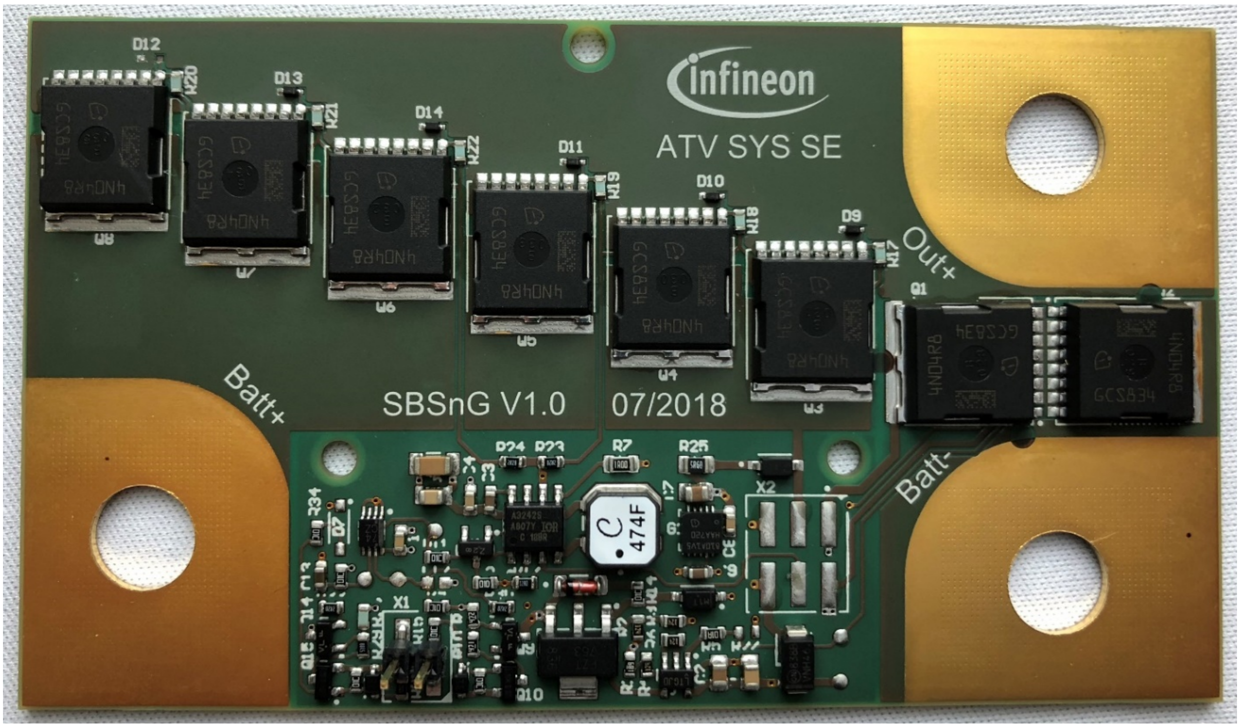
SBS nextGen Demonstrator

Board User Manual



About this document

Scope and purpose

This Board User Manual provides a short introduction to the 12 V Smart Battery Switch (SBS) nextGen Demonstrator and its application.

Intended audience

Electrical engineers who are qualified and familiar with the challenges of handling high current circuits as well as automotive relays or solid state switches.

Note: *The SBS nextGen Demonstrator is only intended to be used as an engineering demonstrator. It is not intended for extensive use or to be re-used in a product or system that is sold to consumers.*

Table of contents

1 Overview

The SBS nextGen Demonstrator shows a semiconductor based solution of a unidirectional battery master switch for automotive electrical systems with active or passive freewheeling feature.

