

48V Battery Switch Reference Design

R 48V BATT Switch10

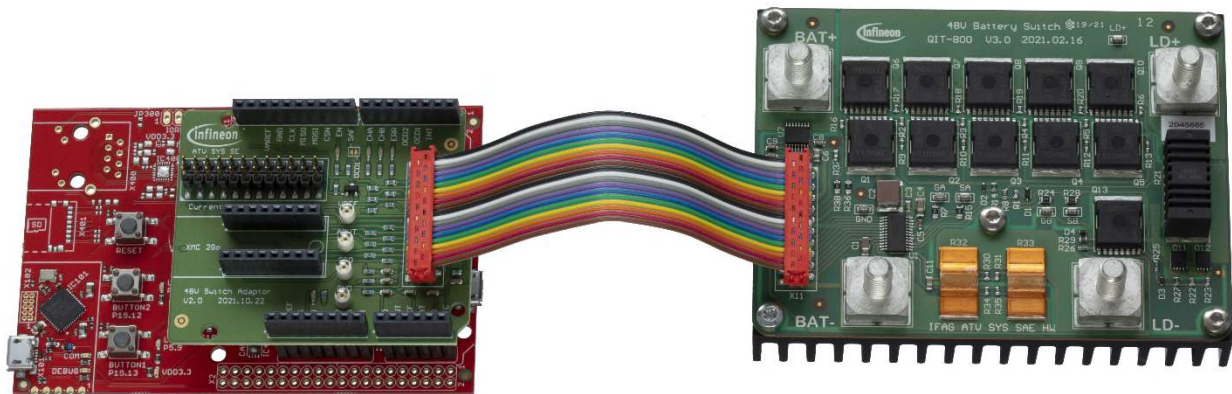
About this document

Scope and purpose

This document describes how to use the 48V battery switch reference design **R 48V BATT SWITCH10**.

The 48V battery switch reference design shows an implementation of an air-cooled high current disconnect switch for automotive 48 V batteries with hall sensor and shunt based current measurement using the following Infineon components:

- OptiMOS™-5 Power-Transistors **IAUT300N08S5N011** and **IAUZ40N10S5N130**
- 48V dual channel high-side MOSFET gate driver **2ED4820-EM** with SPI
- Hall based current sensor **TLE4972-AE35D5**



Intended audience

Users of the 48V battery switch reference design **R 48V BATT SWITCH10**.

Reference Board/Kit

Product(s) embedded on a PCB, with focus on specific applications and defined use cases that can 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

Important notice

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Safety precautions

Safety precautions

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

Table 1 Safety precautions





	Caution: The heatsink and the 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 qualified personnel familiar with the challenges of handling high current circuits 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.

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The kit at a glance

1 The kit at a glance

1.1 Scope of supply

The 48V battery switch reference design consists of

- Power board mounted on a heatsink
- Adaptor board in Arduino shield form factor
- XMC4700 Relax Kit Lite microcontroller board
- Flat ribbon cable for connecting the adaptor board to the power board

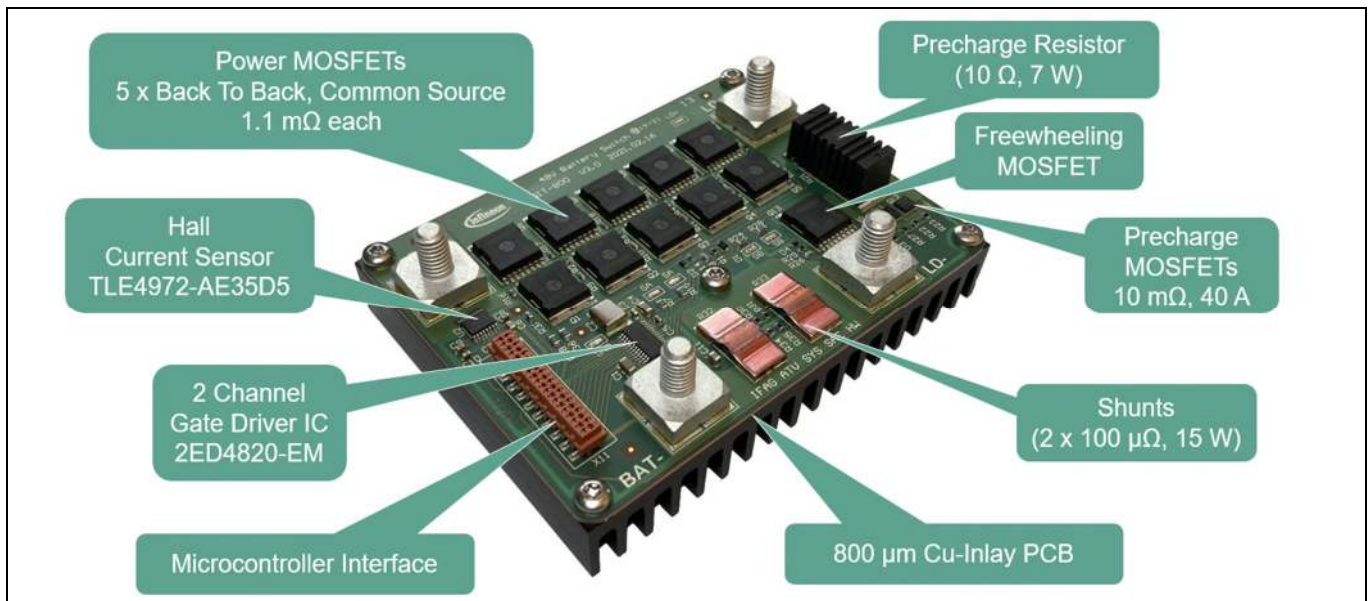


Figure 1 48V battery switch power board on heat sink

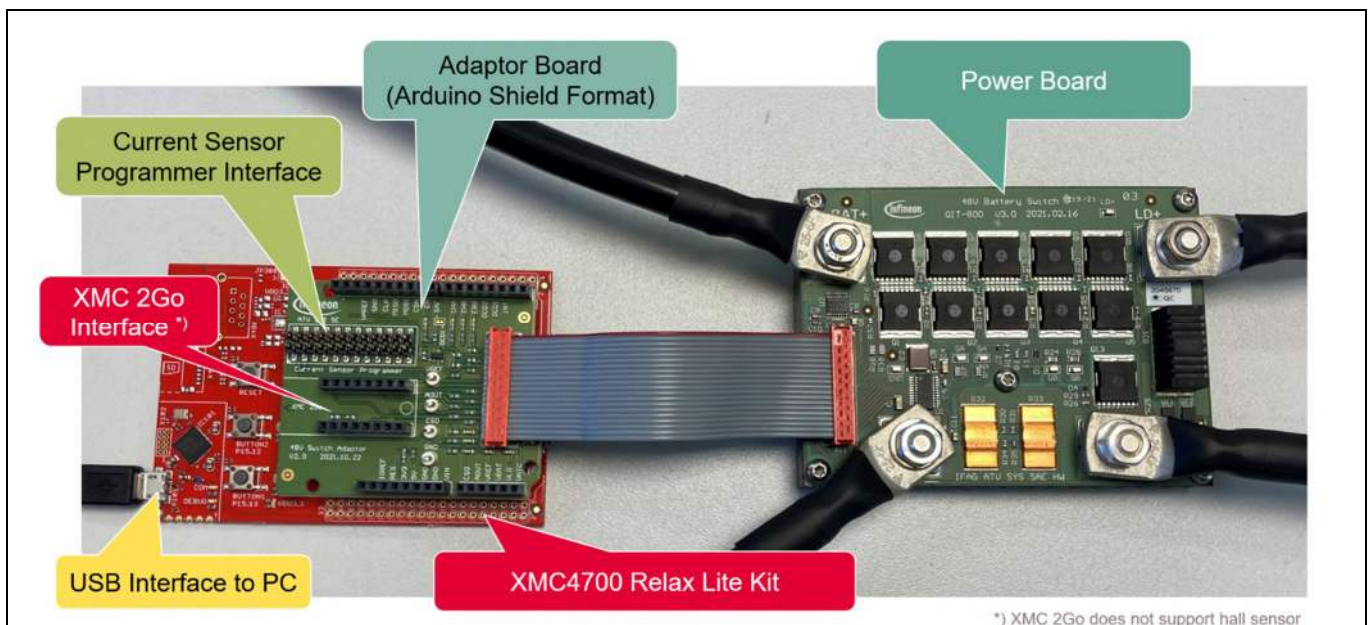


Figure 2 The 48V battery switch with control board

The kit at a glance

1.2 Block diagram

The design of the switch revolves around the 2 channel MOSFET gate driver **2ED4820-EM**. Channel A is used to control the power MOSFETs for (dis-)connecting the battery. Channel B drives the MOSFETs for the DC-link precharge circuit.

In order to improve functional safety there are two diverse methods implemented for current monitoring and overcurrent protection – shunt based current sensing on the low side and hall based current sensing with the **TLE4972-AE35D5** on the high side.

The switch is controlled by a XMC4700 microcontroller kit which also provides a user interface via USB port.

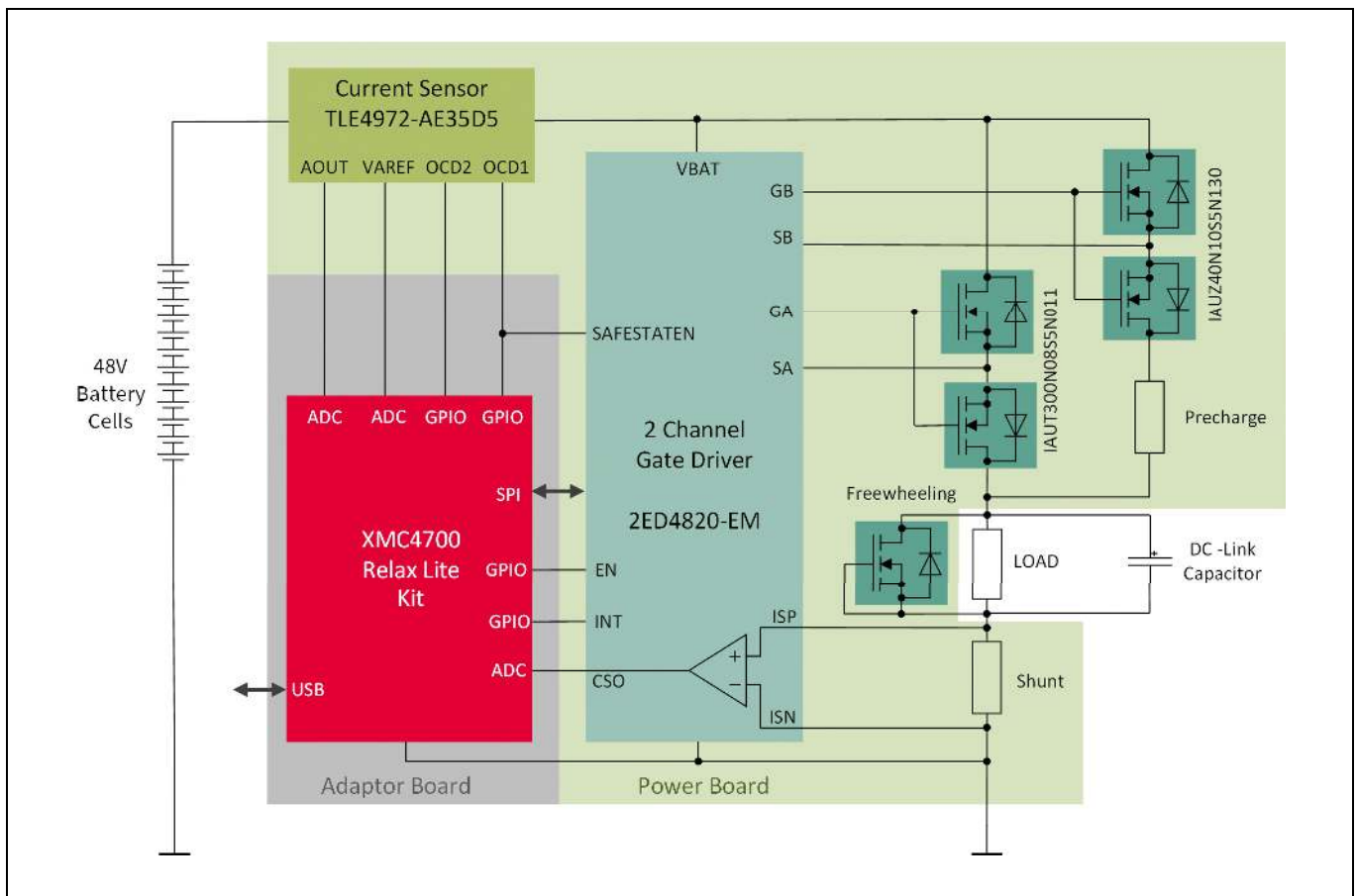


Figure 3 Block diagram

1.3 Main features

- Bidirectional 48V battery switch for continuous currents up to 300 A
- Precharge path for capacitive loads (e.g. DC-Link capacitor, EMC filter)
- Passive freewheeling (active freewheeling optional)
- Shunt based current measurement and monitoring in low side path
- Hall based current measurement and monitoring in high side path
- Current sensor programmer interface for calibration and configuration of the hall sensor
- Over current protection with adjustable thresholds
- Pre-installed firmware including command line interface

The kit at a glance

1.4 Technical data

Table 2 System parameters

Parameter	Symbol	Comment	Value	Unit
Board size power board	L x W x H	Including heat sink	75 x 100 x 31	mm
Board size adaptor board	L x W x H		53 x 64 x 19	mm
Operating voltage	V _{BAT}		24 ... 54	V
Maximum supply voltage	V _{max}		70	V
Digital supply voltage	V _{DD}	Provided by microcontroller kit	3.3	V
Continuous Current Capability	I _{max}	Forced air cooling	300	A
Combined MOSFET on state resistance	R _{DS(on)}	typ. @ 25°C	400	μΩ
Precharge resistor	R _{precharge}		10	Ω
Shunt resistance	R _{Shunt}		50	μΩ

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2 System and functional description

2.1 Getting started

Connecting supply and load

The 48 V supply has to be connected to the M6 screw terminals marked “BAT+” and “BAT- “. The BAT- terminal is the ground reference of the board. The load is connected to the screw terminals marked “LD+” and “LD-“.

For driving high currents use properly sized cables and cable lugs. Use a maximum 9 Nm mounting torque for tightening the nuts on the screw terminals.

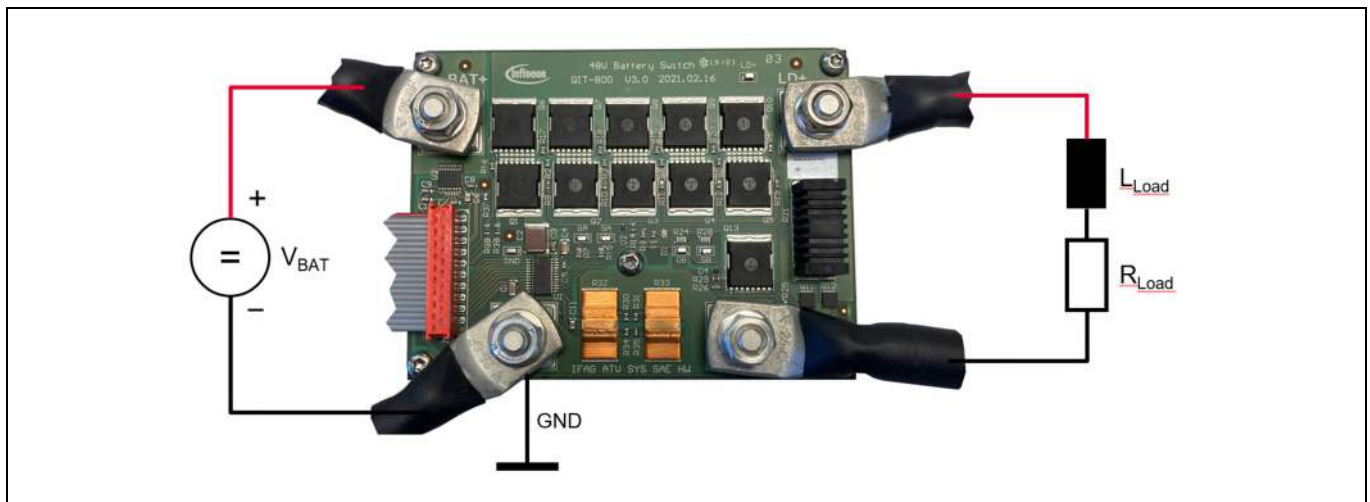


Figure 4 Connecting supply and load

Note: Please ensure the right supply polarity as there isn't any reverse polarity protection implemented.

Connecting the microcontroller

To connect the XMC4700 Relax Lite Kit to the power board use the provided flat ribbon cable as shown in Figure 5.

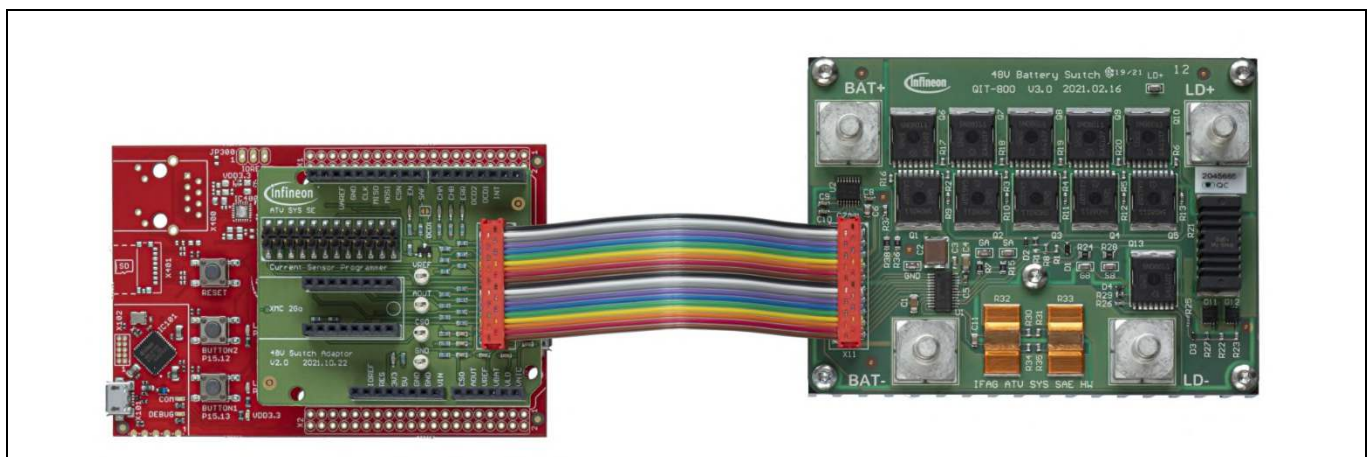


Figure 5 Connecting the microcontroller board to the power board

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Compatibility with other microcontroller boards

By default, the reference kit comes equipped with the XMC4700 Relax Lite Kit. However, thanks to the adaptor board in Arduino shield form factor the switch can also be connected to other Arduino UNO compatible microcontroller boards like the AURIX TC375 Lite Kit.

Note: Since the hall based current sensor is a 3.3 V device this reference kit was designed for a digital supply voltage of 3.3 V. Therefore, the microcontroller board has to be a 3.3 V type.

2.2 Description of the functional blocks

2.2.1 Power supply

The kit requires two power supplies, the battery voltage VBAT and the digital supply voltage VDD.

VBAT can be provided by a 48 V DC power source, like a 48 V battery or a lab power supply. It supplies the gate driver **2ED4820-EM** and the power stage.

The digital supply voltage VDD is derived from the 3.3 V supply of the microcontroller kit, which is powered via the USB connector. VDD supplies the digital interface of the gate driver and the hall based current sensor **TLE4972-AE35D5**.

