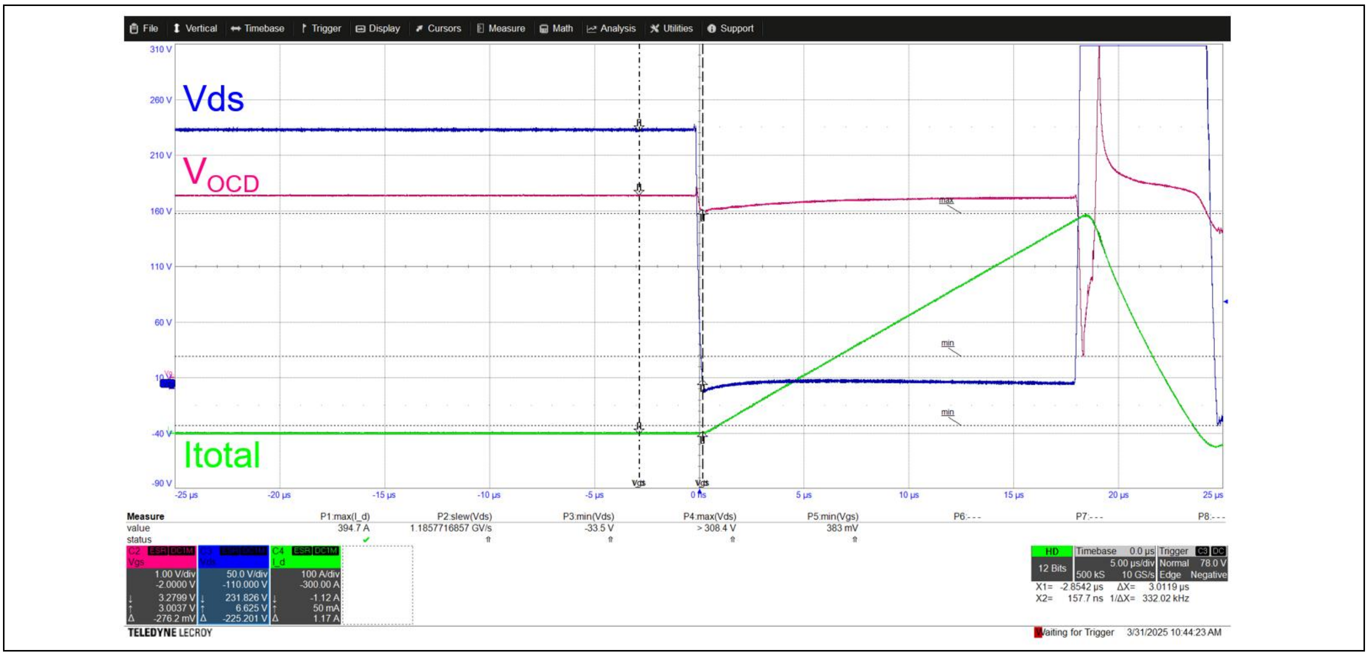

Figure 43 A typical shutdown event with overcurrent detection

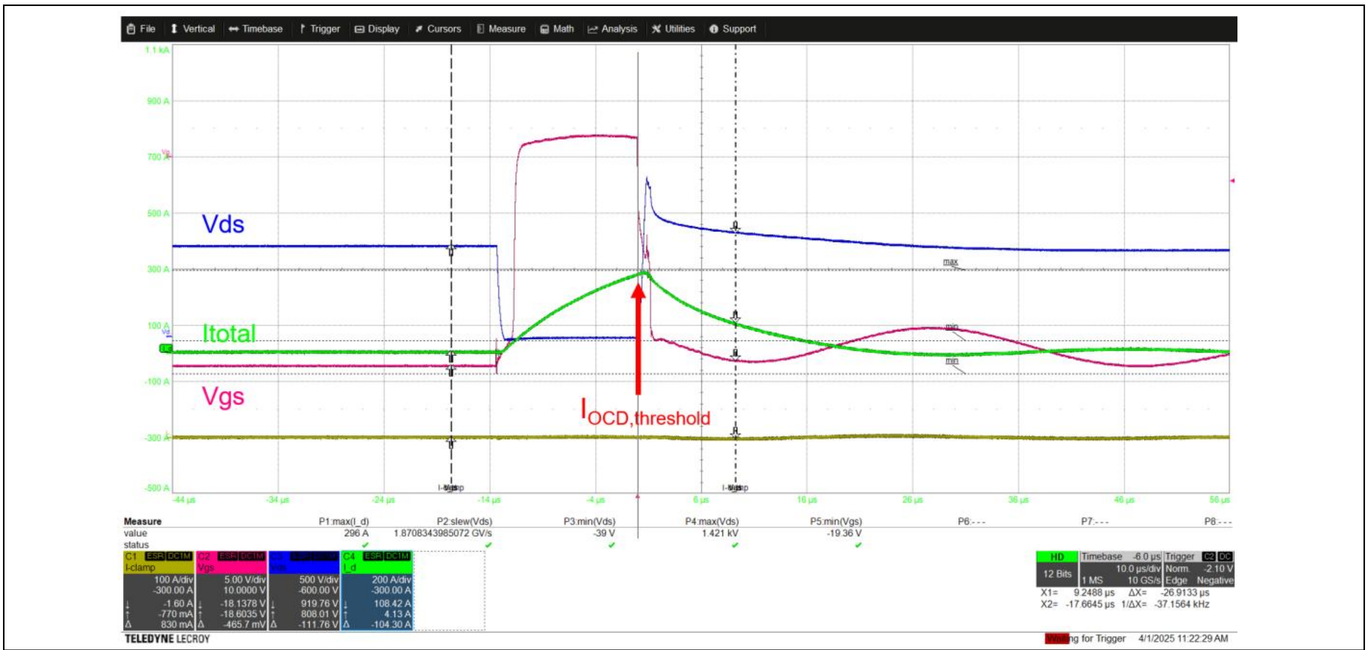

Figure 44 Fast overcurrent detection switch-off at 400 A

The overcurrent detection threshold is dependent on the sensing structure, the sensor-frequency response, and the OCD-detection delay. Therefore, the fast OCD circuitry is characterized for different threshold levels and different current slew rates (di/dt). Figure 45 shows the overcurrent detection thresholds for different di/dt values and duty cycles.

