High-current power distribution switch unit

Reference design user guide

EiceDRIVER™ APD
2ED2410-EM

About this document

Scope and purpose

The high-current power distribution switch unit (HC-PDU) with coreless Hall-based current measurement reference design, presents the latest Infineon Power MOSFETS, automotive Gate Driver (EiceDRIVER™ APD), and sensors.

HC-PDU enables the user to make a speedy startup with innovative high current power distribution applications. The features include MOSFET temperature protection, I-t wire protection, short circuit protection, cooling via cables, and a pre-charge option for capacitive loads.

Table 1 Overview of HC-PDU switch

Versions	**12 V Hall based**
Sales product name	R_12V_PDU_Switch20
Sales product number	SP005595887
Nominal voltage range	11 V to 16 V
Current measurement method	TLE4972-AE35D5 (XENSIV™ Hall sensor)
Power MOSFET	IAUTN04S7N003 (OPTIMOS™ 7, 40 V) 2x4, back2back, common source
Total terminal to terminal resistance R_{TTR}	244 µΩ
DC current capability (@ 13 W power losses)	231 A
PCB label	V2.00 01/2022 bid-sw-hall_v2.PcbDoc
MOSFET gate driver	2ED2410-EM (EiceDRIVER™ APD, two high-side gate driver outputs)
Gate control	1 driver output per 4 MOSFET
Short-circuit protection	Yes
I-t wire protection	Yes
Temperature protection	Yes
Wrong polarity protection	Yes
MOSFET avalanche protection	Yes
Pre-charge of capacitor function	Yes

Intended audience

The intended audience for this document is design engineers, technicians, and developers of electronic systems.

Reference board/kit

Product(s) embedded on a PCB with a focus 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*

Important notice

“Evaluation Boards and Reference Boards” shall mean products embedded on a printed circuit board (PCB) for demonstration and/or evaluation purposes, which include, without limitation, demonstration, reference and evaluation boards, kits and design (collectively referred to as “Reference Board”).

Environmental conditions have been considered in the design of the Evaluation Boards and Reference Boards provided by Infineon Technologies. The design of the Evaluation Boards and Reference Boards has been tested by Infineon Technologies only as described in this document. The design is not qualified in terms of safety requirements, manufacturing and operation over the entire operating temperature range or lifetime.

The Evaluation Boards and Reference Boards provided by Infineon Technologies are subject to functional testing only under typical load conditions. Evaluation Boards and Reference Boards are not subject to the same procedures as regular products regarding returned material analysis (RMA), process change notification (PCN) and product discontinuation (PD).

Evaluation Boards and Reference Boards are not commercialized products, and are solely intended for evaluation and testing purposes. In particular, they shall not be used for reliability testing or production. The Evaluation Boards and Reference Boards may therefore not comply with CE or similar standards (including but not limited to the EMC Directive 2004/EC/108 and the EMC Act) and may not fulfill other requirements of the country in which they are operated by the customer. The customer shall ensure that all Evaluation Boards and Reference Boards will be handled in a way which is compliant with the relevant requirements and standards of the country in which they are operated.

The Evaluation Boards and Reference Boards as well as the information provided in this document are addressed only to qualified and skilled technical staff, for laboratory usage, and shall be used and managed according to the terms and conditions set forth in this document and in other related documentation supplied with the respective Evaluation Board or Reference Board.

It is the responsibility of the customer’s technical departments to evaluate the suitability of the Evaluation Boards and Reference Boards for the intended application, and to evaluate the completeness and correctness of the information provided in this document with respect to such application.

The customer is obliged to ensure that the use of the Evaluation Boards and Reference Boards does not cause any harm to persons or third party property.
The Evaluation Boards and Reference Boards and any information in this document is provided "as is" and Infineon Technologies disclaims any warranties, express or implied, including but not limited to warranties of non-infringement of third party rights and implied warranties of fitness for any purpose, or for merchantability.

Infineon Technologies shall not be responsible for any damages resulting from the use of the Evaluation Boards and Reference Boards and/or from any information provided in this document. The customer is obliged to defend, indemnify and hold Infineon Technologies harmless from and against any claims or damages arising out of or resulting from any use thereof.

Infineon Technologies reserves the right to modify this document and/or any information provided herein at any time without further notice.

Safety precautions

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

Table 2 Safety precautions

	**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:** *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.*

Table of contents

Table of contents

1 The board at a glance

The HC-PDU consists of power MOSFET-transistors in OptiMOS™ technology in back2back configuration in order to cut current from both directions. To increase current capability a parallel configuration is used. The gates are controlled by the 2ED2410-EM gate driver. This isolation switch has several protection features and a dedicated pre-charge function. A magnetic coreless current sensor (Hall sensor) TLE4972-AE35D5, measures the current. No freewheeling diodes are implemented. The target nominal current at room temperature is 200 A with cooling via cables. The maximum ratings of the semiconductor devices have to be considered according to the datasheet [1] such as avalanche energy and L/R value.

This is Design guide number is Z8F80416441.

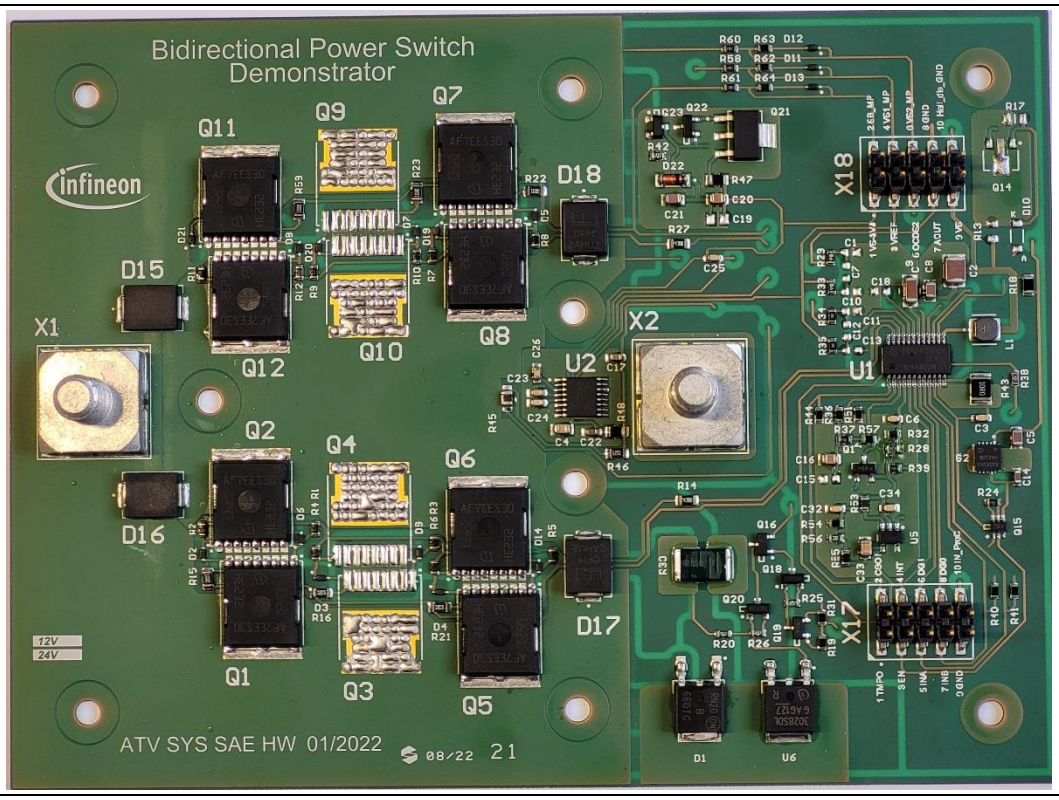

Figure 1 Illustration of the HC-PDU with Hall-based current measurement

1.1 Delivery content

- A high current power distribution switch (HC-PDU) on one single heavy copper printed circuit board (PCB)

1.2 Getting started

The equipment required to get started with the HC-PDU is:

- Power supply for V1 = 12 V/2 A and V2 = 5 V
- Resistor R1= 47 Ω/3 W
- Voltmeter

Note: *There is a SAFESTATE mode in the 2ED2410-EM. To reset from SAFESTATE, the EN input needs to go to low for more than 30 µs. As soon the enable pin is switched to 5 V the 2ED2410-EM enters the IDLE mode and the 2ED2410-EM internal pre-charge function (I_{SOURCE}) and as well the boost converter is turned on.*

Note: *INA is the control input of: Q7; Q8; Q11; Q12*
INB is the control input of: Q1; Q2; Q5; Q6

Step by step setup

Step 1: Connect X2 and GND (X18.8) to your power supply V-DC1: 12 VDC

Step2: Check the voltage across R1, should be 0 V (switch is off)

Step 3: Enable the 2ED2410-EM by connecting the enable input (X17.3) to 5 V (SLEEP mode > IDLE mode)

Step 4: Check the SAFESTATE of the 2ED2410-EM, INT (X17.4) shall be high, otherwise the SAFESTATE mode is triggered

Step 5: Check the voltage across R1, this should be some hundreds of mV (the 2ED2410-EM internal IDLE pre-charge function is turned on)

Step 6: Switch-on the main channel INA (X17.5) and/or INB (X17.7) (IDLE mode → ON mode)

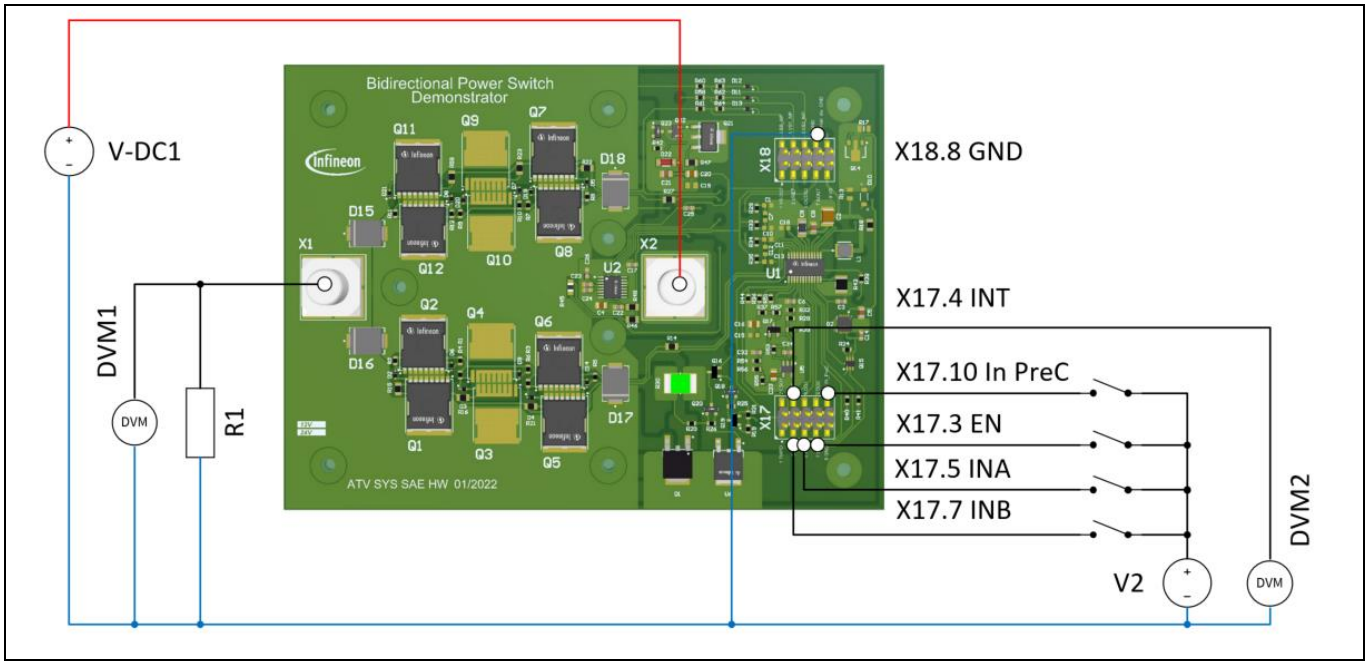

Figure 2 Setup for commissioning/static version

It is possible to control INA, INB and In_PreC (In_PreC is the control of the capacitive pre-charge path) as well with a pulse generator. See Figure 3

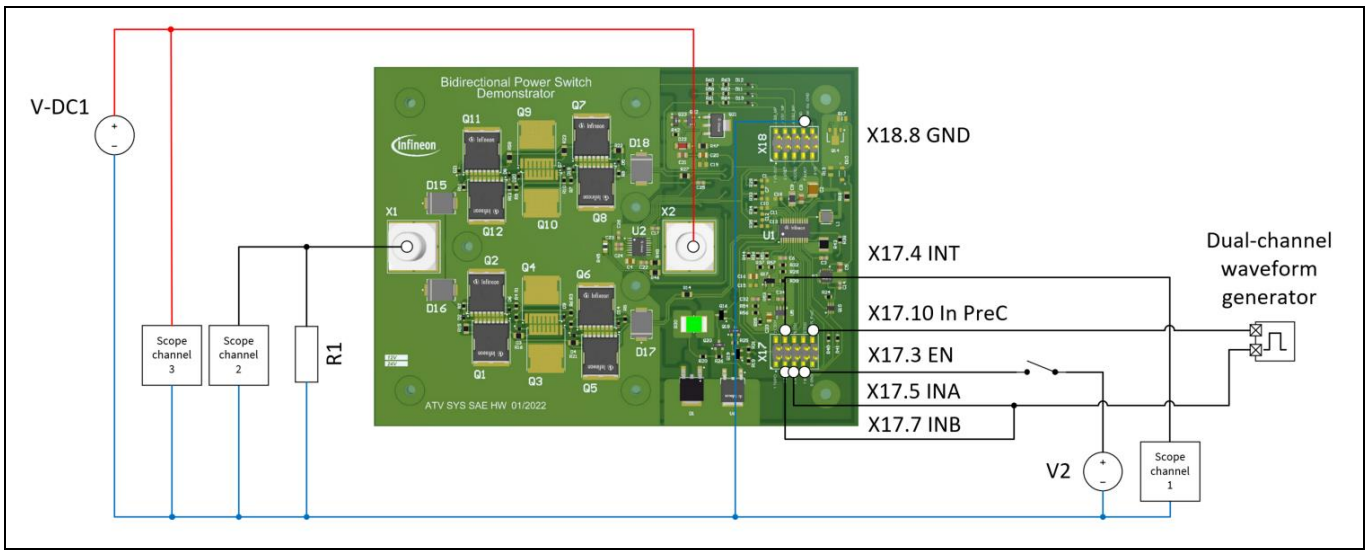

Figure 3 Setup for commissioning/dynamic version

The setup with a two-channel scope and a two-channel waveform generator is illustrated in the figure above. Consider a capacitor parallel to V-DC1 if higher currents are used then please monitor V-DC1 with a third channel of the scope.

1.3 Block diagram

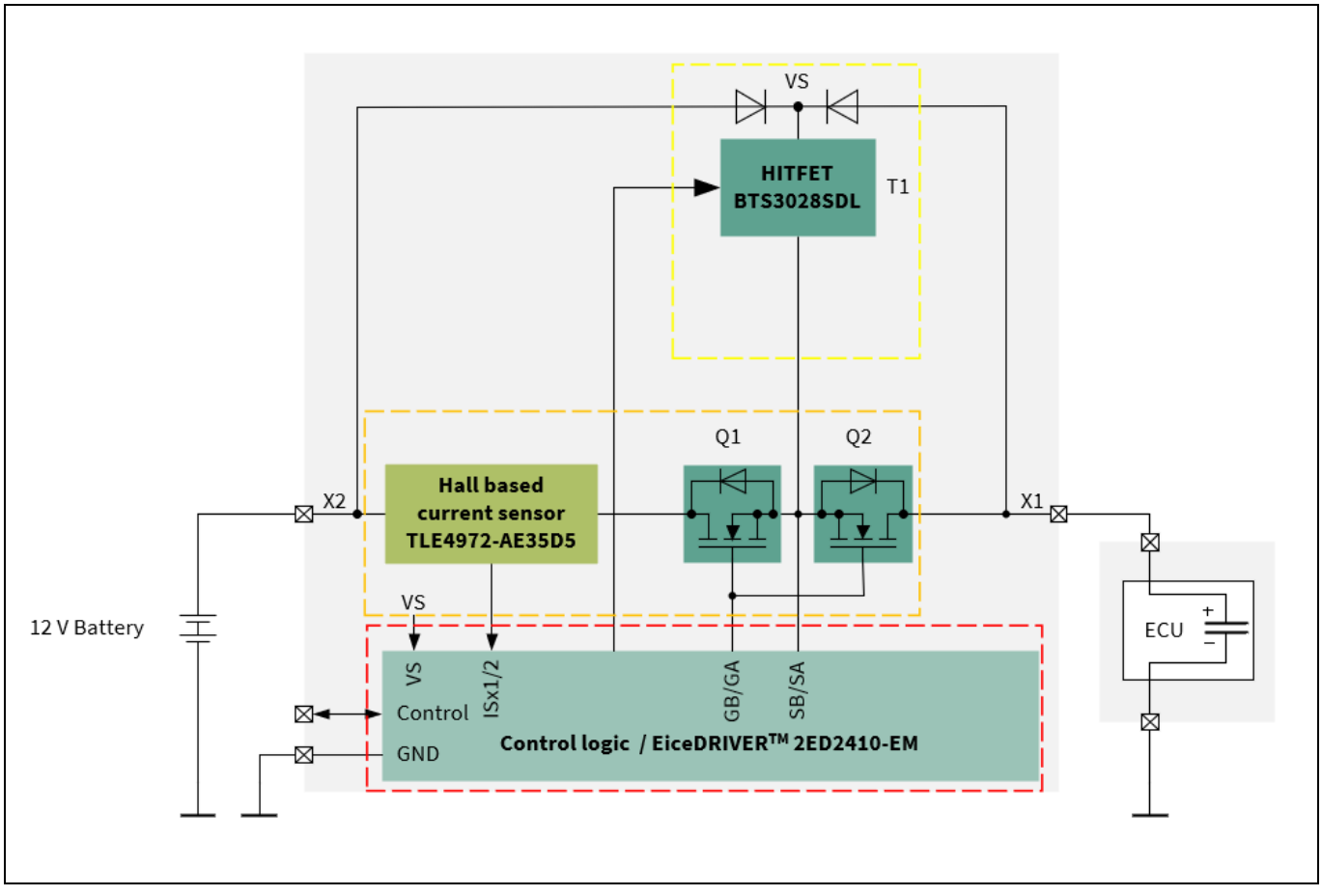

Figure 4 Block diagram of the HC-PDU Hall-based current measurement

The HC-PDU is made up of three main parts:

- Control and driver (red)
- Power with current measurement (orange)
- Pre-charge (yellow)

1.4 Pre-charge

For a capacitive load, a pre-charge circuit is needed in order not to trigger the short circuit protection during switch-on.

For the **HC-PDU** the requirements are as follows:

- Pre-charge time: 30 ms to 200 ms depending on the capacitive load
- Pre-charge capacitive load: 30 mF max. for 12 V system
- Pre-charge resistive load: no resistive load during pre-charge
- The pre-charge circuit is short circuit protected within nominal voltage range

1.5 HC-PDU functional range and key parameters

Table 3 Functional range

Parameter	Min.	Typ.	Max.	Unit
Nominal voltage range (12 V system)	11	–	16	V

Note: The overvoltage range for a 12 V system is 35 V.

Table 4 Protection parameter

Parameter	Symbol	Nominal	Unit
Maximum static current	$I_{I\text{-}t}$	240	A
Short circuit protection*	I_{SC}	610	A
Temperature protection	T_{PS}	120	°C

*Note: *Range of I_{sc} due to range of $k_{CSO1(TH)}$: 585 A to 634 A*

2 Product design and functional description

2.1 Hall based current measurement

Table 5 Hall based current measurement version

Schematic part	Function
HW-01	Interface connector X17 and X18
HW-02	Power supply signals
HW-03	Power supply pre-regulator
HW-04	Power supply for 5 V
HW-05	High side gate driver 2ED2410-EM
HW-06	Gain and input filter for CSO1
HW-07	Gain for CSO1
HW-08	Output signals of 2ED2410-EM
HW-09	Signal conditioning of the input signal for the 2ED2410-EM
HW-10	Gain and input filter for CSO2
HW-11	Gain for CSO2 and I-t filter for I-t wire protection
HW-12	CP comparator input signals adaption (Temperature and I-t protection) Comparator reference voltage
HW-13	Voltage diagnosis
HW-14	NTC resistor for temperature protection
HW-15	Temperature protection comparator with filter; gain and reference voltage
HW-17	TVS diodes for avalanche protection
HW-18	Power MOSFETS
HW-19	Power supply decoupling diodes
HW-20	Pre-charge current limitation
HW-21	Power supply for the high precision cordless current sensor current sensor
HW-22	High precision cordless current sensor

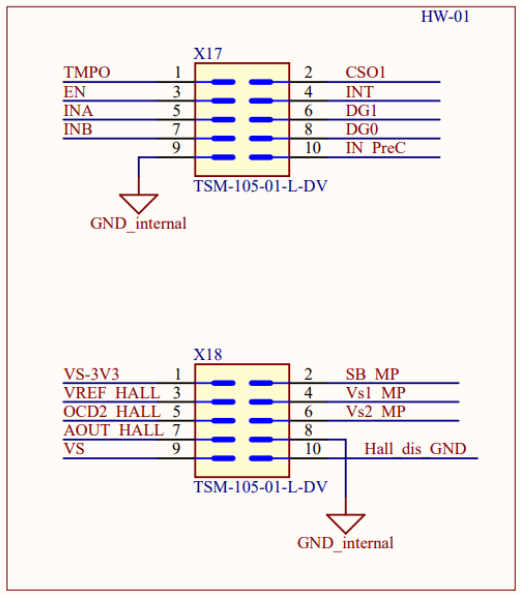

Figure 5 HW-01 control interface

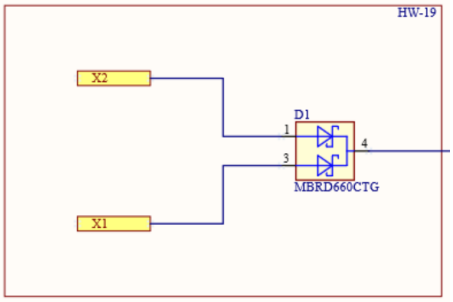

Figure 6 HW-19 V_S generation

HW-19: Internal V_S is generated by D1 from X1 and X2.