Table 3 Functional Range

Parameter	Symbol	Min.	Max.	Unit
Battery Voltage	VBAT	24	54	V
Logic Supply Voltage	VDD	3.1	3.5	V

2.2.2 Power stage

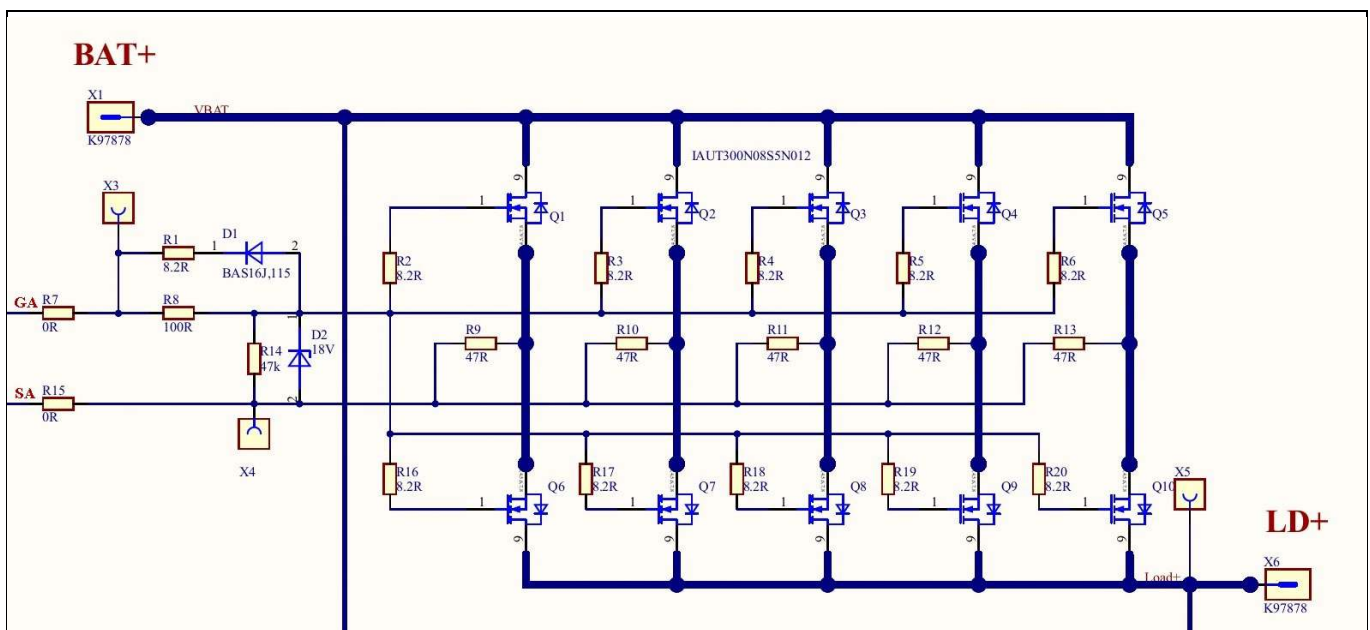


Figure 6 Power stage schematics

The power stage consists of five pairs of best in class OptiMOST™-5 Power-Transistors **IAUT300N08S5N011** (80V, 1.1 mΩ) in common source topology. The common source topology has been chosen because it allows the

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control of the five MOSFET pairs by a single gate driver channel and leaves the second gate driver channel of the **2ED4820-EM** available for the control of the precharge circuit.

The power stage is controlled by channel A of the gate driver. Special care has been taken to ensure an even current distribution between the MOSFETs. This includes decoupling of the sources of the different MOSFET pairs by source resistors (R9 ... R13) as well as equal trace length for each current branch in the layout.

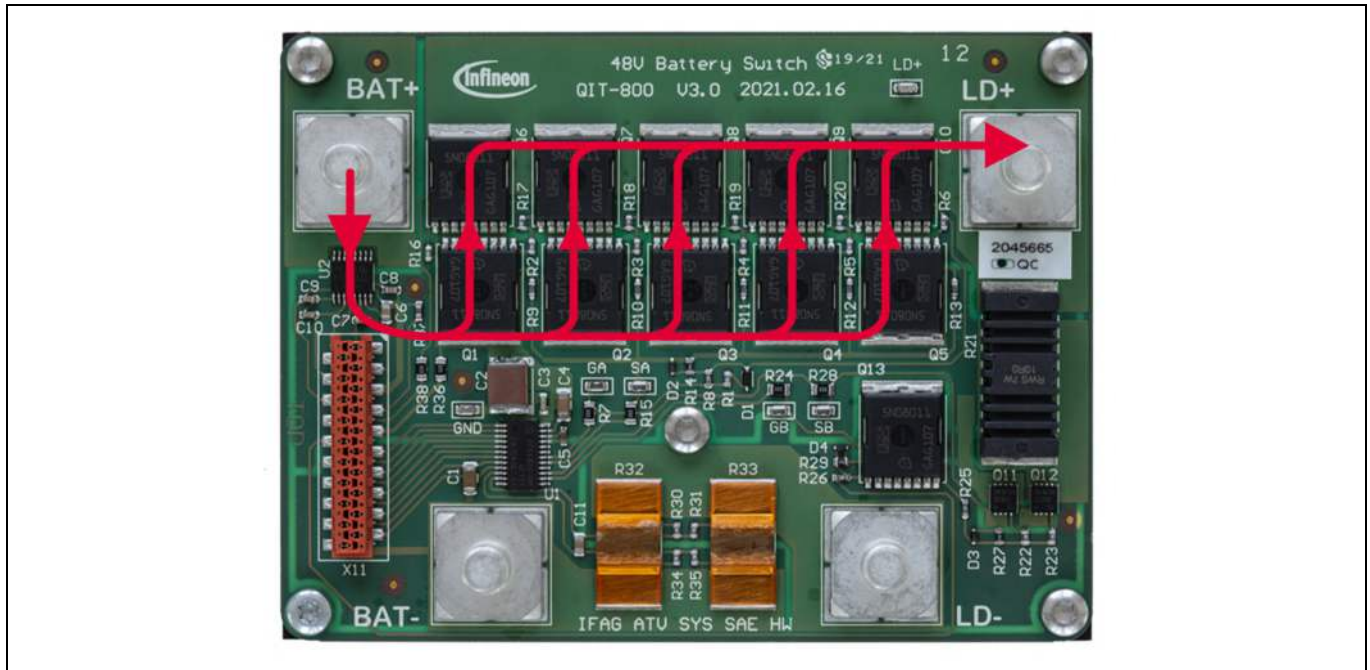


Figure 7 Even current distribution by equal trace length for each current branch

2.2.3 Precharge circuit

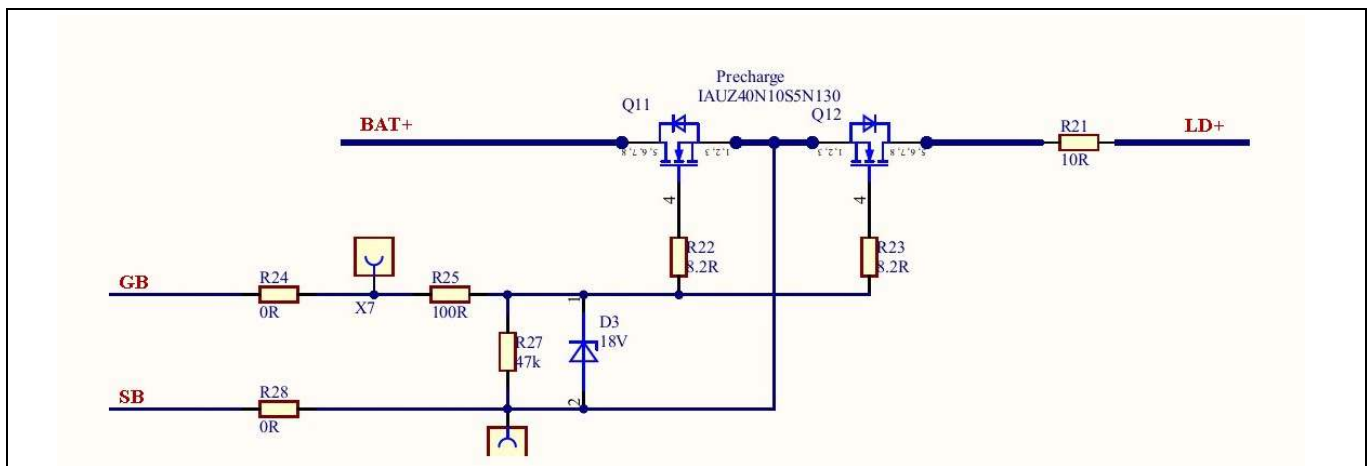


Figure 8 Precharge circuit

Many loads on the 48V power domain have a big capacitance like a DC-link capacitor or EMC filter at their input. Switching onto an uncharged capacitor will cause a high inrush current, limited only by the ESR of the capacitor as well as other resistances (cables, connectors, battery) in the system.

The high inrush current may inadvertently trip the overcurrent protection. To avoid this, the capacitor needs to be precharged before activating the main switch. Therefore, a separate precharge path is implemented in

System and functional description

parallel to the power switch. The **2ED4820-EM** gate driver channel B is driving a pair of **IAUZ40N10S5N130** MOSFETs to turn the precharging path ON and OFF. The precharge current is limited by a 10 Ω power resistor.

At the beginning of the charge pulse the power resistor will see the whole battery voltage. The initial power dissipation at 48V therefore is as big as:

$$P = \frac{V^2}{R} = \frac{(48V)^2}{10\ \Omega} = 230.4\ W$$

However, while the capacitor gets charged, the voltage across the resistor will decay exponentially. In spite of the large initial power surge the energy of the charging pulse is limited and the resistor will not even get hot. Nevertheless, a power resistor with high pulse current capability has to be used to withstand the high inrush current. Wire wound resistors usually can handle a multiple of their DC power rating for short pulses and are well suited for this application.

The time needed to charge the DC link capacitor is specified by the time constant $\tau = RC$ of the RC circuit formed by the precharge resistor and the DC link capacitor. After 5τ the voltage at the capacitor will have reached 99.3 % of the supply voltage and the capacitor can be considered fully charged. Assuming a 10 mF DC-link capacitor we get a precharge time of

$$t_{precharge} = 5\tau = 5 * RC = 5 * 10\ \Omega * 10\ mF = 500\ ms$$

The energy that will be dissipated in the resistor during that precharge pulse is the same as the energy stored in the capacitor and can be calculated as

$$E = \frac{1}{2} CV^2 = \frac{1}{2} * 10\ mF * (48\ V)^2 = 11.52\ J$$

According to the specification the resistor can handle five times the rated power for five seconds. This would amount to $5 * 7\ W * 5\ s = 175\ J$ and should give us enough headroom for charging even bigger DC-link capacitors.

A problem however might occur when there is a short circuit or a low ohmic load at the output of the switch and the precharge switch is engaged. In that case the dissipated power would quickly exceed the resistor rating and the resistor could be damaged. Therefore, the precharge resistor is monitored by the microcontroller. Whenever channel B is switched on, the voltage across the resistor is measured and the dissipated power is calculated. If the power exceeds 5 W the microcontroller starts integrating the power over time to get the energy in the resistor. As soon as it exceeds 100 J, channel B is switched off.

2.2.4 MOSFET gate driver

The **2ED4820-EM** is a gate driver designed for high current 48 V automotive applications, with two powerful gate outputs that allow to drive many MOSFETs in parallel. It supports the back-to-back configuration, both common source and common drain topology.

The gate driver generates the supply for the gate outputs with the help of on an integrated one-stage charge pump with external pump and tank capacitors. Except for the supply and charge pump capacitors there is little external circuitry needed.

For shunt based current monitoring and overcurrent detection the **2ED4820-EM** contains a current sense amplifier with programmable gain. The voltage drop at the shunt resistor is amplified and the amplified voltage is provided at the CSO output. The current sense amplifier gain as well as the overcurrent threshold can be configured by SPI.

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In general, all the extensive diagnosis as well as configuration and control of the gate driver is handled via the SPI interface.

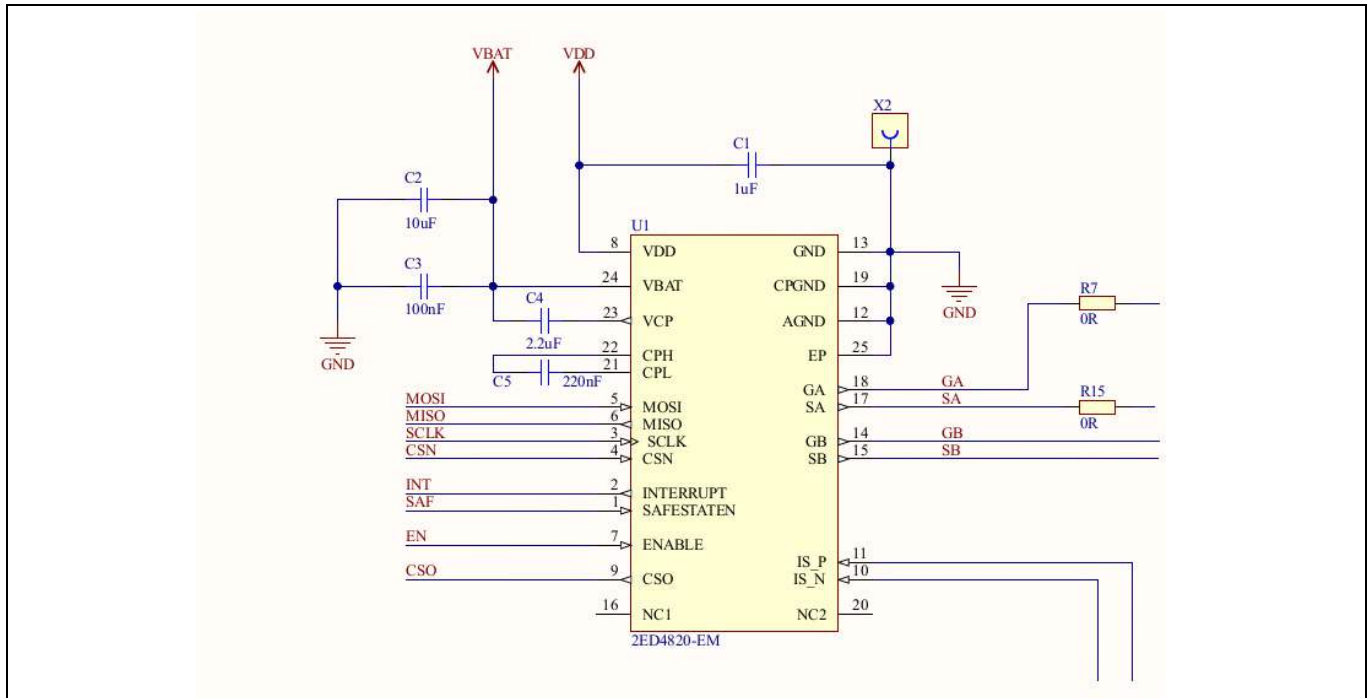


Figure 9 Dual channel MOSFET gate driver 2ED4820-EM

2.2.5 Shunt based current sensing

With continuous currents up to 300 A power dissipation in the shunt resistor can be a concern. Even with a shunt as low as 100 $\mu\Omega$ this amounts to of 9 W power loss in the resistor. Since we wanted to use SMD mounted shunts we decided to use two of them in parallel. Of course, this comes to the cost of halving the sensitivity, but thanks to the programmable gain amplifier implemented in the **2ED4820-EM** this can easily be compensated.

Another concern is the parasitic inductance of the shunt. In the event of a short circuit the current is limited only by the inductance of the cables. Assuming 1 m cable with an inductance of 1 μH , the slewrate dI/dt will be 48 A/ μs for a supply voltage of 48V ($dI/dT = V/L$). The high current slew rate will lead to a voltage drop in the shunt inductance. This is added to the voltage drop at the resistive part and introduces a measurement error.

According to the datasheet the parasitic inductance of the selected shunt resistor ranges between 0.5 nH and 5 nH. Calculated based on the physical dimensions of the section between the sense terminals it should be about 1.8 nH [1]. For two shunts in parallel the inductance is halved, which amounts to 0.9 nH.

With the given current slew rate this inductance induces an error voltage of

$$V_L = L \frac{dI}{dt} = 0.9 \text{ nH} \cdot 48 \frac{\text{A}}{\mu\text{s}} = 43.2 \text{ mV}$$

which would translate to a measurement error of

$$I_{err} = \frac{V_L}{R_{shunt}} = \frac{43.2 \text{ mV}}{50 \mu\Omega} = 864 \text{ A} !$$

In order to compensate that error, a RC low pass filter has to be added between the shunts and the gain amplifier of the 2ED4820-EM. The time constant of that RC filter should be equal to the time constant formed by the shunt resistor and the parasitic inductance:

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$$\frac{R_{shunt}}{L_{shunt}} = \frac{1}{RC}$$

Since resistors placed in series to the amplifier inputs will influence the gain factor they should be kept as small as possible. With a chosen filter resistor value of $R = 8.2 \Omega$ we get a capacitor value of

$$C = \frac{L_{shunt}}{R_{shunt} R} = \frac{0.9 \text{ nH}}{50 \mu\Omega \cdot 8.2 \Omega} = 2.2 \mu\text{F}$$

Because the current distribution between the two shunts may be unequal, the two shunt voltages may differ and therefore need to be balanced. This can be achieved by the compensation network shown in Figure 10. In this circuit the voltage across the capacitor is the arithmetic mean value of the two shunt voltages while the RC filter time constant remains the same.

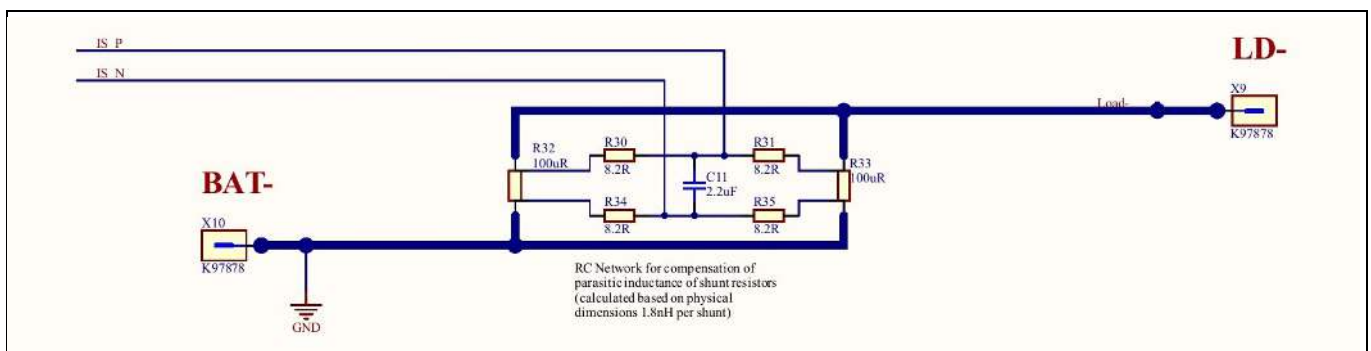


Figure 10 Paralleled shunt resistors with parasitic impedance compensation

The chosen shunt resistors don't have separate sense pins. Instead there is only a recommendation in the datasheet on where to attach the sense lines to the footprint of the shunt. If you follow this recommendation the voltage drop in the solder connection between the PCB pad and the shunt would be part of the sensor signal. Since we are using very low ohmic shunt resistors, every $\mu\Omega$ would add an additional measurement error. Therefore, the footprint of the shunt was modified by introducing separate power and sense pads.