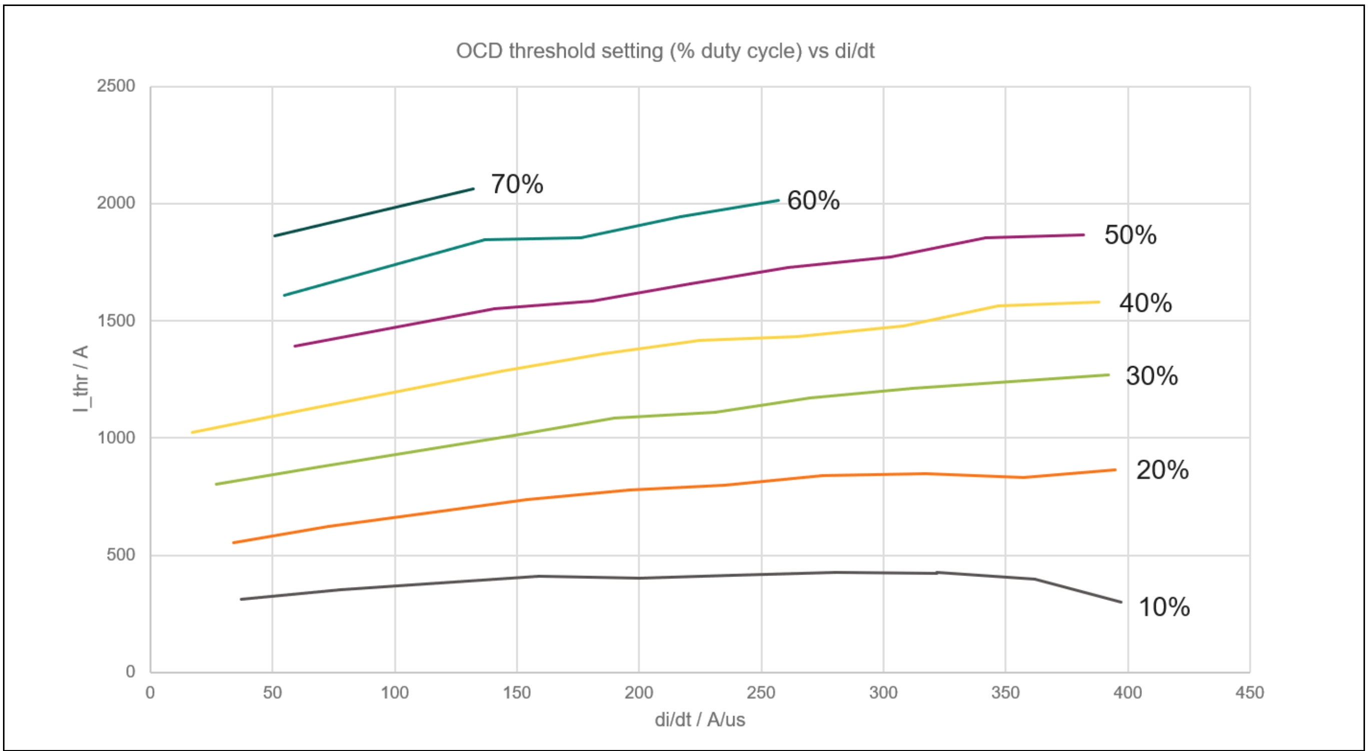

Figure 45 Measuring the fast overcurrent-detection threshold

After linear regression of the curves shown in Figure 45, the threshold values for a steady state current can be calculated. The threshold can then be calculated from the set threshold value of the duty cycle. The transfer function of the magnetic current sensor is dependent on the positioning of the sensor versus the busbar. Therefore, the calibration should be done for each PCB to keep the threshold errors to a minimum. One result of this calibration would result in following OCD calculation formula:

$$I_{thr} = 23.417 \cdot DutyCycle + 115.99$$

Figure 46 Setting the threshold for fast overcurrent detection

The overshoot for different di/dt values and threshold settings relative to the set threshold value is shown in Figure 47. The main contributor to the overshot is introduced from the sensing structure as the sensor's intrinsic delay—typically 105 ns—would only account for 36.75 A of overshoot at a di/dt of 350 A/µs.

Considering a maximum slew rate in the system and the accuracy of the OCD threshold detection, the worst-case switch-off current for the minimum threshold of overcurrent detection can be calculated. In this test, the maximum slew rate or 120 A/µs with a minimum threshold of 900 A resulted in a maximum switch-off current of ~1500 A as shown in Figure 48.

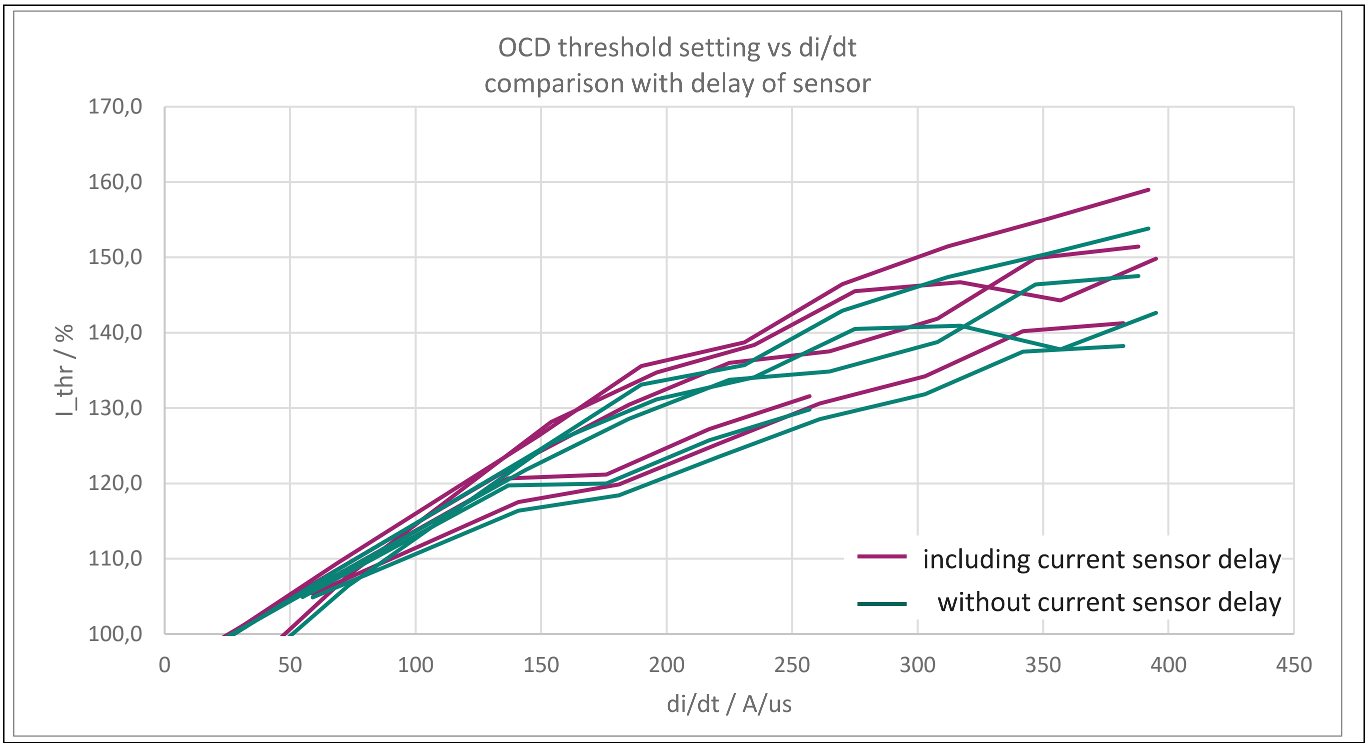

Figure 47 Fast overcurrent-detection overshoot vs. slew rate at different threshold levels