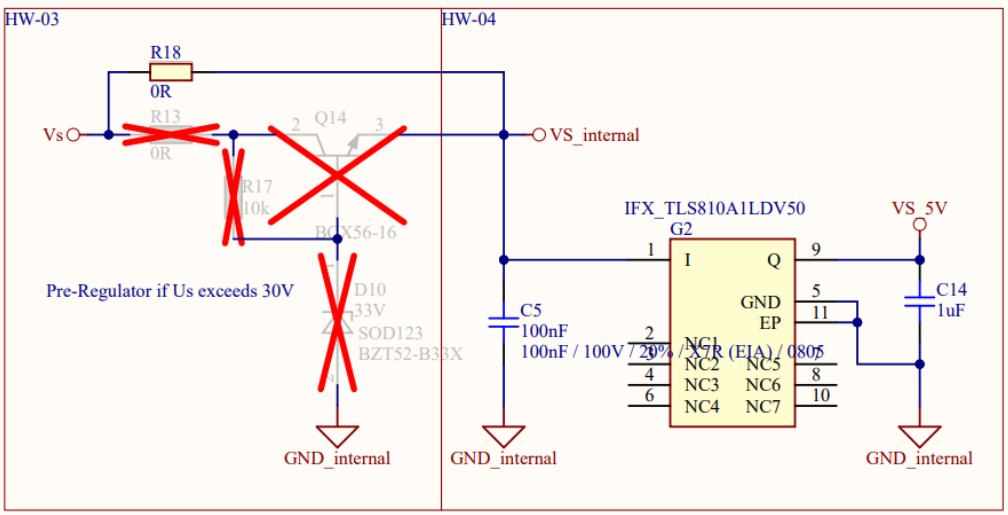

Figure 7 HW-03 and HW-04 5 V power supply

HW-03 and HW-04:
The pre-regulator is disabled for the 12 V version. The maximum input voltage of the TLS810A1Lxx is 42 V

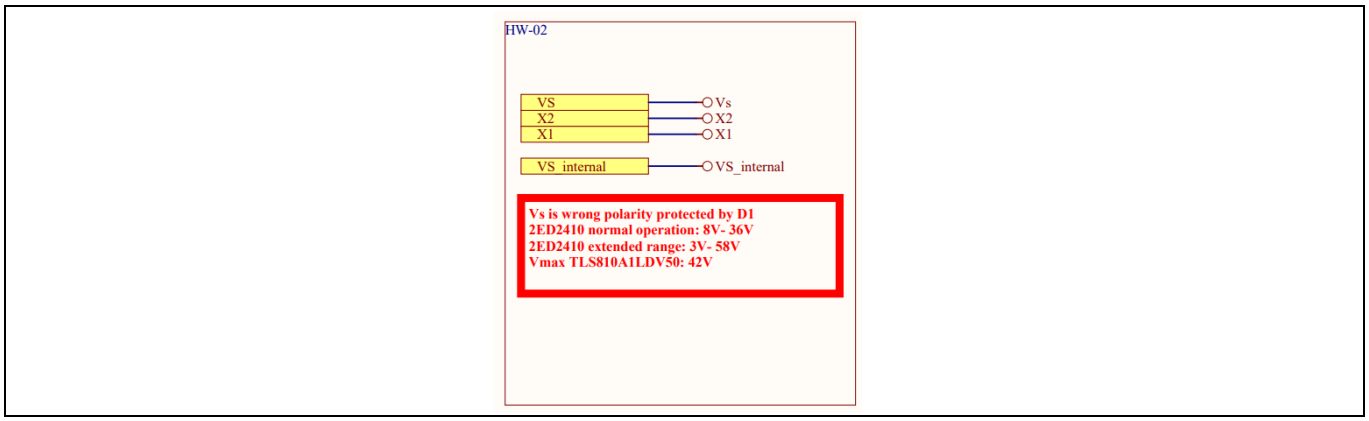

Figure 8 HW-02 Power supply signals

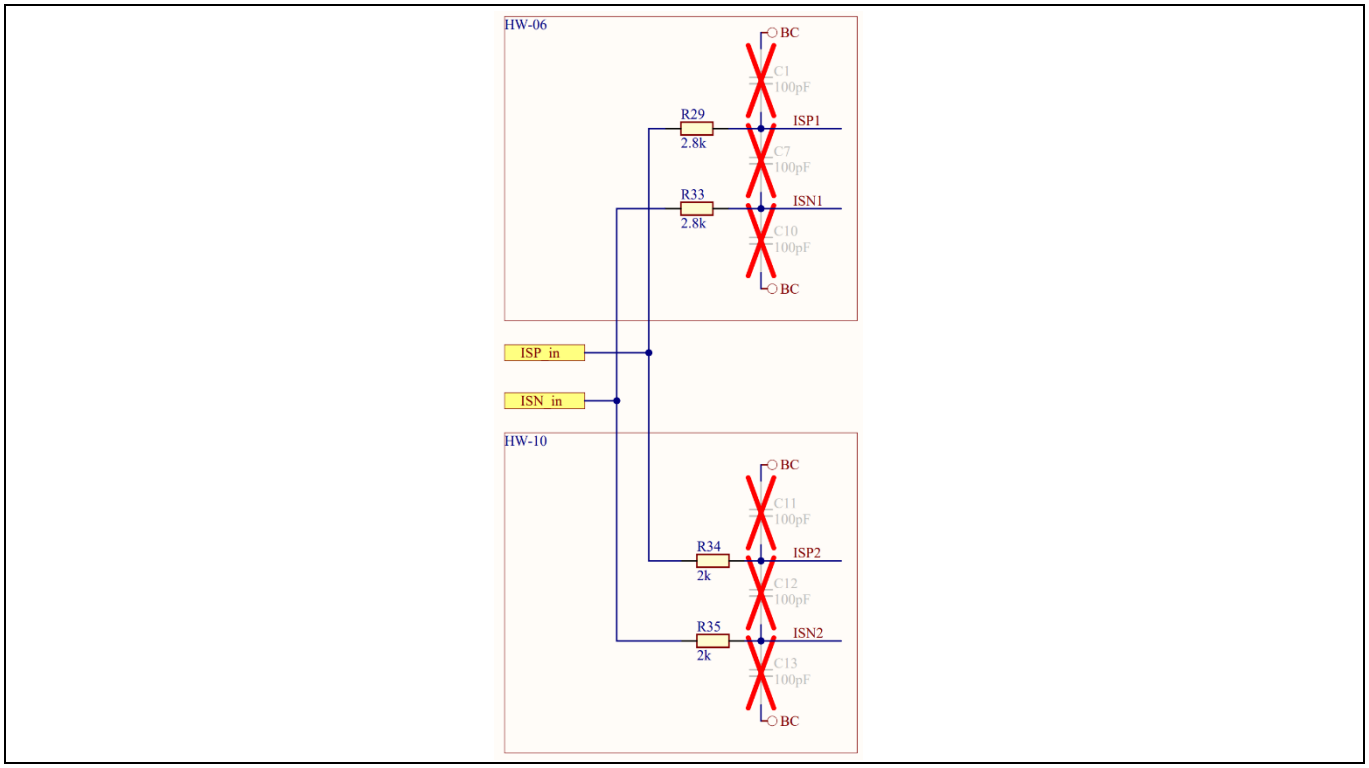

Figure 9 HW-06 and HW-10 short circuit and I-t protection gain resistors

The current measurement input filters (C1; C7; C10; C11; C12; C13 are not populated) and the gain resistors.
HW-06 and HW-07 define the gain of Current sense amplifier [1], CSA1/short circuit protection
HW-10 and HW-11 define the gain of CSA2/I-t protection

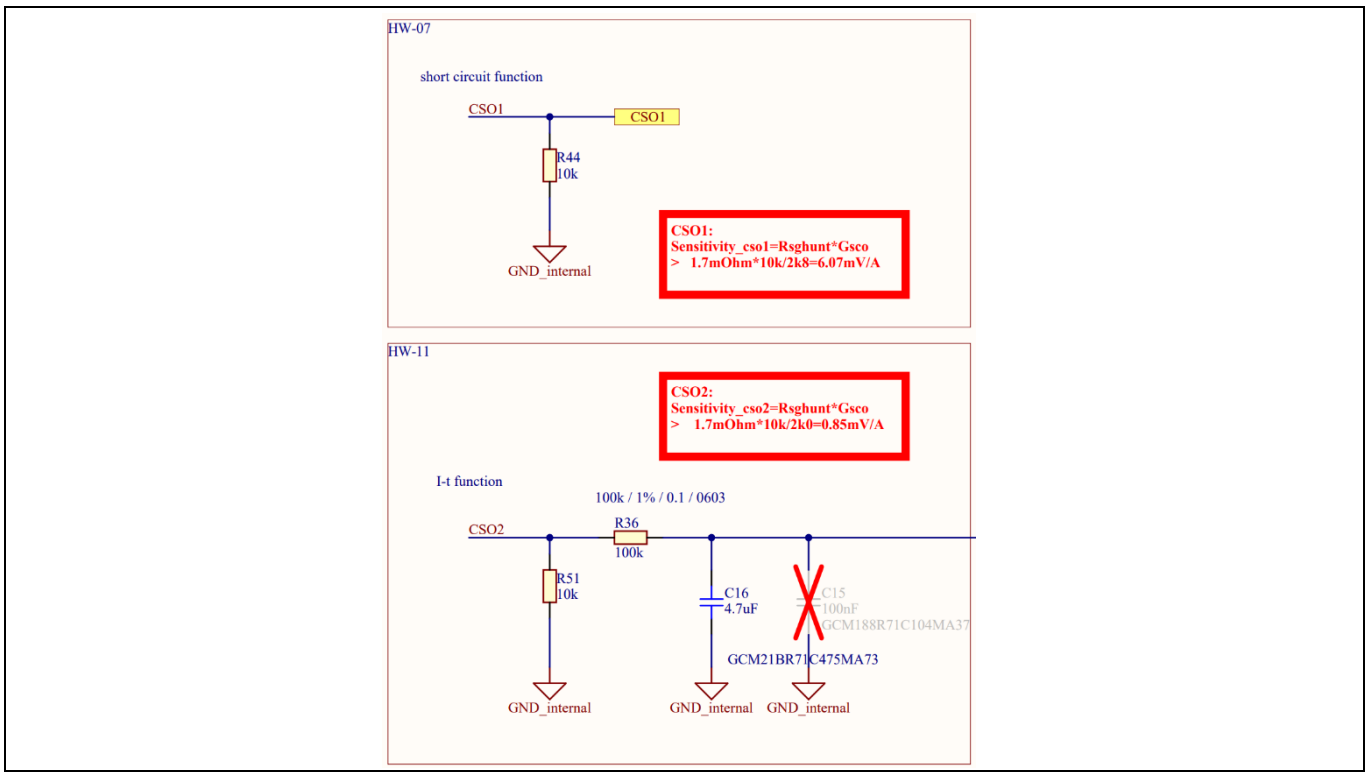

Figure 10 HW-07 and HW-11 I-t protection

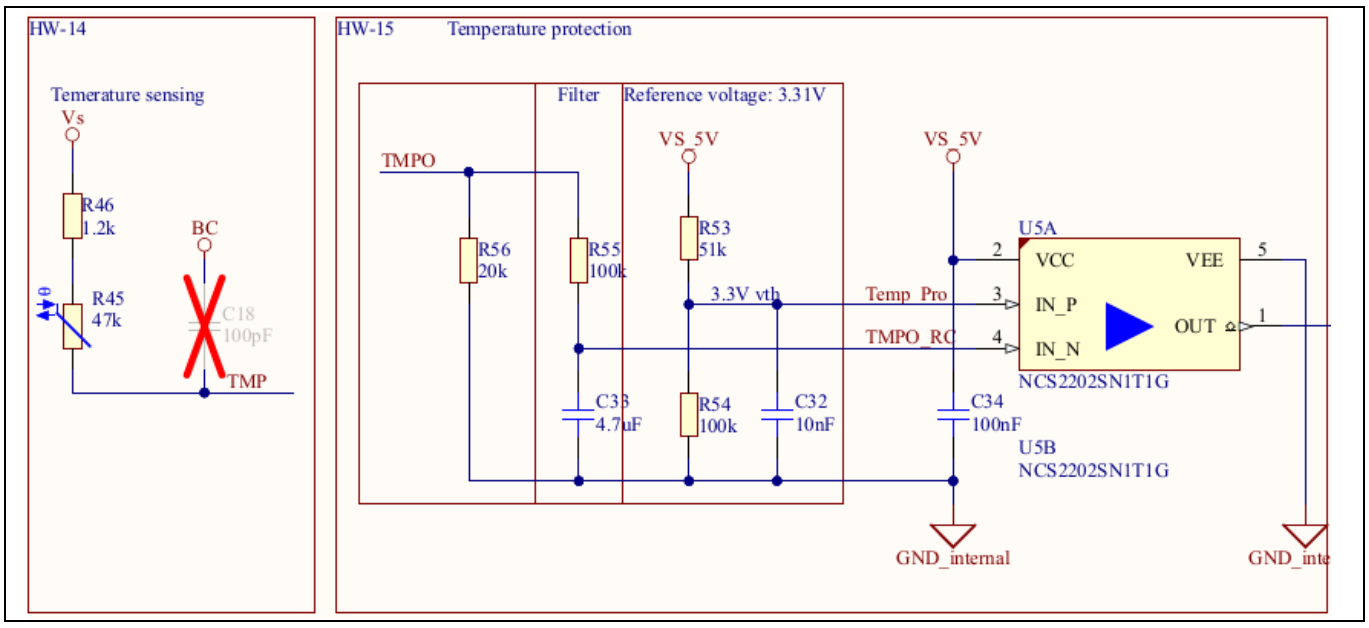

Figure 11 HW-14 and HW-15 temperature protection

The NTC resistor R45 is used as a temperature sensor and amplified by the 2ED2410-EM. The comparator U5 monitors this temperature signal and the output signal is then connected via Q17 back to the 2ED2410-EM internal comparator CP. This comparator CP is used to monitor the I-t signal, but can also be overwritten by the temperature signal. Both events would trigger the 2ED2410-EM internal latch. Refer to Chapter 0.

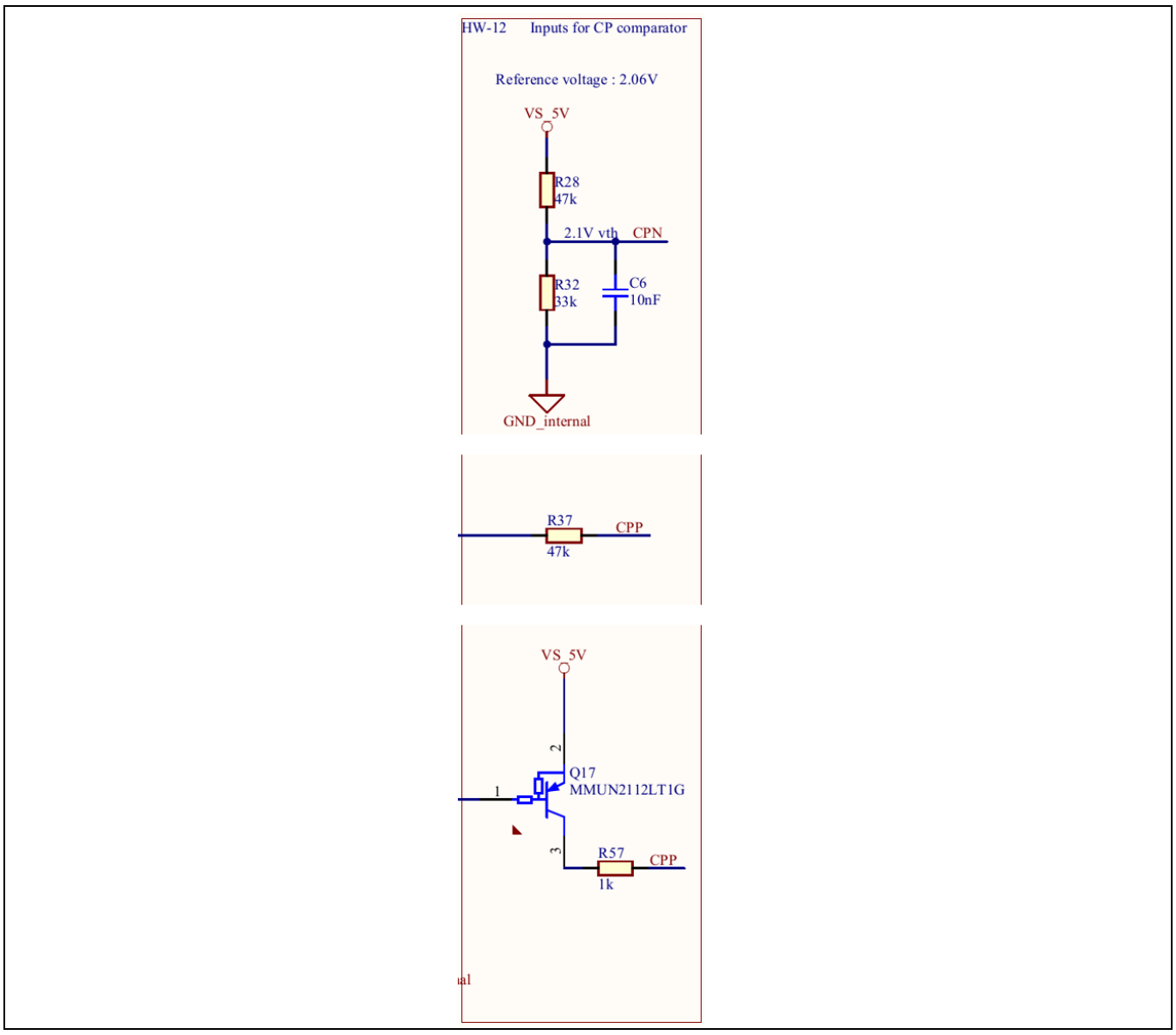

Figure 12 HW-12 comparator input signal creation

An analog signal from the I-t protection is fed into the 2ED2410-EM comparator CP, but can be overwritten by the temperature signal. The 2ED2410-EM comparator CP can trigger the internal latch to switch-off the 2ED2410-EM

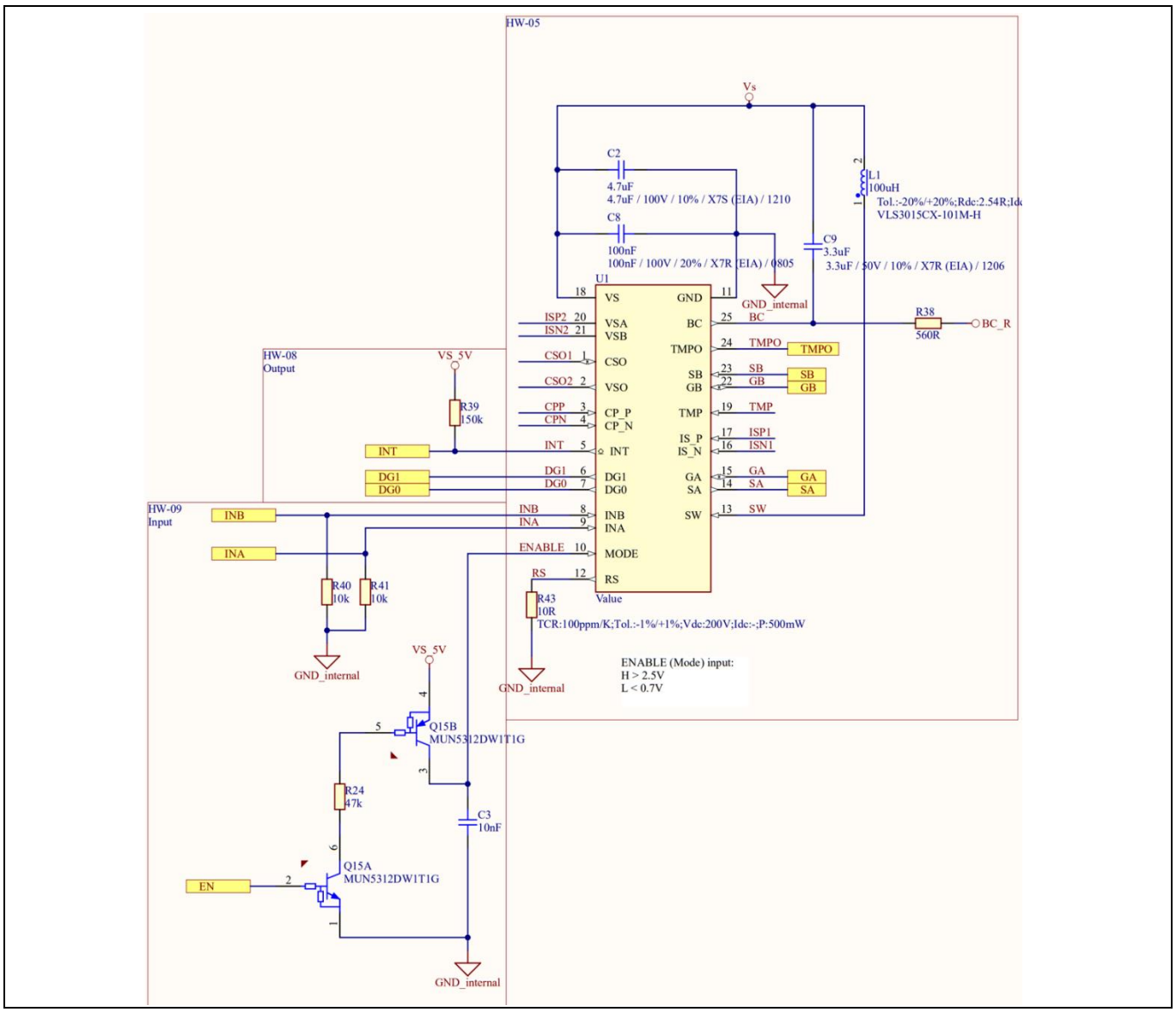

Figure 13 HW-05 and HW-08 and HW-09 high side gate driver

HW-08: Output signals of the 2ED2410-EM.

HW-05: The high side gate driver 2ED2410-EM

HW-09: Signal conditioning of the input signal for the 2ED2410-EM

The switch-off level for the short circuit protection is generated internally by the 2ED2410-EM from the voltage of the enable input. Refer to the datasheet [1]: V_{EN}* $k_{CSO1(TH)}$ Therefore an input decoupling is used (Q15) in order to generate a stable 5 V on signal on the input of the 2ED2410-EM.

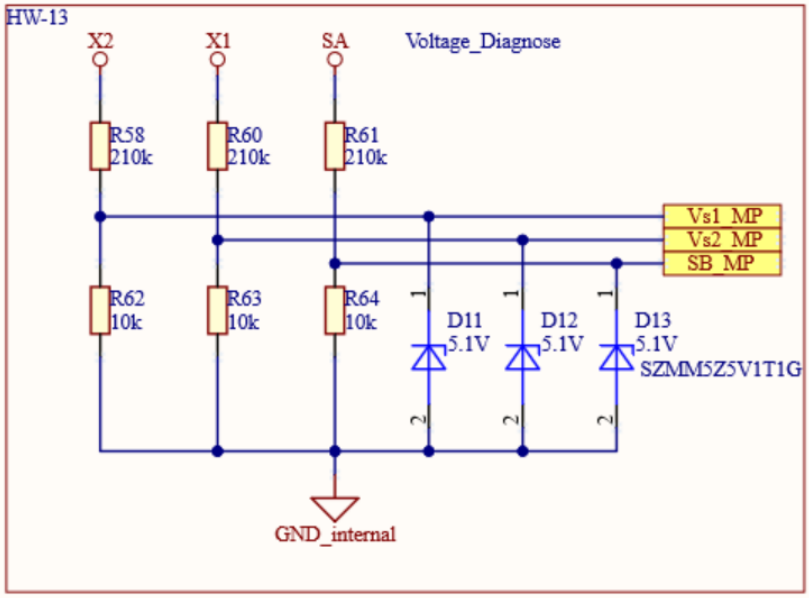

Figure 14 HW-13 Voltage diagnosis

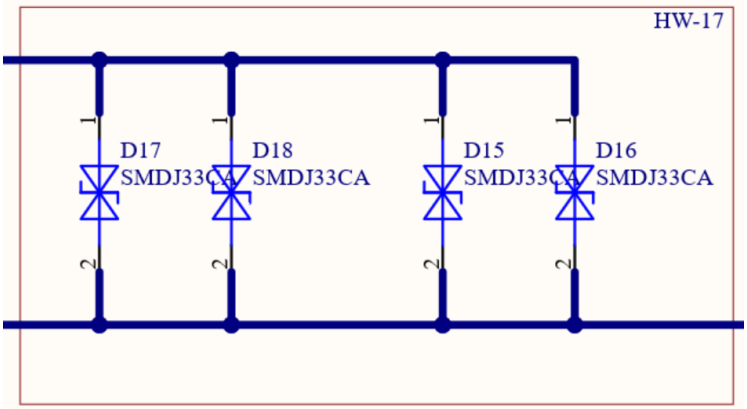

Figure 15 HW-17 avalanche protection

For 40 V MOSFETs the TVS diodes SMDJ33CACT-ND (bi-directional) 36.7 V to 40.6 V are used. They are placed between X1 and X2.

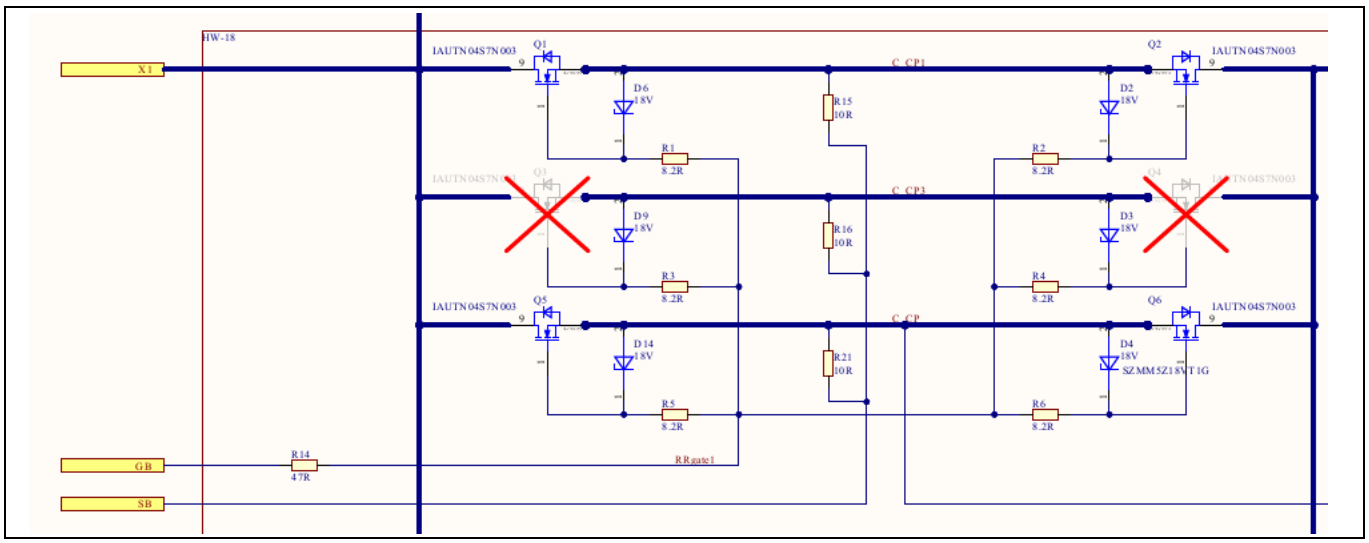

Figure 16 HW-18 power switch bank B

A common source architecture is selected. In order to avoid a current cross-flow, the common source areas are decoupled. The gates are decoupled as well by a resistor. There are two banks of Power MOSFETS to be controlled by INA and INB.

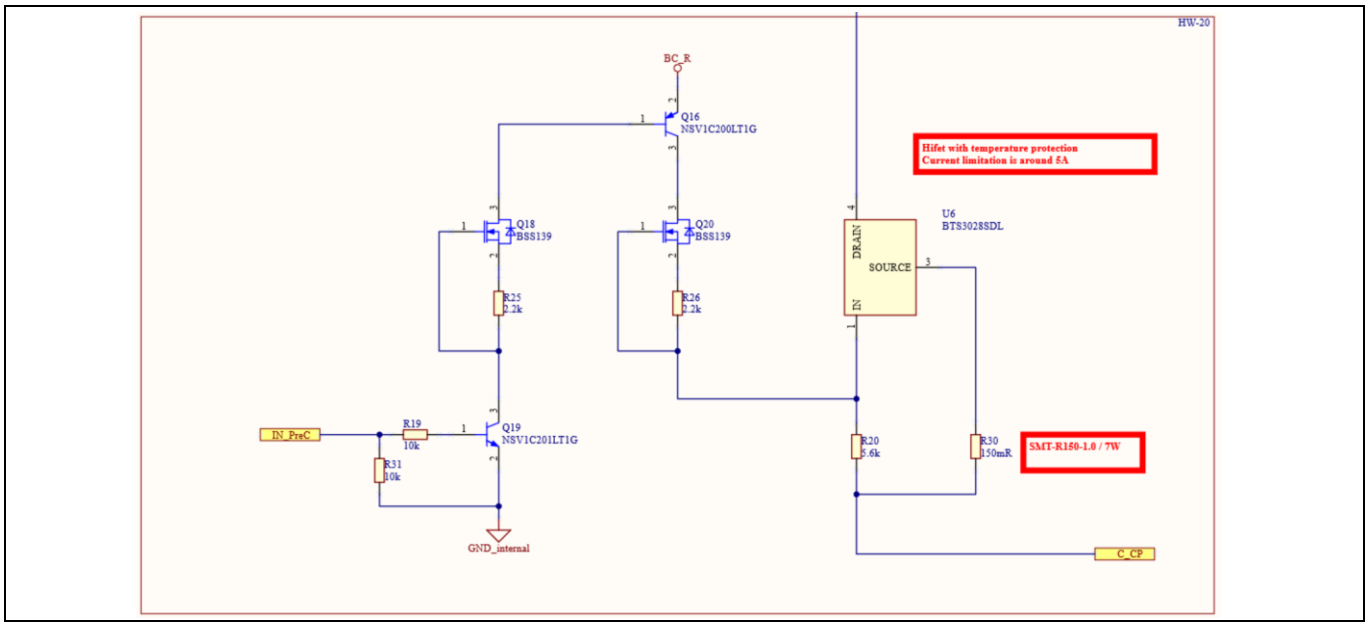

Figure 17 HW-20 pre-charge circuit

U6 works in linear mode in order to limit the inrush current through the **HC-PDU**. The required control voltage is supplied by the 2ED2410-EM boost converter output, see R38 on Figure 13. Q19 and Q16 work as a level shifter translating the input signal coming from the input X17.10

Q18 + R25 and Q20 + R26 limit the current to around 0.5 mA. This current is used to control U6 as R30 works as a negative voltage feedback.