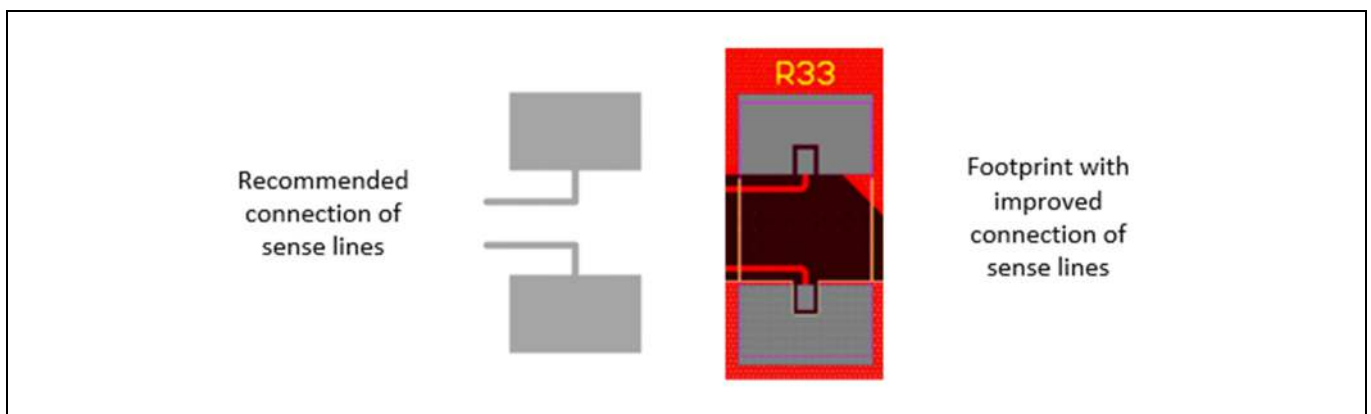


Figure 11 Improved connection of sense lines

2.2.6 Hall based current sensor

In addition to the shunt based current measurement there is a hall based current sensor implemented to provide an alternative current monitoring path for improved functional safety. It is located on the high side, directly after the BAT+ input terminal. Thanks to the intrinsic galvanic isolation of the **TLE4972-AE35D5** there is no need for additional isolators or level shifters. It can be directly connected to the microcontroller. The sensor offers two analog outputs for differential current measurement and two digital outputs for fast overcurrent detection with programmable thresholds.

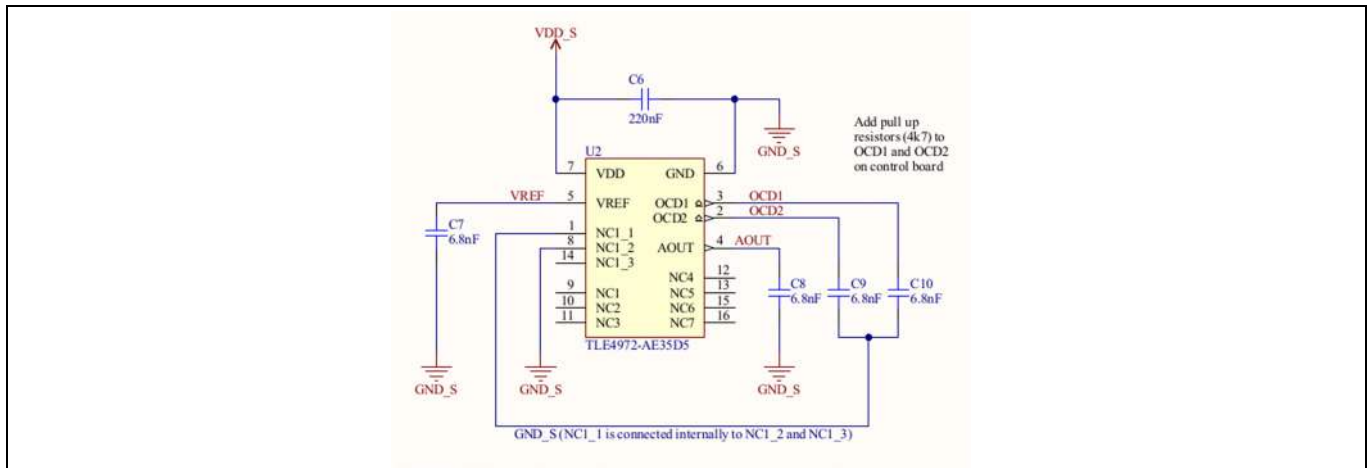


Figure 12 Hall based current sensor TLE4972-AE35D5 with peripheral components

The sensor itself actually measures the magnetic field caused by a current conductor. Only in conjunction with that conductor (or current rail) it becomes a current sensor. In our case the conductor is a short piece of PCB trace in the middle layer right below the sensor where all the load current is forced through. The trace is only 3 mm wide but also only 1 mm short and 800 μm thick, with a resistance of only 7 $\mu\Omega$. The resulting power dissipation therefore is 7 times smaller than that of the shunt resistors.

Two hall probes in the sensor measure the magnetic field around the conductor differentially. This ensures high robustness against stray magnetic fields.

To avoid disturbances due to eddy currents in adjacent conductors the area beneath the current rail is kept free from metal. That means that there is a cutout in the bottom layer around the current rail as well as a milled-out area in the heatsink below that structure (see Figure 29 and Figure 34).



Figure 13 Hall sensor placement above current rail in middle layer

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At the location of the hall probes this structure yields a magnetic field strength of $\sim 45 \mu\text{T/A}$. This so-called current rail transfer factor can be determined either by simulation or by measuring the output voltage of the hall sensor at a given current and using the selected sensitivity range value from the data sheet (in mV/mT) to calculate the transfer factor in $\mu\text{V/A}$.

The TLE4972-AE35D5 can be configured and calibrated on board by programming the sensor internal EEPROM with the TLE4972 current sensor programmer kit¹, which can be connected to the adaptor board as shown in Figure 14.

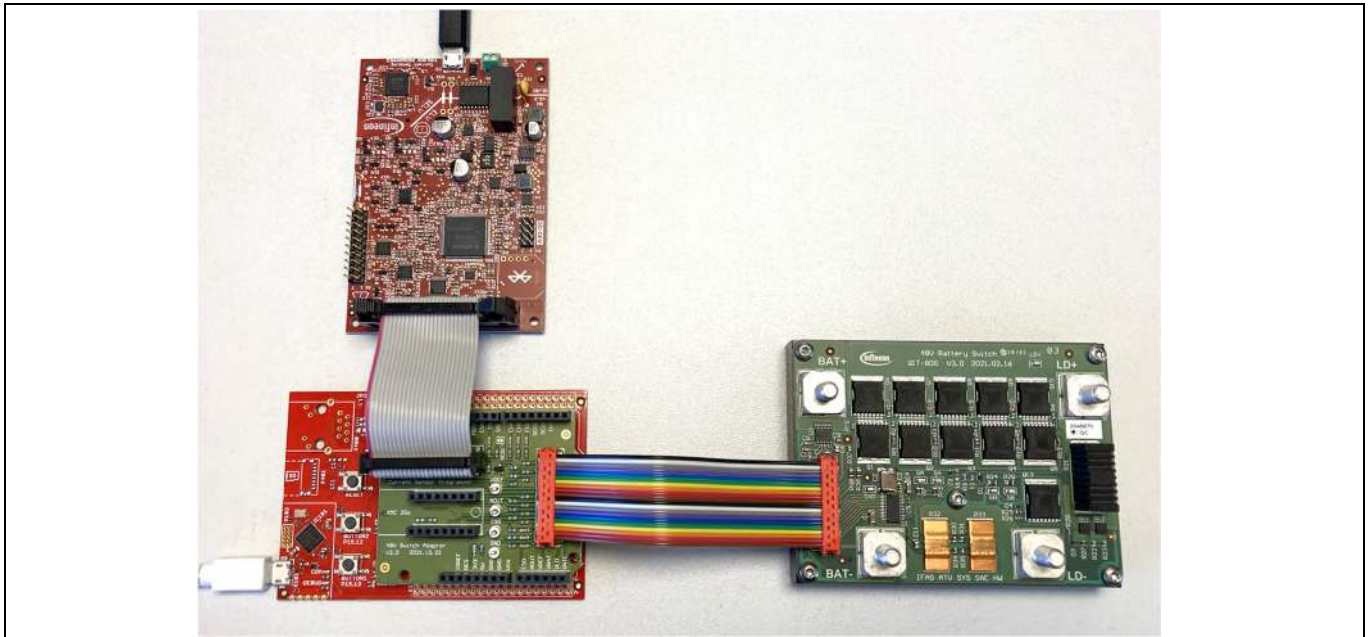


Figure 14 Connection of the current sensor programmer

The hall sensor on each board is calibrated and set to the following values:

Table 4 TLE4972-AE35D5 Configuration

Parameter	Setting	Value
Output Mode	Fully differential	
Sensitivity Range	S2	46.5 mV / mT
OCD1 Threshold	6	389 A
OCD2 Treshold	10	246 A
Sensitivity (single ended)		2.4 mV/A
Sensitivity (fully differential)		4.8 mV/A

According to the data sheet full scale for the TLE4972-AE25D5 is defined as 1200 mV in single ended mode and 2400 mV in fully differential mode, which amounts to a default measurement range of $\pm 500 \text{ A}$.

Due to the orientation of the sensor in respect to the current flow, a current flowing from positive supply to ground will be reported as a negative current on the analog output.

¹ Order name: „CUR SENSOR PROGRAMMER“, Order number: SP004441438

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The fast overcurrent detection output OCD of the current sensor can be connected to the SAFESTATEN pin of the gate driver in order to provide a second switch off path for overcurrent events. To enable this functionality the solder jumper on the adaptor board has to be bridged as shown in Figure 15.

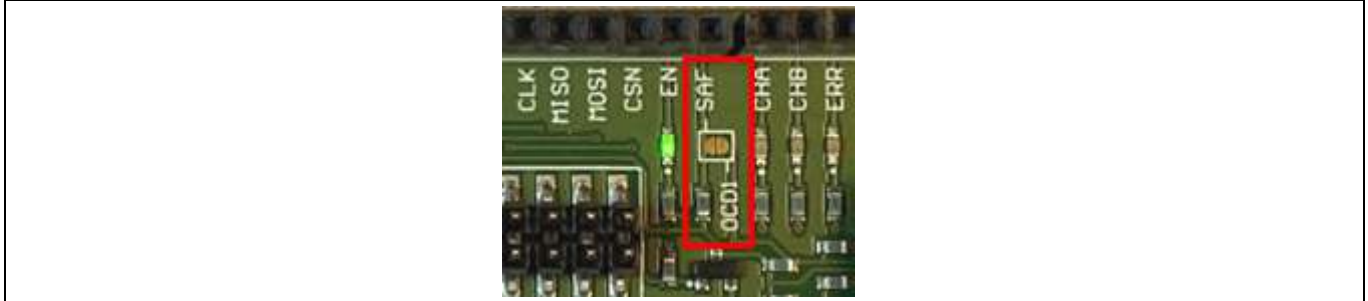


Figure 15 Solder jumper on adaptor board to connect OCD1 to SAFESTATEN

Note: For calibration of the current sensor the solder jumper needs to be open, because the OCD1 may be pulled low during calibration, which would cause an unintended switch off via the SAFESTATEN signal.

2.2.7 Freewheeling

When the MOSFETs are switched off, the sudden drop in current flow will induce a large voltage in the output inductance which pulls the output (LD+) below ground potential (LD-). To protect the switch MOSFETs against overvoltage a freewheeling MOSFET (Q13) is placed between LD+ and LD-.

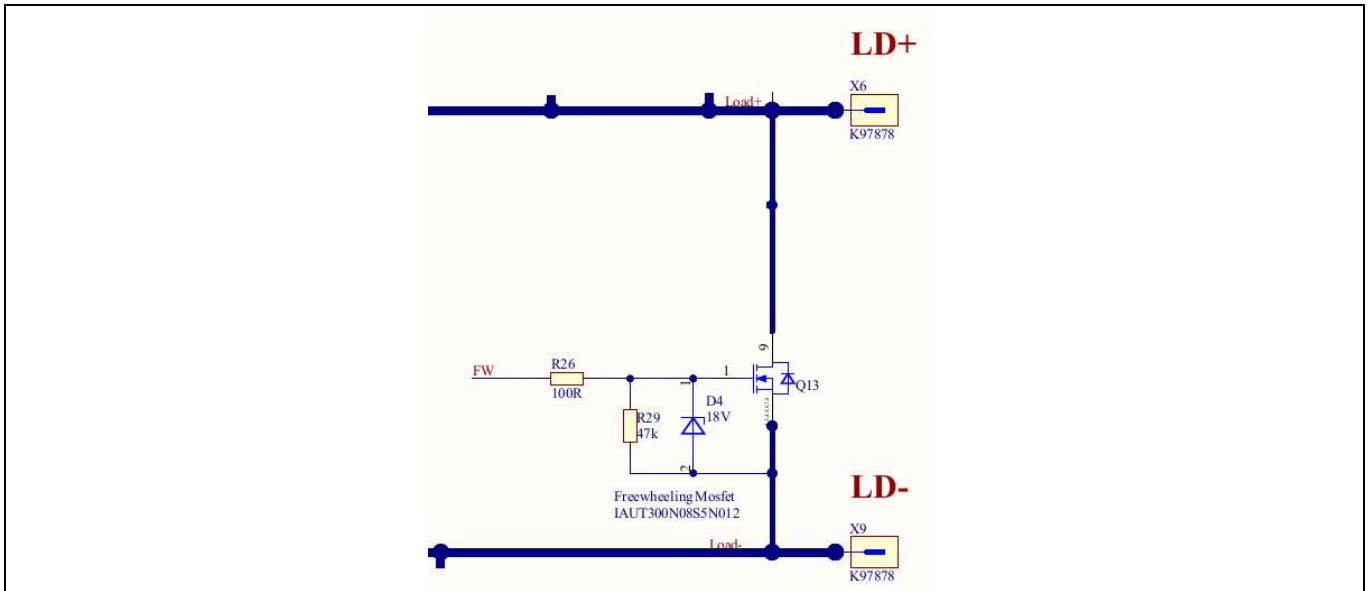


Figure 16 Freewheeling MOSFET

Due to its intrinsic body diode, the MOSFET allows freewheeling without being switched on. Nevertheless, the gate signal is routed to the interface connector to provide the option to add an active control circuit.

2.2.8 Microcontroller interface

The 20-pin connector X11 provides the interface of the power board to the microcontroller. For the connector pin assignment see Table 5 below. Figure 18 shows the port and pin assignment of those signals for the microcontroller.

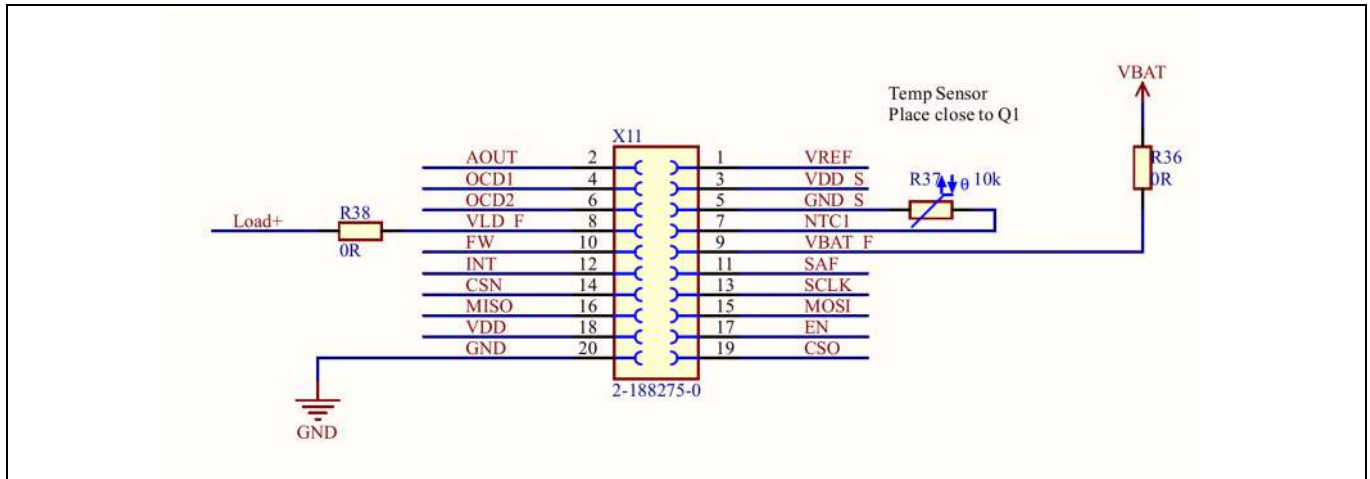


Figure 17

Table 5 Pin Assignment Microcontroller Interface Connector

PIN	Label	Function
1	VREF	TLE4972- AE35D5 Reference Voltage (Output)
2	AOUT	TLE4972- AE35D5 Analog Out
3	VDD_S	TLE4972- AE35D5 Sensor Supply
4	OCD1	TLE4972- AE35D5 Overcurrent Detection Output 1
5	GND_S	TLE4972- AE35D5 Sensor Ground
6	OCD2	TLE4972- AE35D5 Overcurrent Detection Output 2
7	NTC1	Thermistor
8	VLD_F	Load Voltage
9	VBAT_F	Battery Voltage
10	FW	Freewheeling (Gate of freewheeling MOSFET)
11	SAF	2ED4820-EM SAFESTATEN (Safe State Enable)
12	INT	2ED4820-EM INT (Interrupt)
13	SCLK	2ED4820-EM SCLK (SPI Clock)
14	CSN	2ED4820-EM CSN (SPI Chip Select)
15	MOSI	2ED4820-EM MOSI (SPI Master Out Slave In)
16	MISO	2ED4820-EM MISO (SPI Master In Slave Out)
17	EN	2ED4820-EM EN (Enable)
18	VDD	2ED4820-EM VDD (Digital Supply Voltage 3.3 V)
19	CSO	2ED4820-EM CSO (Current Sense Output)
20	GND	Ground

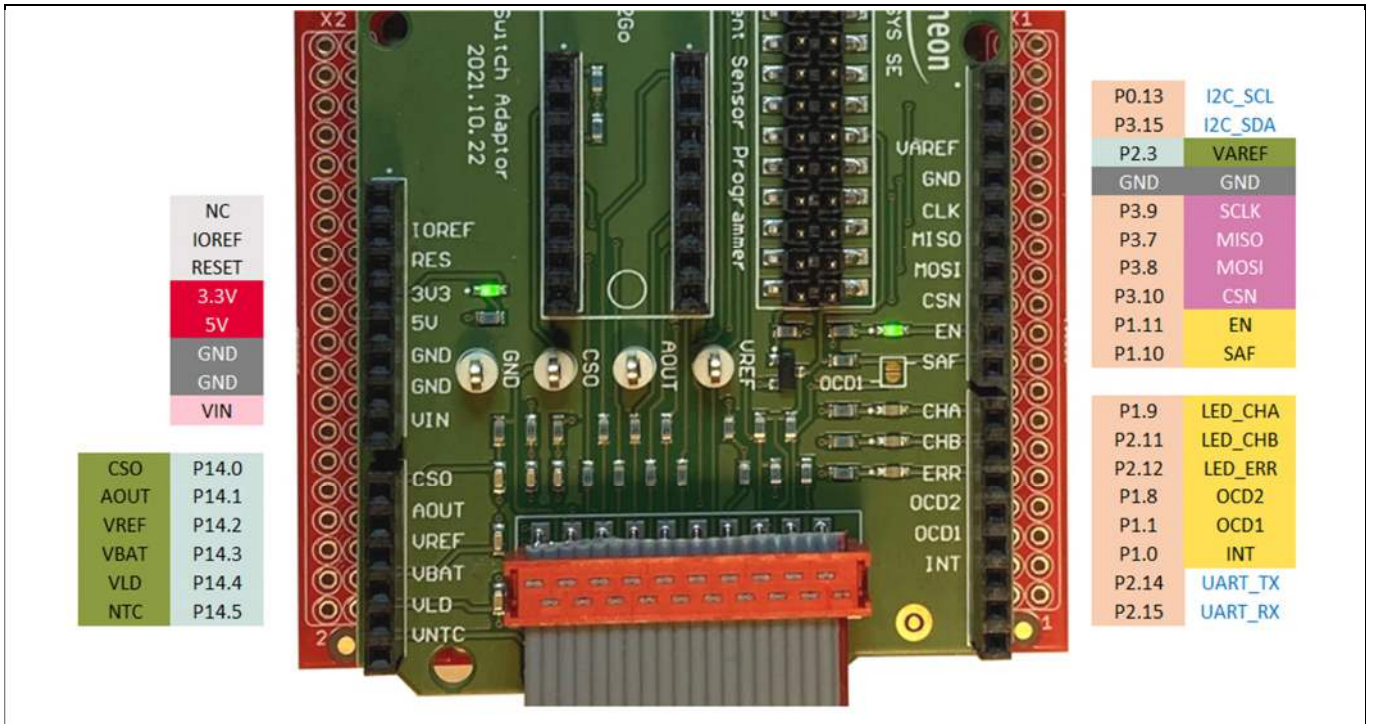


Figure 18 Port and pin assignment XMC4700 Relax Lite Kit

2.3 Basic operation

2.3.1 Operating the switch via buttons and status LEDs

The switch can be controlled by the buttons mounted on the XMC4700 Relax Lite Kit. Several LEDs provide status and diagnosis information. For extended configuration, control, and diagnosis there is a command line interface available (see chapter 2.3.2).