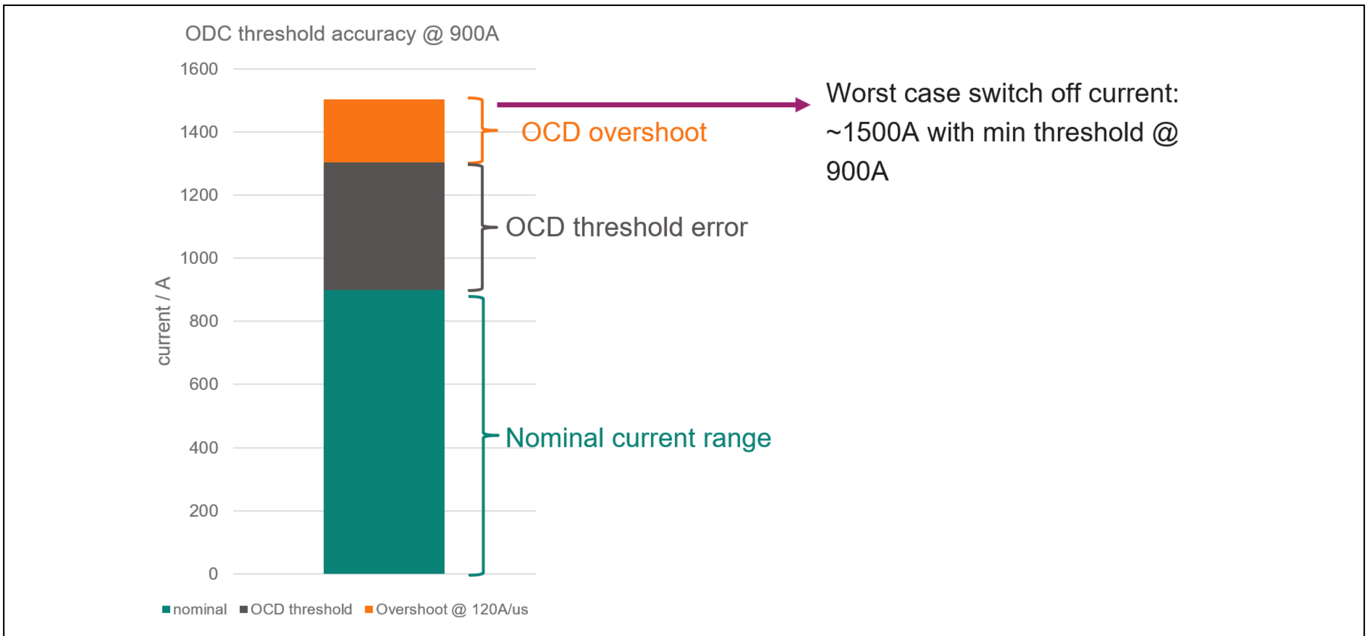

Figure 48 The worst case switch-off current for the demonstrator

6.7 Thermal measurements

For thermal measurements, the on-board NTCs as well as a thermal IR camera were used. Figure 49 shows the thermal measurement setup with the IR camera and a readout of the GUI.

The results of the thermal measurement for a load current of 600 A at room temperature with active air cooling is shown in Figure 50. Figure 51 and Figure 52 show the thermal camera images captured after 15 min and 18 min of load current, respectively. The images indicate that the power devices at the center reach higher temperatures than the outer devices. The current-carrying PCB traces fall within a similar temperature range as the power devices.

Figure 53 shows the thermal measurement results for different continuous load currents at the NTC_ext location. It gives a good indication of the junction temperature in the steady state.

Figure 49 Setup for thermal measurements, Results with a 600 A load current after 22 minutes