Note: *This demonstrator does not cover all aspects of diagnostics. Its focus lies solely on the switching element and the demonstration of the current carrying and short circuit handling capabilities.*

The demonstrator consists of six MOSFETs with very low on resistance (R_{DSON}) connected in parallel. The switches are mounted on a structured 1 mm copper inlay board 2.0, manufactured by Schweizer Electronic AG. For more information see section 7.1. A gate driver circuitry for controlling the ON and OFF states of the MOSFETs is also embedded in the demoboard circuitry. The top and bottom views of the PCB board are illustrated in Figure 1 and Figure 2. Two additional MOSFETs are used to implement active freewheeling and reverse polarity protection features on the board.

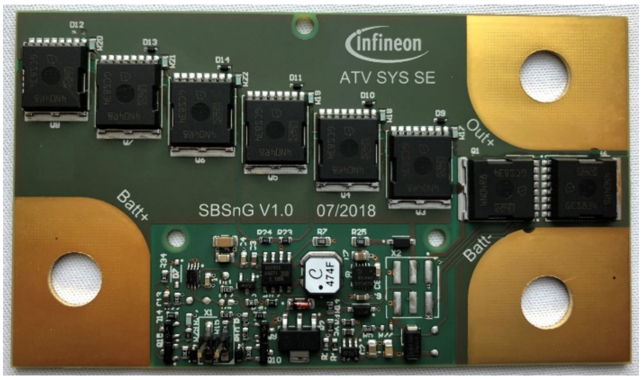


Figure 1 Top View

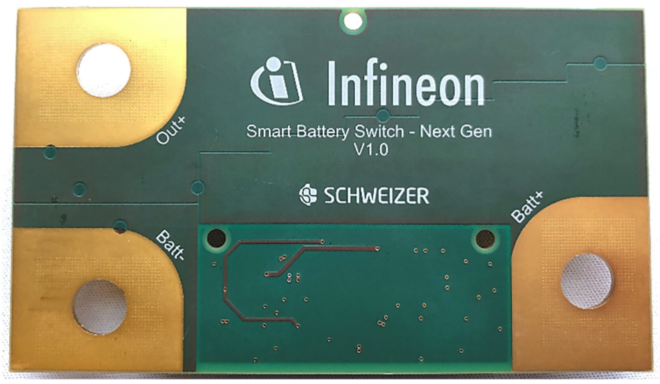


Figure 2 Bottom View.

The main components used for the SBS nextGen Demonstrator are listed in Table 1.

Table 1 Main Components

Component	Type	Comment
MOSFETs (6x)	IPLU300N04S4-R8	300 A, 40 V, 0.53 mOhm typ.
MOSFET	IPLU300N04S4-R8	Active/Passive Freewheeling
MOSFET	IPLU300N04S4-R8	Reverse Polarity Protection
Gate Driver	AUIR3242S	Input latched through Flip Flop, initial state after power up is normally on

Thanks to the low ohmic MOSFETs, the typical on state resistance of the whole switch is less than 160 uΩ, measuring from the positive battery terminal to output terminal at room temperature. The six parallel MOSFETs account for typically 88 uΩ at room temperature. At 120°C board temperature and 500 A current this value will increase to roughly 125 uΩ.

Please note that the SBS nextGen Demonstrator is a unidirectional switch. This means that it will interrupt current flowing from the battery to the load but not current flowing into the battery. The reason for this is the intrinsic body diode of the power MOSFETs as shown in Figure 3. Therefore charging through the MOSFETs should be avoided or at least limited to currents below 20 A when the switch is deactivated (off).