After power-up or after a reset the microcontroller will load the driver configuration from the internal flash. The configuration can be changed by the user (see chapter 2.4 Configuration).

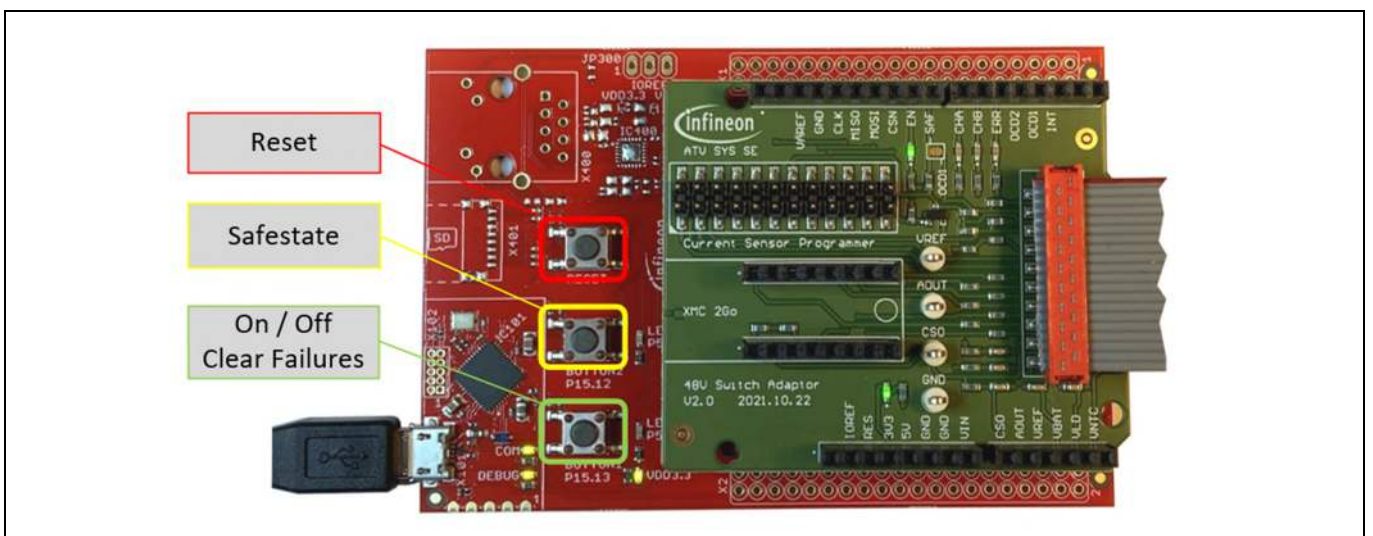


Figure 19 Buttons on XMC4700 Relax Lite Kit

Table 6 Button functionality

Button	Function	Description
RESET	Reset	Microcontroller reset
BUTTON2	Safestate	Pull SAFESTATEN pin low to initiate the 2ED4820-EM safe state
BUTTON1	ON/OFF	Switch on or off, including initialisation and precharge If failure occurred (error LED on): clear failure flag

Switching on

When the switch is off and button 1 is pressed, the driver is enabled and initialized with the configuration settings. Then the precharge path (channel B) is switched on for the configured precharge time to charge up the load capacitor. When the precharge time is expired, the power switch (channel A) is activated and the precharge path is switched off.

The status of the 2ED4820-EM outputs channel A (power switch) and channel B (precharge path) is displayed by the respective status LEDs on the adaptor board. LED1 next to button 1 on the XMC Relax Lite Kit shows the status of channel A.

Switching off

When the switch is on and button 1 is pressed, both channels are switched off and the driver is disabled.

Clearing failures

In case of a failure the error LED will light up. The failure flag can be cleared by pressing button 1.

Safestate

Pressing button 2 will initiate the safe state functionality of the gate driver 2ED4820-EM. Safe state is indicated by LED2 next to this button.

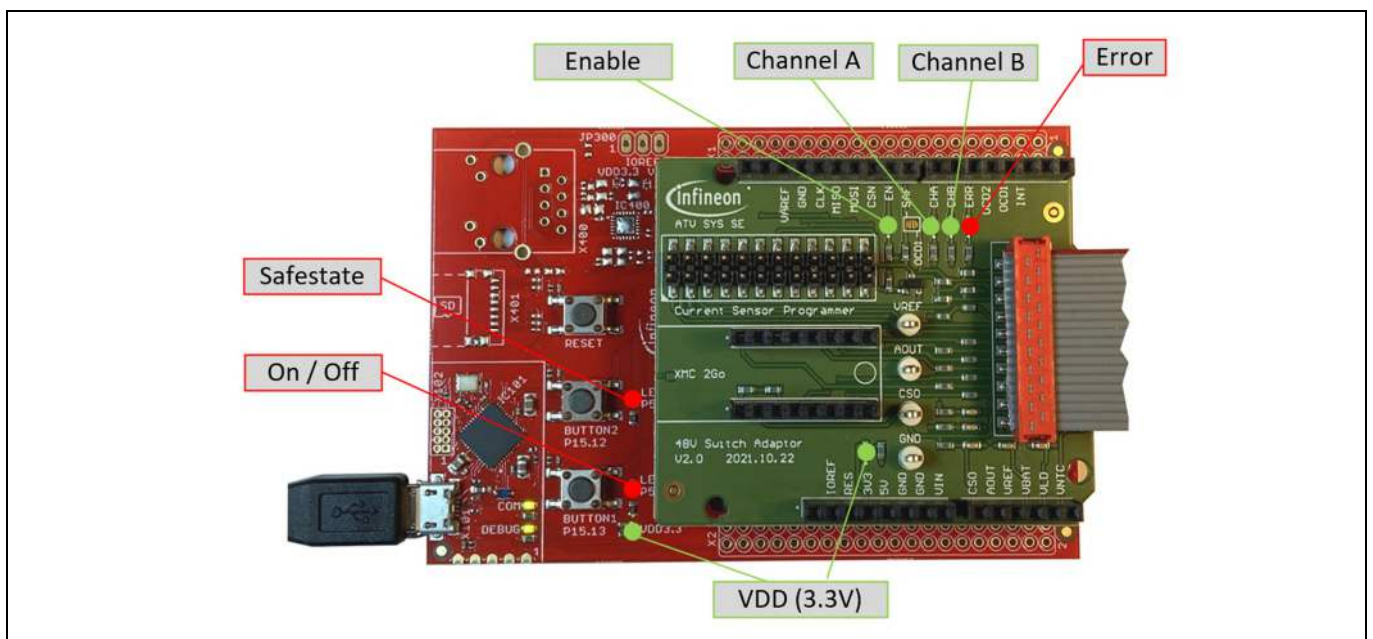


Figure 20 Location of Status LEDs

2.3.2 Operating the switch via command line interface

The firmware of the XMC4700 microcontroller provides a simple command line interface for extended configuration, control, and diagnosis of the 48V Battery Switch. To use it a standard terminal emulator program for serial port communication like TeraTerm or PuTTY is needed.

The command line interface uses a virtual COM port via the USB interface for communication. The COM port gets assigned automatically when the USB cable to the XMC4700 Relax Lite Kit is plugged in. To locate the COM port number on a Windows PC, check the port assignment in the device manager (Figure 21). The assigned virtual COM port number is shown in brackets next to the port named “JLink CDC UART Port”.

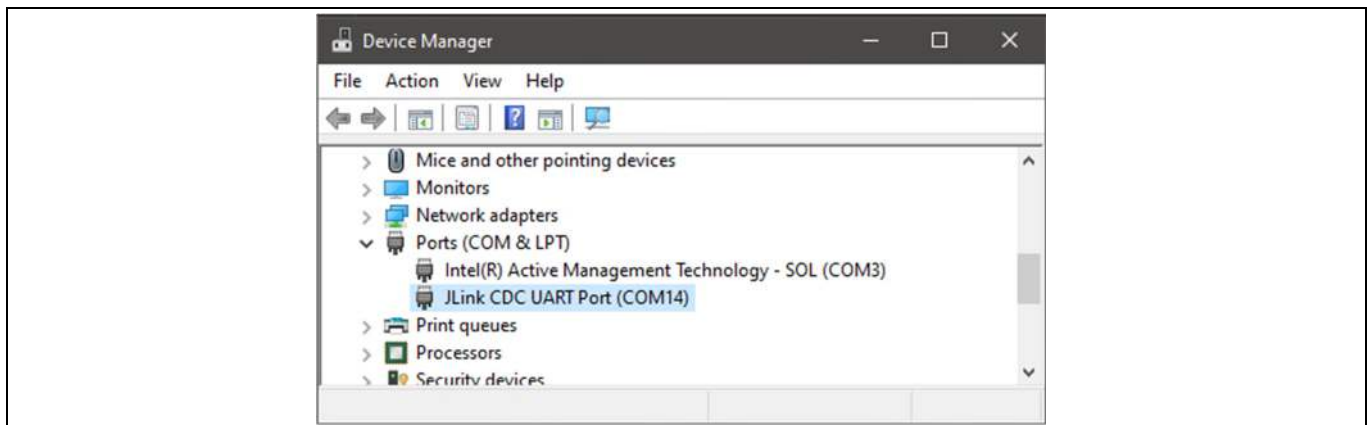


Figure 21 Locating the virtual COM port in the device manager

Following settings have to be set in the terminal emulator for the serial port communication:

- Baud Rate: 115200 bps
- 8 data bits
- No parity bits
- 1 stop bit

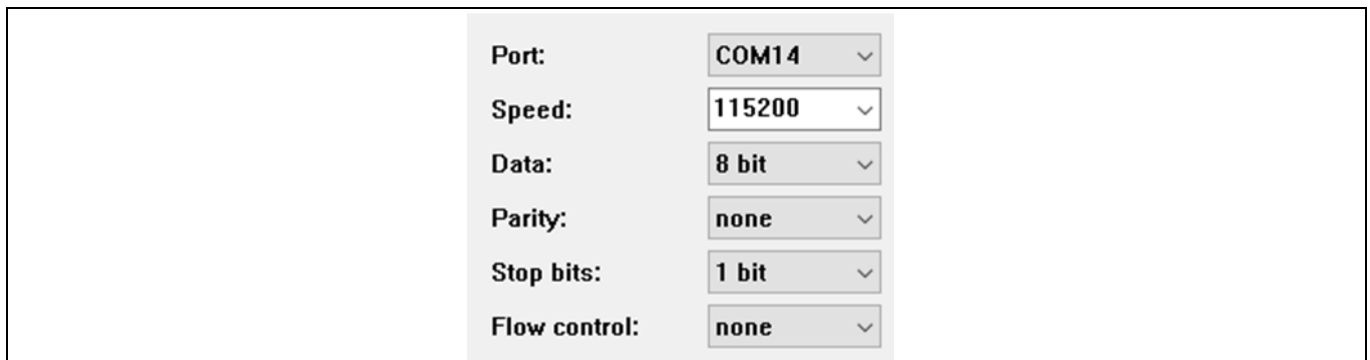


Figure 22 Virtual COM port settings

The terminal window size should be at least 100 characters wide to avoid line wrapping.

After power-up or reset a welcome message and a command prompt is displayed

System and functional description

```
-----
48V Battery Switch command line interface, Rev. 1.0, 2022-02-02
To display the list of available commands please enter '?'
-----
>
```

Figure 23 Welcome message

As mentioned in the welcome message, the command “?” will list all available commands with a short explanation on how to use them.

```
>?
48V Battery Switch command line interface, Rev. 1.0, 2022-02-02
-----
Command Argument1 Argument2 Example Description
-----
? - - '?' show available commands
on - - 'on' switch on (incl. init & precharge)
off - - 'off' switch off & disable
e -/0/1 - 'e'/'e 0'/'e 1' enable pin toggle/low/high
s -/0/1 - 's'/'s 0'/'s 1' safestaten pin toggle/low/high
r adr/all - 'r 5' 'r all' read register / read all registers
w adr data (hex) 'w 4 ff' write register
cf - - 'cf' clear failures
a -/0/1 - 'a'/'a 0'/'a 1' channel A toggle/low/high
b -/0/1 - 'b'/'b 0'/'b 1' channel B toggle/low/high
pa time[ms] - 'pa 10' generate a pulse on channel A
pb time[ms] - 'pb 15' generate a pulse on channel B
v - - 'v' show Vbat and Vld
i - - 'i' show Ishunt and Ihall
t - - 't' show NTC temperature
-----
configuration settings
-----
uvrt 0..3 - 'uvrt 2' vbat undervoltage restart time
ovrt 0..3 - 'ovrt 2' vbat overvoltage restart time
dsov a/b 0..7 'dsov a 2' vds overvoltage threshold ch. A/B
sst a/b 0/1 'sst a 1' safe state ch. A/B
blk a/b 0..3 'blk b 2' blanking time ch. A/B
flt a/b 0..3 'flt a 2' filter time ch. A/B
pt time[ms] - 'pt 500' precharge time in ms for 'on' command
xctr 0/1 - 'xctr 0' channel cross control
cshs 0/1 - 'cshs 0' current sense on high side
csld 0/1 - 'csld 1' current sense output load (1: >100pF)
csag 0..7 - 'csag 3' current sense amplifier gain
octh 0..3 - 'octh 2' overcurrent threshold
hss time[ms] - 'hss 4800' hall sensor sensitivity in µV/A
c - - 'c' show configuration
fc - - 'fc' factory configuration
sc - - 'sc' save configuration to uC flash memory
lc - - 'lc' load configuration from uC flash memory
init - - 'init' initialise driver with last config
-----
```

Figure 24 Command Overview

Arrow Keys

The left and right arrow keys behave like the “Delete” or “Space” keys.

With the up and down arrow keys you can scroll through the last ten commands.

System and functional description

Switching on and off

Similar to the push buttons on the microcontroller boards the switch can be turned on or off by the commands “on” and “off”.

The “on” command will enable the gate driver, initialize it with the last configuration, apply the precharge pulse and then turn on channel A.

The “off” command will switch off both channels and disable the gate driver.

Switch on sequence

Of course, the switch on sequence can also be performed step by step, starting with enabling the driver with the command “e” or “e 1”.

Note: If no load is connected and the gate driver is enabled, a voltage of ~7 V can be measured at the output of the switch when the mosfets are still off. This is due to a biasing current of ~130 µA flowing from the source pin to ground, which causes a voltage drop at the voltage divider for the load voltage measurement.

After enabling the driver, it will report a VDD undervoltage error to indicate that it is in reset state and to avoid unintended switching with the wrong configuration. The failure flag has to be cleared with the command “cf” (clear failures) before attempting to switch on.

The default configuration after reset most likely isn’t the desired target configuration, so it has to be reprogrammed any time the gate driver is enabled. To avoid having to set every parameter individually, the stored configuration (see chapter 2.4 Configuration) can be applied using the command “lc” (load configuration).

This initialisation sequence – enabling, clearing failures, and loading the configuration (“e”, “cf”, “lc”) – can also be executed by the single command “init”.

For precharging you can generate a pulse on channel B with the command “pb” (pulse channel B), followed by the desired pulse time in milliseconds. For example, the command “pb 500” will generate a 500 ms pulse on channel B.

Channel A can then be switched on by the command “a” or “a 1”. The complete step by step command sequence for switching on with precharge therefore would be “e”, “cf”, “lc”, “pb 500”, “a”.

Register overview

One of the most useful commands to get a quick overview of the status of the 2ED4820-EM gate driver is the command “r”, which will give you an overview of all registers and the settings of the single bits.

```
>r
0: STDIAG: 40 | FAIL | VCPURDY | MEM | OTWARN | TSD | VDDUV | VBATUV | VBATOV |
1: CHDIAG: 00 | VCPUV | OC | VGSUVB | VDSOVB | VSOVB | VGSUVA | VDSOVA | VSOVA |
2: DIAG: 00 | D7 | D6 | D5 | LOG_A | LOG_D | LOG_CP | ADD_NA | SST_EN |
3: MOSCTR: 80 | XCTRL | ITRPCL | VGSCLB | VDSCLB | CHB_ON | VGSCLA | VDSCLA | CHA_ON |
4: FCLEAN: 00 | CPUVCL | D6 | SST_CL | INT_CL | TSD_CL | VDDUCL | VBOVCL | VBUVCL |
5: VDSTH: AA | SST_B | VDS_B2 | VDS_B1 | VDS_B0 | SST_A | VDS_A2 | VDS_A1 | VDS_A0 |
6: FLTBLK: EE | BLK_B1 | BLK_B0 | FLT_B1 | FLT_B0 | BLK_A1 | BLK_A0 | FLT_A1 | FLT_A0 |
7: CSAOCT: 1F | D7 | COUT | HSS | OCTH1 | OCTH0 | CSAG2 | CSAG1 | CSAG0 |
8: VBRES: 00 | D7 | D6 | D5 | D4 | UVRT1 | UVRT0 | OVRT1 | OVRT0 |
9: RESETS: 00 | D7 | D6 | FRES1 | SRES1 | D3 | GENINT | FRES0 | SRES0 |
10: SPARE: F0 | SPARE7 | SPARE6 | SPARE5 | SPARE4 | SPARE3 | SPARE2 | SPARE1 | SPARE0 |
```

Figure 25 Register Overview

System and functional description

Column 1 is the register number, column 2 the register name, column 3 shows the hex value of the register content. Columns 4 to 11 show the register bit names.

The register names and the bit names are shortened versus the naming in the specification for space reasons and to make it easier to read.

If a bit is set to “1” (high), its name is printed in **inverse** font.

Reporting of changed bits

The register content is constantly monitored for changes. If a bit is set or cleared it will be reported.

Failure reporting

In case of an interrupt or if the failure bit is set, the diagnosis bits are checked and the failures are reported.

```
>e 1
Bits Set: FAIL, VCPRDY, VDDUV
[INTERRUPT]
[FAILURE]: Vdd undervoltage
>cf
Bits Cleared: FAIL, VDDUV
```

Figure 26 Example for reporting of failures and changed bits

2.4 Configuration

Displaying the configuration

The configuration settings can be displayed using the command “c”. For each setting the corresponding command and the resulting typical data sheet value for the chosen setting is mentioned in brackets.

```
>c
----- VBAT -----
VBAT undervoltage restart time....(uvrt): 0 (1 ms)
VBAT overvoltage restart time....(ovrt): 0 (10 µs)
----- Channel A -----
VDS overvoltage threshold A....(dsov a): 3 (250 mV)
VDS overvoltage safe state A....(sst a): 0 (deactivated)
Mosfet voltage blanking time A...(blk a): 2 (50 µs)
Mosfet voltage filter time A....(flt a): 2 (2 µs)
----- Channel B -----
VDS overvoltage threshold B....(dsov b): 3 (250 mV)
VDS overvoltage safe state B....(sst b): 0 (deactivated)
Mosfet voltage blanking time B...(blk b): 2 (50 µs)
Mosfet voltage filter time B....(flt b): 2 (2 µs)
Precharge time.....(prt): 500 ms
-----
Channel cross control.....(xctr): 1 (activated)
----- Current Sense -----
Hall sensitivity.....(hss): 4800 µV/A
Current sense shunt location.....(cshs): 0 (low side)
Current sense output load.....(csld): 1 (>100 pF)
Current sense amplifier gain.....(csag): 6 (40 V/V)
Overcurrent detection threshold...(octh): 2 (VDD/2 +- 0.25 VDD)
Overcurrent threshold [A].....: 413 A
-----
```

Figure 27 Display of configuration settings

System and functional description

The gate driver doesn't need to be enabled to display or change the configuration. When the driver is disabled, the current configuration is stored to be used in the next initialisation with the command "init".