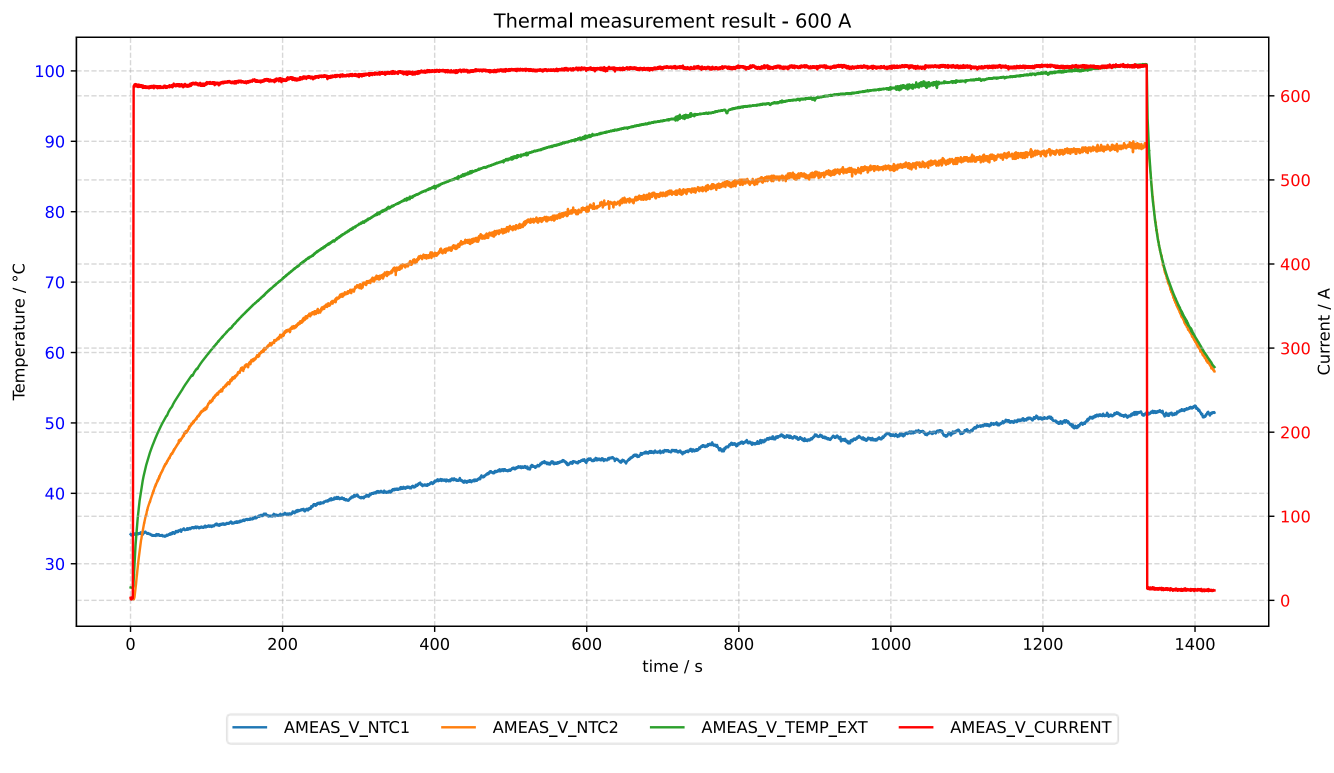

Figure 50 Thermal measurement result – with 600 A after 20 minutes

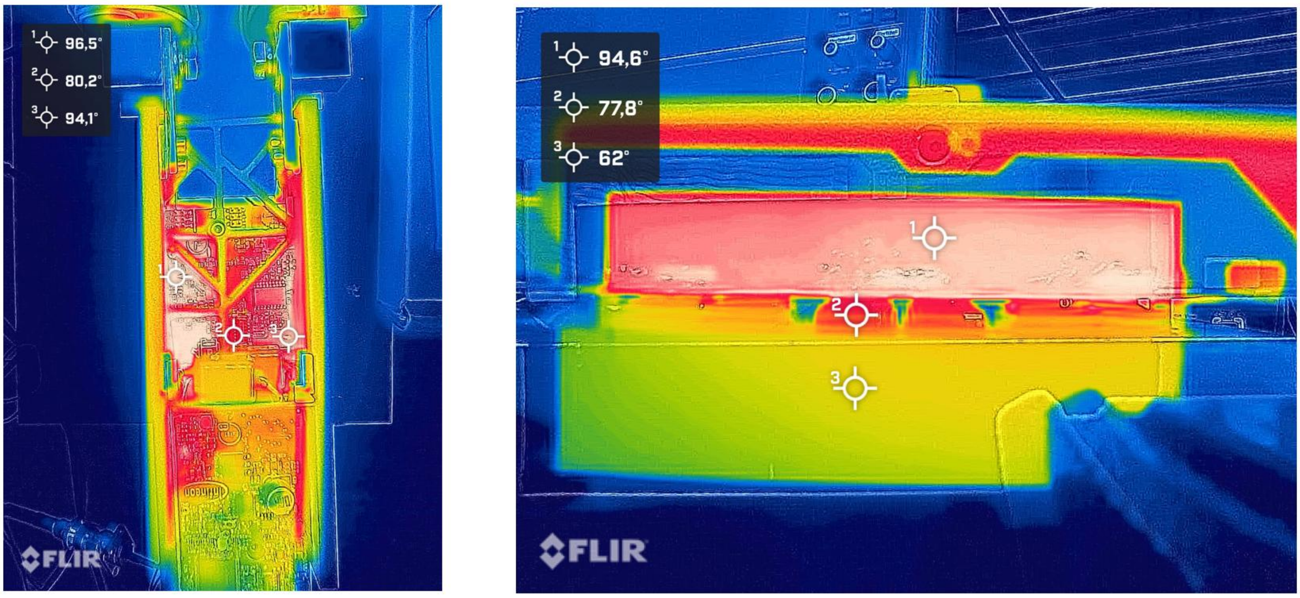

Figure 51 Thermal measurements result – with 600 A after 15 minutes

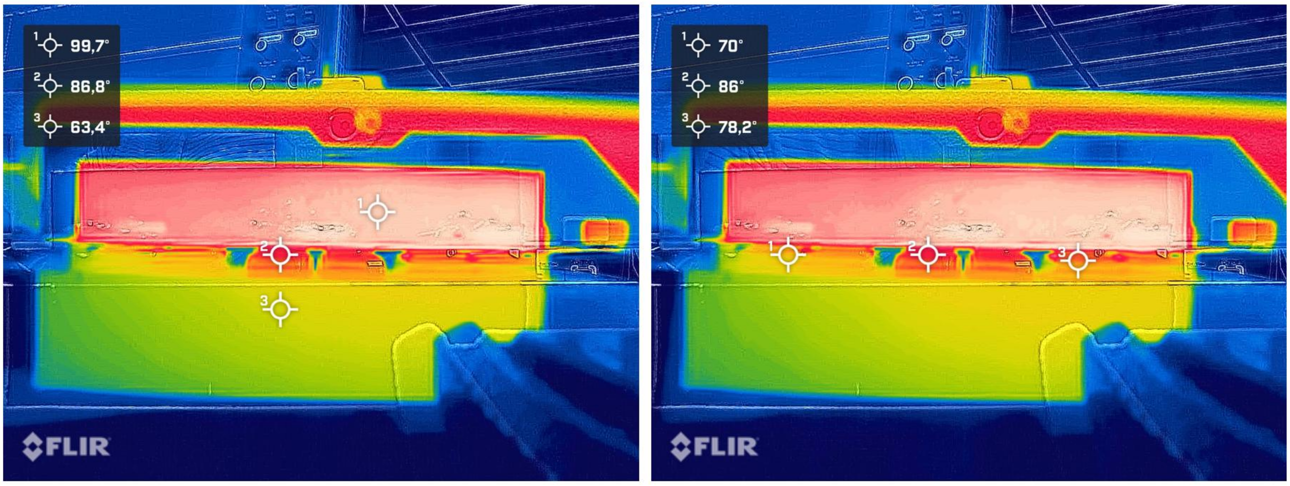

Figure 52 Thermal measurements result – with 600 A after 18 minutes

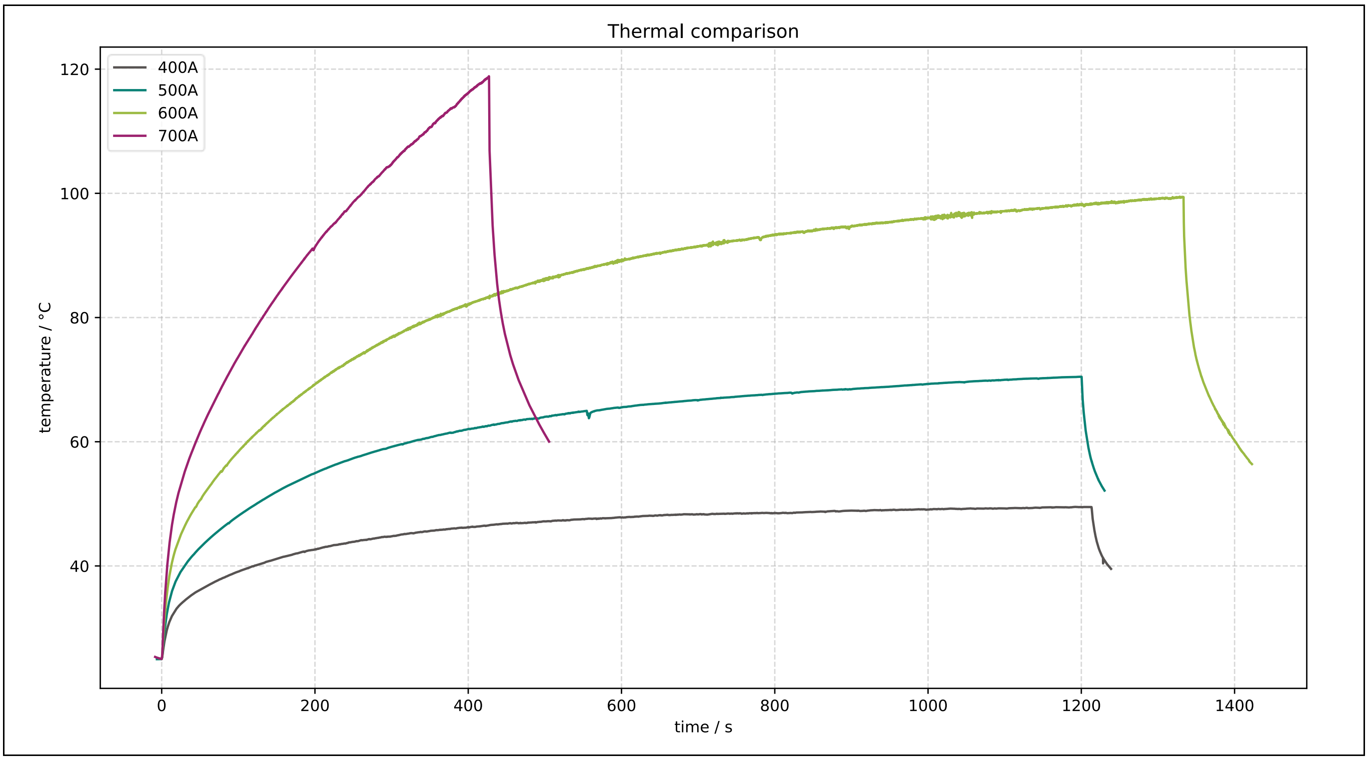

Figure 53 Thermal measurement results for various load currents

6.7.1 Increasing current capabilities

To increase the demonstrator's current capability with the existing cooling solution, the design can be modified to reduce PCB losses and improve heat transfer from the busbars. Copper plates can be placed on the solder-resist openings at the source and drain sides of the power devices to reinforce the PCB current tracks, and lower the conduction losses.

Cooling adapters can also be added on to the heat sink to attach the busbars and reduce their temperature. To maintain galvanic isolation, an electrically isolating thermal interface material (TIM) can be applied to couple the busbars with the heat sink thermally. The TIM materials that were used for the measurement are listed in Table 21.

These measures, as shown in Figure 54, can improve the thermal performance and enable a higher current capability. After implementation, the settled NTC_EXT temperature decreases by approximately 15°C, as shown in Figure 55. The comparison between the IR camera images in Figure 57 shows an approximately 25°C decrease in the busbar temperature with the same current load.

Table 21 TIM materials

TIM	Material	Thermal conductivity
Power devices - thermal grease	Thermal Grizzly TG-K-030-R	12.5 W/mK
Busbars cooling adapter	TRU components 2617839 0.5mm	6 W/mK