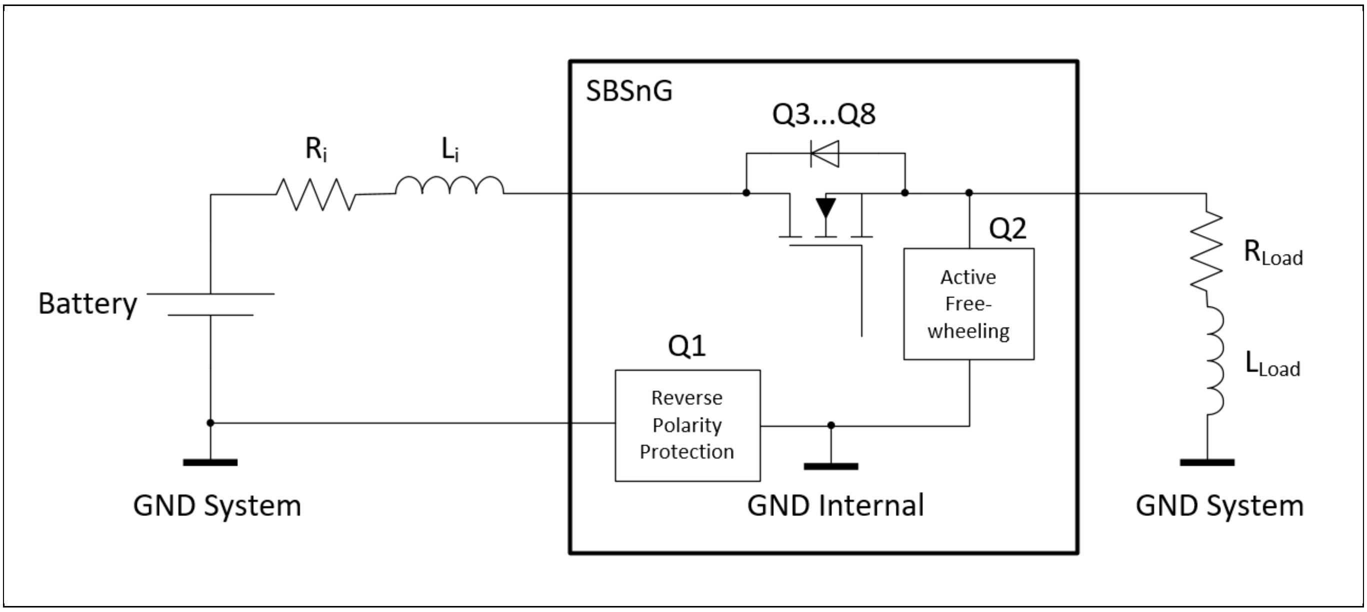


Figure 3 **Block Diagram of Unidirectional Switch due to MOSFET Body Diode**

In Figure 3 the block diagram of the battery switch is given. R_i and L_i are lumped elements for resistance and inductance connected to the input terminal of the battery switch. They are coming from the internal construction of the battery and the cabeling to the switch. R_{Load} and L_{Load} are lumped elements which represent the load connected to the output terminal of the battery switch.

The internal GND is protected against reverse polarity connection though a MOSFET added in the GND Path. The active freewheeling feature is implemented through a MOSFET between “GND Internal” and “Out+”. Figure 27 is showing a detailed description of the circuitry responsible for reverse polarity protection and active freewheeling.

2 Connecting the Switch

In this chapter the control of the SBS nextGen Demonstrator is discussed. There is only one assembly option for 12 V electric systems with active freewheeling feature available. The switch shall be connected between battery and load as pictured in Figure 4.