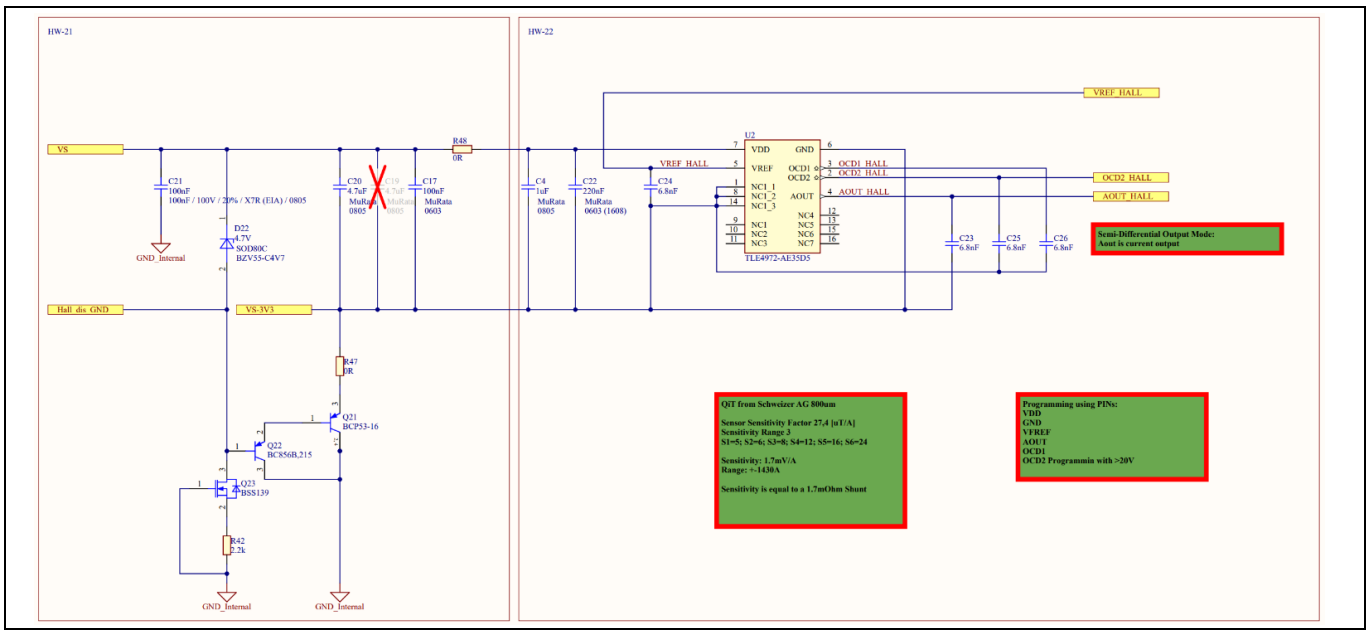

Figure 18 HW-21 and HW-22 power supply and Hall sensor

The 3.3 V operating voltage for the Hall sensor (U2) must be on high side. For programming reasons, it is necessary to disable the power supply of the **HC-PDU**. This can be achieved by connecting the signal Hall_dis_GND X18.10 to VS X18.9. Refer to Chapter 2.6.

2.2 Operating modes of the 2ED2410-EM

The 2ED2410-EM has 4 operating modes including SLEEP, IDLE, ON, SAFESTATE.

Please refer to the datasheet [1] for further details.

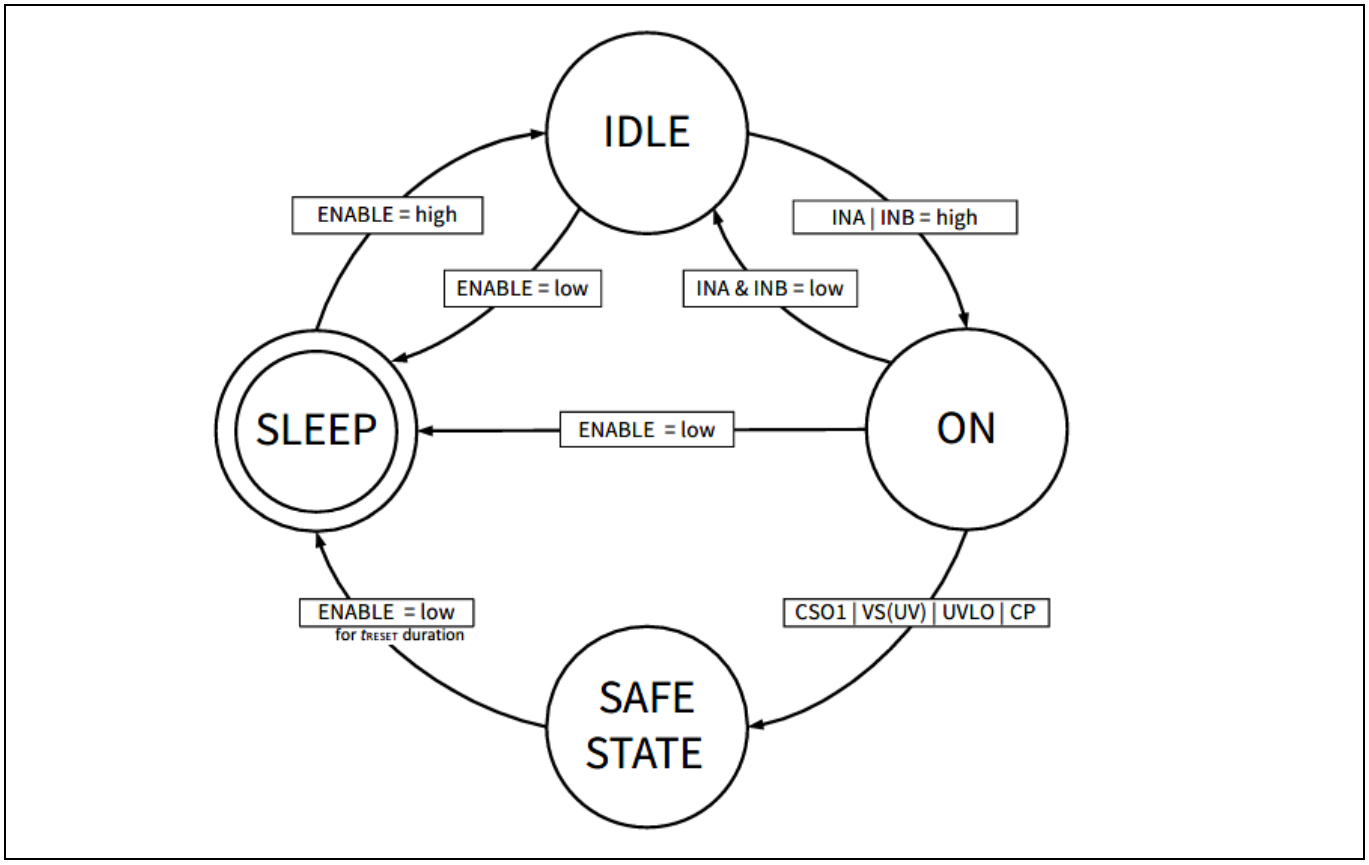

Figure 19 State machine of 2ED2410-EM

As a reminder, the SAFESTATE mode of the 2ED2410-EM can be triggered only from ON mode by:

- By the CSA1 comparator so called short circuit (SC)
- By the UV (Undervoltage protection)
- By UVLO (Undervoltage lockout)
- By CP comparator

The SAFESTATE mode is a latched mode and needs active action from the controller in order to be reset, see 2ED2410-EM datasheet [1] for details on reset operation.

On this board, the CP comparator is used to trigger SAFESTATE mode for both temperature and I-t wire protection.

2.3 2ED2410-EM diagnostics

2ED2410-EM features 6 outputs for diagnostics listed below:

INT: Open-drain output, flags low when 2ED2410-EM enters SAFESTATE

DG0, DG1: Digital outputs for which the output signal varies according to the driver mode. Refer to the datasheet [1] for details.

CSO1, CSO2: Analog outputs of transconductance amplifiers measuring usually the shunt voltage or MOSFET VDS voltage, or in our case here the hall sensor output voltage difference.

TMPO: Analog output of transconductance amplifier measuring the NTC voltage

2.4 VDS monitoring feature of the 2ED2410-EM

2ED2410-EM features in IDLE mode two comparators that monitor the voltage of the source pins (SA, SB) with respect to the VS pin voltage. The output of this comparison can be read on pins (DG0, DG1) respectively.

- If the voltage of SA is close to VS, it can be detected because DG0 will go from 0 to 1 when $V_{SA} = V_{DS\_DIAG(TH)}$
- If the voltage of SB is close to VS, it can be detected because DG1 will go from 0 to 1 when $V_{SB} = V_{DS\_DIAG(TH)}$

See Datasheet [1] 2ED2410-EM for parameter PRQ-91.

This monitoring feature is used to check if the pre-charge of the capacitors is completed when using the pre-charge circuit before switching to ON mode, so that the inrush current expected at turn-on, is greatly reduced.

2.5 Connectors and pin assignment

- X1 and X2: Würth Elektronik PowerOne SMD Bolt 97878 M6
- X17 and X18: TSM-105-01-L-DV

Table 6 Connectors and pin assignment

Pin	Label	Function
X1	X1	NET_X1
X2	X2	NET_X2
X17.1	TMPO	Output TMPO of U1
X17.2	CSO1	Output CSO2 of U1
X17.3	EN	Input EN of U1
X17.4	INT	Output INT of U1
X17.5	INA	Input INA of U1 (pre-charge)
X17.6	DG1	Output DG1 of U1
X17.7	INB	Input INB of U1 (Main Switch)
X17.8	DG0	Output D0 of U1
X17.9	GND	GND
X17.10	INB_PreC	Control input for the pre-charge function
X18.1	VS-3V3	Do not connect during normal operation*
X18.2	SB_MP	Measurement output common point
X18.3	VREF	Do not connect during normal operation*

Pin	Label	Function
X18.4	VS1_MP	Measurement output of X2 (NET2)
X18.5	OCDS2	Do not connect during normal operation*
X18.6	VS2_MP	Measurement output of X1 (NET1)
X18.7	AOUT	Do not connect during normal operation*
X18.8	GND	GND
X18.9	VS	Output Diode wired X1/X2
X18.10	Hall_dis_GND	Do not connect during normal operation*

*See Programming Interface Hall Sensor in chapter: 2.6

2.6 Hall sensor programming TLE4972-AE35D5

All **HC-PDU** come with a pre-programmed TLE4972-AE35D5. The setup is bidirectional with a sensitivity of 1.7 mV/A. Calibration is done with 100 ADC.

There is an isolated programmer available for the TLE4972-AE35D5: Please see [7].

For programming the Hall sensor, the programmer needs to have full control over the power supply of the TLE4972-AE35D5. Therefore it is necessary to disable the **HC-PDU** Hall sensor power supply for programming reasons. This can be achieved by connecting the signal Hall_dis_GND X18.10 to Vs X18.9 (see Figure 18)

See the power-supply architecture of the **HC-PDU** hall sensor power supply, below.

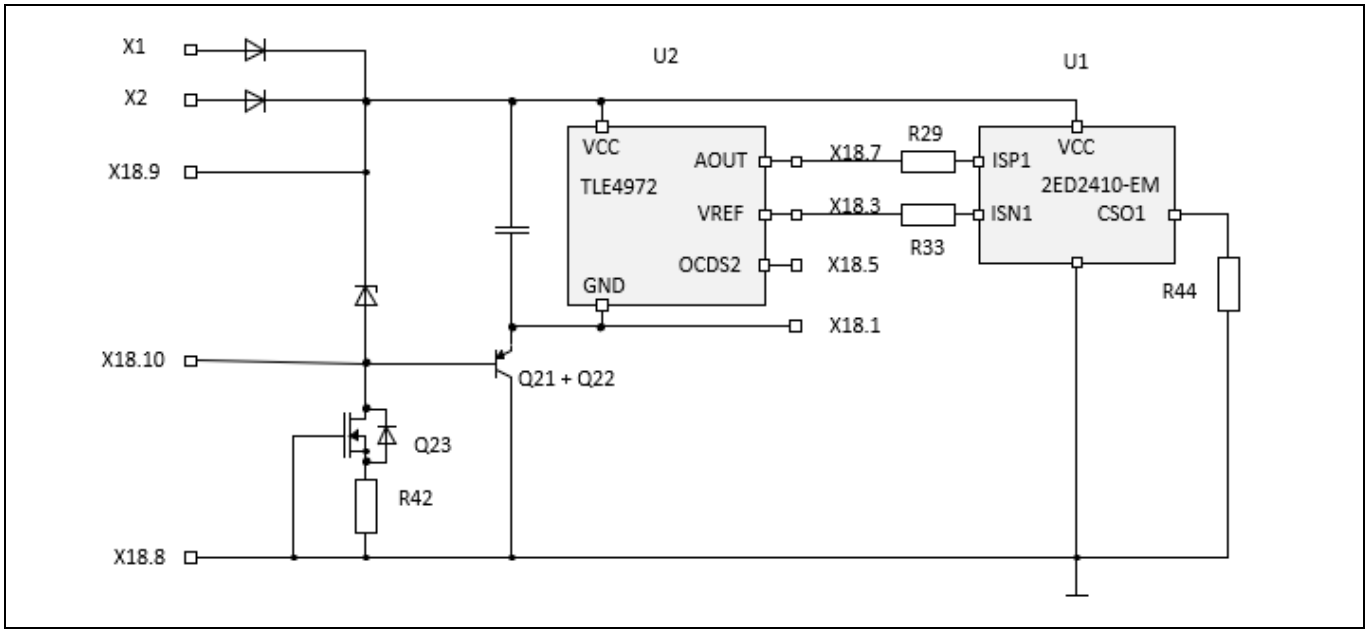

Figure 20 Power-supply architecture for the 2ED2410-EM

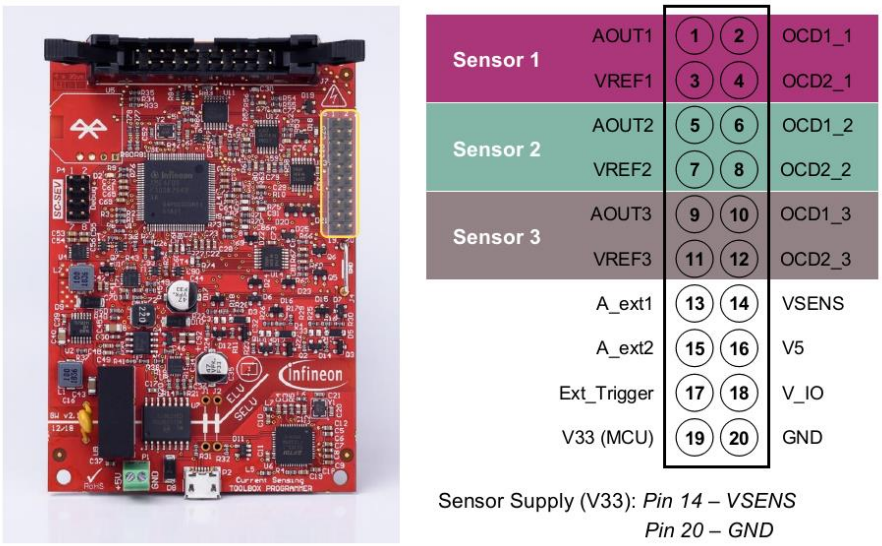

Figure 21 **Excerpt from the TLE4972 current sensor programmer user guide.** Error! Reference source not found.

Table 7 **Pinout for the programming cable**

Signal	HC-PDU	**Programmer (Sensor 1)**
Supply voltage	X18.9 VS	14 VSENS
GND	X18.1 VS-3V3	20 GND
OCDS2	X18.5 OCD2_HALL	04 OCDS2_1
VREF	X18.3 VREF_HALL	03 VREF1
AOUT	X18.7 AOUT_HALL	01 AOUT1
Hall_dis_GND	X18.10 connected to X18.9 VS	–

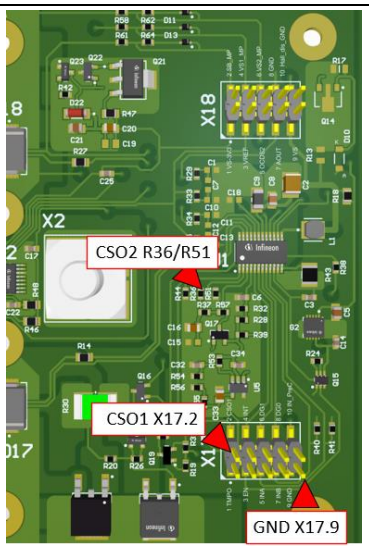

Figure 22 **Location of CSO1 and CSO2 for programming the 2ED2410-EM on PCB**

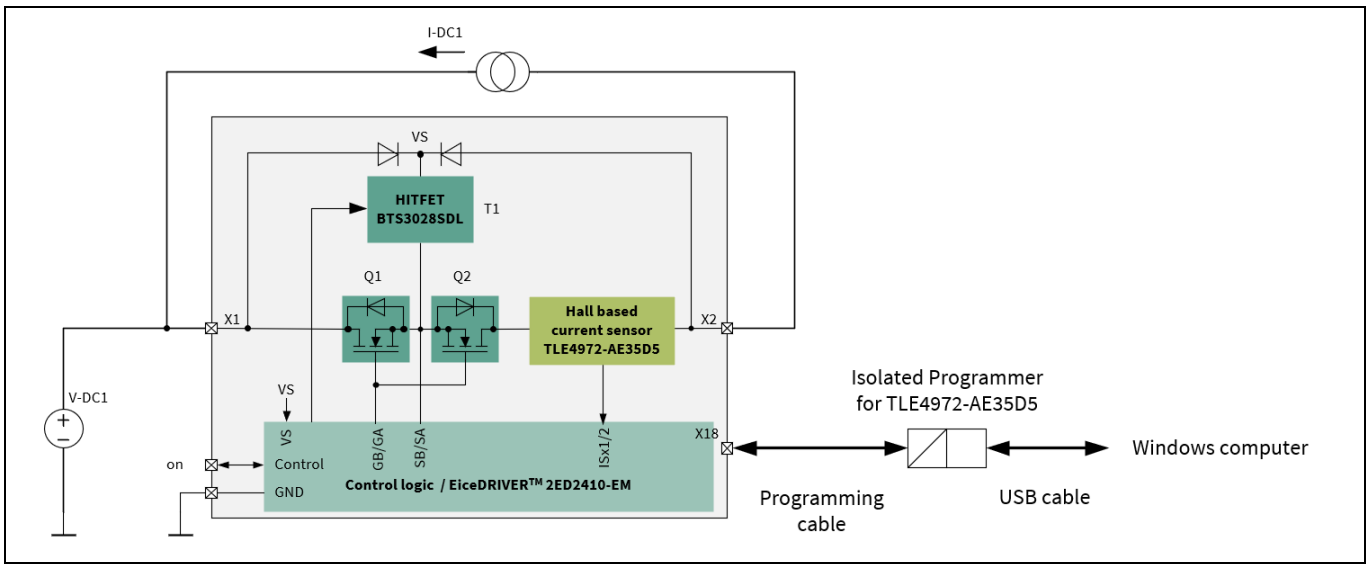

Figure 23 Block diagram for programming the TLE4972-AE35D5

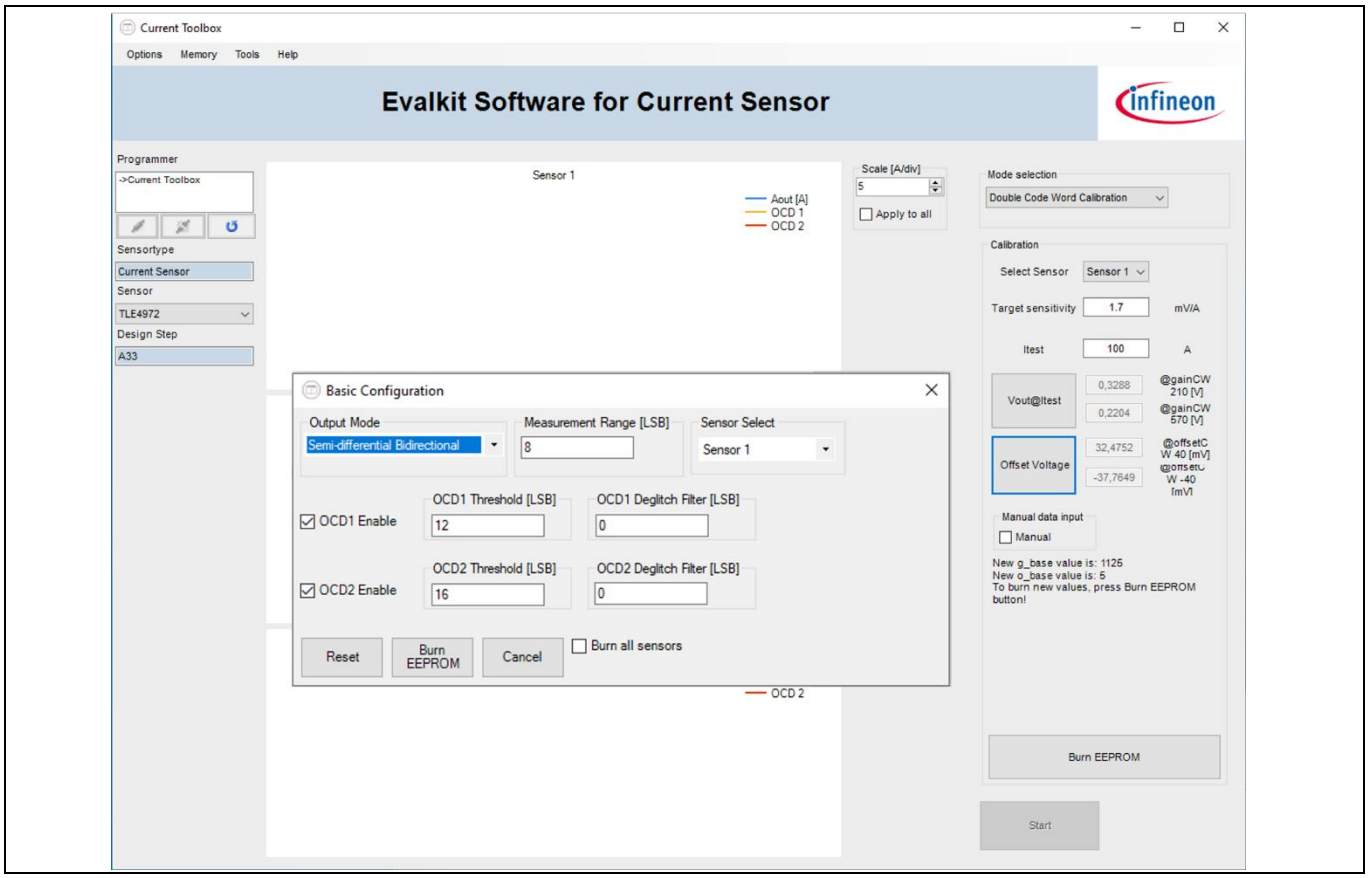

Figure 24 Screenshot current toolbox TLE4972-AE35D5 (basic configuration)

The programming flow is as follows:

1. Install the software for the programmer
2. Power up the **HC-PDU** with 12 V (V-DC1: 12V)
3. Prepare I-DC1 to generate a current in order to calibrate the TLE4972-AE35D5
4. Disable the **HC-PDU** internal power supply for the TLE4972-AE35D5 (X18.10 connected to X18.9 VS)
5. Connect the programmer to X18 of the **HC-PDU** programming interface as described in Table 6
6. Start the programming GUI (see Figure 24)
    a. Programmer > Current Toolbox and Connect to the selected programmer
    b. Enter sensitivity setting for sensor 1: 1.7 (mV/A)
    c. Select sensor TLE4972. The design step will be displayed
    d. Program the basic configuration: Memory > Basic Configuration: Semi-differential bi-directional (OCD1 and OCD2 is not used on the **HC-PDU**, does not matter whether they are selected or not)
    e. Mode selection > Double Code Word Calibration
    f. Select Sensor > Sensor 1
    g. Enter Target sensitivity > 1.7mV/A
    h. Enter Itest > 100 A (I-DC1)
7. Short CSO1 and CSO2 of U1 to GND of U1 (CSO1 on X17.2; CSO2 on PCB)
8. Switch-on the **HC-PDU**
9. Apply the calibration-current to calibrate the TLE4972-AE35D5 (value entered in 6.h, as described above)
10. Click on “Vout@Itest”, inside the Current Toolbox
11. Wait until button Offset Voltage is active
12. Switch-off the calibration-current
13. Click on “Offset Voltage”
14. Click on “Burn EEPROM” to store the calibration values to the TLE4972-AE35D5

The calibration is complete.