2ED4820-EM gate driver configuration settings

Table 7 lists the possible configuration settings for the gate driver 2ED4820-EM

Table 7 Driver configuration settings

Command	Description	Setting	Value
ovrt	VBAT overvoltage auto-restart time	0	10 μ s
		1	50 μ s
		2	200 μ s
		3	1 ms
uvrt	VBAT undervoltage auto-restart time	0	1 ms
		1	5 ms
		2	20 ms
		3	50 ms
blk (a/b)	MOSFET voltage blank time	0	10 μ s
		1	20 μ s
		2	50 μ s
		3	100 μ s
flt (a/b)	MOSFET voltage filter time	0	0.5 μ s
		1	1 μ s
		2	2 μ s
		3	5 μ s
dsov (a/b)	Drain-source overvoltage threshold	0	100 mV
		1	150 mV
		2	200 mV
		3	250 mV
		4	300 mV
		5	400 mV
		6	500 mV
		7	600 mV
sst (a/b)	Safe state in case of VDS overvoltage	0	channel is deactivated
		1	channel stays active
xctr	Channel cross-control		

System and functional description

Command	Description	Setting	Value
		0	cross control deactivated
		1	cross control activated
csag	Current sense amplifier gain		
		0	10 V/V
		1	15 V/V
		2	20 V/V
		3	25 V/V
		4	31.5 V/V
		5	35 V/V
		6	40 V/V
		7	47.7 V/V
cshs	Current sense position		
		0	shunt on low side
		1	shunt on high side
csls	Current sense output load		
		0	< 100 pF
		1	> 100 pF
octh	Overcurrent detection threshold		
		0	VDD/2 ± 0.1 VDD
		1	VDD/2 ± 0.2 VDD
		2	VDD/2 ± 0.25 VDD
		3	VDD/2 ± 0.3 VDD

The actual overcurrent threshold value in Ampere is depending on the setting of the current sense amplifier gain (csag) and the overcurrent detection threshold setting (octh). Table 8 shows the resulting values for a 50 μΩ shunt resistor. The default factory setting is csag 6 and octh 2 which amounts in an overcurrent threshold of 413 A.

Table 8 Overcurrent threshold values vs. csag and octh setting

	csag 0	csag 1	csag 2	csag 3	csag 4	csag 5	csag 6	csag 7
octh 0	660 A	440 A	330 A	264 A	210 A	189 A	165 A	138 A
octh 1	1320 A	880 A	660 A	528 A	419 A	377 A	330 A	277 A
octh 2	1650 A	1100 A	825 A	660 A	524 A	471 A	413 A	346 A
octh 3	1980 A	1320 A	990 A	792 A	629 A	566 A	495 A	415 A

Precharge time

When the switch is turned on with BUTTON1 on the microcontroller board or with the “on” command, a precharge pulse is applied via channel B before engaging the main switch (channel A). The precharge time can be set with the command “prt”, followed by the pulse length in milliseconds.

System and functional description

Hall sensor sensitivity

Before shipment the sensitivity of the hall sensor is set to 4.8 mV/A. If this value should be changed by the user, the configuration setting has to be adjusted accordingly in order to ensure a correct current measurement. The value can be set with the command “hss”, followed by the sensitivity in $\mu\text{V/A}$.

Saving the configuration

The current configuration can be saved in the microcontroller flash memory by the command “sc” (save configuration). The saved configuration will be loaded after power up or after a reset of the microcontroller. With the command “lc” (load configuration) the saved configuration can be restored manually.

Restoring the factory settings

To restore the default configuration for this switch, use the command “fc” (factory configuration). Don't forget to save this configuration with the command “sc” to make it permanent.

Table 9 Factory configuration settings

Command	Description	Setting	Value
ovrt	VBAT overvoltage auto-restart time	0	10 μs
uvrt	VBAT undervoltage auto-restart time	0	1 ms
blk (a/b)	MOSFET voltage blank time	2	50 μs
flt (a/b)	MOSFET voltage filter time	2	2 μs
dsov (a/b)	Drain-source overvoltage threshold	3	250 mV
sst (a/b)	Safe state in case of VDS overvoltage	0	channel is deactivated
xctr	Channel cross-control	1	cross control activated
csag	Current sense amplifier gain	6	40 V/V
cshs	Current sense position	0	shunt on low side
csld	Current sense output load	1	> 100 pF
octh	Overcurrent detection threshold	2	$V_{DD}/2 \pm 0.25 V_{DD}$

3 System design

3.1 Power board

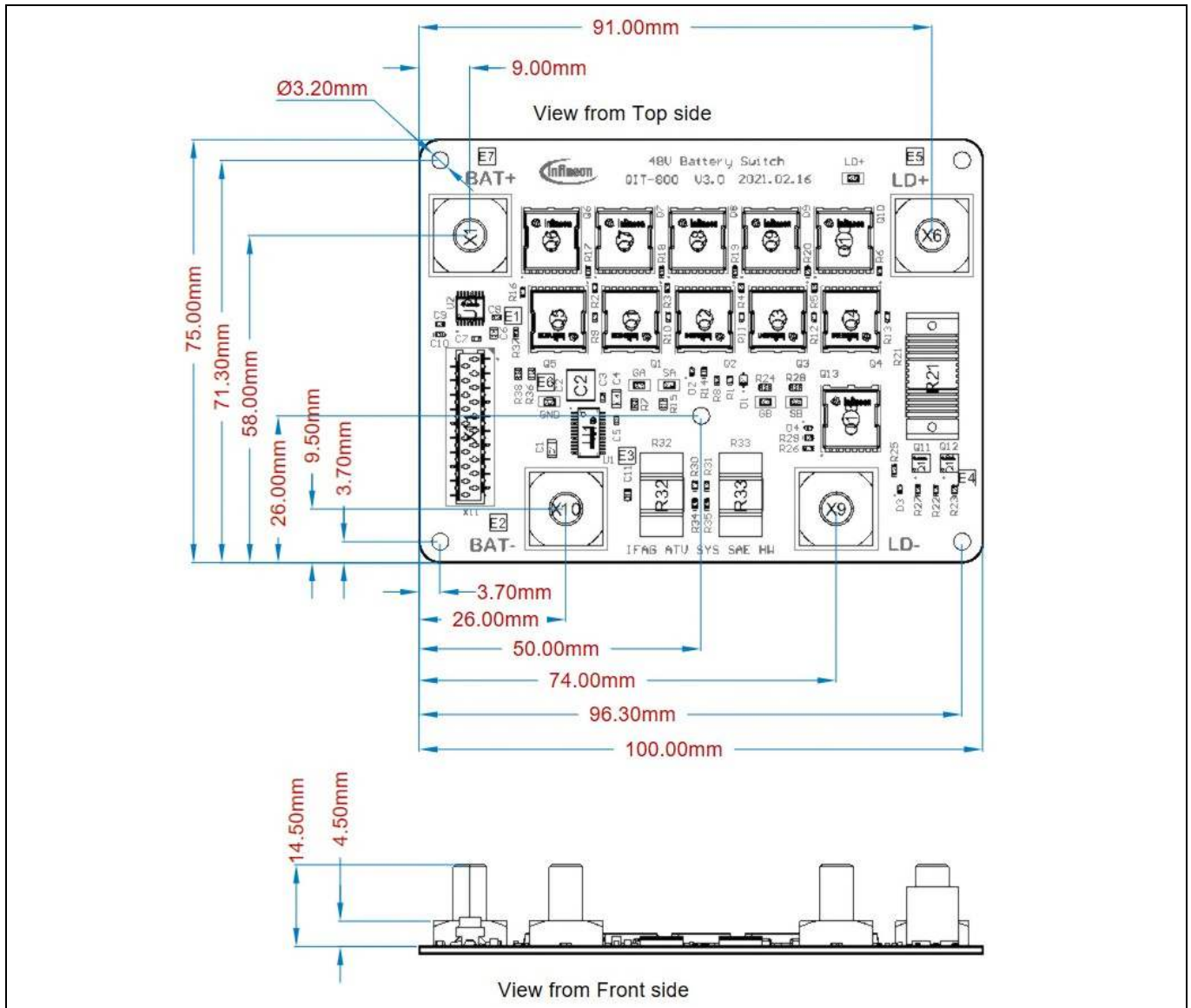


Figure 28 Power board dimensions

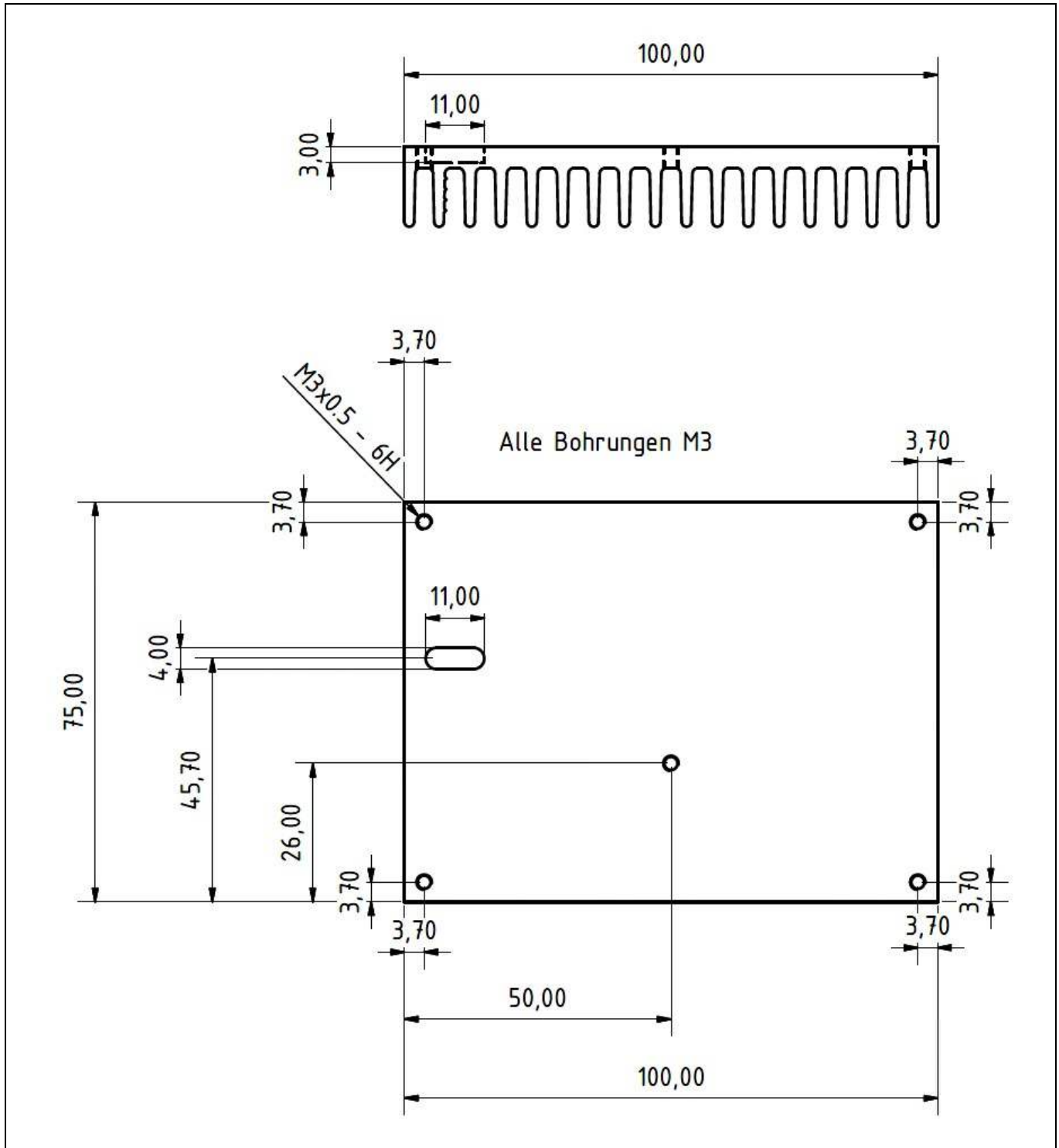


Figure 29 Heatsink dimensions

The heatsink is based on the SK 81/75/SA from Fischer Elektronik with a specified Rth of 2.5 K/W.

3.1.1 Power board schematics

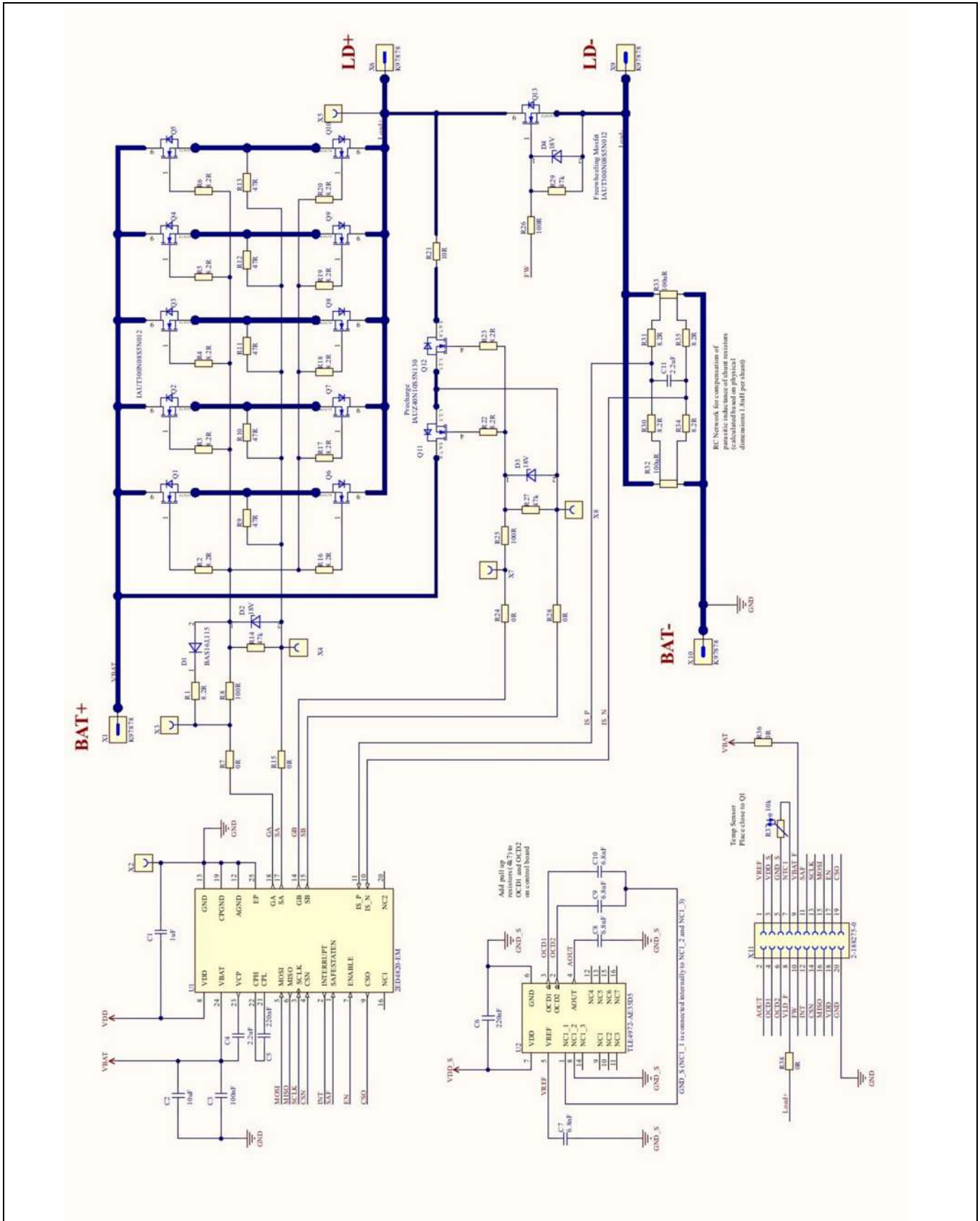


Figure 30 Power board schematics

3.1.2 Power board layout

The power board PCB is manufactured in the QIT technology from Schweizer Electronics AG. It is a three-layer board with an 800 μm inner copper core and two outer layers with 70 μm each.

In contrast to standard IMS (insulated metal substrate) boards the thick copper core can be structured and used to route high current PCB traces.

For a high current connection between the top layer and the copper core densely stitched microvias are used. Since these microvias are copper filled by design, SMD components can be soldered right on top of them, providing an excellent electrical and thermal connection to the thick copper layer in the middle.

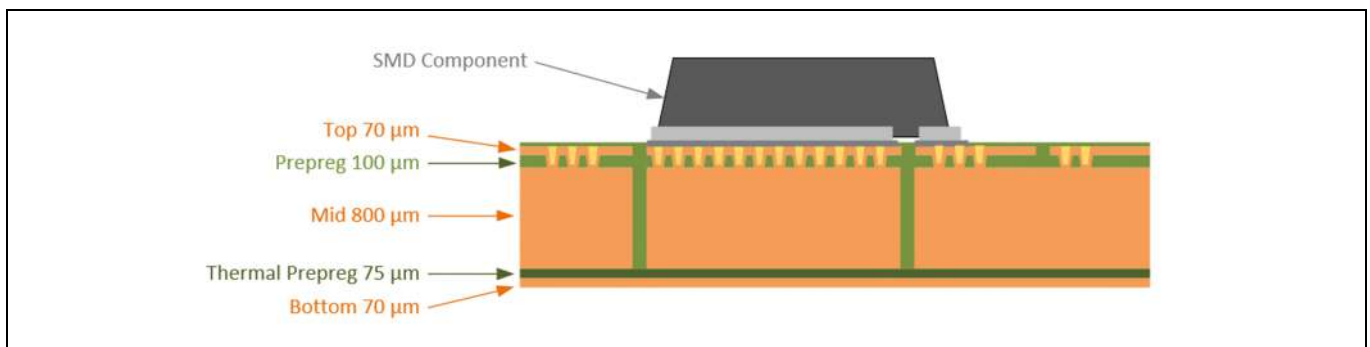


Figure 31 Power board PCB Layer Stack

Between the mid layer and the bottom layer a thermal prepreg with a conductivity of 1,8 W/mK provides electric isolation while still maintaining a good thermal performance. Therefore, there is no need for electrical isolation between the PCB and the heatsink, which allows the use of electrically conductive thermal interface materials.