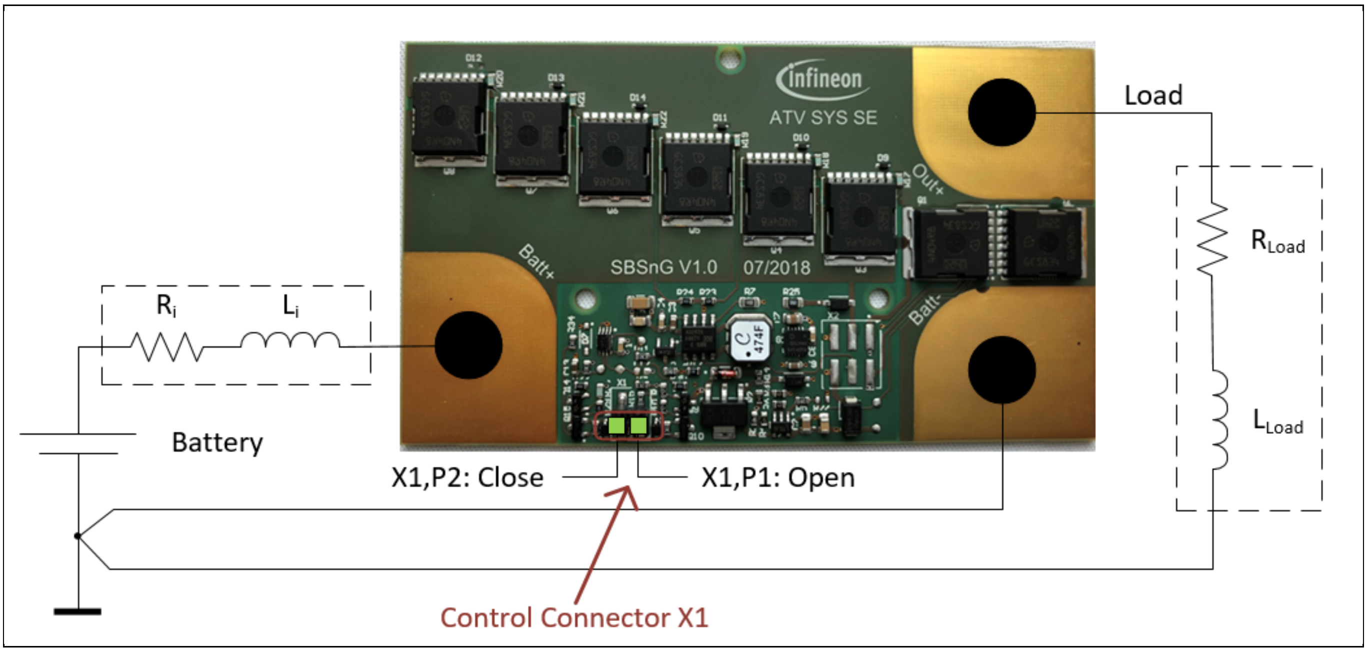


Figure 4 **Basic Connection Diagram**

During a shut off event, the energy which is stored in the inductances of the circuitry need to be released via avalanche and freewheeling.

The energy which is stored in L_{Load} behind the MOSFETs will decay by freewheeling through the active freewheeling circuitry. Energy which is stored in L_i and energy which is coming out of the battery will be dissipated to heat through an avalanche event in the MOSFETs [1]. Keep the connection from battery poles to the SBS nextGen Demonstrator as short as possible. This will keep the total inductance L_i and total resistance R_i in front of the switching MOSFETs as small as possible.

In chapter 3, the operating conditions and the thermal behaviour of the SBS nextGen Demonstrator are shown. A description to change from active freewheeling to passive freewheeling is given.

More information about the switching behaviour and switching constraints can be found in chapter 4.

Mechanical dimensions of the board and mounting holes can be found in chapter 5. Furthermore the schematic, PCB design and technology as well as the bill of materials are disussed in chapter 6, 7 and 8.

2.1 Pin Assignment

In Figure 5 the control logic of the SBS nextGen is shown. The initial state of the battery switch is conducting, after connecting it to the voltage of the battery, it is normally on like a pyro-electric fuse. The switch is controlled by logic pulses on Header X1. It is a standard 2-pin single row 2.54 mm header (Samtec, TSM-102-01-T-SV).