The programming can be checked by selecting: Mode selection > continuous readout > see Sensor 1

Attention: ***For normal operation of the sensor, the current sensor programmer needs to be unplugged!***

3 Current path through the board

The current enters the PCB via X18 and exits the PCB via X17 or vice versa. The resistance between these two terminals is the Total Terminal to Terminal resistance (R_{TTR}). This resistance consists of:

- Track on the PCB
- Terminals
- Power MOSFETS
- Solder joints

Because of the copper track resistance and the current, the PCB heats up because of the power loss. The target is to avoid hotspots, and distribute the thermal flow evenly on the PCB.

3.1 Layout structure for the coreless Hall sensor

In this design a coreless Hall sensor is used. The layout structure needed for the hall sensor contributes to the Total Terminal to Terminal Resistance (R_{TTR}). The estimated R_{TTR} for this PCB, excluding Power MOSFETS is 84 µΩ; measured at 25°C, including an estimated 22 µΩ for the copper structure needed for the hall sensor.

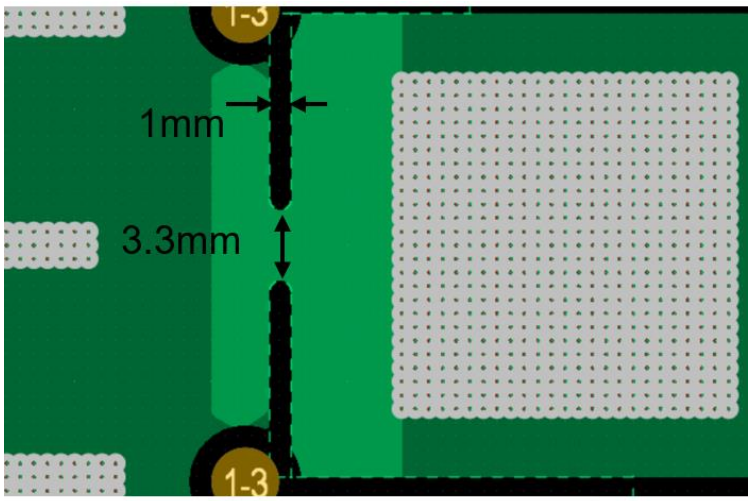

Figure 25 PCB copper structure needed for the coreless Hall-based measurement

3.2 Layout considerations for paralleling of MOSFETs

When MOSFETs are connected in parallel it must be ensured that the load current is equally distributed amongst them in order to avoid hot spots on the PCB and thermal overload of a single MOSFET. Especially for very low ohmic MOSFETs, the PCB layout plays a major role because the resistance of the PCB trace and the on-resistance of the MOSFET are in the same order of magnitude and so the current distribution will be influenced by the trace length.

The following are examples of different configurations.

3.2.1 Unidirectional configuration displays two possible options

Option 1: Input (drain) and output (source) are routed to the same side of the board

The trace length for Q1 is much shorter than that of Q4. Therefore, Q1 will take more current and will gets hotter than Q4.

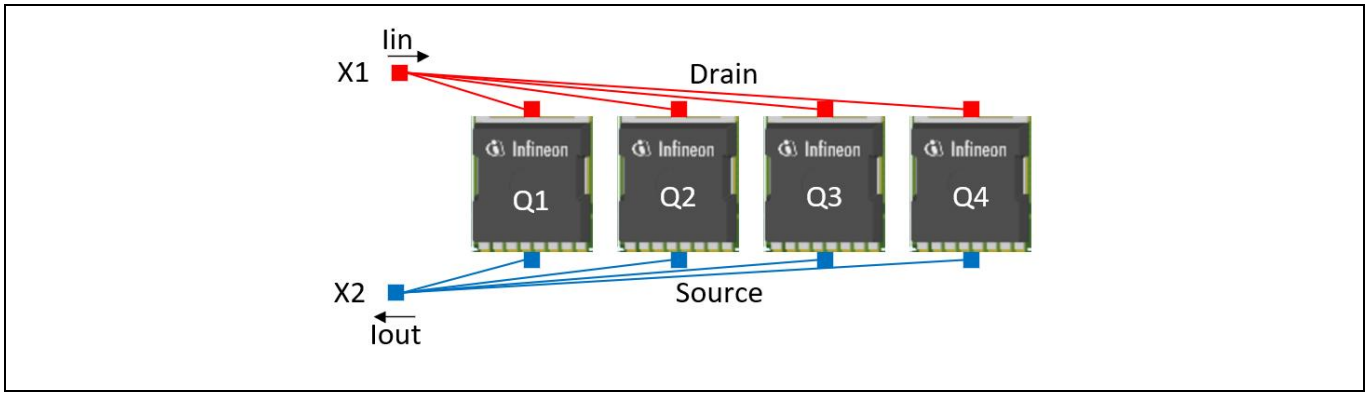

Figure 26 Current path unidirectional configuration option 1

Option 2: Input (drain) and output (source) are routed to opposite sides of the board

The trace length is the same for all the MOSFETs. Therefore, the current will be distributed evenly among the MOSFETs.

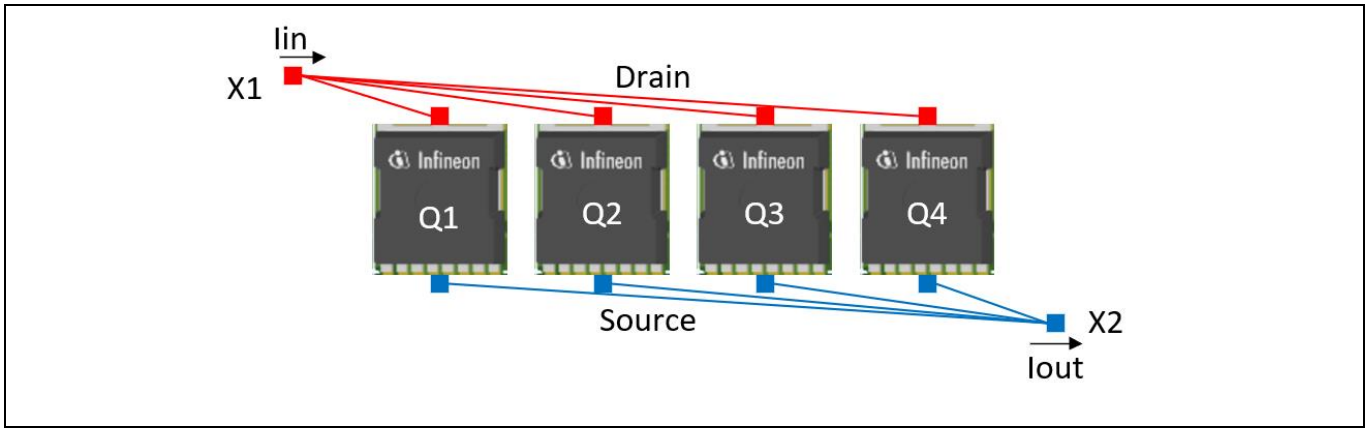

Figure 27 Current path unidirectional configuration option 2

3.2.2 Anti-serial configuration displays four possible options

Consider the results of the unidirectional configuration, only two options are promising. It is evident that opposite sides for input and output are to be used. It is necessary to connect all the sources together to control the Power MOSFETs.

Anti-serial option 1:
Input (drain) and output (drain) routed to opposite sides of the board but all sources are connected together with one big trace.

The example in Figure 28 is not sufficient:
Shortest path from X1 to X2 is via Q1 and Q8 as the current flows along the big trace connecting all the sources directly together.

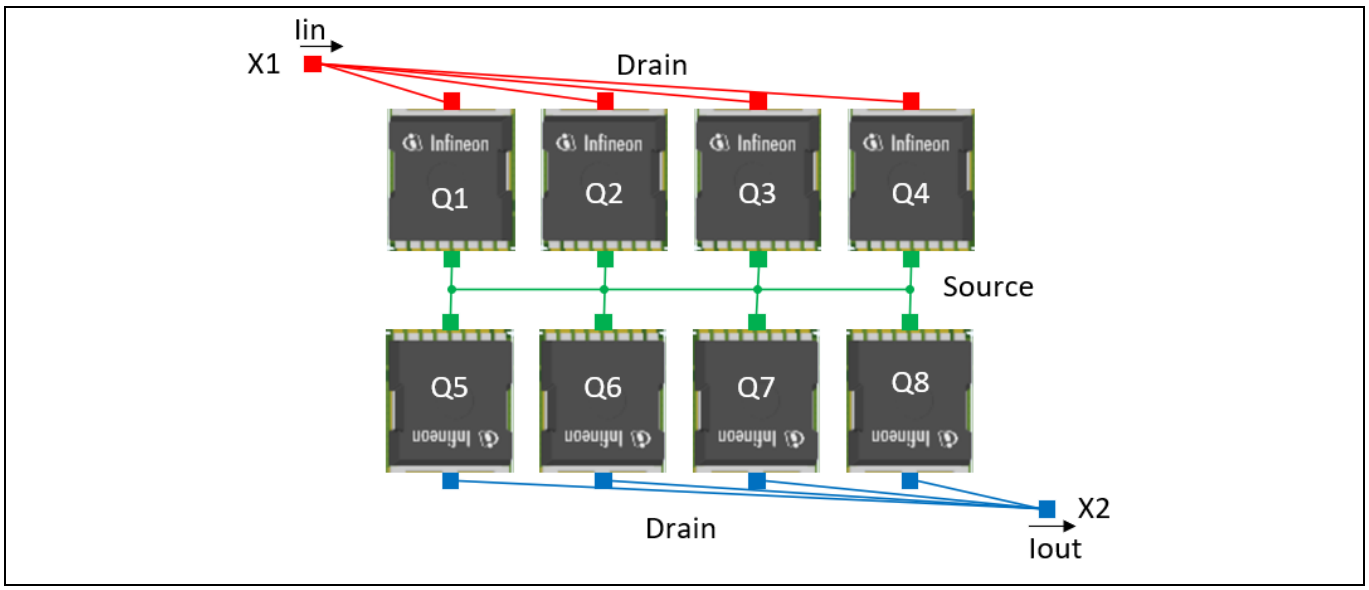

Figure 28 Current path anti-serial configuration option 1

Antiserial option 2:
Input and output (both drain) are routed to opposite sides of the board and no common source is implemented

Figure 29: Avoid cross current on the source area (green). Only the two sources from two Power MOSFETS are connected.

In the example with one gate-source signal only, it is necessary to connect the source islands. This connection can be done with a resistor in the range of a few ohms (e.g. 2 Ω ≤ x ≤ 10 Ω). Nevertheless, the track width for the main power path (between two MOSFET) needs to be suitably chosen for the current and the expected power dissipation.

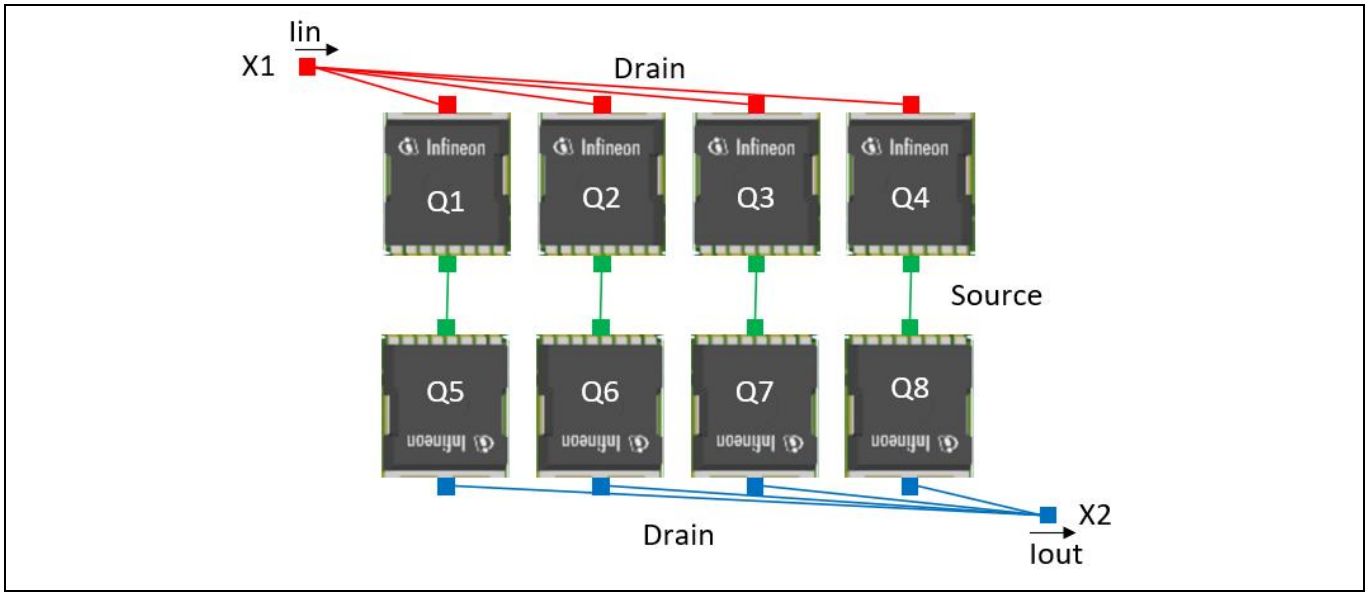

Figure 29 Current path anti-serial configuration option 2

4 Product performance

Measurements are done at room temperature.

Two different directions of current are used:

X1 is connected to the battery voltage and X2 acts as the output:
X1 = VBatt/X2 = output
Swap X1 and X2: X1 = output/X2 = VBatt

4.1 Pre-charge test

The purpose of this test is to analyze the pre-charge feature of the HC-PDU. An external ECU is emulated with the 34 mF capacitor C-ECU. The pre-charge current is set around 4 A given the resistor on the HC-PDU board.

Note: The digital diagnosis outputs of the 2ED2410-EM, DG0 and DG1, indicate the Pre-charge status in this case. When the voltage of the Source pins SA or SB comes close to the battery voltage, DG0 and DG1 flags high. See 2ED2410-EM datasheet chapter 7.1.

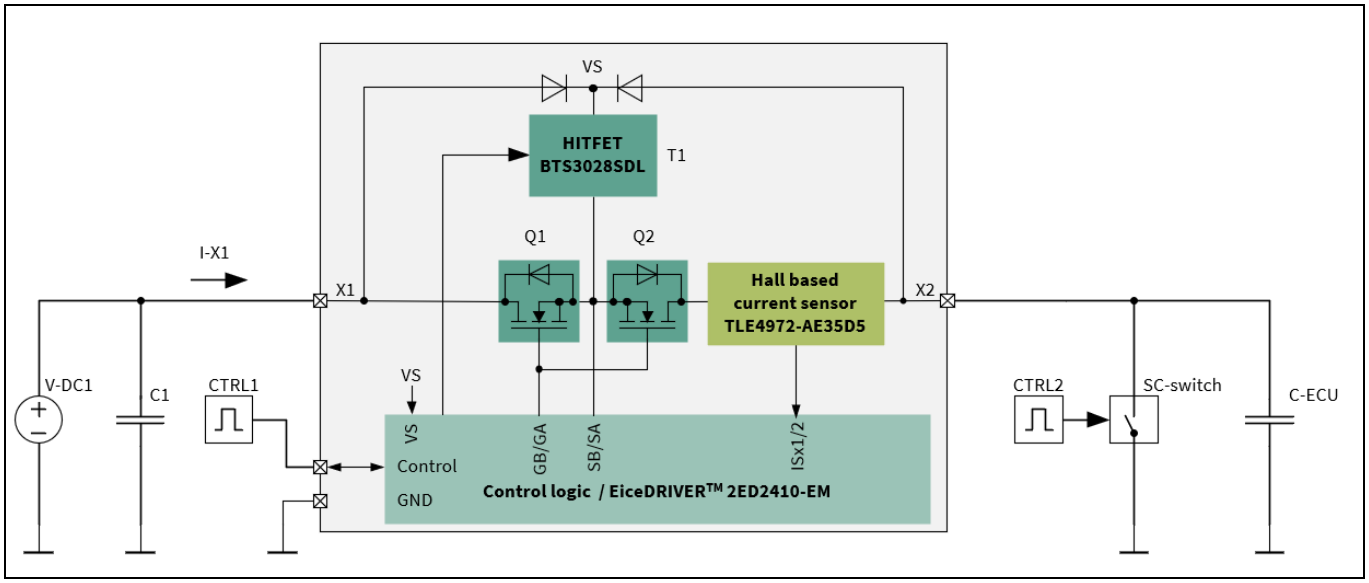

Figure 30 Block diagram of pre-charge test setup

The following devices are used for the pre-charge test:

- Oscilloscope: MSO58 5-BW-500
- Current measurement I-X2: current transducer LEM LF1005-S
- C1: Capacitor Epcos B41456B8100M000 63 V 100 mF 5x parallel
- C-ECU: 34 mF
- SC-switch: Potential free controlled semiconductor switch
- For all voltage measurements differential probes are used: THDP0200

Setup:

X1 = VBatt = V-DC1: 14 V

X2 = output

Scope setup:

- Channel1: [2 V/DIV] Voltage across X1 and X2
- Channel2: [2 V/DIV] VBATT+ to GND
- Channel3: [2 V/DIV] Vout to GND
- Channel6: [10 A/DIV] Current of X2
- Channel5: EN input of the 2ED2410-EM
- Channel7: INA input of the 2ED2410-EM
- Channel4: DG0 output of the 2ED2410-EM
- Channel8: DG1 output of the 2ED2410-EM

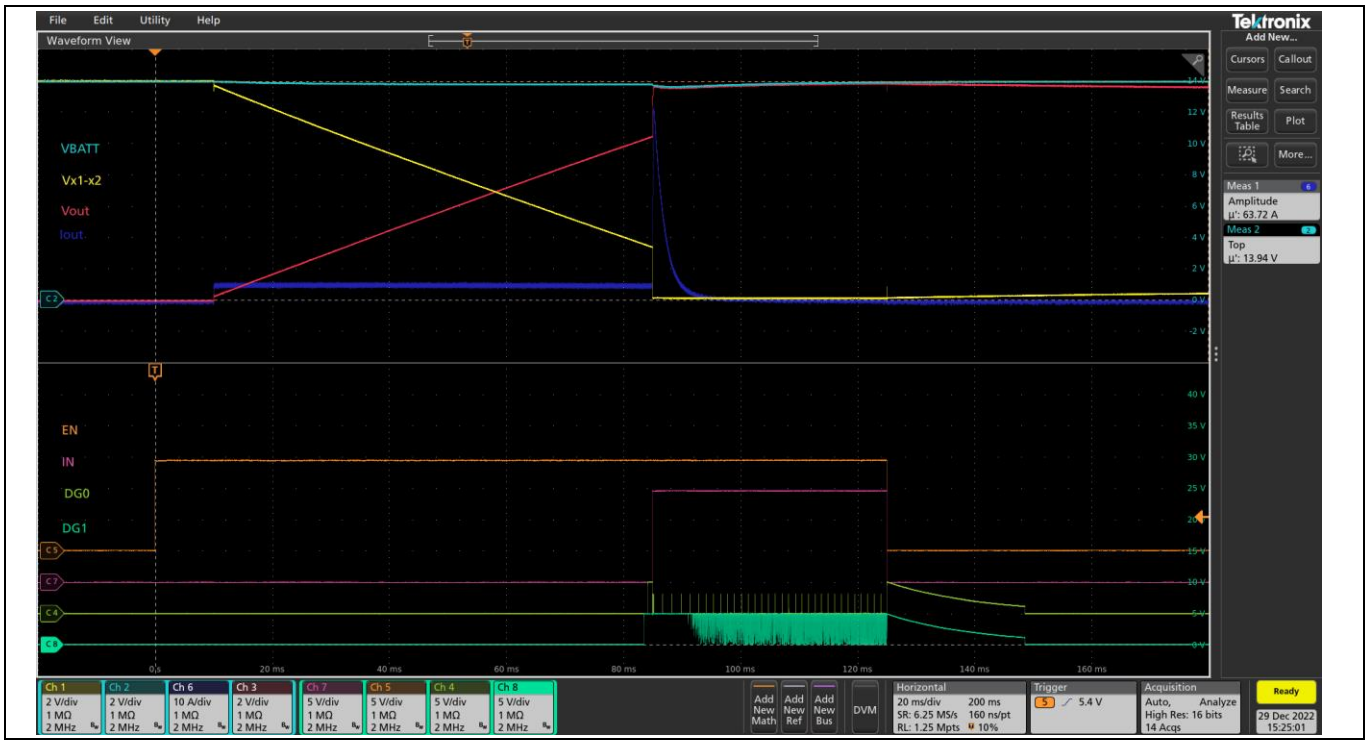

Figure 31 Pre-charge: 20 ms/DIV graph

4.2 Short circuit protection cutoff test

The purpose of this test is to analyze the short circuit protection feature of the HC-PDU. The current is switched either by an external switch (short circuit case 1) or by the HC-PDU switching into a short circuit (short circuit case 2) The short circuit protection limit is set to 618 A. If this protection feature is triggered, the HC-PDU switches off. Note that INT signal goes low then SAFESTATE mode is triggered, see figure 33 below.

Short circuit case 1: HC-PDU is switched on and then an external short circuit switch is turned on
Short circuit case 2: A short circuit already exists when the HC-PDU is switched on

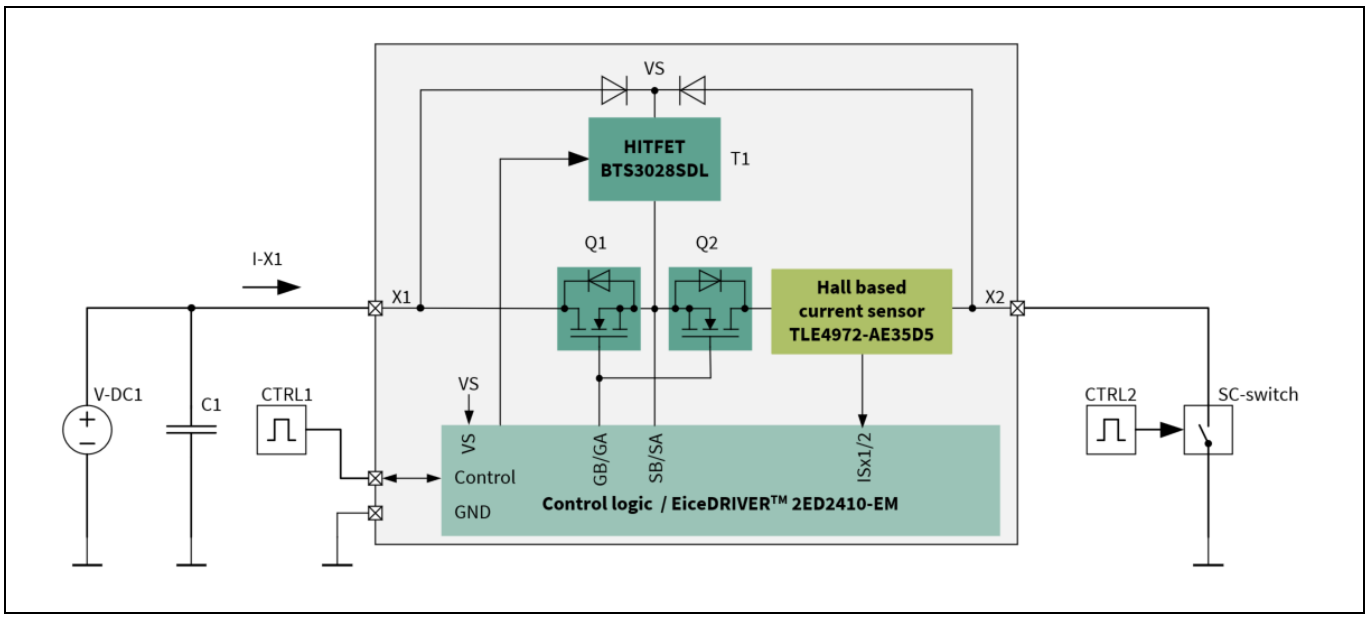

Figure 32 Block diagram of short circuit test setup / short circuit case 1

Following devices are used:

- Oscilloscope: MSO58 5-BW-500
- Current measurement I-X1: current transducer LEM LF1005-S
- C1: Capacitor Epcos B41456B8100M000 63 V 100 mF 5x parallel
- SC-switch: Potential free controlled semiconductor switch
- For all voltage measurements differential probes are used: THDP0200
- In order to reach a high current 50 mm^2 cables are used for the main current path

Setup:

- X1 = VBatt = V-DC1: 14 V
- X2 = output

Scope setup:

- Channel1: [5 V/DIV] Voltage across X1 and X2
- Channel2: [5 V/DIV] VBATT+ to GND
- Channel6: [100 A/DIV] Current of X1
- Channel5: EN input of the 2ED2410-EM
- Channel7: INA + INB input of the 2ED2410-EM
- Channel3: INT output of the 2ED2410-EM
- Channel4: CSO1 output of the 2ED2410-EM
- Channel8: SC short circuit control signal