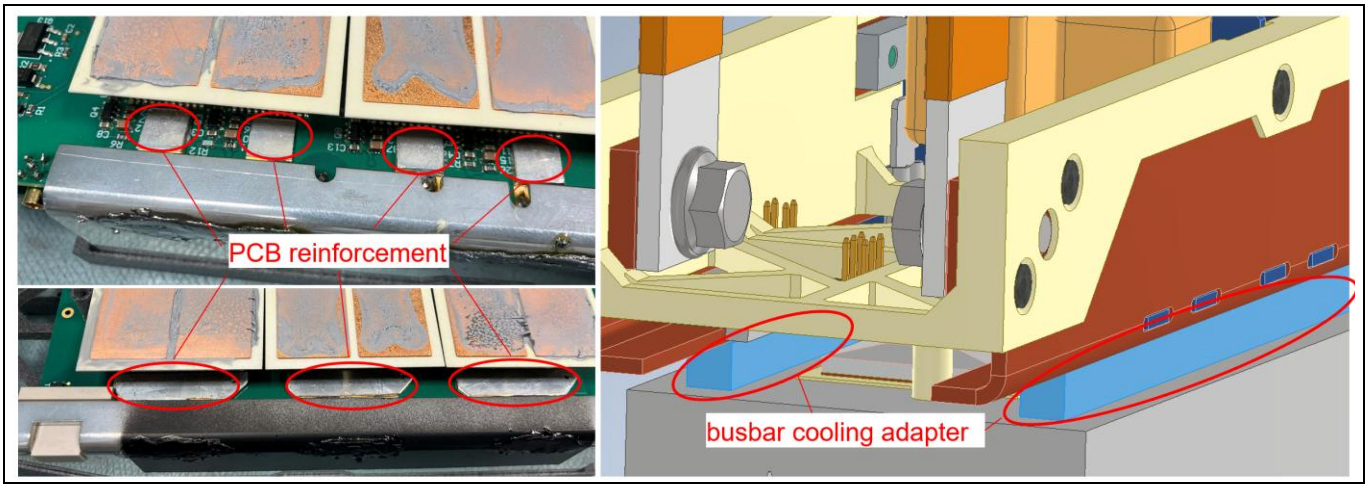

Figure 54 Measures to increase current capabilities

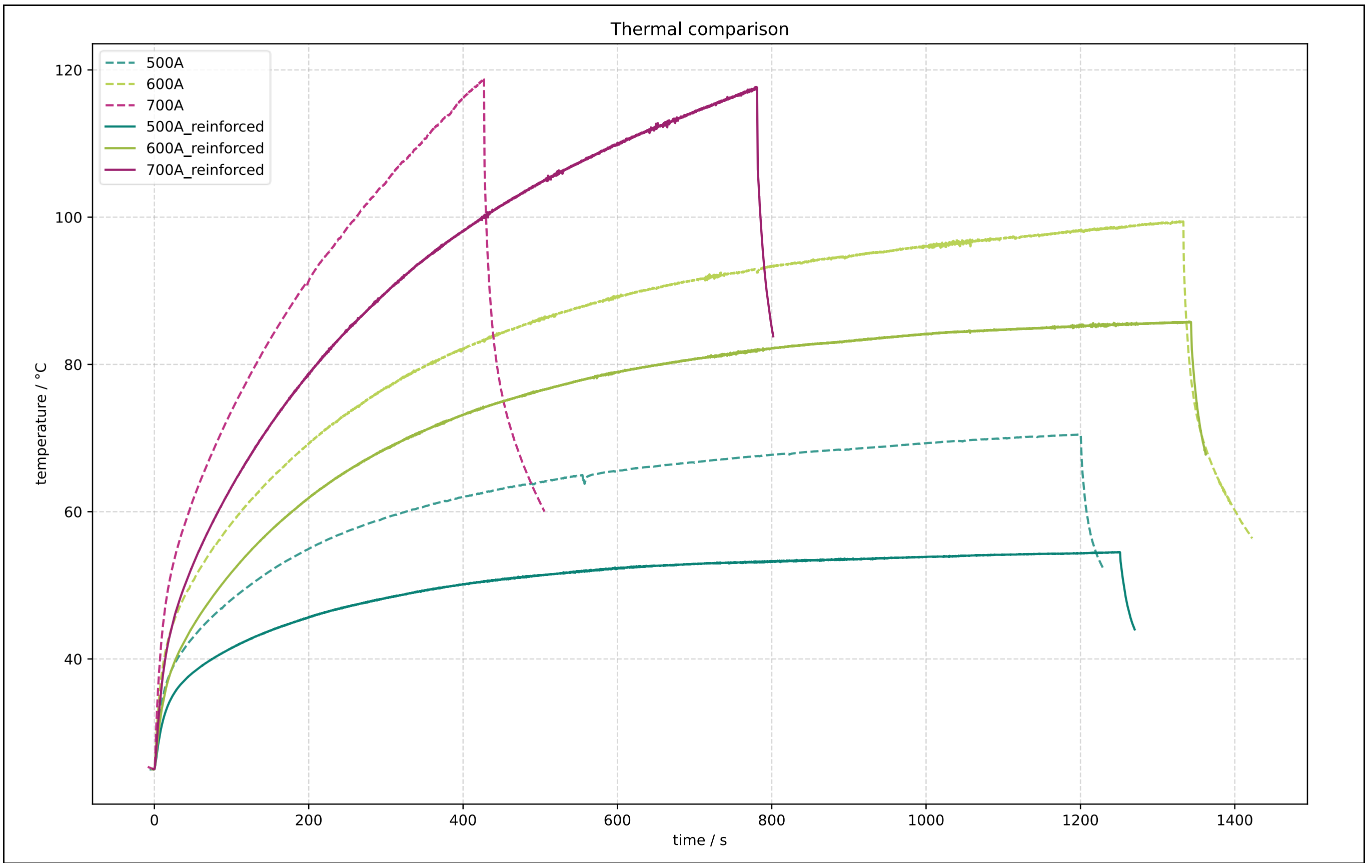

Figure 55 Thermal measurement results with reinforced demonstrator

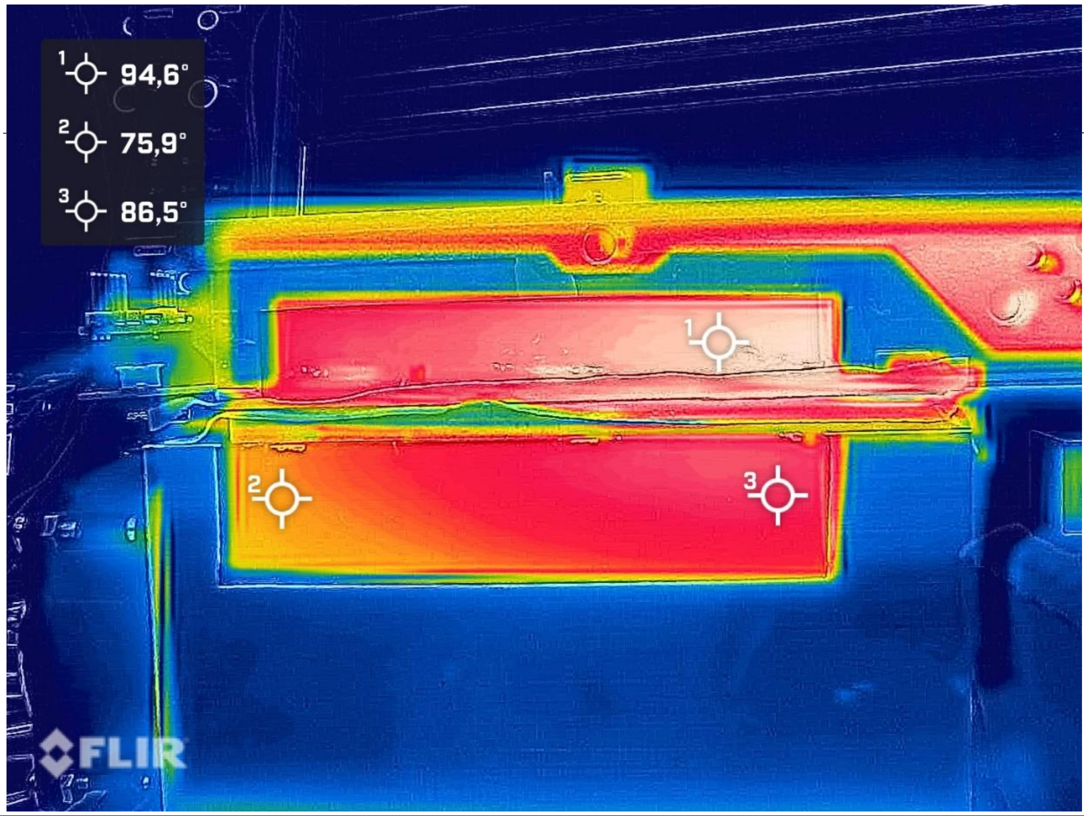

Figure 56 Thermal measurement result (reinforced) – with 700 A after 13 minutes

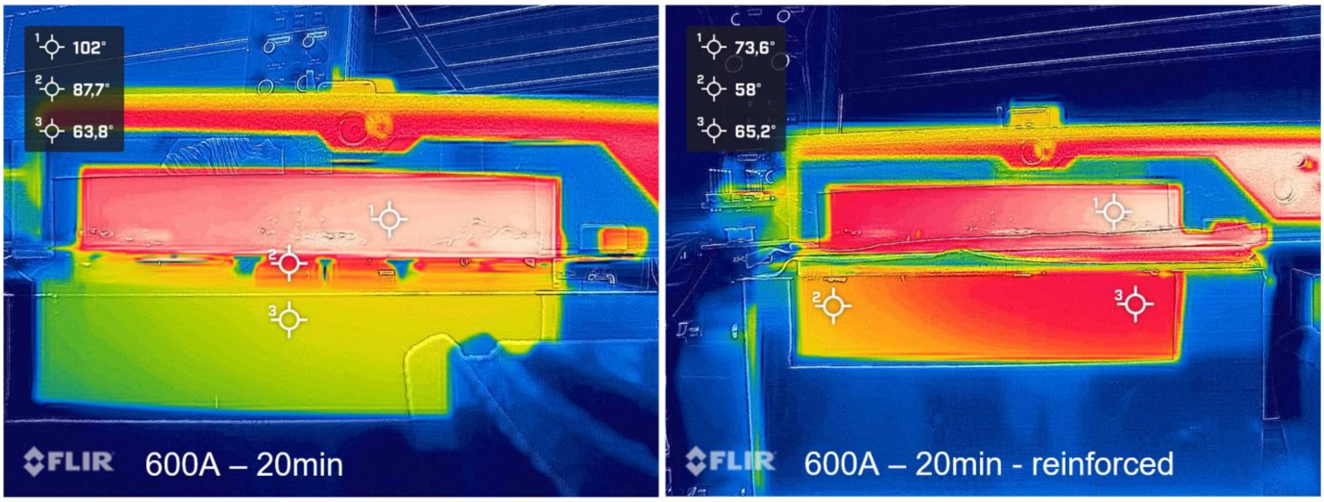

Figure 57 IR camera results from a standard and a reinforced demonstrator – with 600 A after 20 min

6.7.2 Parasitic turn-on test

In battery disconnect applications, a mechanical contactor is typically placed in series with the eBDU switch. To prevent unintended activation, the eBDU power stage must remain disabled during the contactor closure (see section 3.2). The susceptibility for parasitic turn-on was evaluated using a contactor in series with the eBDU demonstrator, as shown in Figure 58.

Measurements were conducted at V_{bat} = 800 V using a TE Connectivity ECP600B relay as the mechanical contactor. No parasitic turn-on was observed in the drain-current or gate-voltage waveforms; even with the contactor-induced transients, the JFET was kept in a pinch-off (VGS ≤ Vp). Contact bounce and arcing of the mechanical contactor are visible in the measurement results shown in Figure 59 and Figure 60.