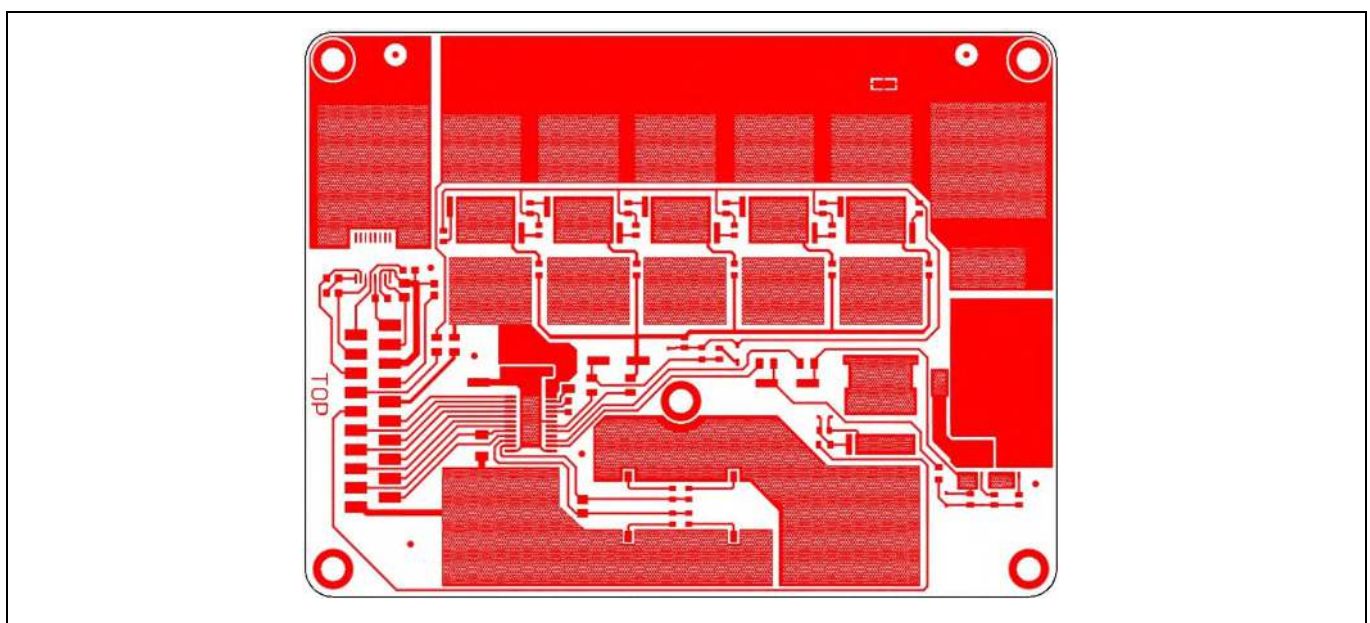


Figure 32 Power board top layer

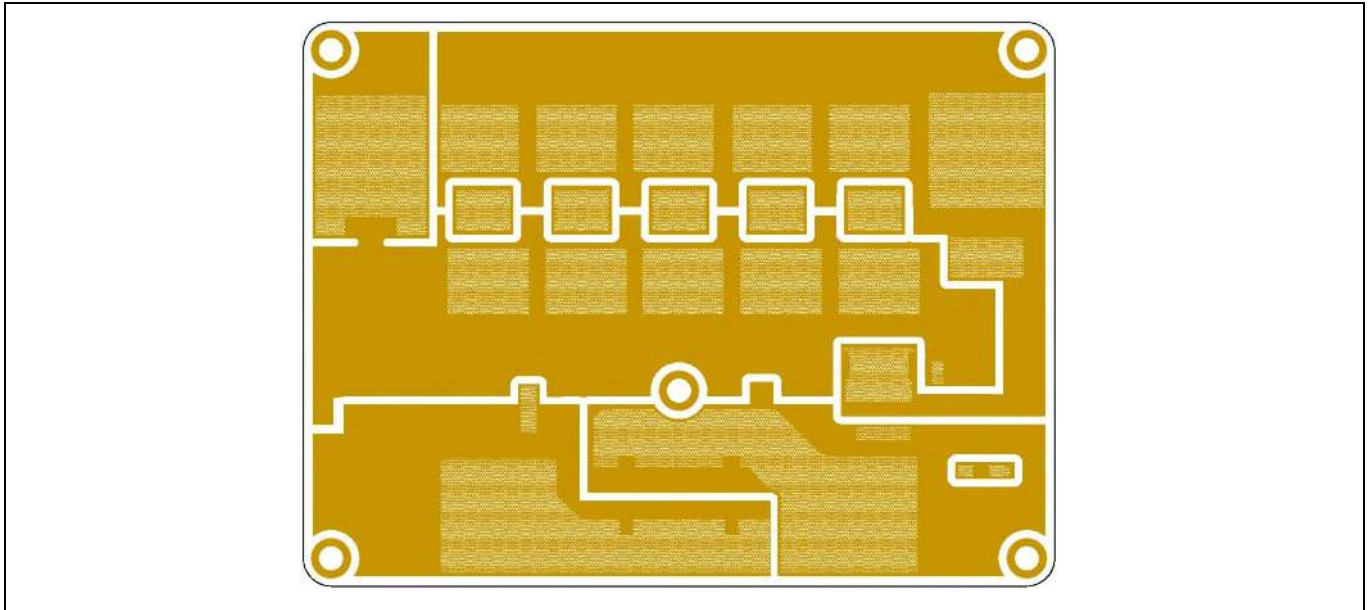


Figure 33 Power board middle layer

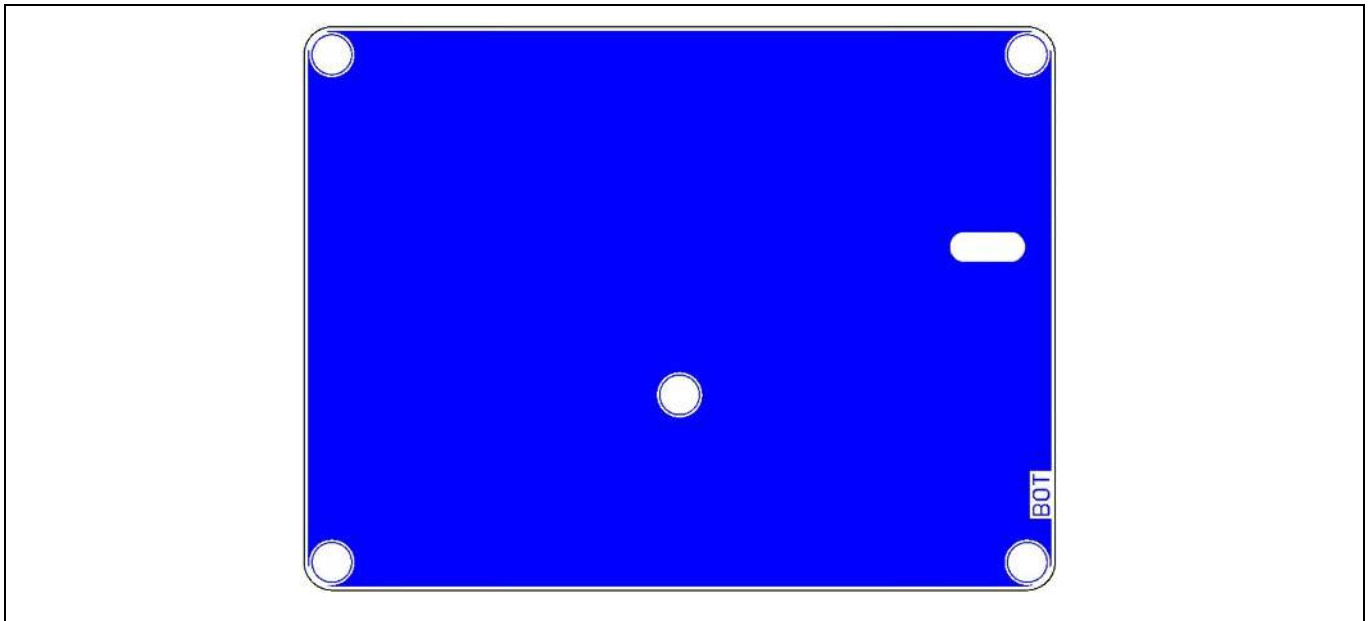


Figure 34 Power board bottom layer

3.1.3 Power board bill of material

Table 10 BOM Power Board

Qt.	Designator	Value	Package	Description	Manufacturer	Man. Ord. Num.
1	C1	1uF	1206	GRM-Series General Purpose Monolithic Ceramic Capacitor	MuRata	GRM31CR72A105KA01
1	C2	10uF	SMD	Multilayer Ceramic Chip Capacitor	TDK Corporation	CGA9N3X7S2A106K23 0KB
1	C3	100nF	603	Surface Mount Ceramic Capacitor	AVX	06035C104KAT2A
1	C4	2.2uF	CAPC321 6X180N	Chip Monolithic Ceramic Capacitor	MuRata	GRM31CR72A225KA73
1	C5	220nF	0603 (1608)	General Purpose Surface Mount Ceramic Capacitor	MuRata	GRM188R71H224KAC 4
1	C6	220nF	805	Multilayer Ceramic Capacitor	Kemet	C0805F224K5RACTU
4	C7, C8, C9, C10	6.8nF	CAPC160 8X90N	CAP / CERA / 6.8nF / 25V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	MuRata	GCM188R71E682KA37
1	C11	2.2uF	805	CAP / CERA / 2.2uF / 6.3V / 10% / X7R (EIA) / -55°C to 125°C / 0805 / SMD / -	Würth Elektronik	885012207001
1	D1	BAS16J,1 15	SOD323F (SC-90)	High-Speed Switching Diode, 100V	Nexperia	BAS16J,115
3	D2, D3, D4	18V	SOD-523	Zener Voltage Regulator	onsemi	MM5Z18VT1G
11	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q13	IAUT300 N08S5N0 12	PG-HSOF-8-1	OptiMOS 5 Power-Transistor, VDS 80V	Infineon	IAUT300N08S5N011
2	Q11, Q12	IAUZ40N 10S5N13 0	PG-TSDSON-8-33	OptiMOS 5 Power-Transistor	Infineon	IAUZ40N10S5N130
17	R1, R2, R3, R4, R5, R6, R16, R17, R18, R19, R20, R22, R23, R30,	8.2R	603	Standard Thick Film Chip Resistor, RES / STD / 8.2R / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603 / SMD / -	Vishay	CRCW06038R20FK

48V Battery Switch Reference Design

R 48V BATT Switch10



System design

Qt.	Designator	Value	Package	Description	Manufacturer	Man. Ord. Num.
	R31, R34, R35					
6	R7, R15, R24, R28, R36, R38	0R	805	RES / STD / 0R / 500mW / - / - / -55°C to 155°C / 0805 / SMD / -	Vishay	CRCW08050000Z0EAHP
3	R8, R25, R26	100R	603	RES / STD / 100R / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603 / SMD / -	Yageo	RC0603FR-07100RL
5	R9, R10, R11, R12, R13	47R	603	RES / STD / 47R / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603 / SMD / -	Yageo	RC0603FR-0747RL
3	R14, R27, R29	47k	603	Standard Thick Film Chip Resistor	Vishay	CRCW060347K0FK
1	R21	10R	SMD	Precision Power Wirewound SMD Resistor	ARCOL	RWS7 10R J
2	R32, R33	100uR	5931	RES / STD / 100uR / 15W / 1% / 300ppm/K / -65°C to 170°C / 5931 / SMD / -	Vishay	WSLP5931L1000FEA
1	R37	10k	603	NTC for Temperature Sensor	MuRata	NCP18XH103F03RB
1	U1	2ED4820-EM	PG-TSDSO-24-21	2 Channels High Side Gate Driver	Infineon	2ED4820-EM
1	U2	TLE4972-AE35D5	PG-TDSO-16	High precision coreless current sensor for AC/DC Measurements	Infineon	TLE4972-AE35D5
4	X1, X6, X9, X10	K97878	SMD	PowerOne SMD high current terminal	Würth Elektronik	K97878
6	X2, X3, X4, X5, X7, X8	RCT-0C		SMD Circuit Probe Pad	TE Connectivity	RCT-0C
1	X11	2-188275-0		Female Connector, ON Board, Top Entry, SMD, Micro Match, 20 Pins (Without Vacuum Tape)	TE Connectivity	2-188275-0