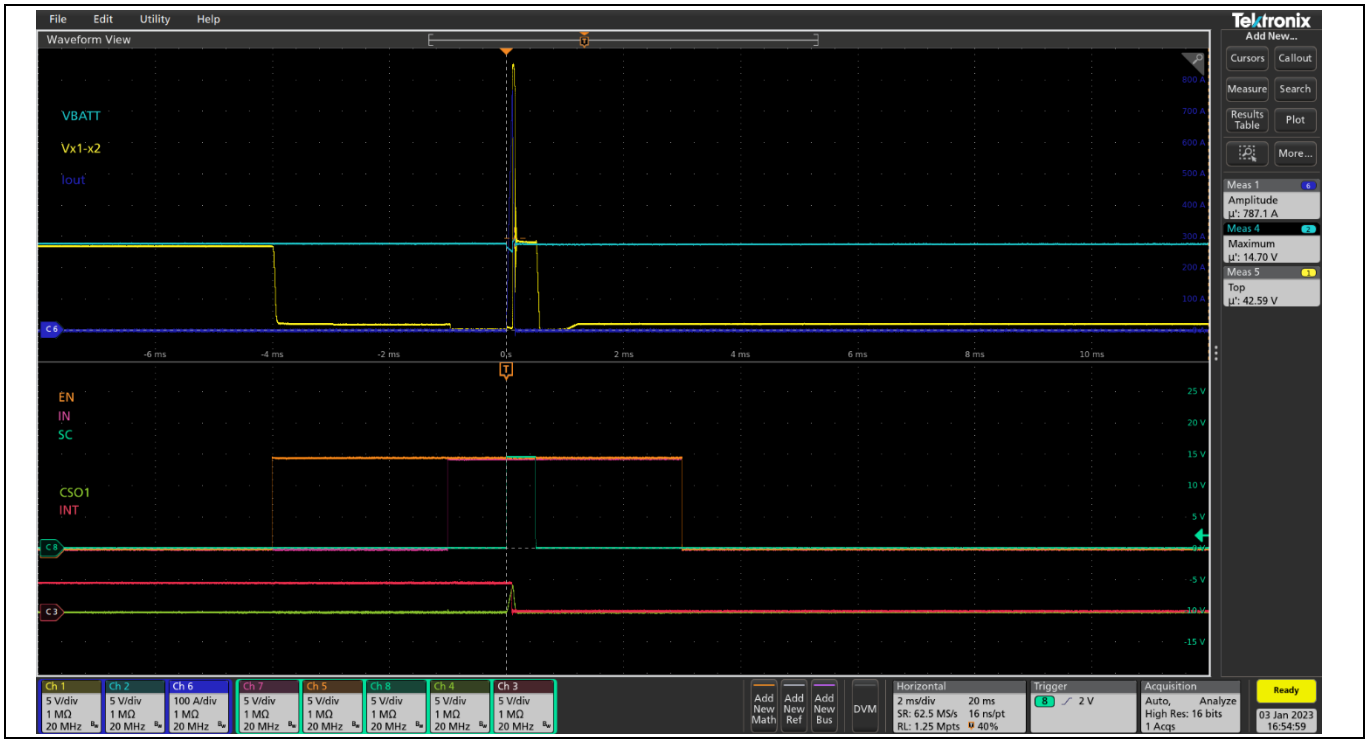

Figure 33 Short circuit case 1 graph depicting 2 ms/DIV

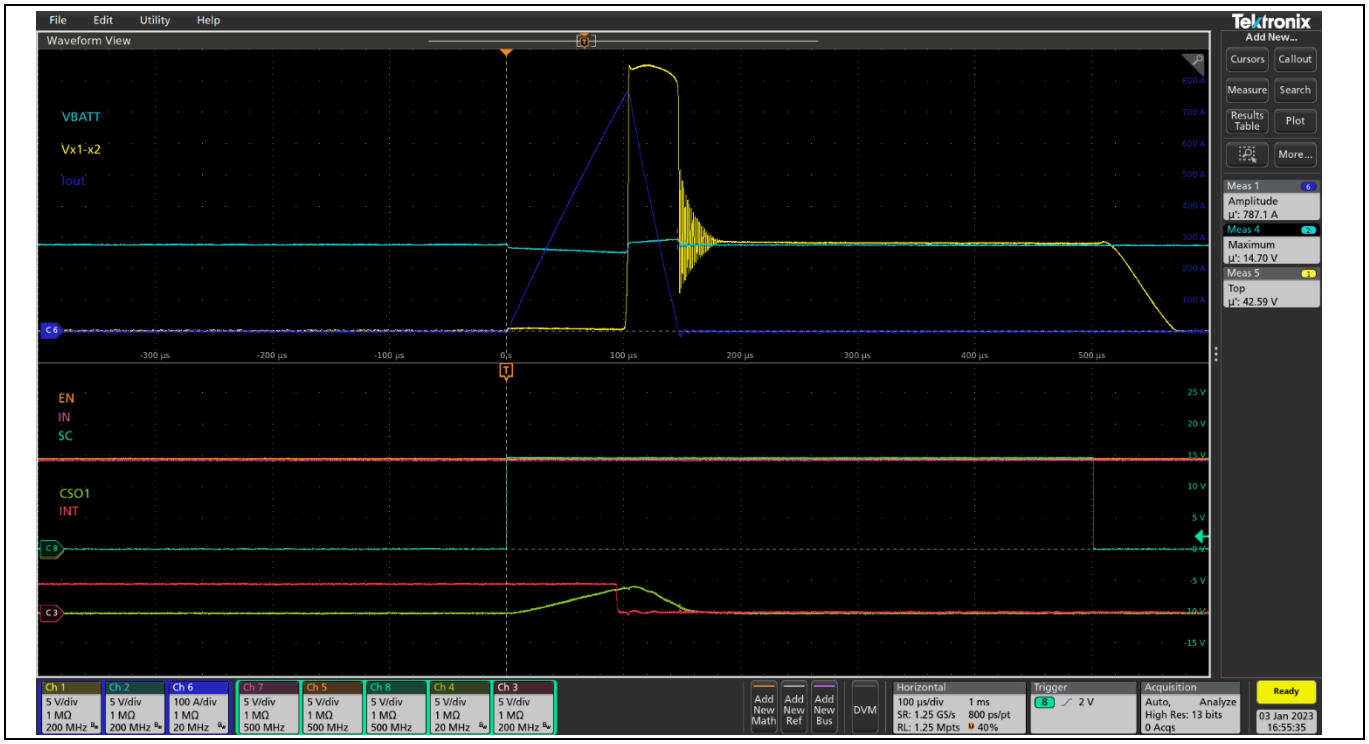

Figure 34 Short circuit case 1 graph depicting 100 µs/DIV

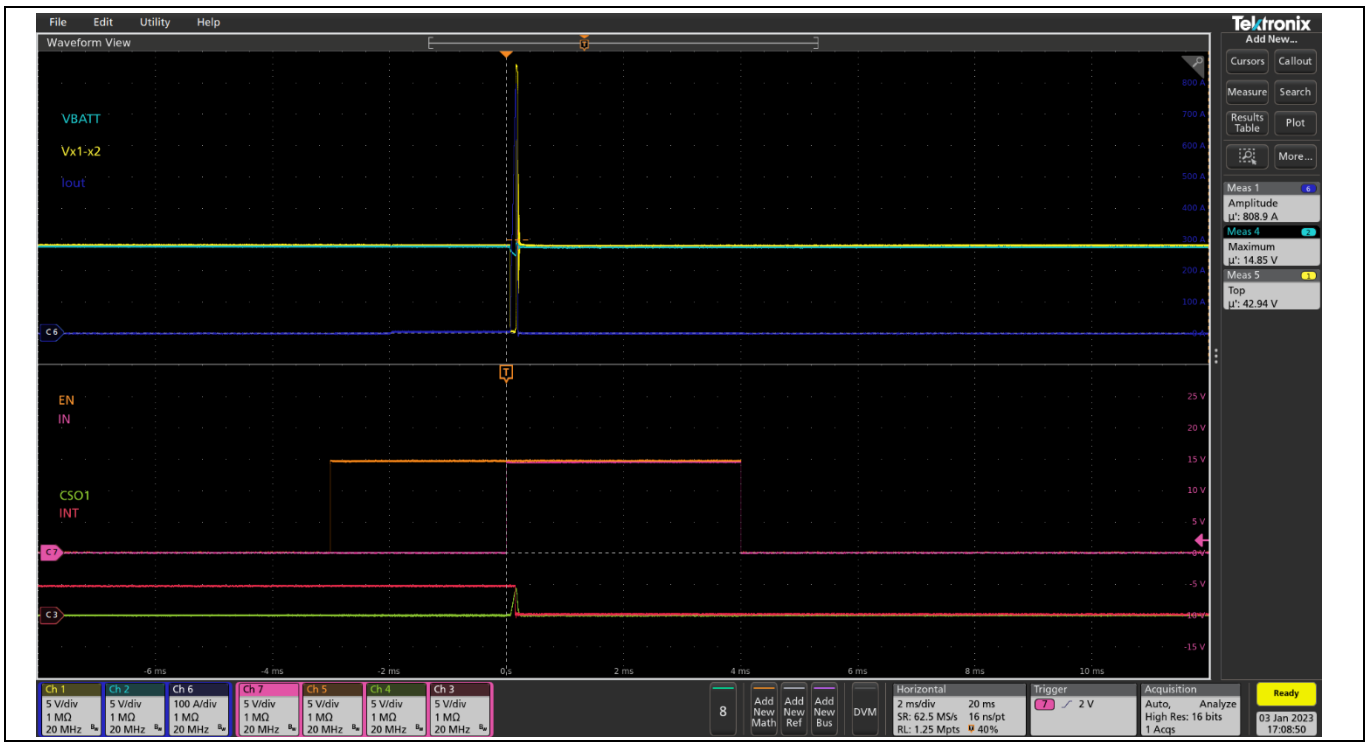

Figure 35 Short circuit case 2 graph depicting 2 ms/DIV

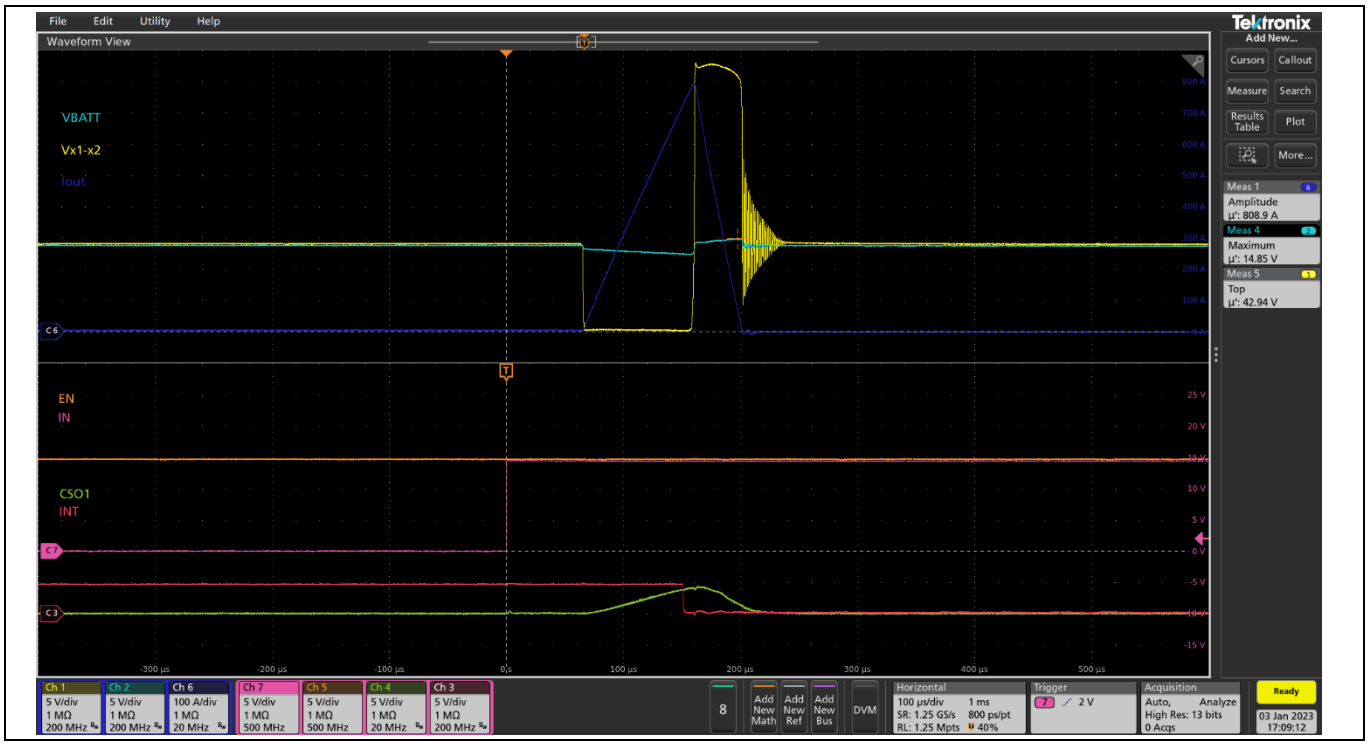

Figure 36 Scope picture (100 us/DIV) Short circuit case 2

Short circuit protection test with inverse current

The purpose of this test is to analyze the short circuit protection feature of the HC-PDU with inverse current. For this test, the setup of chapter Figure 31 is used, connections to X1 and X2 are swapped. The short circuit

protection limit is set to 618 A. Once this protection feature is triggered the HC-PDU is switching off. Please note the open-drain diagnostic output of the 2ED2410-EM(Se, INT, which is indicatingis indicating the cutoff (=SAFESTATE mode triggered).

Setup:

- The same as in chapter 4.2 figure 32.
- X2 = VBatt = V-DC1: 14 V
- X1 = output
- Current measurement I-X2: current transducer LEM LF1005-S

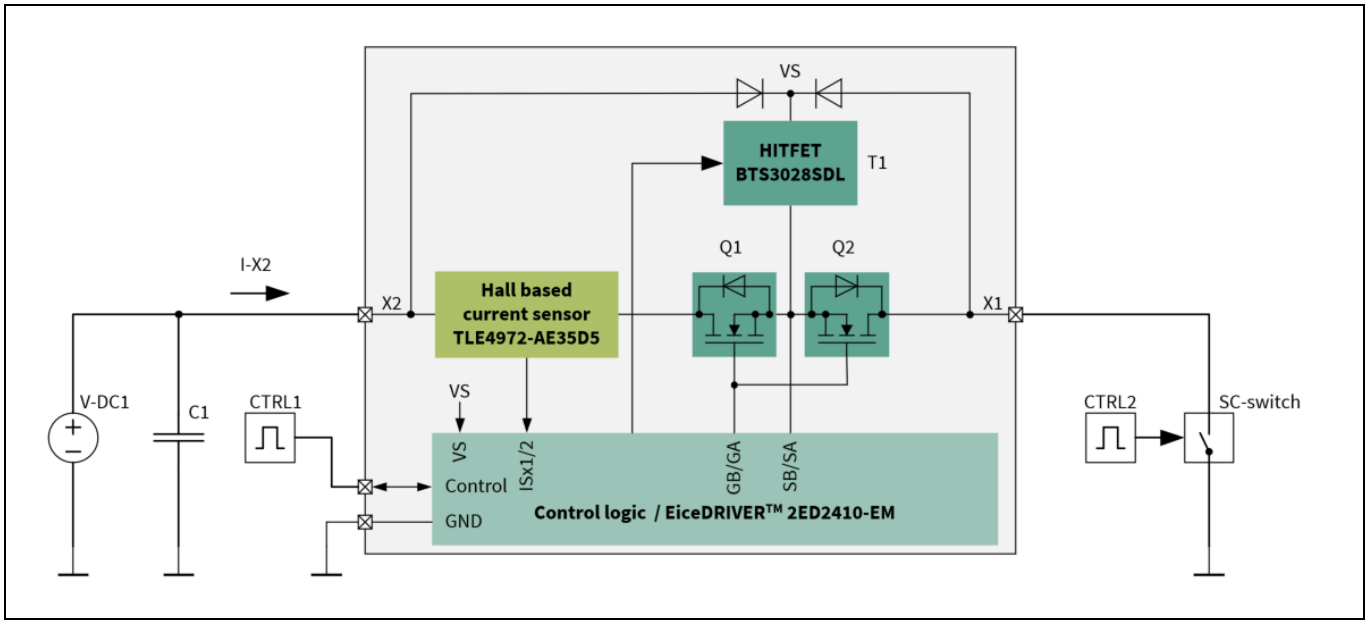

Figure 37 Block diagram of inverse current cutoff test setup / short circuit case 1

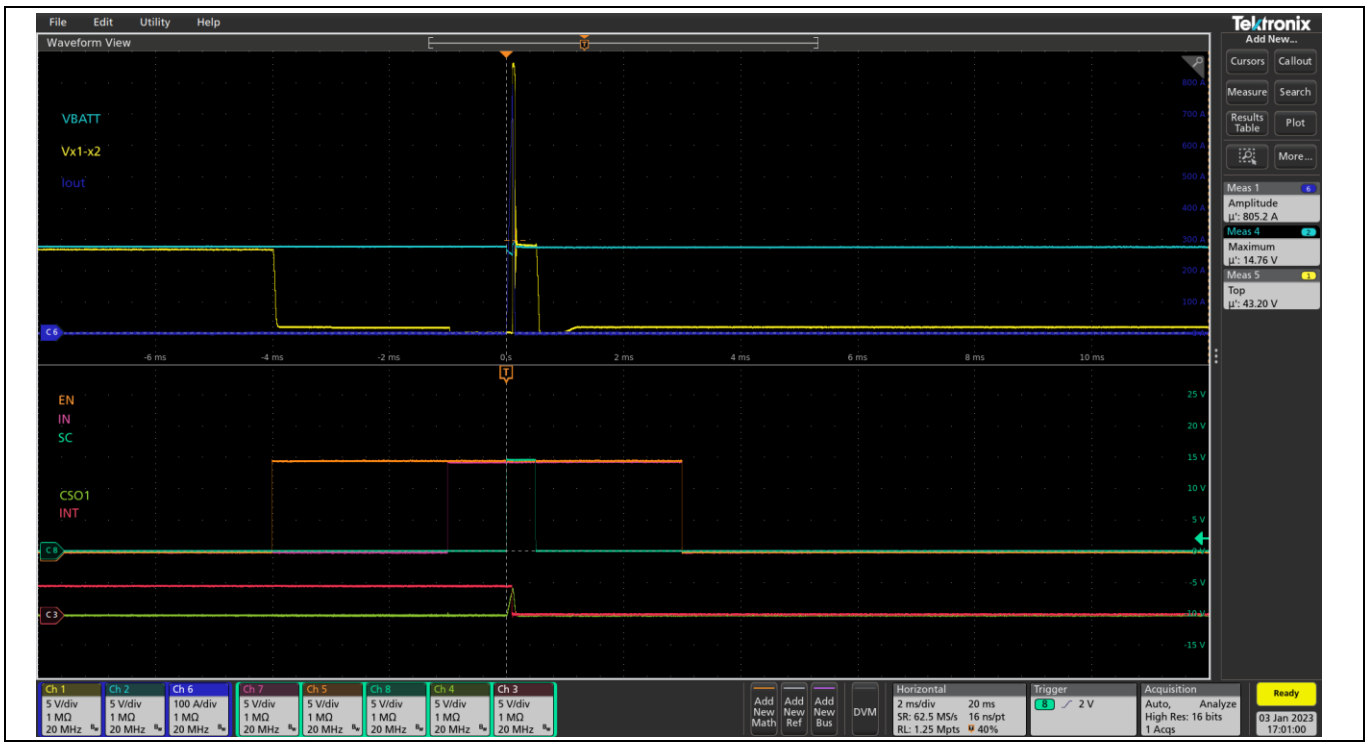

Figure 38 Scope picture (2 ms/DIV) / inverse current cutoff test / short circuit case 1

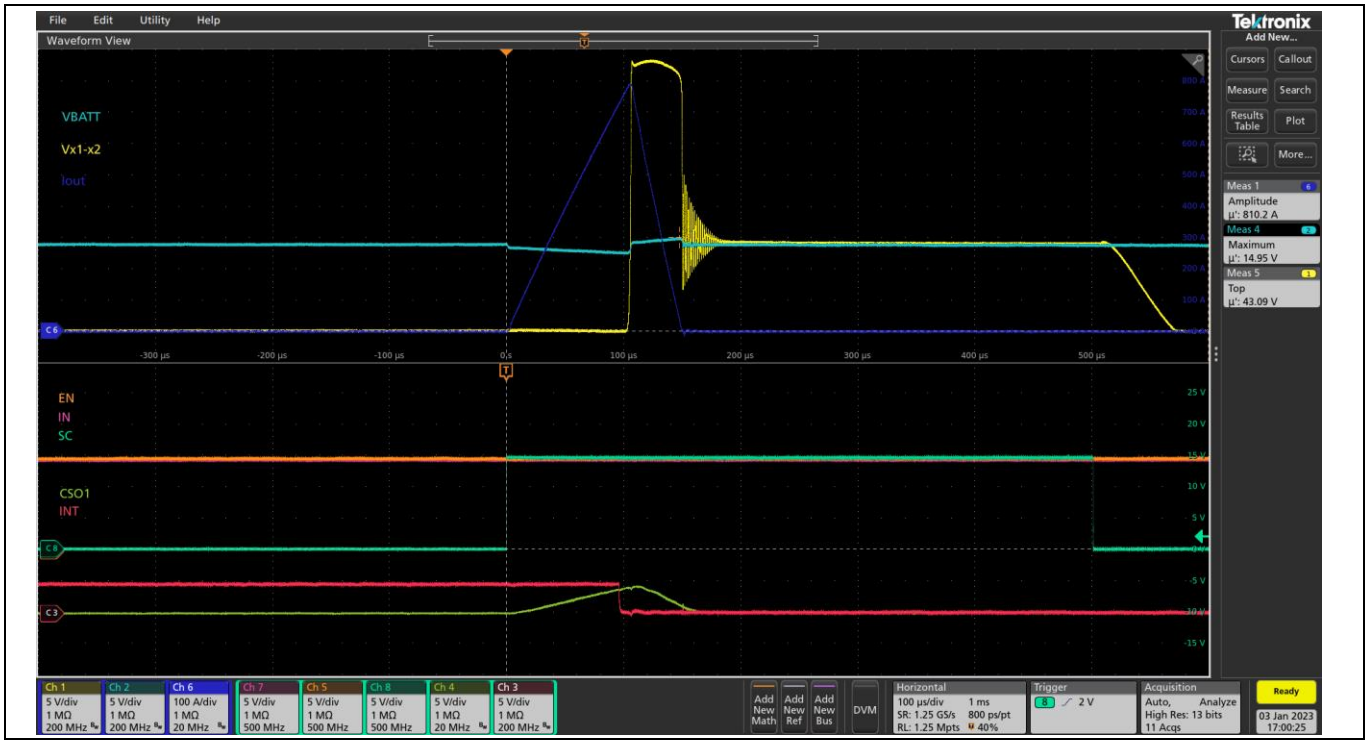

Figure 39 Scope picture (100 us/DIV) / inverse current cutoff test / short circuit case 1

I-t wire protection test with dynamic current

The purpose of this test is to analyze the I-t wire protection feature of the HC-PDU with a dynamic current. The current is switched by the HC-PDU and the current value is limited by resistors R-LLoad. If this protection feature is triggered the HC-PDU switching off. Please note the diagnose outputs of the 2ED2410-EM (See chapter 0) as INT signal goes low when SAFESTATE mode is triggered.

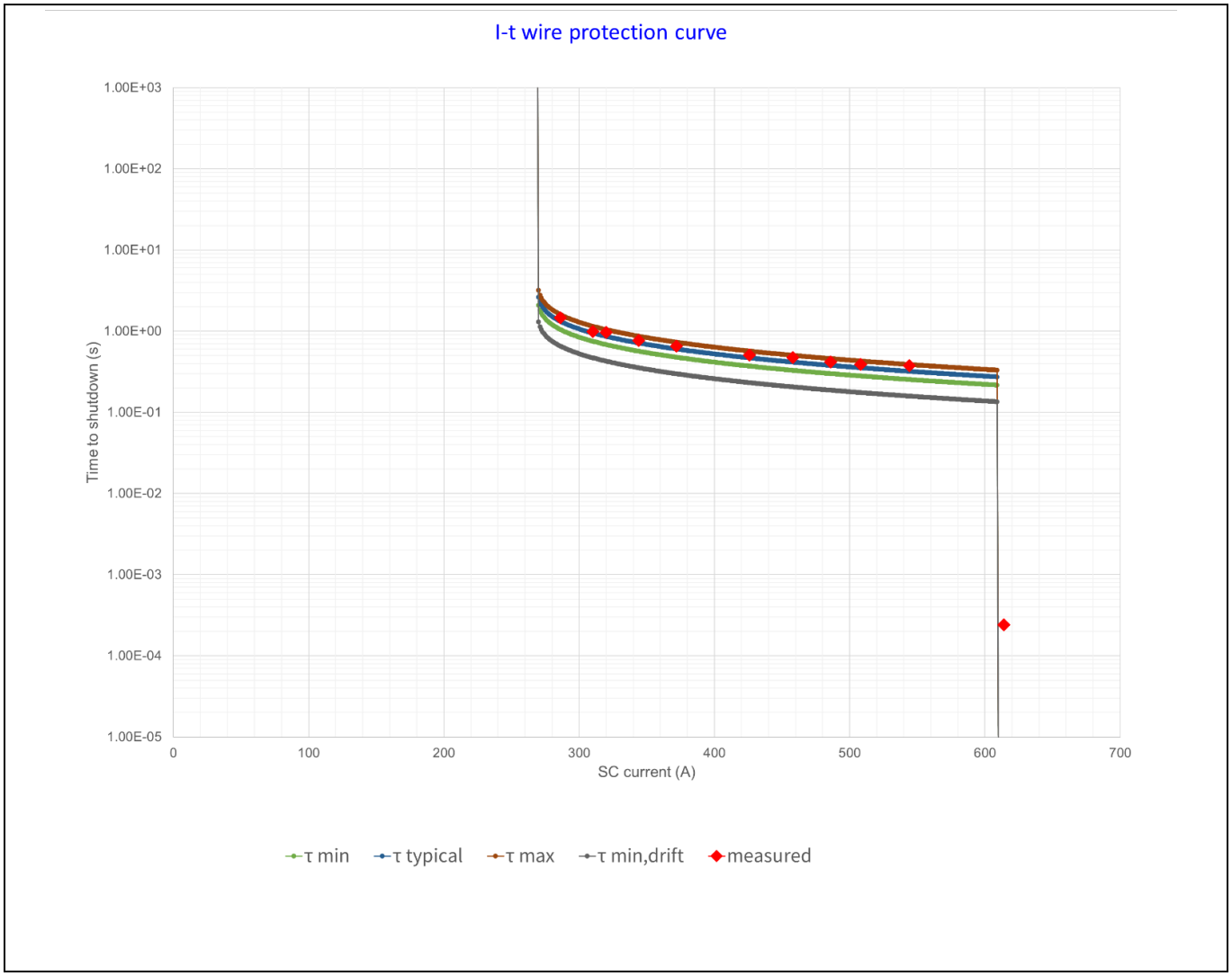

Figure 40 I-t wire protection target curve and measurement points

The curve can be checked and adapted to new conditions easily using the excel workbook that can be found on BP_myICP.