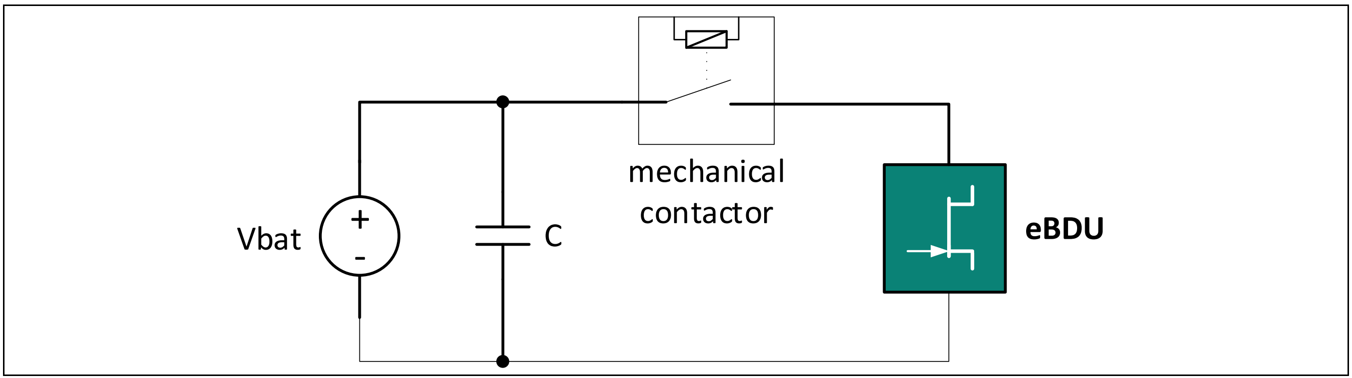

Figure 58 Setup for the parasitic turn-on test

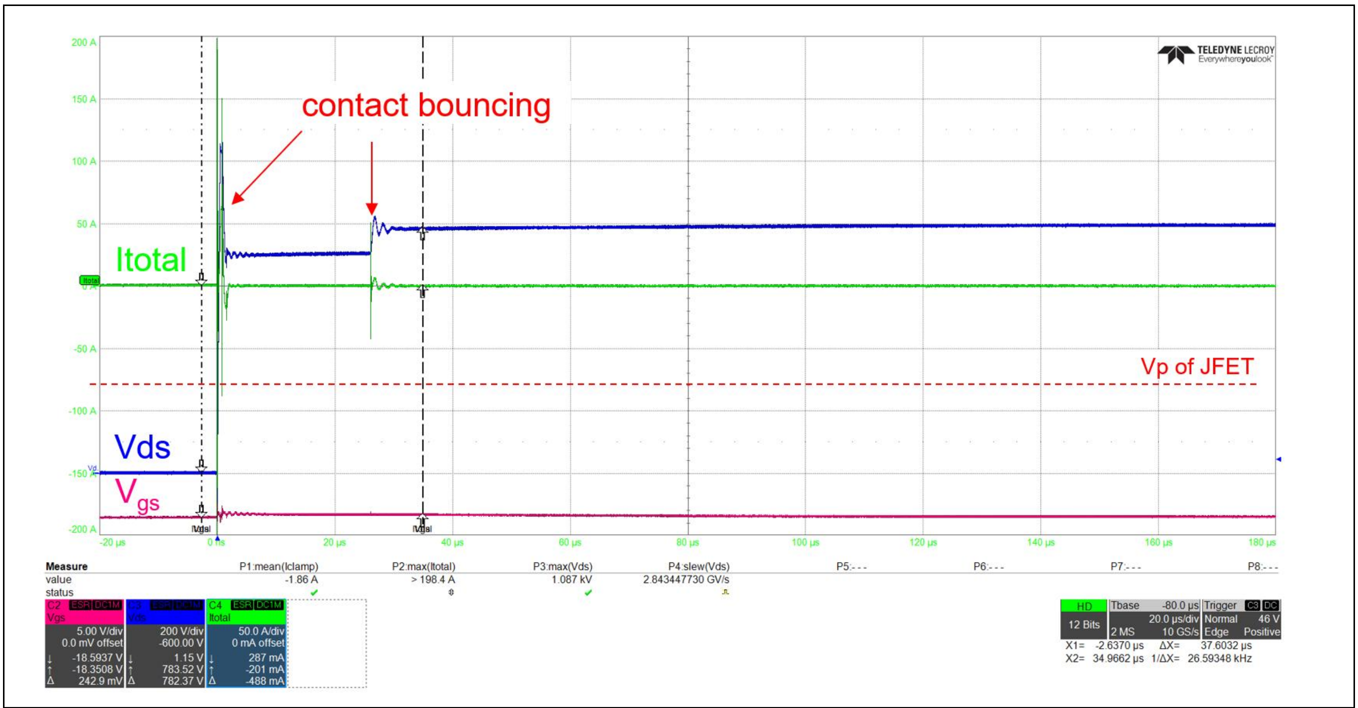

Figure 59 Test results of the parasitic turn-on

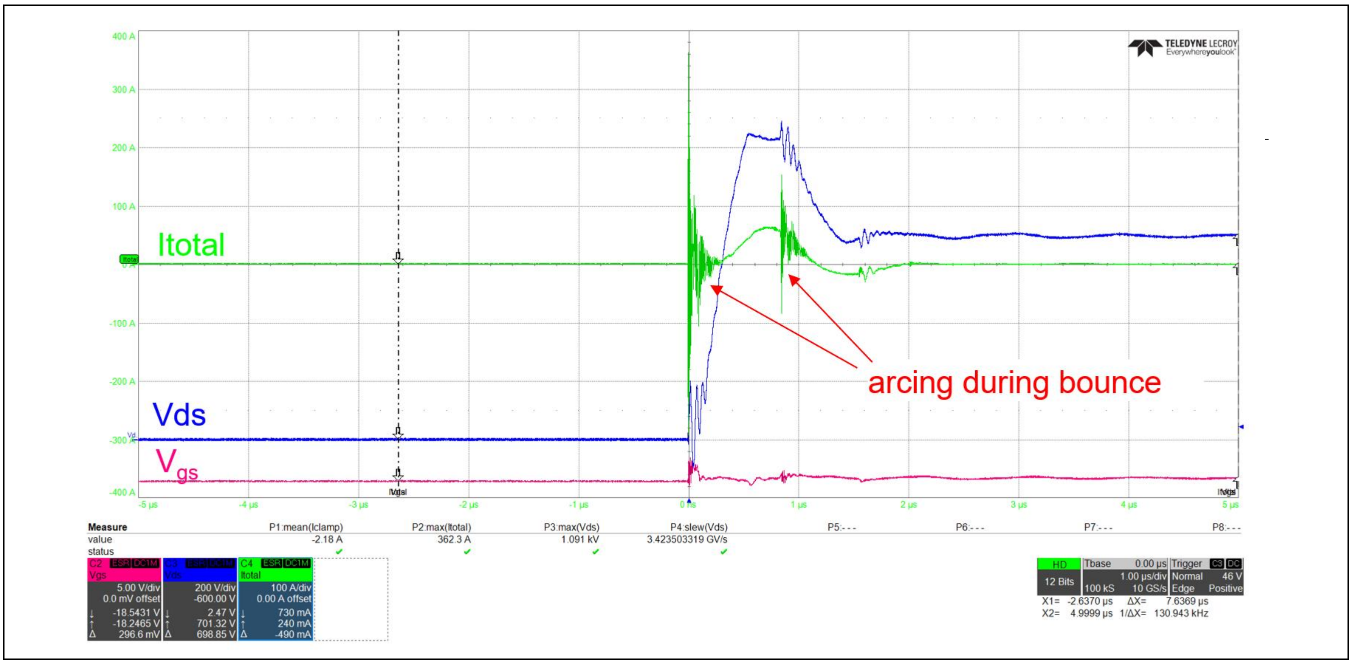

Figure 60 Detailed results of the parasitic turn-on test

7 Related resources

- Infineon CoolSiC™ JFET
- IJCQ120RM25J1
- eBDU demonstrator REF-SSBD800VDCJCQJ1
- Application note AN-2025-12 Solid-state battery disconnect unit with CoolSiC™ JFET technology
- Application note AN-2025-04: JFET Application Note

References

[1] Application note AN_2025-12: Solid-state battery disconnect unit with Infineon CoolSiC JFET technology; Infineon Technologies AG; 2025.

Glossary

CAN
Controller area network

CCS
Combined charging standard

CRC
Cyclic redundancy check

DBC
Direct bonded copper

DBC
Direct bonded copper

DUT
Device under test

eBDU
Electronic battery disconnect unit

eCAV
Electric commercial, construction, and agricultural vehicle

ECU
Electronic control unit

EOF
End of frame

GUI
Graphical user interface

HV
High voltage

IC
Integrated circuit

IEC
International Electrotechnical Commission

IR
Infrared

JFET
Junction field effect transistor

LDO
Low dropout regulator

LV
Low voltage

MCS
Megawatt charging standard

MCU
Microcontroller unit

MOSFET
Metal oxide field effect transistor

MOV
Metal oxide varistor

NTC
Negative temperature coefficient

OCD
Overcurrent detection

OVL
Overload protection

OVP
Overvoltage protection

OVT
Overtemperature protection

PC
Personal computer

PCB
Printed circuit board

PDU
Power distribution unit

RX
Receive

SIDAC
Silicon diode for alternating current

SOF
Start of frame

SSR
Solid-state relay

SWD
Single-wire debug

TIM
Thermal interface material

TJ
Junction temperature

TMR
Tunnel magnetoresistance

TSC
Top-side cooling

TVS
Transient voltage suppressor

TX
Transmit

USB
Universal serial bus

UVP
Undervoltage protection

Revision history

Document revision	Date	Description of changes
1.0	2025.10.21	Initial version

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Edition 2026-02-12

Published by

Infineon Technologies AG

81726 Munich, Germany

Do you have a question about this document?

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Document reference

User guide number