3.2 Adaptor board

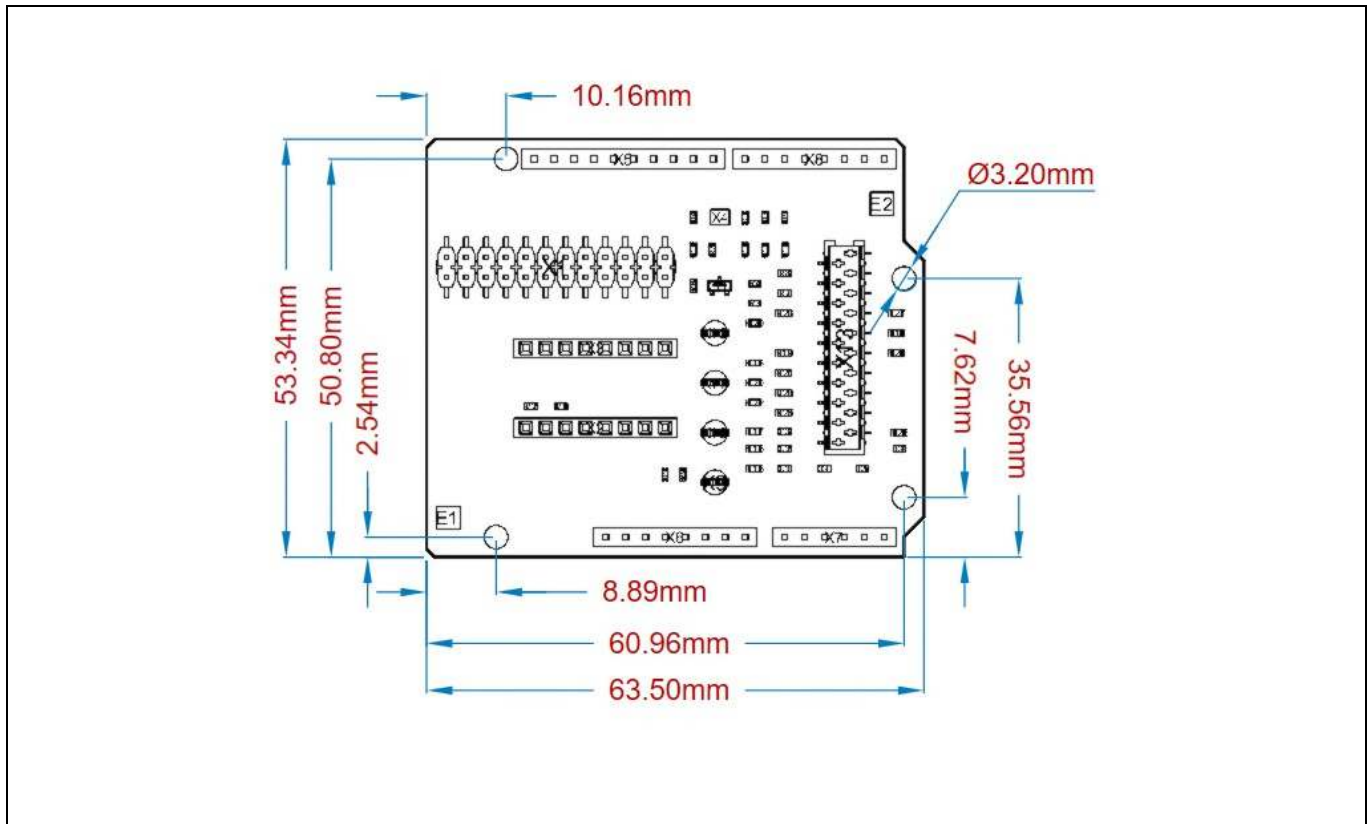


Figure 35 Adaptor board dimensions

3.2.1 Adaptor board schematics

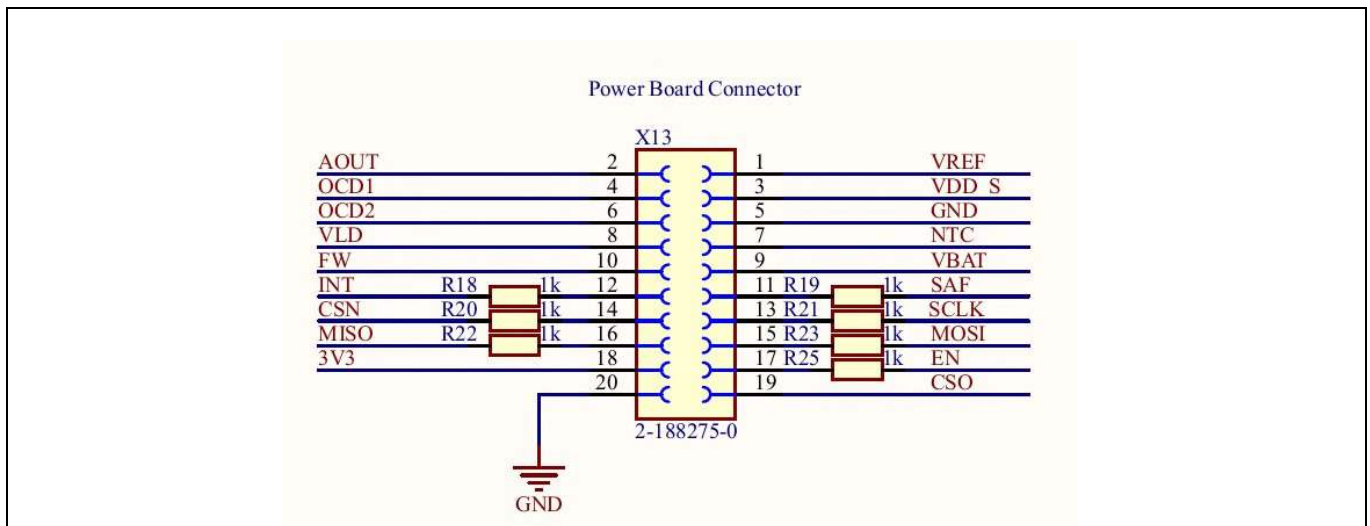


Figure 36 Adaptor board connector to power board

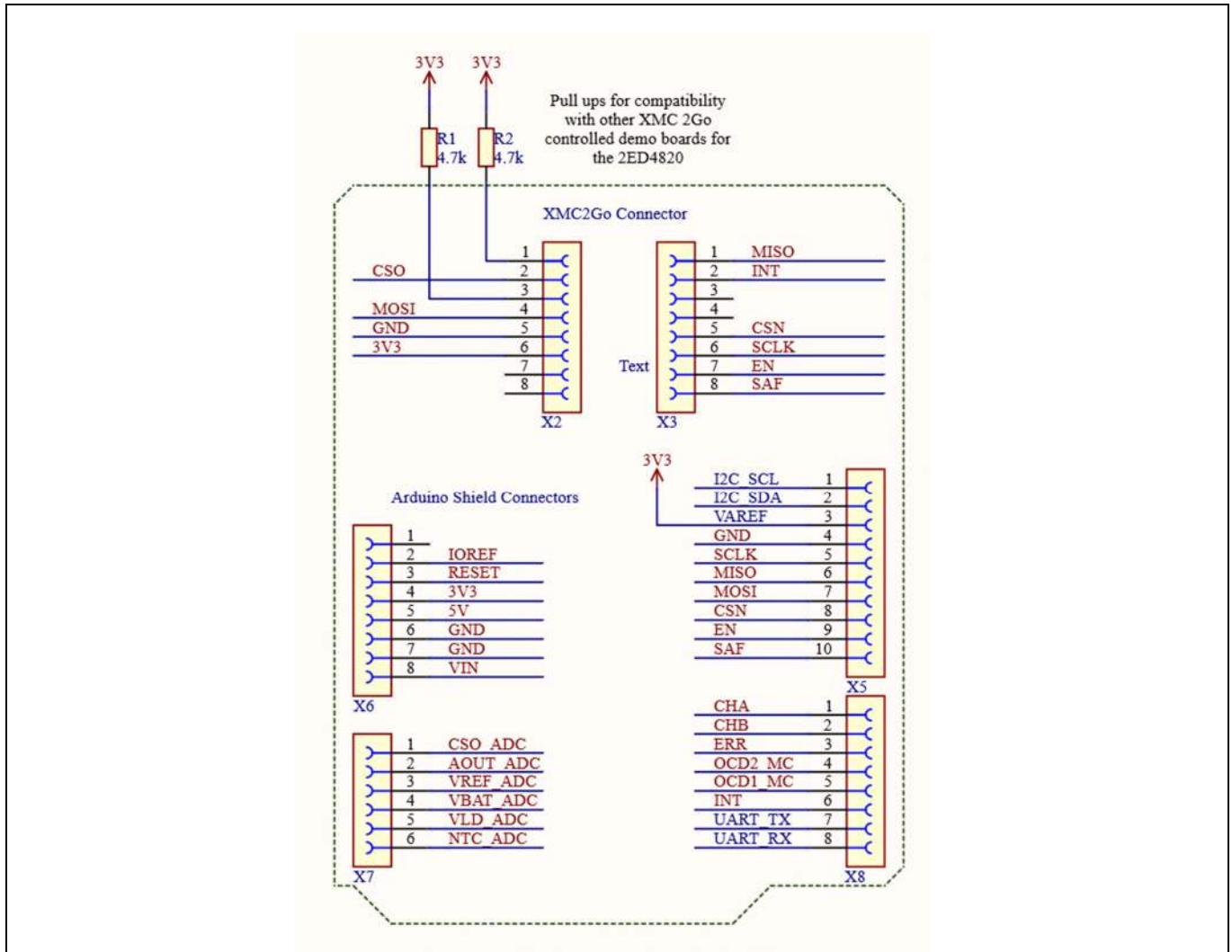


Figure 37 Adaptor board connectors to microcontroller

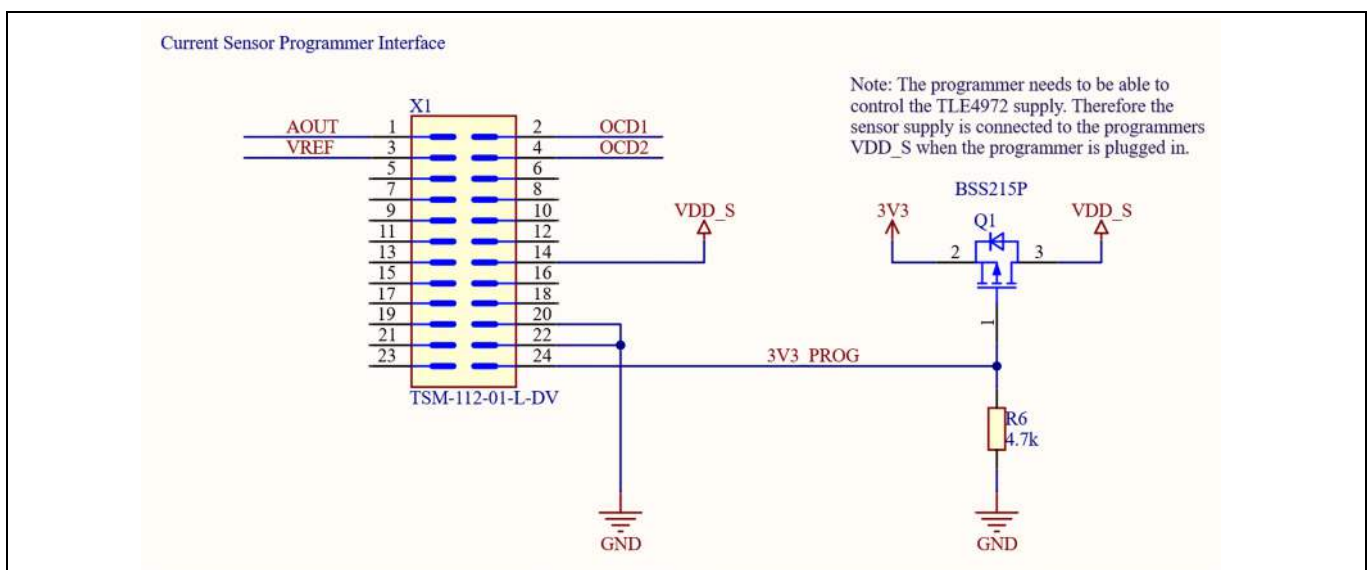


Figure 38 Adaptor board current sensor programmer interface

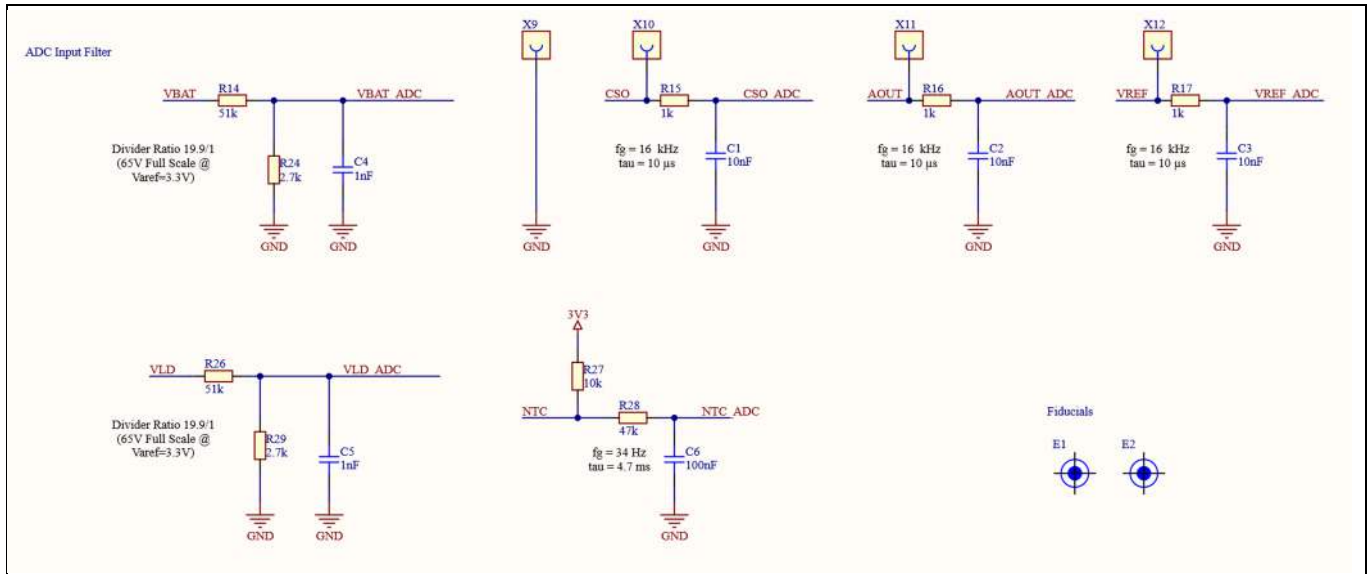


Figure 39 Adaptor board analog input filters

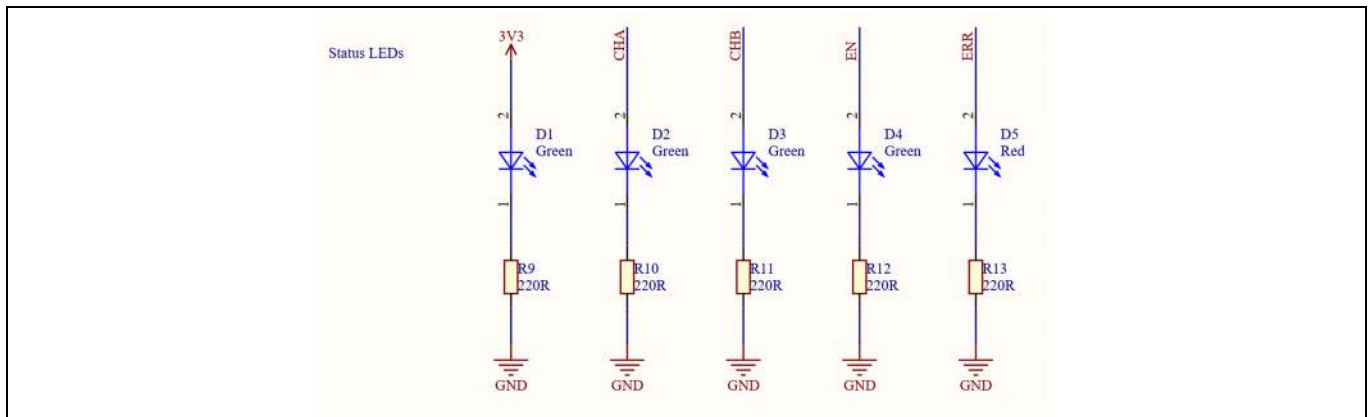


Figure 40 Adaptor board status LEDs

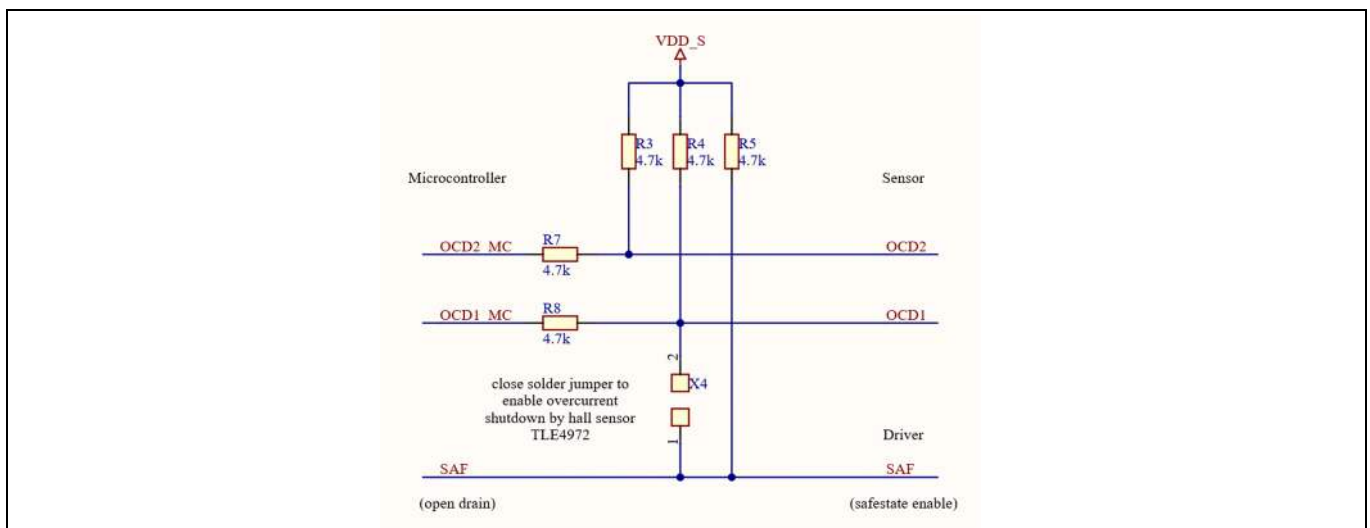


Figure 41 Adaptor board hall sensor connection of OCD

3.2.2 Adaptor board layout

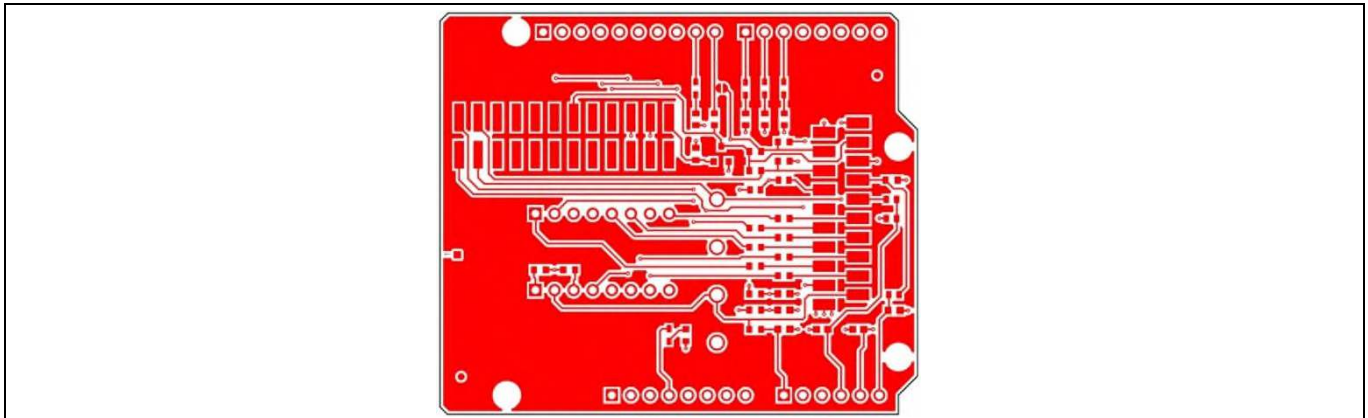


Figure 42 Adaptor board layer 1 - TOP

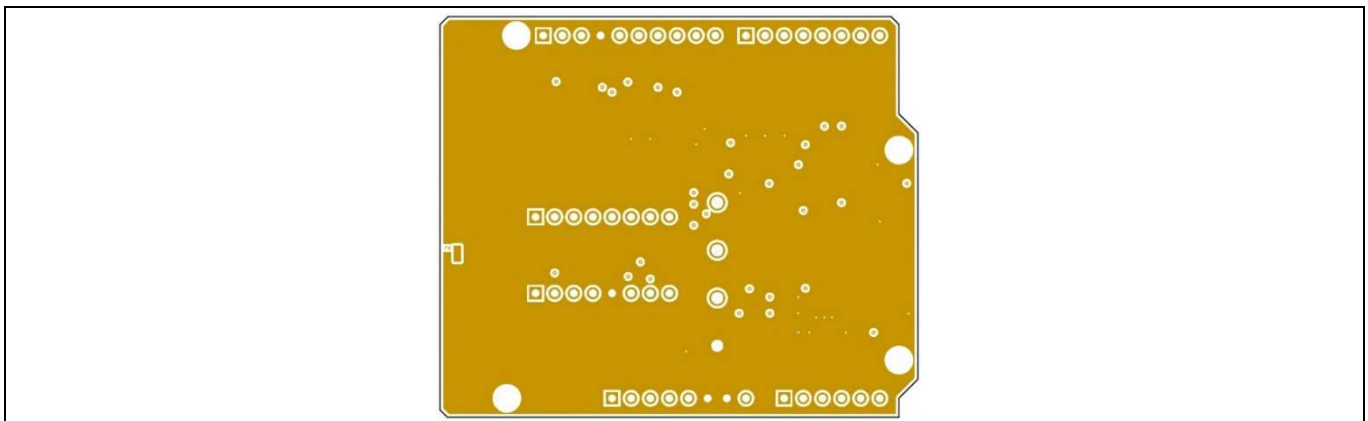


Figure 43 Adaptor board layer 2 - GND

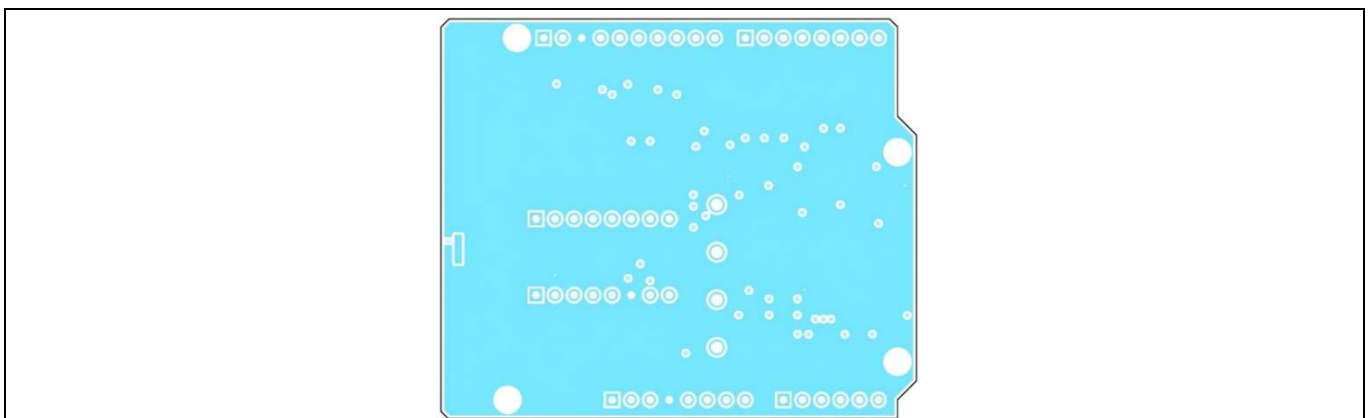


Figure 44 Adaptor board layer 3 - 3V3

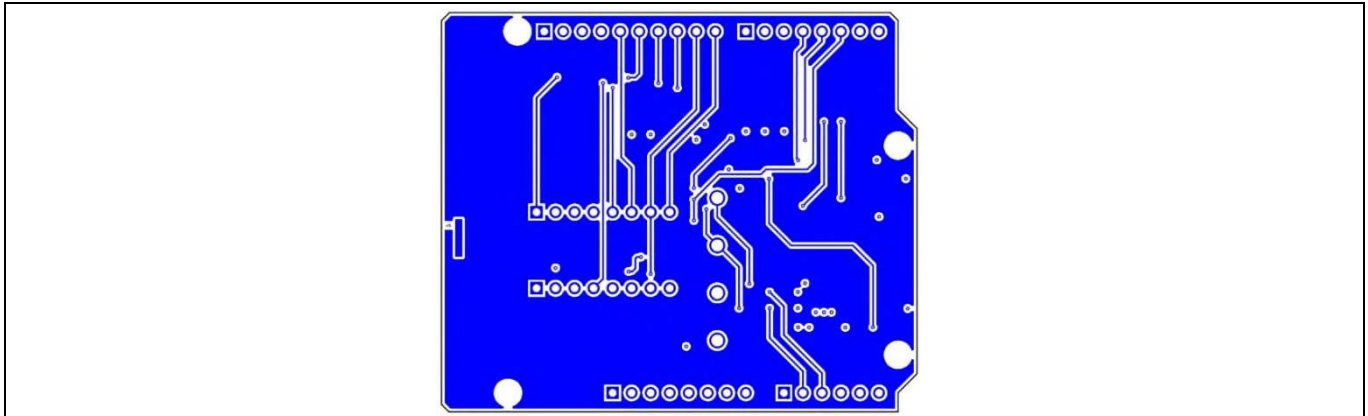


Figure 45 Adaptor board layer 4 - BOT

3.2.3 Adaptor board bill of material

Table 11 BOM Adaptor Board

Qt.	Designator	Value	Package	Description	Manufacturer	Man. Ord. Num.
3	C1, C2, C3	10nF	0603 (1608)	CAP / CERA / 10nF / 50V / 5% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	AVX	06035C103JAT2A
2	C4, C5	1nF	0603 (1608)	CAP / CERA / 1nF / 50V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	Würth Elektronik	8,85012E+11
1	C6	100nF	603	CAP / CERA / 100nF / 50V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	Kemet	C0603C104K5RACAUTO
4	D1, D2, D3, D4	Green	603	EXCELED Series Chip LED, Green, 560nm	ROHM Semiconductors	SML-D12P8WT86
1	D5	Red	1608 (0603)	EXCELED Series Chip LED, Red, 620nm	ROHM Semiconductors	SML-D12U8WT86
1	Q1	BSS215P	PG-SOT23-3-5	OptiMOS P2 Small-Signal-Transistor	Infineon	BSS215P
8	R1, R2, R3, R4, R5, R6, R7, R8	4.7k	603	RES / STD / 4.7k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603 / SMD / -	Yageo	RC0603FR-074K7L
5	R9, R10, R11, R12, R13	220R	603	RES / STD / 220R / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603 / SMD / -	Yageo	RC0603FR-07220RL

48V Battery Switch Reference Design

R 48V BATT Switch10



System design

Qt.	Designator	Value	Package	Description	Manufacturer	Man. Ord. Num.
2	R14, R26	51k	603	RES / STD / 51k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603 / SMD / -	Vishay	CRCW060351K0FK
10	R15, R16, R17, R18, R19, R20, R21, R22, R23, R25	1k	603	RES / STD / 1k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603 / SMD / -	Yageo	RC0603FR-071KL
2	R24, R29	2.7k	603	RES / STD / 2.7k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603 / SMD / -	Vishay	CRCW06032K70FK
1	R27	10k	603	RES / STD / 10k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603 / SMD / -	Yageo	RC0603FR-0710KL
1	R28	47k	603	Standard Thick Film Chip Resistor	Vishay	CRCW060347K0FK
1	X1	TSM-112- 01-L-DV		SMT .025 SQ Post Header, 2.54mm Pitch, 24 Pins, Vertical, Double Row	Samtec	TSM-112-01-L-DV
2	X2, X3	SSW-108- 01-G-S		Through hole .025" SQ Post Socket, 2.54mm pitch, 8 pin, vertical, single row	Samtec	SSW-108-01-G-S
1	X5	SSW-110- 03-T-S	THT	SMT 0.25 SQ post Socket Strip, 10 Pins, Single row	Samtec	SSW-110-03-T-S
2	X6, X8	SSW-108- 03-T-S	THT	SMT .025 SQ POST SOCKET, Single Row, 8 Pins	Samtec	SSW-108-03-T-S
1	X7	SSW-106- 03-T-S	THT	Socket Strip Straight 6 pins, Double Row, 2.54mm Pitch	Samtec	SSW-106-03-T-S
4	X9, X10, X11, X12	5007		PC Test Point- Compact THT, White	Keystone Electronics Corp.	5007
1	X13	2-188275-0		Female Connector, ON Board, Top Entry, SMD, Micro Match, 20 Pins	TE Connectivity	2-188275-0

4 System performance

4.1 Thermal performance

The power board is mounted on an aluminum heat sink for cooling. Due to the thermal prepreg layer between the middle and the bottom layer there is no need for extra isolation between the board and the heat sink. Even without adding thermal grease the performance is sufficient. With moderate air flow provided by a standard 12V PC fan running at low speed, located 20 cm away from the board, the maximum board temperature settles at 80°C after 30 minutes at 25°C ambient temperature. Figure 46 shows the temperature distribution across the board at the end of this test.