In order to adapt the I-t wire protection curve, the following components need to be replaced on the top of the boards. The Hall sensor output is equivalent to a 1.7mR shunt resistor.

- Reference for CPN voltage: resistors R28, R32 (Fig. 12) need to be adapted to change the CPN voltage.
- τ characteristics can be adapted by changing R36, C16 (Fig. 10).

- Gain of amplifier CSA1 can be changed by adapting resistors R29, R33, R44 (Fig. 9 & 10).
- Gain of amplifier CSA2 can be changed by adapting resistors R34, R35, R51 (Fig. 9 & 10).

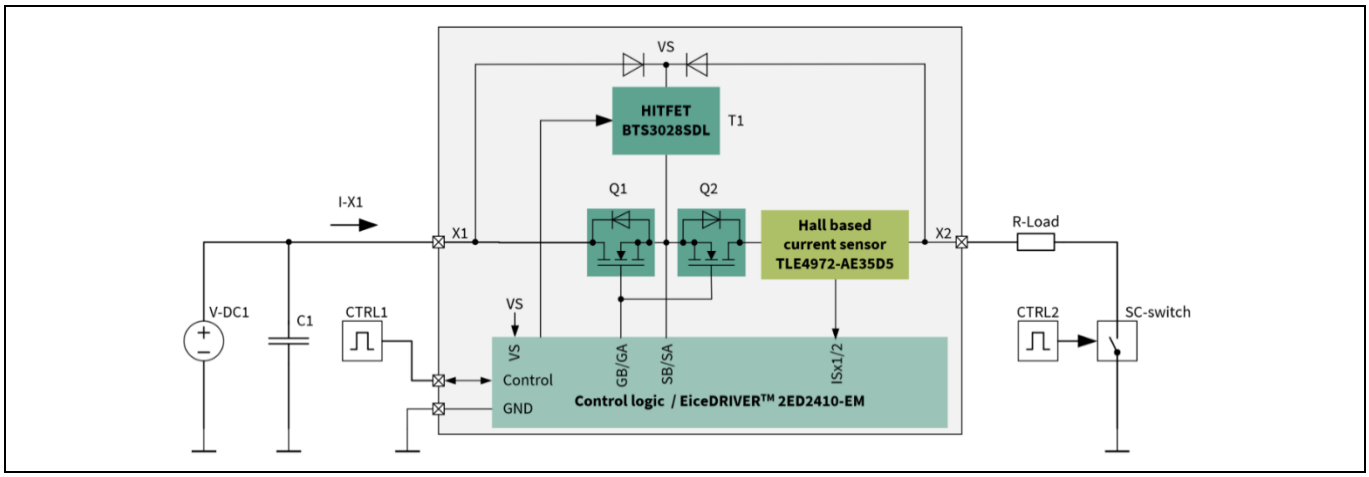

Figure 41 Block diagram of I-t wire test setup

Following devices are used:

- Oscilloscope: MSO58 5-BW-500
- Current measurement I-X1: current transducer LEM LF1005-S
- C1:
  - Capacitor Epcos B41456B8100M000 63 V 100 mF 5x parallel
  - Supercap: KEMETS301RV308R2R7W (2,7 V / 3000 F) / 6 in serial
- R1: Many resistors parallel
- SC-switch: Potential free controlled semiconductor switch
- For all voltage measurements differential probes are used: THDP0200
- In order to reach a high current 50 mm^2 cables are used for the main current path

Setup:

- X1 = VBatt = V-DC1: 14 V
- X2 = output

Scope setup:

- Channel1: [5 V/DIV] Voltage across X1 and X2
- Channel2: [5 V/DIV] VBATT+ to GND
- Channel6: [100 A/DIV] Current of X1
- Channel5: EN input of the 2ED2410-EM
- Channel7: INA + INB input of the 2ED2410-EM

- Channel3: INT output of the 2ED2410-EM
- Channel4: CSO1 output of the 2ED2410-EM

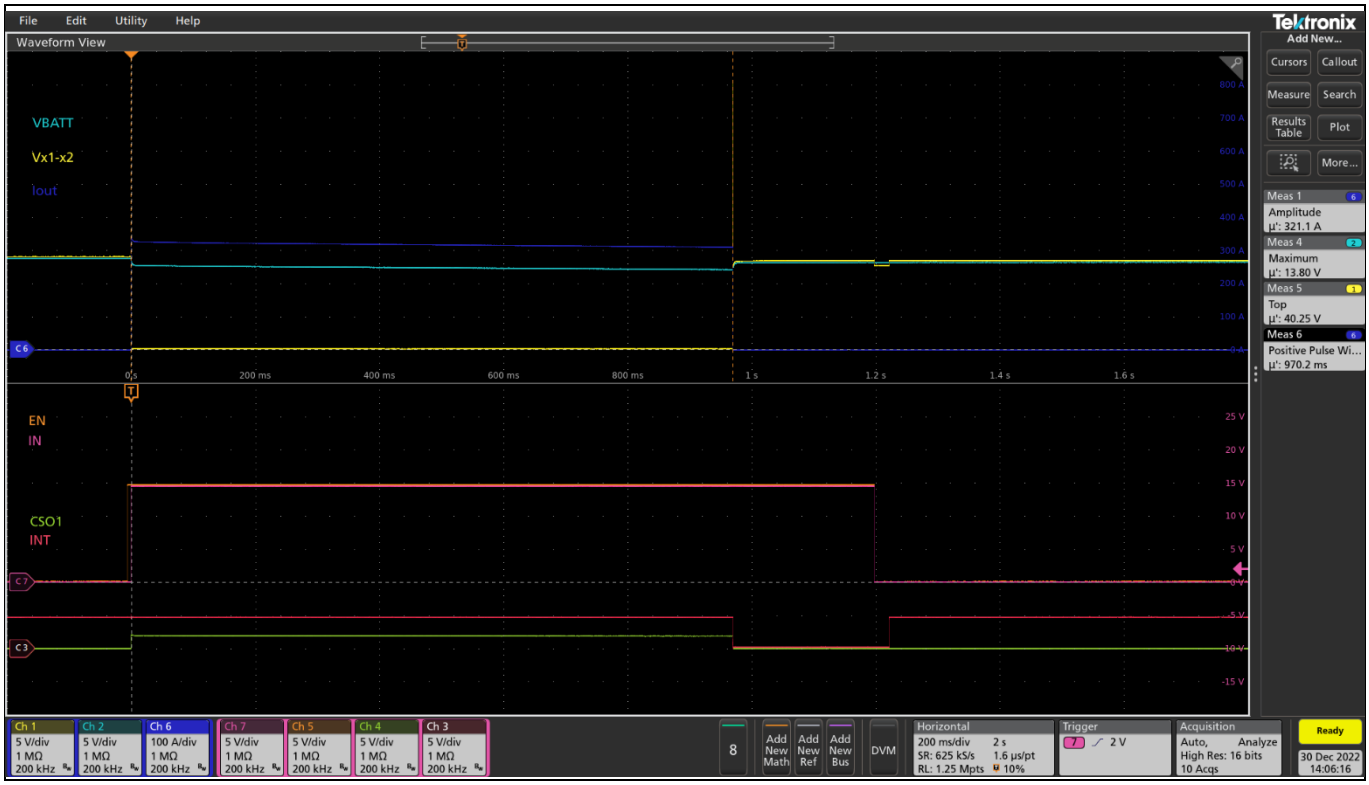

Figure 42 I-t wire protection test with circa 320 A scope depicting 200 ms/DIV

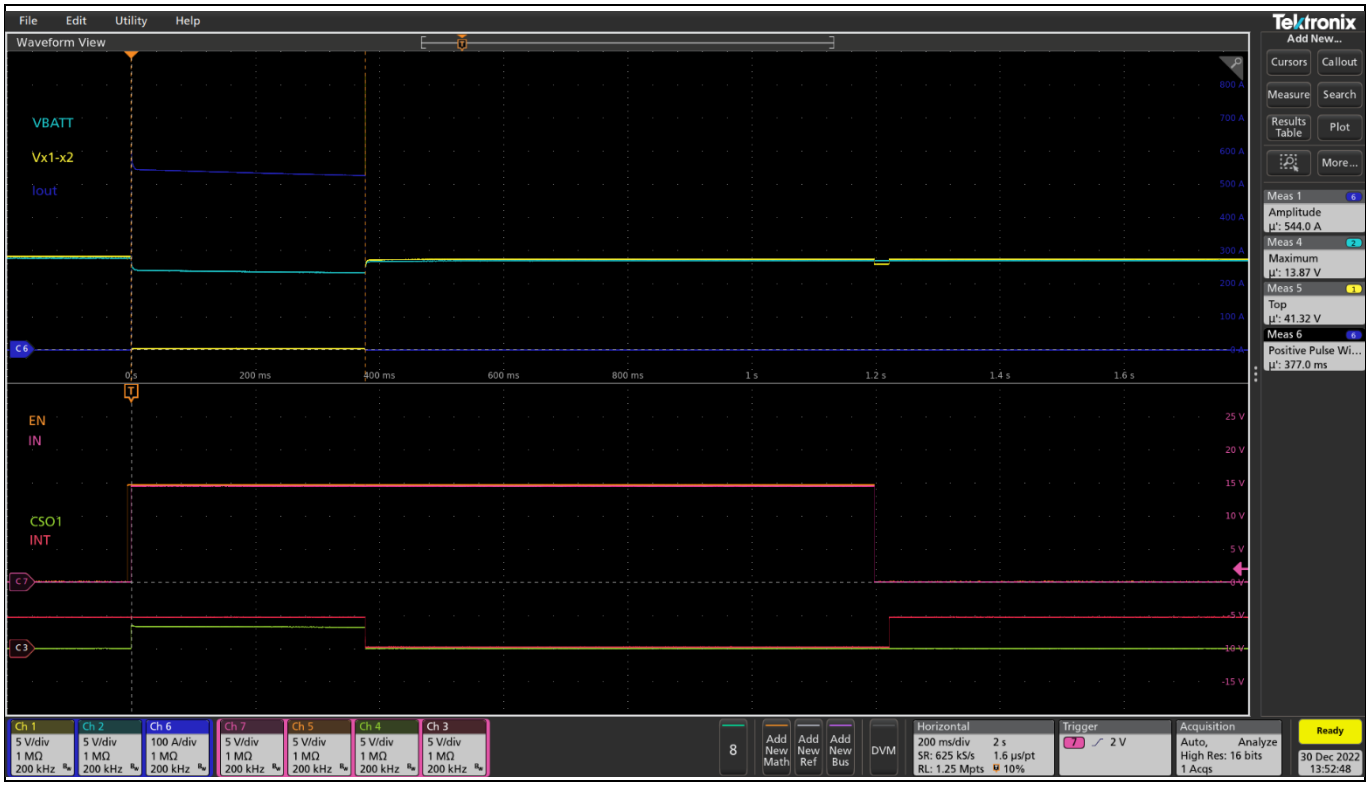

Figure 43 I-t wire protection test with circa 540 A scope depicting 200 ms/DIV

4.5 I-t wire protection test with static current

The purpose of this test is to analyze the I-t wire protection feature of the HC-PDU with a static current. The current can be adjusted by the current source I-DC1.

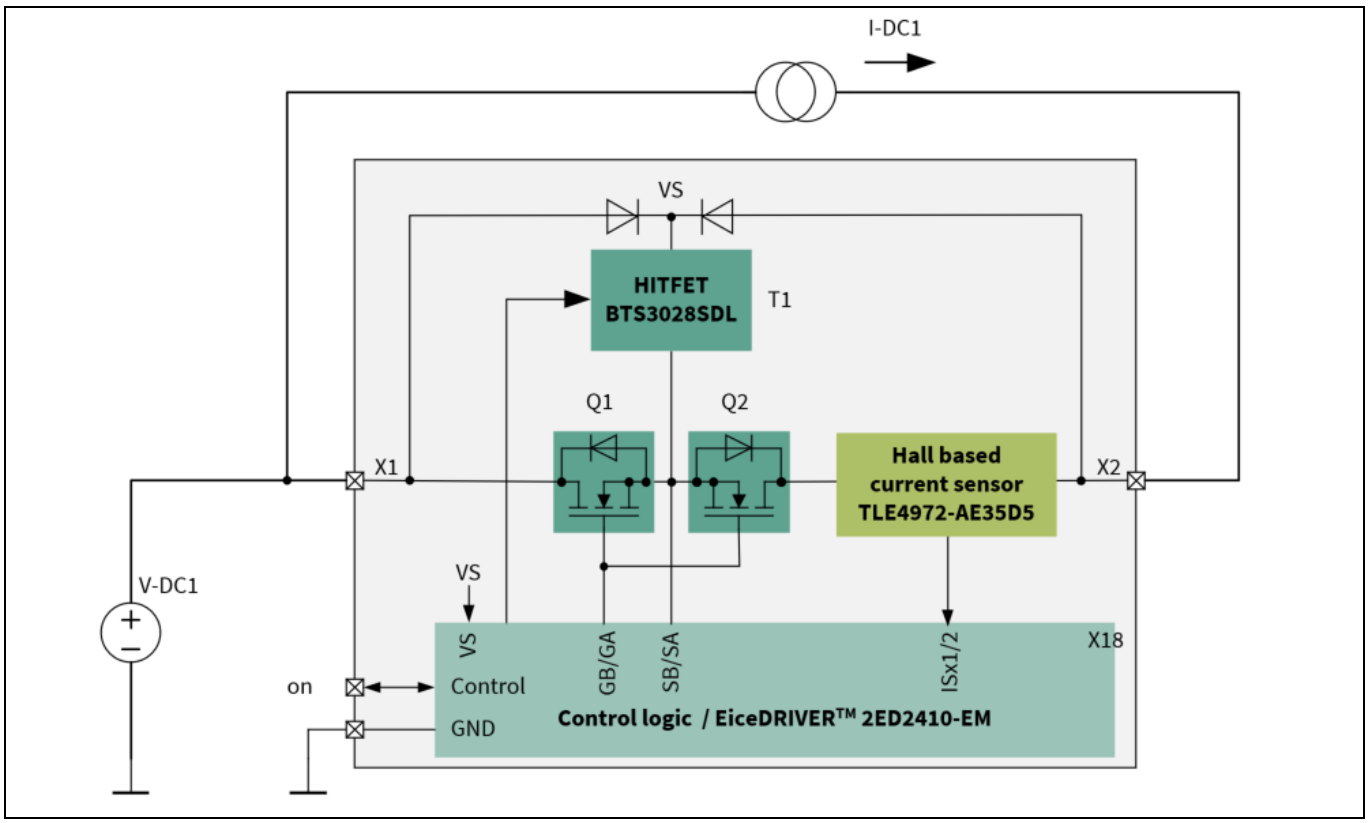

Figure 44 Block diagram of the static current test setup

Setup:

- X1 = VBatt = V-DC1: 14 V
- X2 = output

As the I-t wire protection is set to 242 A the cutoff limit can be measured in a static way by increasing the current I-DC1 slowly until the HC-PDU switches off.

4.6 Temperature protection test

The purpose of this test is to analyze the thermal protection of the HC-PDU. The thermal protection limit is set to around 120°C. Please note the diagnosis outputs of the 2ED2410-EM in Chapter 2.3; as INT signal goes low when SAFESTATE mode is triggered.

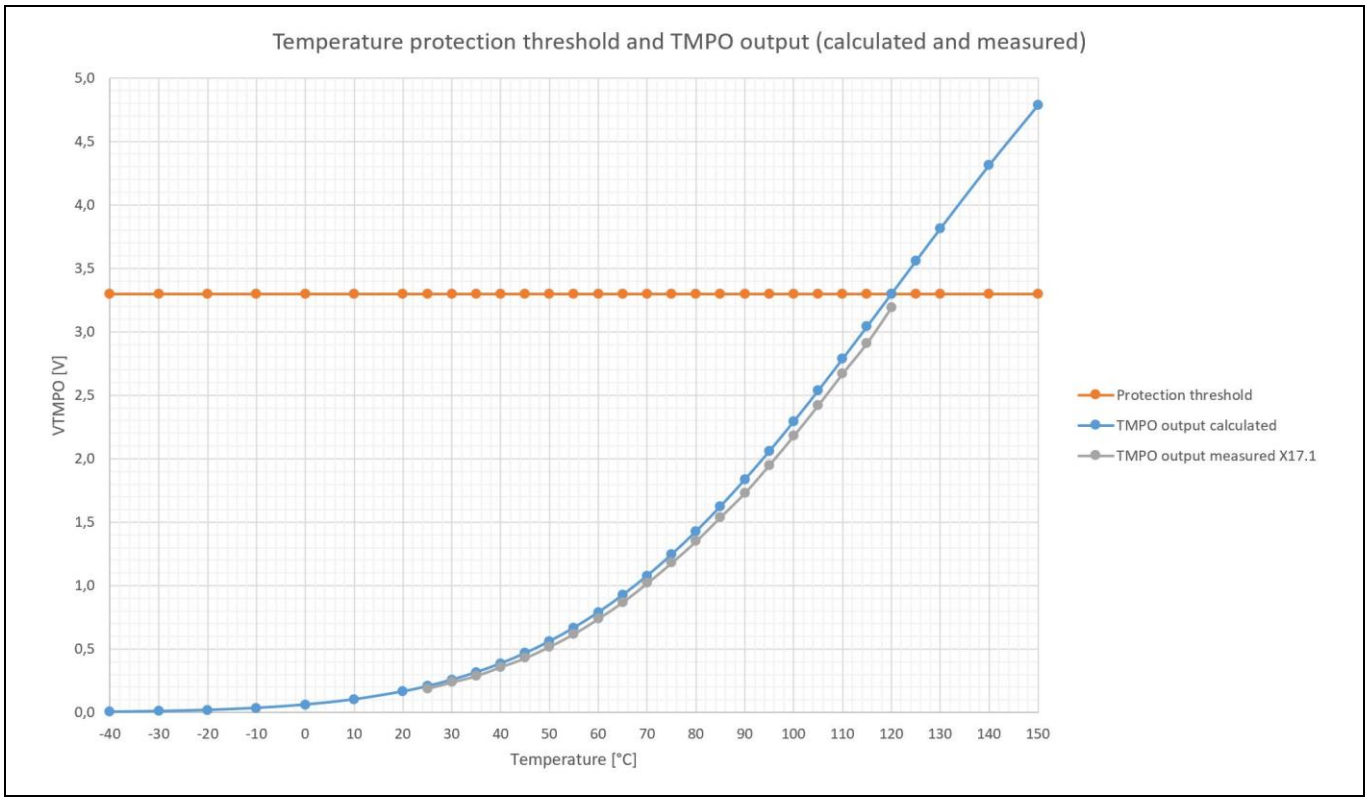

Figure 45 Temperature signal TMPO based on calculation and associated measurement

With:

NTC R45= (B57421V2473J062)
R46=1.2 kΩ
R56=20 kΩ

Temperature protection shutdown (T_{PS}) is set to 120°C

4.7 Thermal performance with static current

The purpose of this test is to analyze the thermal performance of the PCB. The concept of “cooling via cables” is used. The head is transferred to the cables and from there to the air. In order to have more stable test results, a small defined airflow (0.4 m/s) is created. The block diagram of this test is the same as in Chapter 4.5

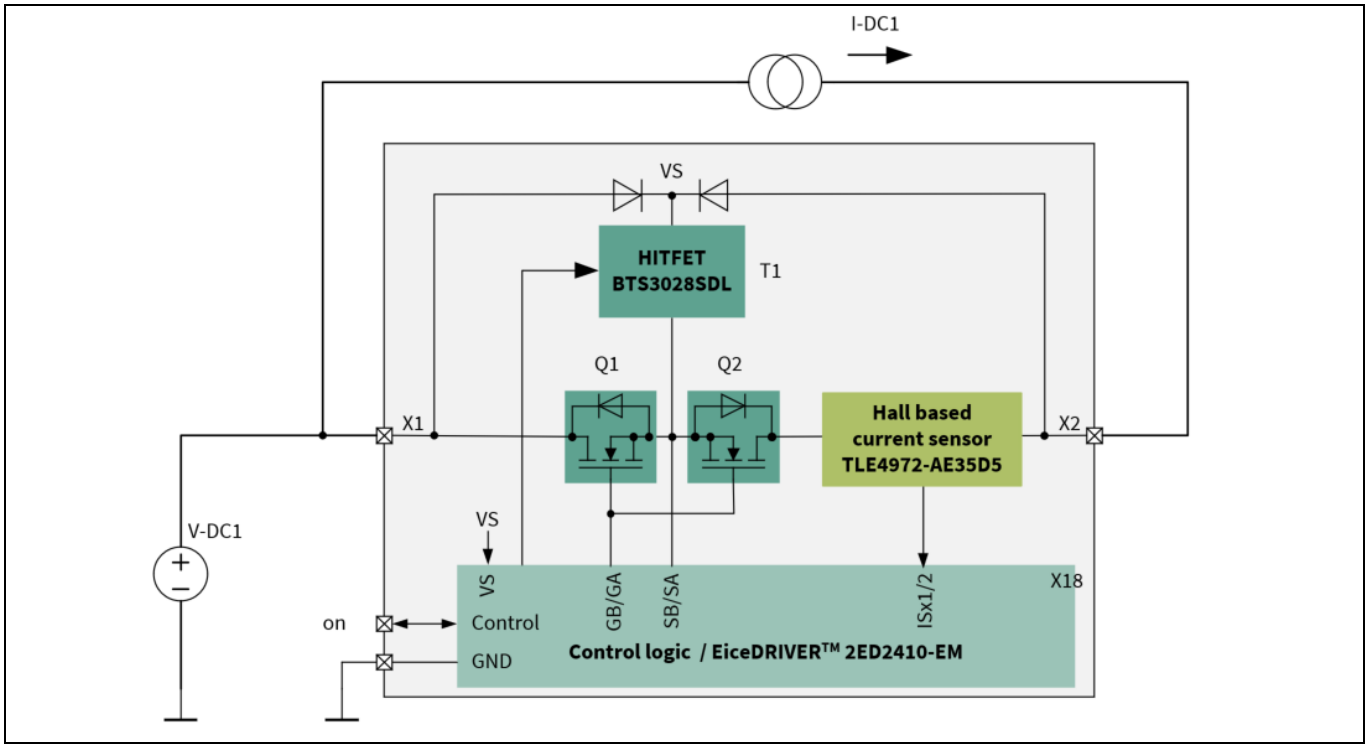

Figure 46 Block diagram of the static current test setup

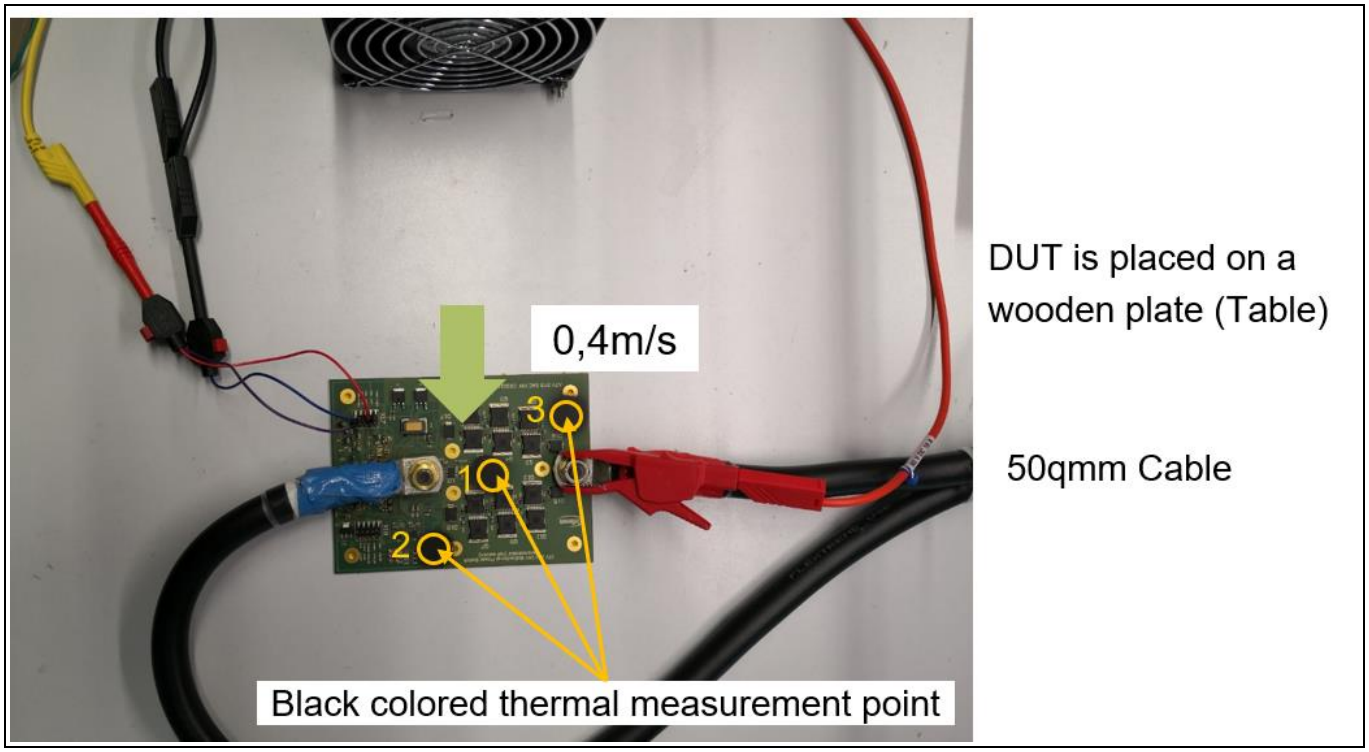

Figure 47 Static current test setup (0.4m/s airflow and 50mm² cable used)

The thermal test points from left to right: PCB_2, PCB_1, PCB_3

The following devices are used:

- FLIR A715
- In order to reach a high current and the required cooling 50 mm² cables are used for the main current path. Cable: Faber 050164 (1 x 50 mm²)
- Cable lugs: Würth Elektronik 5580850 (50 mm²/M8)

Setup:

- X1 = VBatt = V-DC1: 12 V
- X2 = output
- A power supply I-DC1 in CC mode is used to create the static current flow through the semiconductor.