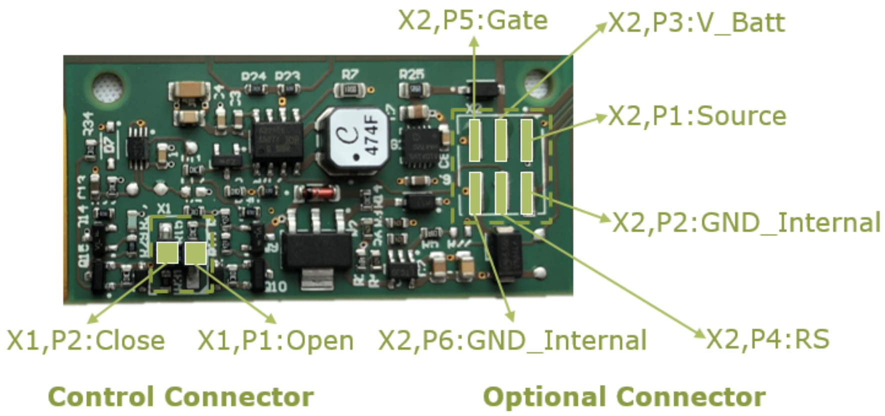


Figure 5 Pin Assignment of Control Connector X1 and Optional Connector X2

Table 2 and Table 3 are showing the pin description and the truth table of the SBS nextGen Demonstrator respectivly. The corresponding states of the battery switch are latched through a D-type flip-flop.

Table 2 Description of X1 Connector

Pin	Name	Function
X1,P1	Open	Positive Pulse disconnects the battery from the load(1)
X1,P2	Close	Positive Pulse resets the switch and connects battery with the load(1)

1) Min. Pulsewidth = 100 us; Max. Frequency = 1 Hz, Continous high level on the inputs should be avoided.

Table 3 Logic Table of X1

Open	Close	SBS nextGen State
LOW	LOW	Unchanged
LOW	HIGH	ON
HIGH	LOW	OFF
HIGH	HIGH	OFF

There is a second connector placed on the board. Via this connector it is possible to measure additional signals on the SBS nextGen Demonstrator (see Table 4). It is a standard 6-pin dual row 2.54 mm header (Samtec, TSM-103-01-T-DV).

Table 4 **Descripiton of X2 Connector**

Pin	Name	Function
X2,P1	Source	Source potential of switching MOSFETs (Q3…Q8)
X2,P2	GND_Internal	Reverse polarity protected GND, see Figure 3
X2,P3	V_Batt	Drain potential of switching MOSFETs (Q3…Q8)
X2,P4	RS	Analog Diagnostic Pin of AUIR3242S
X2,P5	Gate	Gate output of AUIR3242S
X2,P6	GND_Internal	Same Level as GND_Internal

2.2 Input Voltage Range of Control Pins X1

The input will accept a very wide input voltage range. Therefore it is possible to drive the switch with 5 V logic as well as directly from the battery voltage.