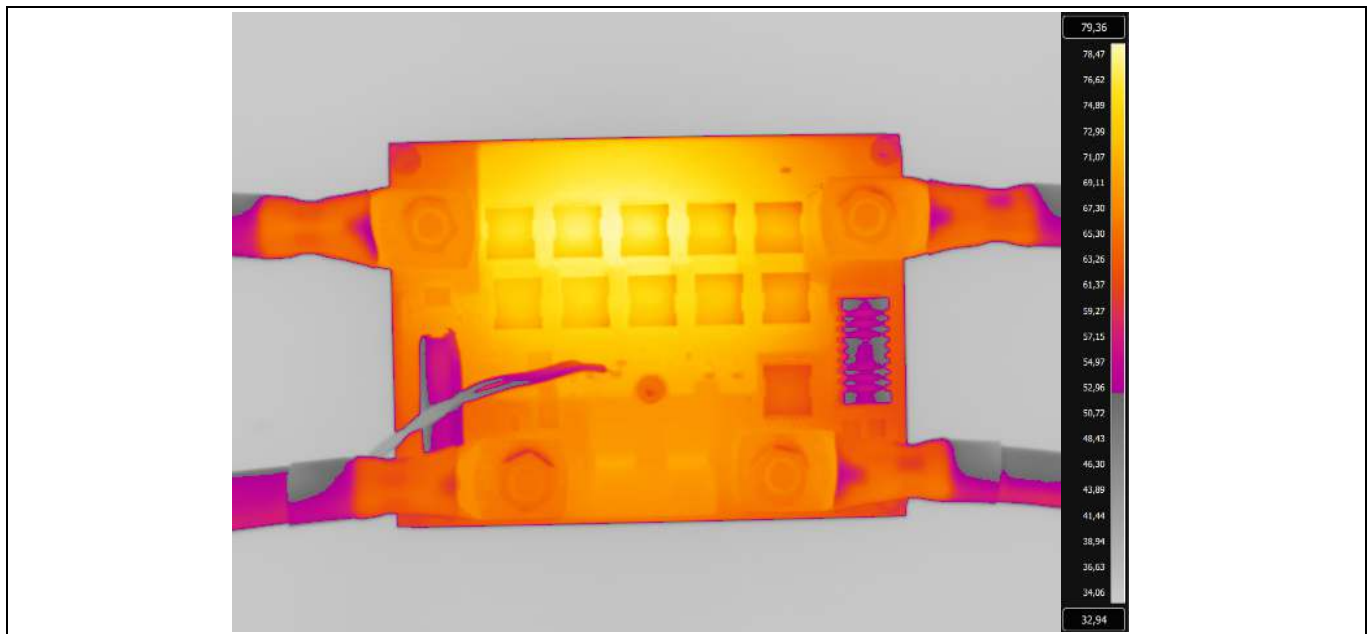


Figure 46 Temperature distribution after 30 min. at 300 A

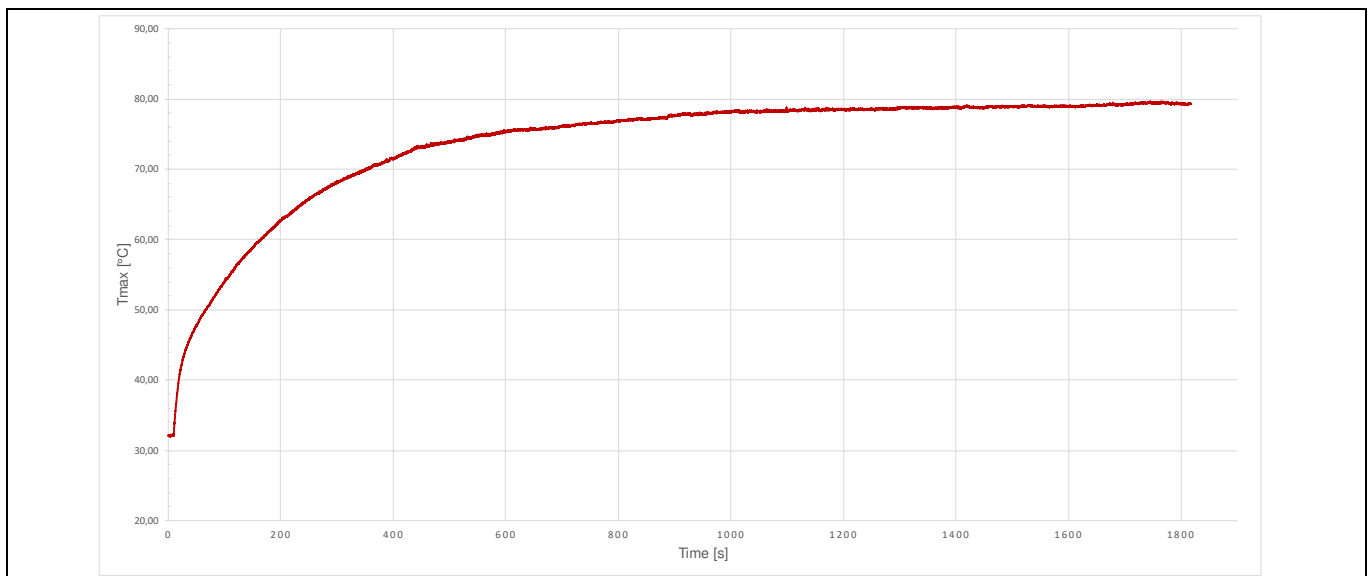


Figure 47 Temperature rise (max. board temperature at 300 A vs. time)

4.2 Precharging

As described in chapter 2.3 “Basic operation”, the precharge path will be activated for a configurable time before switching on the main path, when the switch is turned on by pressing button 1 or with the “on” command in the command line interface. This is done to avoid inadvertent tripping of the overcurrent detection due to excessive inrush currents caused by capacitive loads at the output.

Figure 48 shows the load voltage (VLD) and the load current (ILD) over time when switching on with a 10 millifarad capacitor as load with a precharge time of 500 ms. First the precharge path (channel B) is switched on and the current is limited by the 10 Ω precharge resistor. As the capacitor charges up, the current decreases exponentially. After the precharge time has expired, the main path (channel A) is activated and the remaining capacity gets charged with only the switch and cable resistance as current limitation which results in a short current spike.

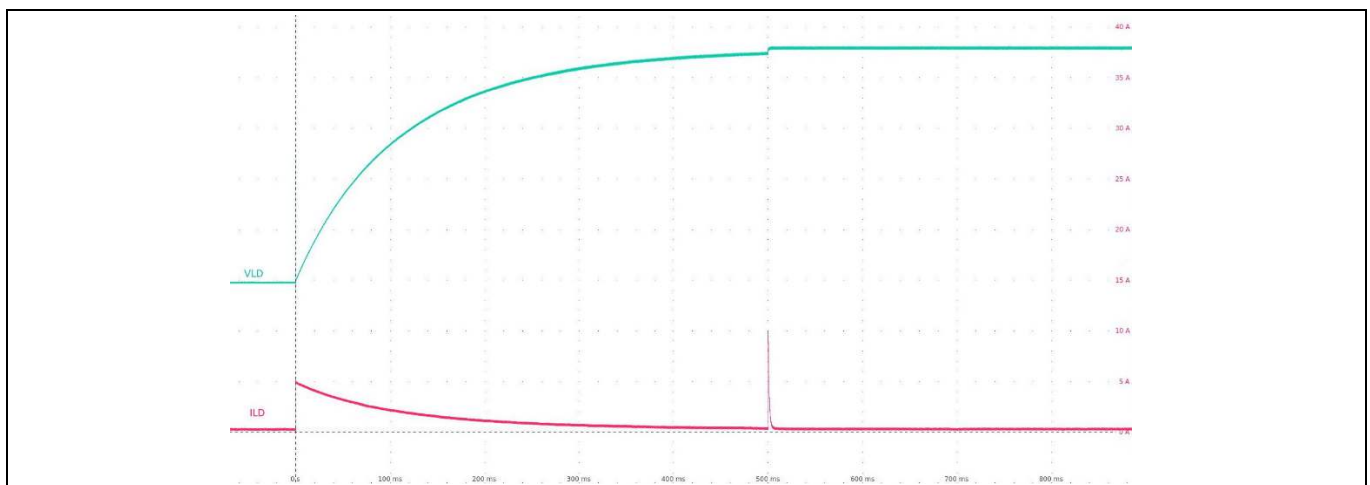


Figure 48 Switching on with 500 ms precharging pulse (10 mF load)

If the precharge time is shortened, the remaining capacity to be charged is bigger and therefore the current spike at activation of channel A is higher, as can be seen in Figure 49.

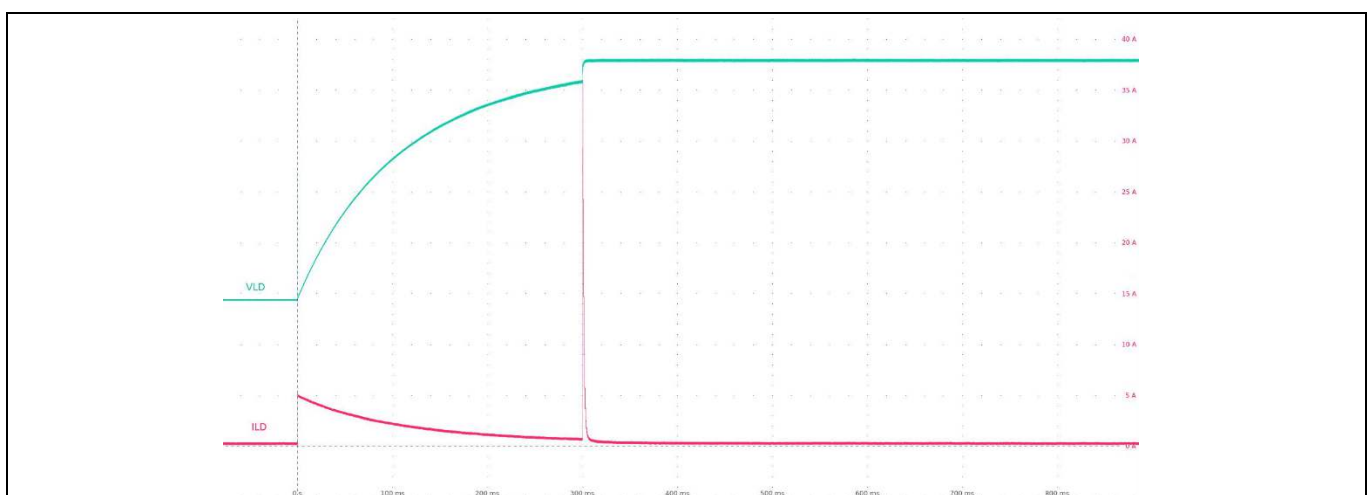


Figure 49 Switching on with 300 ms precharging pulse (10 mF load)

4.3 Overcurrent detection via shunt resistor

As described in chapter 2.4 “Configuration” the factory setting of the overcurrent shutdown threshold for the MOSFET gate driver is 413 A typical. Figure 50 shows the waveforms for a short circuit, applied to an activated switch without load. The green curve marked “Short” shows the trigger for the short circuit switch. When the short is applied, the load current (violet curve “ILD”) starts to rise linearly. The current slew rate is determined by the cable inductance. As soon as the overcurrent threshold is reached, the gate driver **2ED4820-EM** generates an interrupt signal (red curve “INT”) and switches off the MOSFETs.

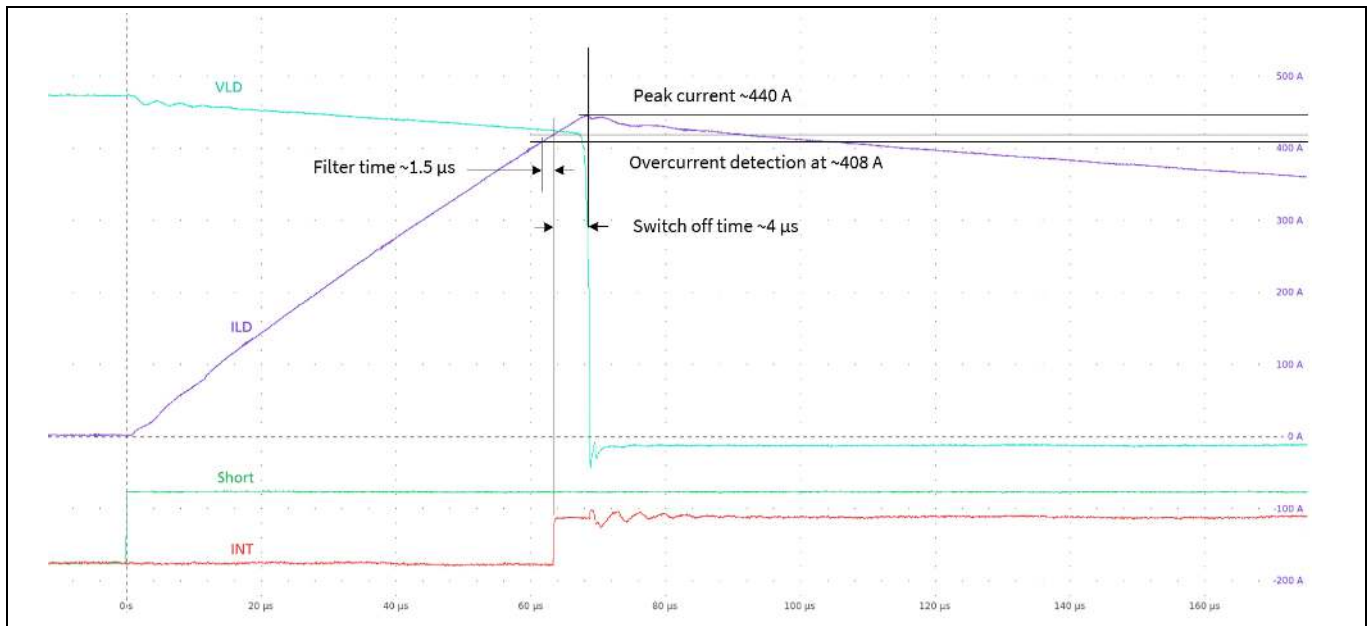


Figure 50 Overcurrent detection – 2ED4820-EM and shunt

Since there is a digital glitch filter time implemented of typically 1.5 μs, the actual overcurrent detection value is the current value at 1.5 μs before the INT signal goes high, in this case approximately 408 A. Deactivating the MOSFETs then takes roughly 4 μs. During this time the current continues to rise, which leads to a peak current of 440 A.

After the deactivation of the MOSFETs the energy stored in the cable inductance between the switch and the location of the short is dissipated by freewheeling through MOSFET Q13.

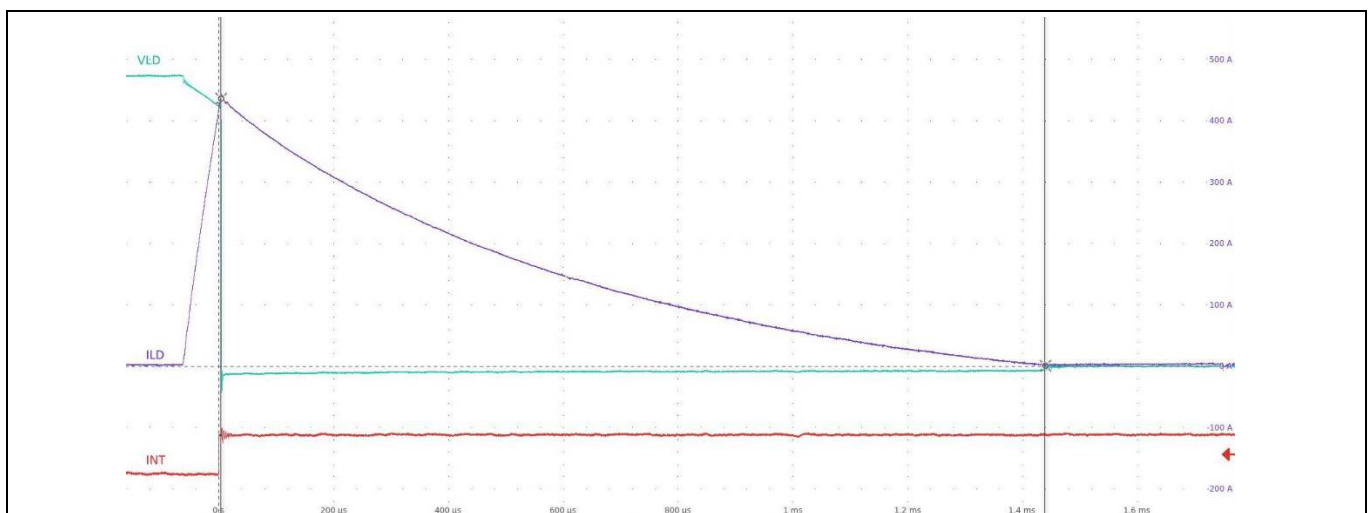


Figure 51 Freewheeling after switching off

4.4 Overcurrent detection with hall sensor

For testing the overcurrent detection of the hall based current sensor **TLE4972-AE35D5** the OCD1 output has to be connected to the SAFESTATEN input of the gate driver **2ED4820-EM** as described in Figure 15. The overcurrent detection threshold of the 2ED4820-EM needs to be disabled by setting it to a significantly higher value in order not to interfere with the hall sensor measurement.

The overcurrent detection threshold OCD1 of the hall sensor is factory-set to 389 A (see Table 4). Depending on the current slew rate the actual current value at start of the switch deactivation may be higher as can be seen in Figure 52. This is caused by time constants of the magnetic circuit formed by the current rail and the hall sensor probes, which lead to a low pass behaviour of the current sensor.

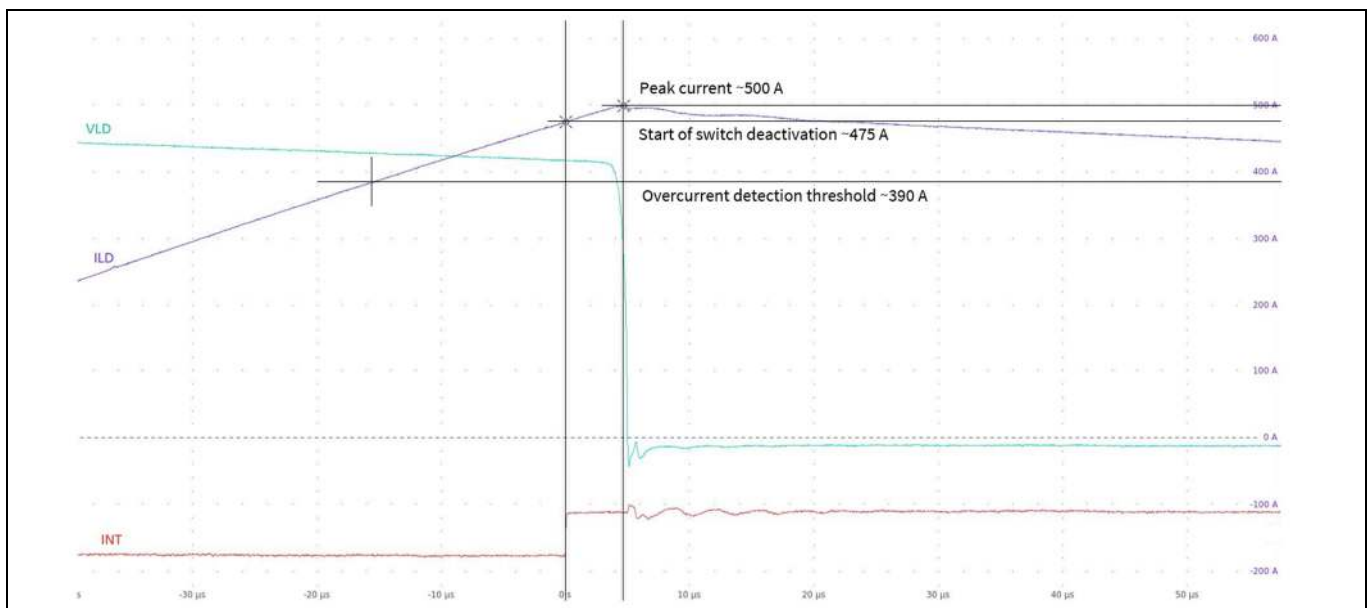


Figure 52 Overcurrent detection – hall sensor TLE4982-AE35D5

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Revision history

Document version	Date of release	Description of changes
Rev. 1.0	2022-03-09	Initial release

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Edition 2022-03-09

Published by

Infineon Technologies AG

81726 Munich, Germany

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Document reference

UG-2021-20

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