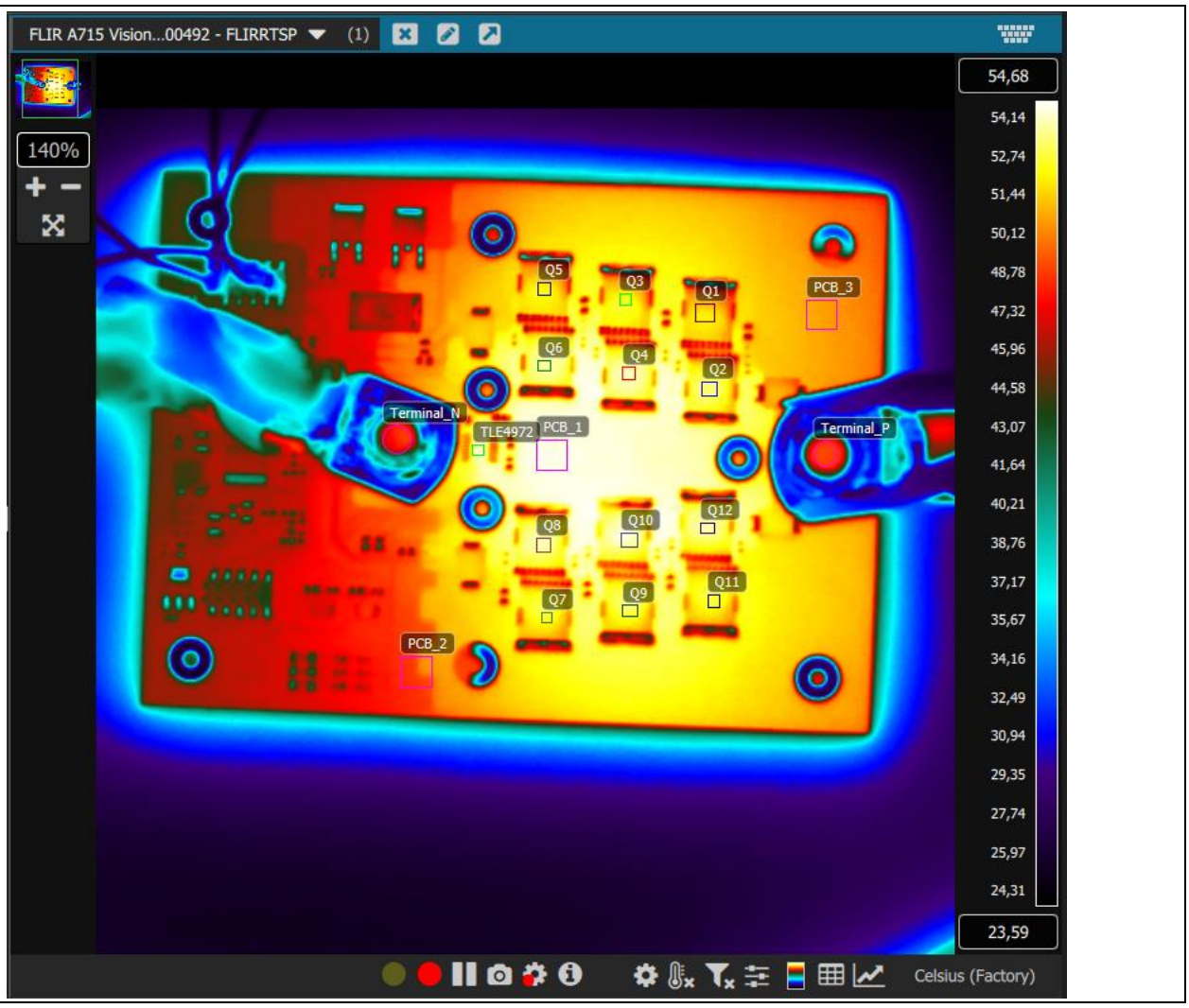

Figure 48 Thermal image from the infrared camera FLIR A715

Figure 48 shows the thermal image of the HC-PDU with a constant current of 200 A after 60 minutes at room temperature. Test point 1 (PCB_1) is the hotspot. The following diagram Figure 49 shows the temperature over time curve for different total power dissipations.

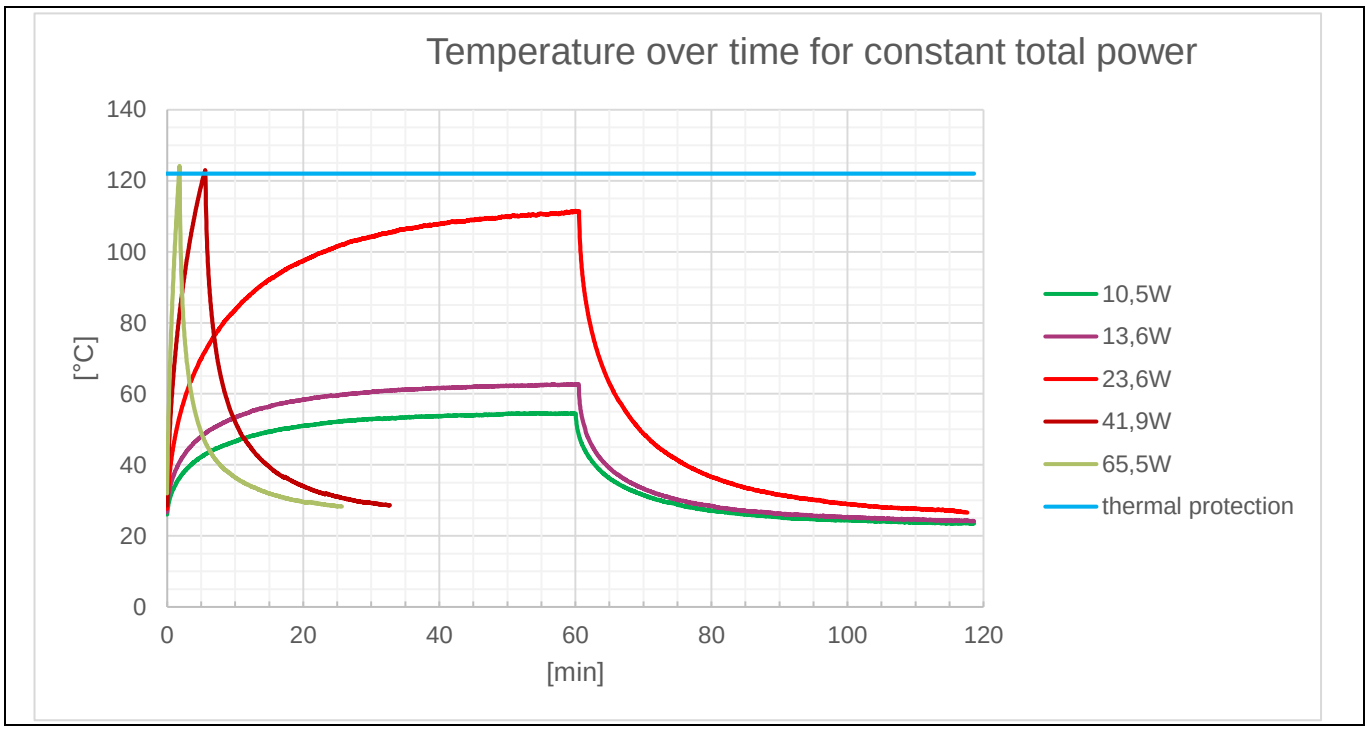

Figure 49 Temperature over time curve

Result: 13.6 W shows a temperature delta of 40 K.

4.8 Current capability at 13 W

The following values are considered in the power dissipation at 13 W:

- Estimated R_{TTR} from Chapter 3.1
- Power dissipation of the PCB with cooling via cables as discussed in Chapter 4.5 at a temperature delta of 40 K
- $R_{DS(on)}$ values of the Power MOSFETS see Chapter 3.2 and [3]

Table 8 Current capability for a power dissipation of 13 W

Parameter	12 V Hall version
MOSFET configuration	4 parallel/2 anti-serial
Power MOSFET	IAUTN04S7N003
$R_{DS(on)}$ (total)	160 µΩ
R_{PCB} + terminals	84 µΩ
R_{TTR}	244 µΩ
DC current capability*	231 A

* 13 W power losses and a temperature delta of 40 K

5 System design

5.1 Schematic for the 12 V Hall-based current measurement version

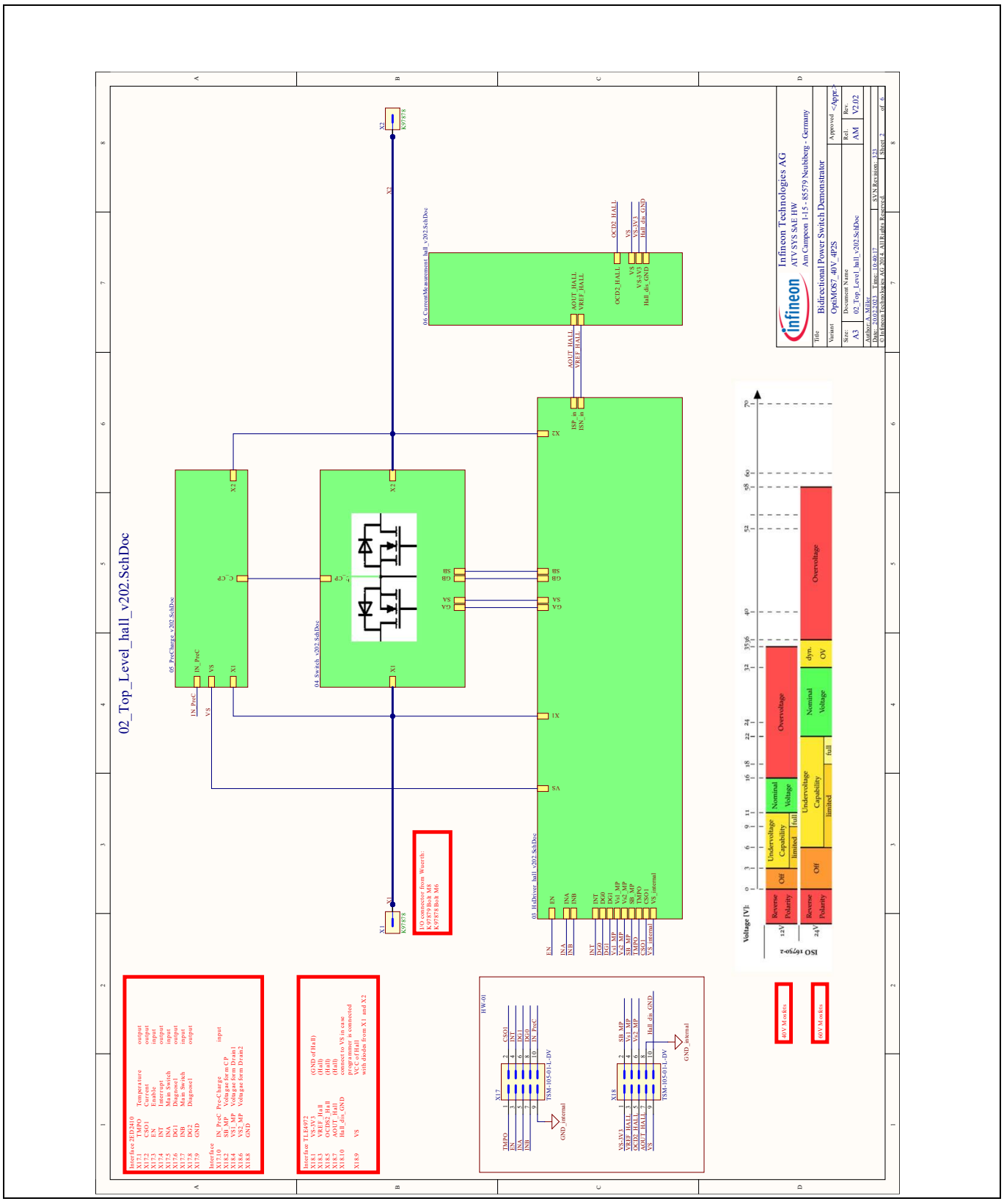

Figure 50 Schematic Top level

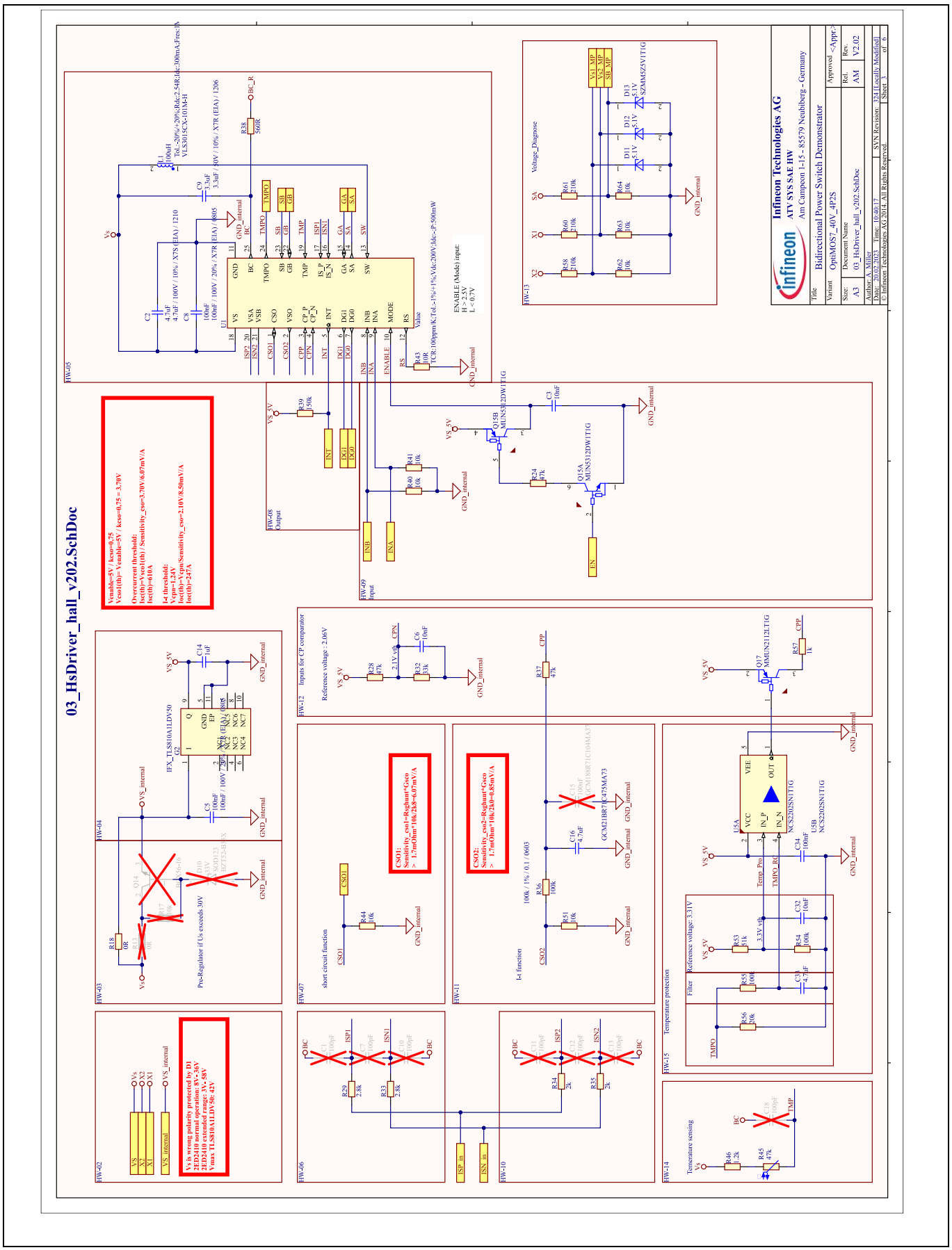

Figure 51 Schematic High side gate driver and control

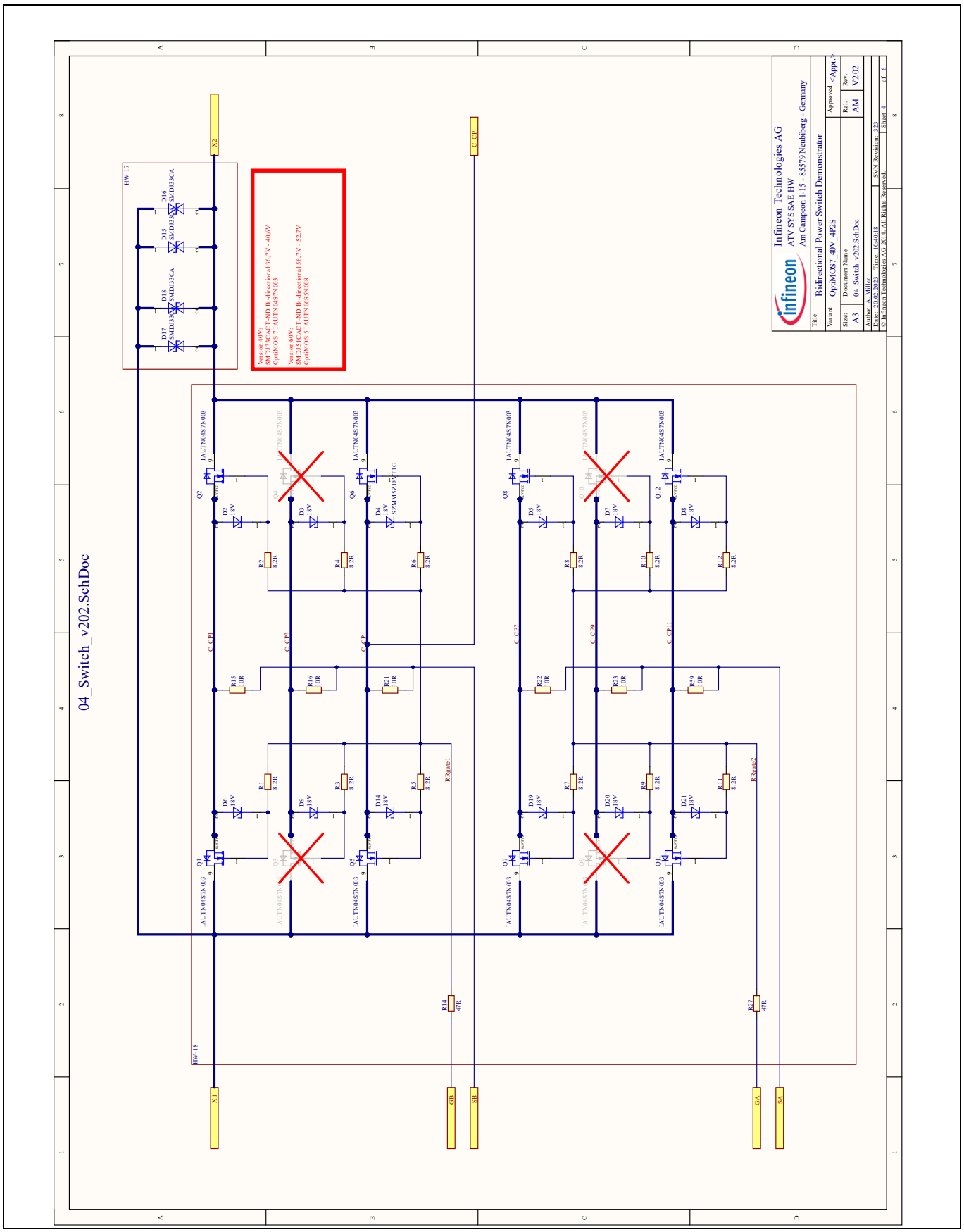

Figure 52 Schematic Power switch

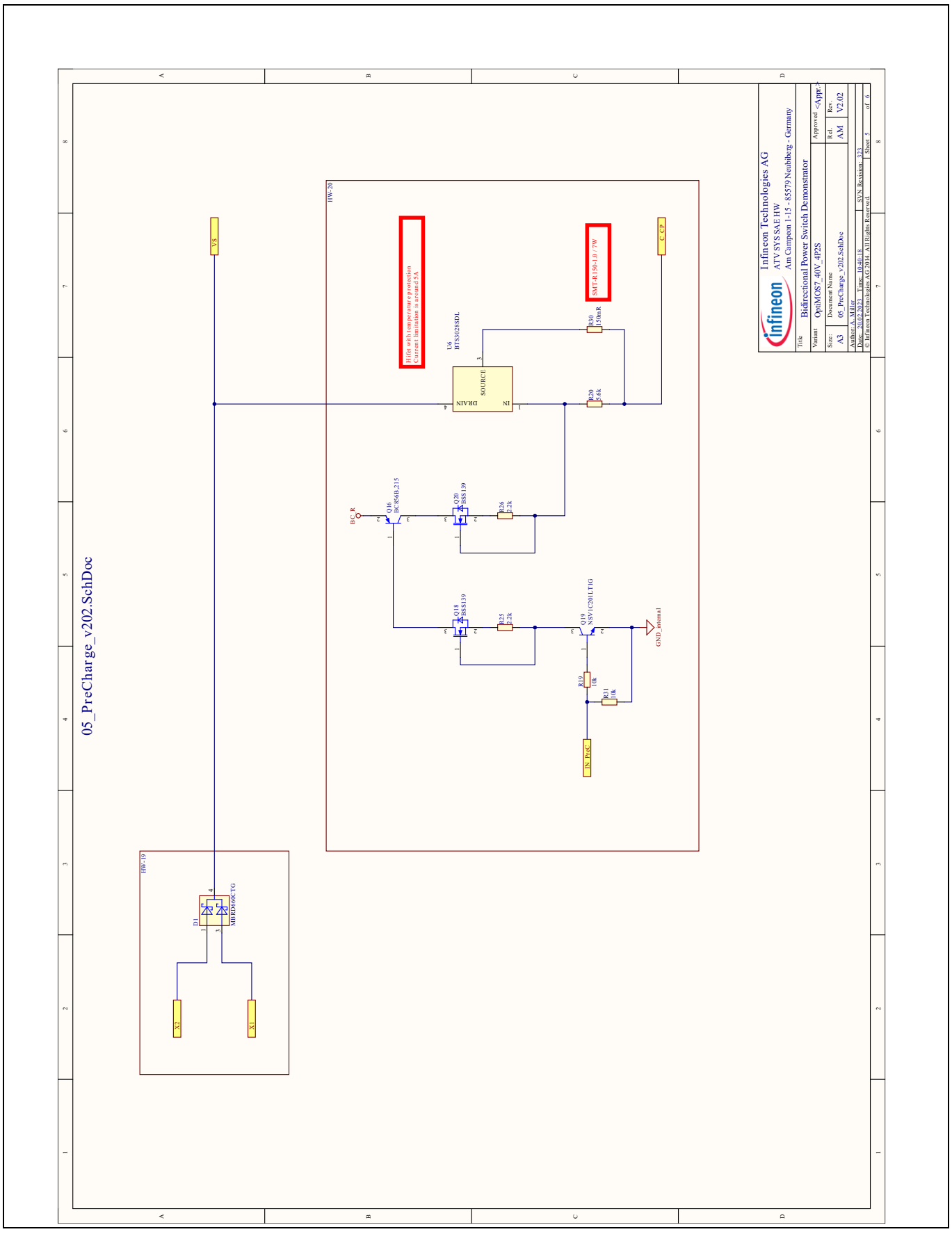

Figure 53 Schematic Pre-charge

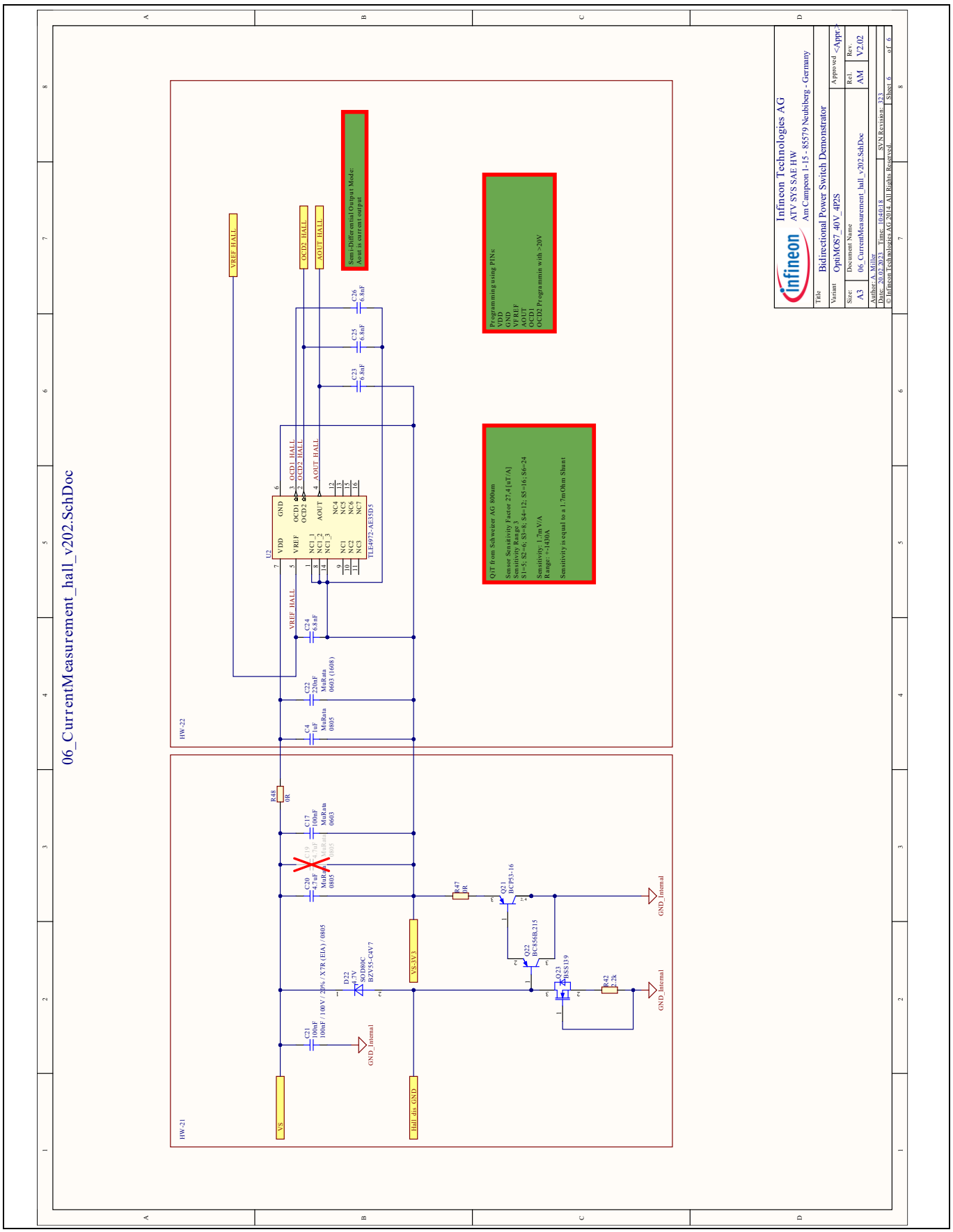

Figure 54 Schematic Hall-based current measurement

5.2 Layout

5.3 Layout for the hall based current measurement version

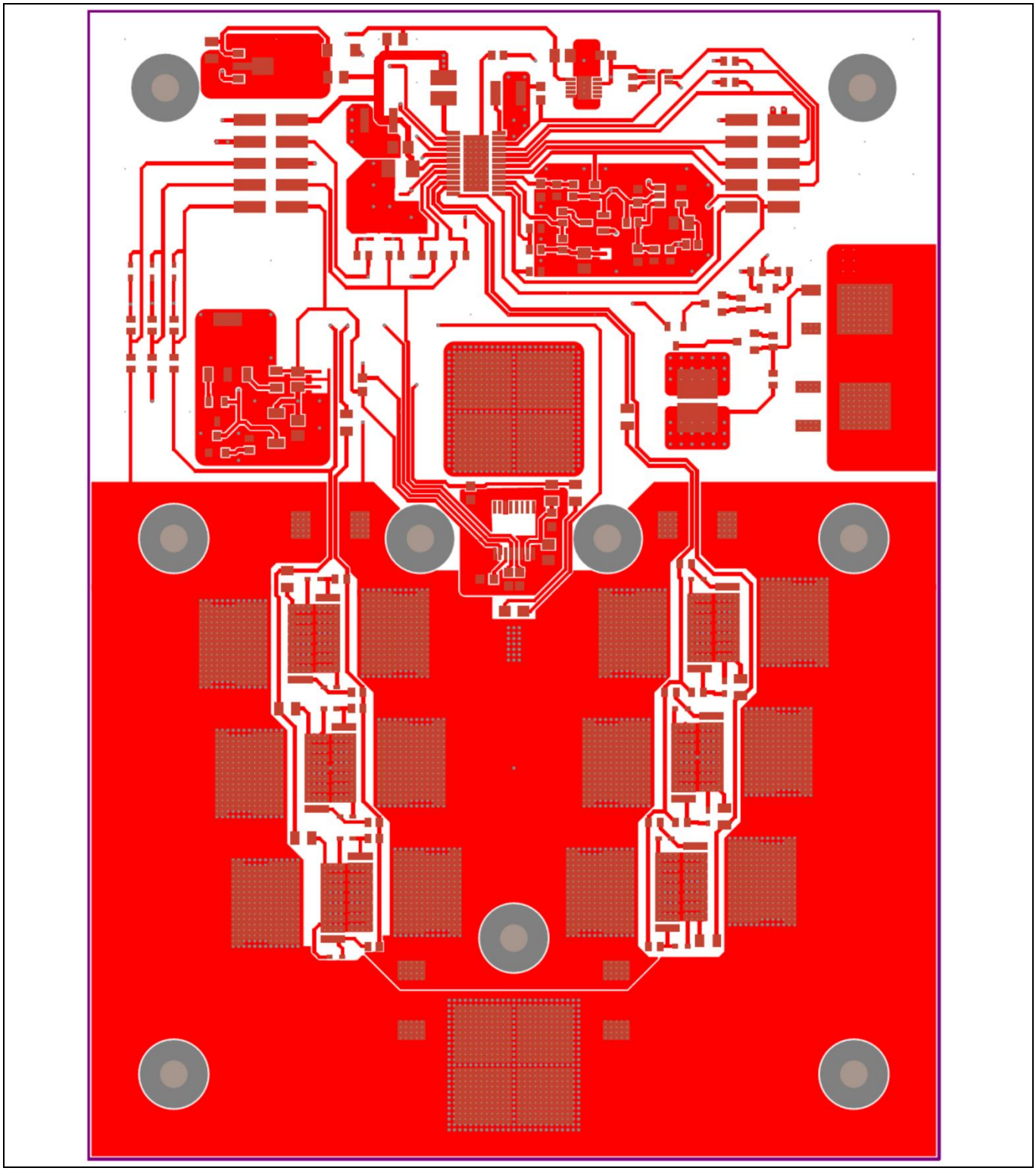

Figure 55 Top layer (Top view)

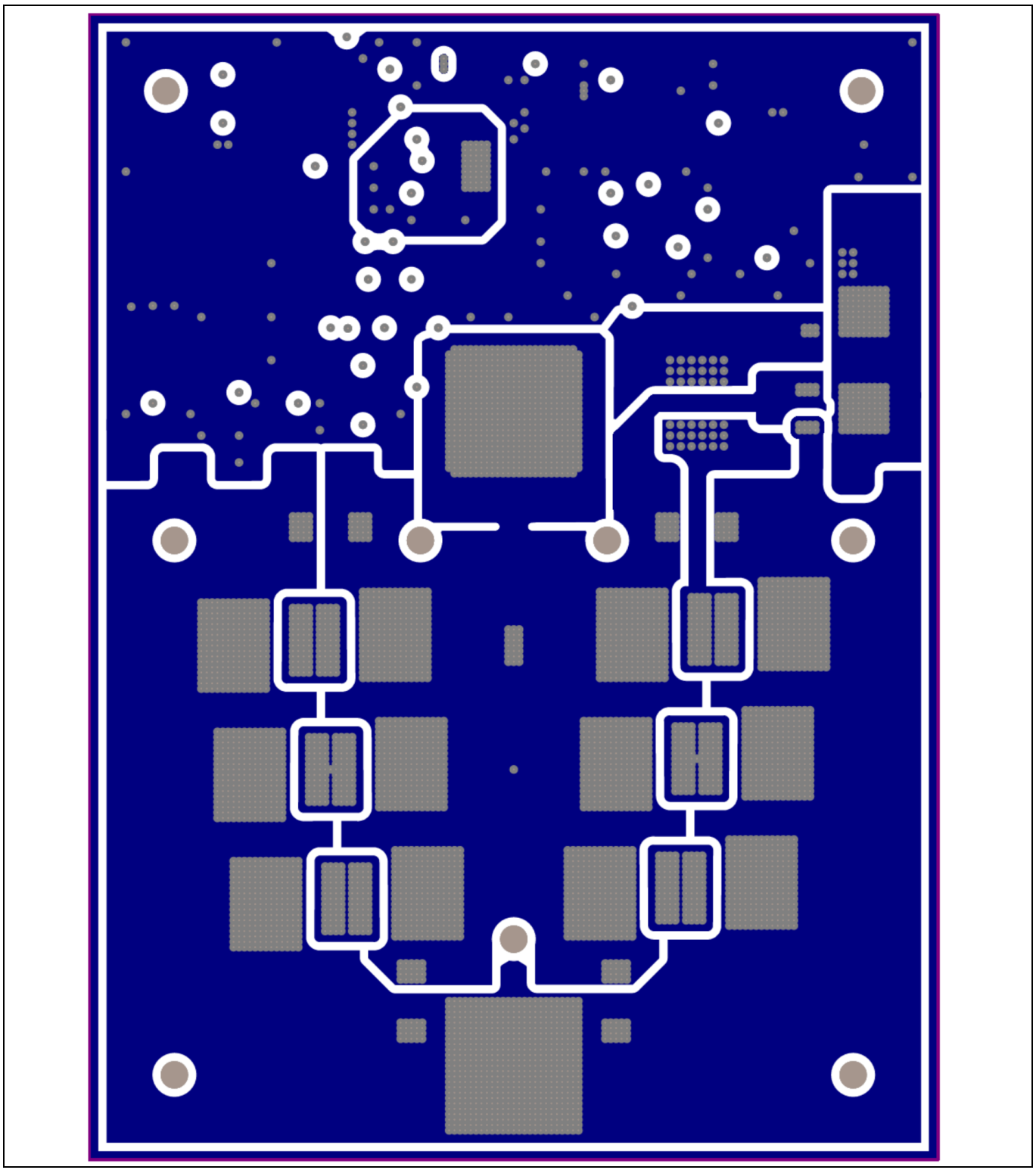

Figure 56 Mid layer (Top view)

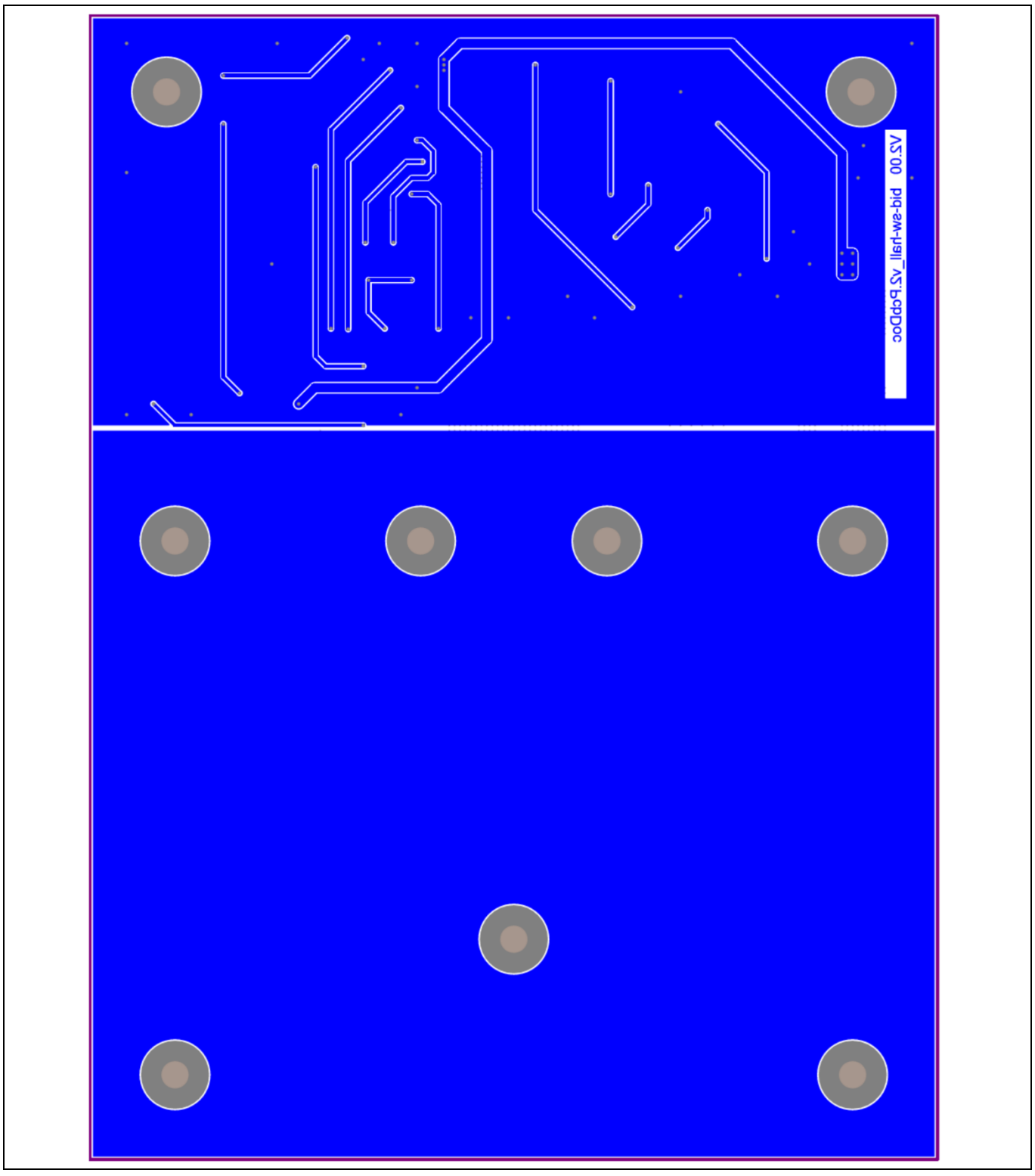

Figure 57 Bottom layer (Top view)

5.4 PCB

The PCB is made in the new quasi inlay technology (QIT) built-up from Schweizer Electronics AG. The inner copper layer has the thickness of 800 µm. This allows extreme high currents with low power losses. The outer copper layers can be populated with normal SMD components. Laser drilled high density micro vias allow the connection of the different copper layers. The QIT PCB offers an optimized electrical conductivity and a low thermal resistance.

Compared to well-known IMS structures, the QIT has following advantages:

- Population with SMD components on the bottom layer too
- Placement of normal through-hole components
- Mid layer can be used for layout (minimum clearance and minimum track with is 1 mm)

On this demonstrator the high-power components are located on the top side. There are two cooling possibilities to consider:

- Cooling from the bottom side via a heat sink: As the cooling elements are on the bottom side, the thermal flow conductivity through the board stack has to be high
- Cooling via cables: The thermal flow works through the connecting terminals to the cables. The mid and top layer is used to transfer the heat to the connecting terminals.

The dielectric prepreg between the mid layer and the outer layer is necessary for the electric isolation. The thermal conductivity is 1.8 W/mK.

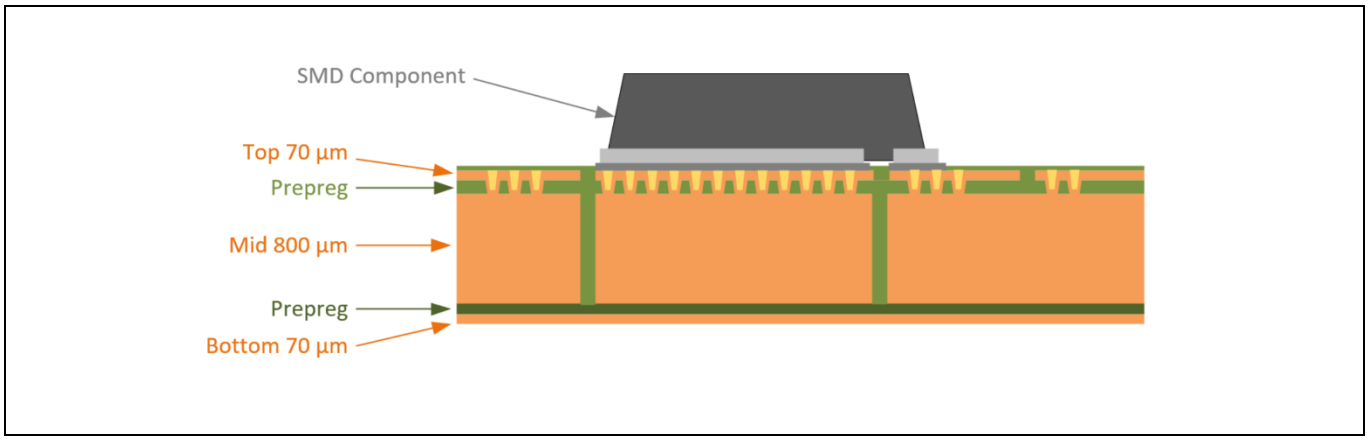

Figure 58 PCB layer stack

5.5 Bill of material

Table 9 BOM of the most important parts of the reference board

Versions	12V Hall based
Q1; Q2; Q5; Q6; Q7; Q8, Q11; Q12	IAUTN04S7N003
Q3; Q4; Q9; Q10	Not fitted
U1	2ED2410-EM
U2	TLE4972-AE35D5
D15–D18	SMDJ33CA
G2	TLS810A1LDV50

6 Products

6.1 EiceDRIVER™ APD 2ED2410-EM

2ED2410-EM SP005072940

2ED2410-EM is a one channel gate driver with two independent gate outputs qualified for automotive applications. Three measurement interfaces are available: two identical current sense amplifiers with adjustable gain, either used with shunt resistor or MOSFET VDS, plus one amplifier dedicated to temperature measurement. Four comparators are integrated for protection purposes, offering a customizable and versatile solution adaptable to any E/E architectural needs. Compatible with all N-channel MOSFET. It also includes a low-quiescent current state, an ECU idle mode supply function, and wire protection capability thanks to the customizable protections. The gate driver is ISO 26262-ready for supporting the integrator in evaluation of hardware element according to ISO 26262.

6.2 OptiMOS™ -7 power-transistor - IAUTN04S7N003

IAUTN04S7N003 SP005567553

- OptiMOS™-7 power MOSFET for automotive applications
- N-channel - Enhancement mode - Normal Level
- Extended qualification beyond AEC Q101
- RoHS compliant
- Enhanced electrical testing
- Robust design
- MSL1 up to 260°C peak reflow
- 175°C operating temperature
- 100% Avalanche tested
- V_{DS} 40 V
- $R_{DS(on)}$ 0.26 mΩ

6.3 XENSIV™ TLE4972-AE35D5 magnetic coreless current sensor

TLE4972-AE35D5 PG-TDSO-16 SP004914362

TLE4972 is a high precision miniature coreless magnetic current sensor for AC and DC measurements with analog interface and two fast overcurrent detection outputs.

Infineon's well-established and robust monolithic Hall technology enables accurate and highly linear measurement of the magnetic field caused by currents. With a full scale, up to ±31 mT it is possible to measure currents up to 2 kA. All negative effects (e.g. saturation, hysteresis) commonly known from open loop sensors using flux concentration techniques are avoided. The sensor is developed in accordance to functional safety standard ISO26262 and is equipped with internal self-diagnostics.

Typical applications are electrical drives, on board chargers, battery main switches, power supplies, over-load and overcurrent detection in high voltage applications.

The digitally assisted analog concept of TLE4972 offers superior stability over temperature and lifetime thanks to the Infineon proprietary digital stress and temperature compensation. The differential measurement principle allows great stray field suppression for operation in harsh environments.

The sensor is available in two packages to support a wide range of different system integration scenarios.

Two separate diagnosis pins (OCD) provide a fast output signal in case the measurement current exceeds the configured thresholds.

The sensor is shipped as a pre-calibrated product, which provides an accurate performance over temperature and stress. The TLE4972 has in-situ calibration capability to achieve maximum accuracy at the system level.

The high configurability enables customization for a wide variety of applications.

6.4 Linear voltage regulator TLS810A1

TLS810A1LD V50 PG-TSON-10-2 SP001425414

- Ultra low quiescent current of 5 µA
- Wide input voltage range of 2.75 V to 42 V
- Output current capacity up to 100 mA
- Low drop out voltage of typically 200 mV @ 100 mA
- Output current limit protection
- Overtemperature shutdown
- Available in PG-TSON-10 package
- Wide temperature range
- Green product (RoHS compliant)
- AEC qualified

7 Mechanical dimensions and weight of the PCB

PCB mass is is 145 g

PCB size is 135 mm x 100 mm

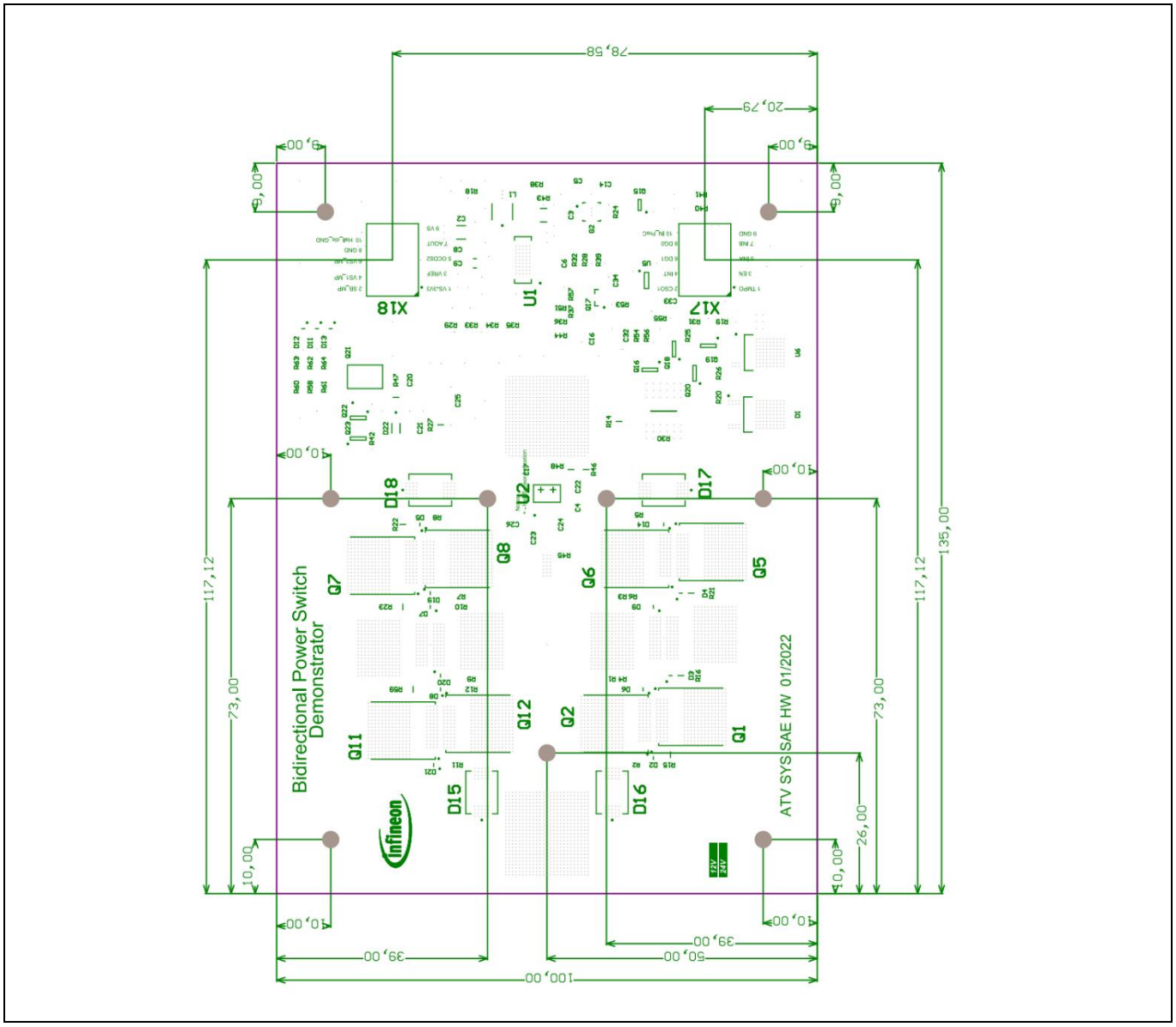

Figure 59 Mechanical dimensions of the PCB

References

[1] Infineon Technologies AG, Datasheet: EiceDRIVER™ 2ED2410-EM

[2] Infineon Technologies AG, Datasheet: OptiMOS™ 5 Power-Transistor - IAUTN06S5N008

[3] Infineon Technologies AG, Datasheet: OptiMOS™ 7 Power-Transistor - IAUTN04S7N003

[4] Infineon Technologies AG, Datasheet: XENSIV™ TLE4972-AE35D5 Rev. 1.02 (SP004914362)

[5] Infineon Technologies AG, Datasheet: HITFET™ – BTS3028SDL Rev. 1.9

[6] Infineon Technologies AG, Datasheet: Linear Voltage Regulator TLS810A1 Rev. 1.0

[7] Infineon Technologies AG, XENSIV™ magnetic current sensors – programmer (SP004441438)

[8] Infineon Technologies AG, XENSIV™ magnetic current sensors – programmer USER GUIDE Rev. 1.01
https://www.infineon.com/dgdl/Infineon-TLE4972_Current_Sensor_Programmer-UserManual-v01_01-EN.pdf?fileId=8ac78c8c821f3890018221a1823b22ac

[9]

Abbreviations

Table 10 Abbreviations

Abbreviation	Meaning
AC	Alternating current
AEC-Q101	Automotive Electronics Council
BOM	Bill of material
CE	Conformité Européenne
CAV	Construction and Agricultural Vehicle
DUT	Device under test
DC	Direct current
EMC	Electromagnetic conformance
EMI	Electromagnetic interference
ECU	Electronic control unit
E/E	Electronic control unit
ESD	electrostatic discharge
GUI	Graphical User Interface
HW	Hardware
HC-PDU	High Current Power Distribution Switch Unit
IC	Integrated Circuit
NTC	Negative Temperature Coefficient
PCN	process change notification
PD	product discontinuation
QIT	Quasi Inlay Technology (Schweizer AG)
RC	Resistor capacitor
RoHS	Restriction of (the use of certain) Hazardous Substances
RMA	Returned material analysis
SMD	Surface mounted device
T_{PS}	Temperature Protection shutdown
R_{TTR}	Total Terminal to Terminal Resistance
TVS diode	Transient-voltage-suppression diode
UL	Underwriters Laboratories

Revision history

Document revision	Date	Description of changes
Revision 1.00	2023-02-28	Release of reference design user guide

Trademarks
All referenced product or service names and trademarks are the property of their respective owners.

Edition 2023-02-28

Published by

Infineon Technologies AG

81726 Munich, Germany

© 2023 Infineon Technologies AG. All Rights Reserved.

Do you have a question about this document?

Email: erratum@infineon.com

Document reference

Z8F80416441

Warnings

Due to technical requirements products may contain dangerous substances. For information on the types in question please contact your nearest Infineon Technologies office.

Except as otherwise explicitly approved by Infineon Technologies in a written document signed by authorized representatives of Infineon Technologies, Infineon Technologies' products may not be used in any applications where a failure of the product or any consequences of the use thereof can reasonably be expected to result in personal injury.