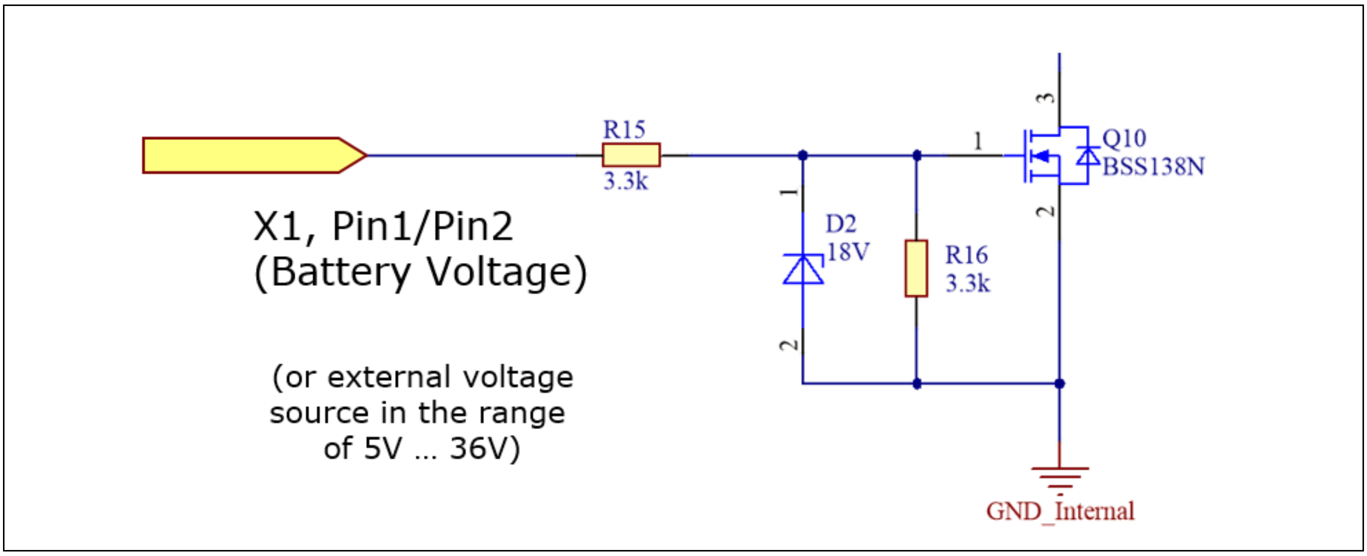


Figure 6 **Input Stage**

3 Operating Conditions

3.1 Voltage Rating and Current Consumption

Figure 7 shows the operating range of the 12 V SBS nextGen Demonstrator. The nominal operating voltage for the Demonstrator is 7 V to 18 V. It is activated by connecting a voltage higher than 7V to its input terminals “Batt+” and “Batt-“. If the electric system is facing an undervoltage, the switch stays on until the voltage is falling below 3 V. During undervoltage condition, the SBS nextGen Demonstrator can be deactivated at any time. It is not possible to activate the switch in the range of undervoltage, to do so, the voltage of the electric system needs to be guided back to the operating range. The switch can handle small overvoltage events, no permanent operation in the overvoltage range is allowed.

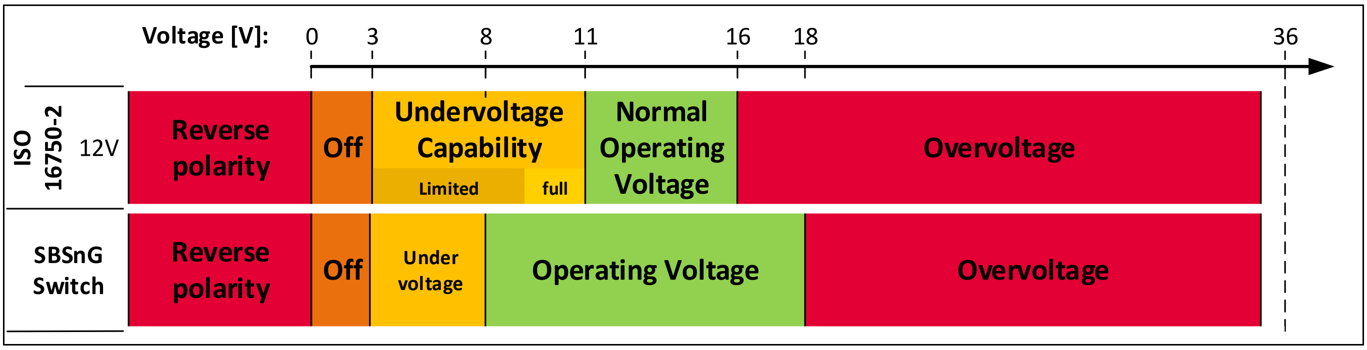


Figure 7 Operating Voltage Range

The 12 V SBS nextGen Demonstrator is delivered with active freewheeling feature assembled. It has a maximum current consumption of 370 µA in on state and 490 µA in off-state. The current consumption of the SBS nextGen Demonstratoris caused mainly by the comparator circuit for active freewheeling detection. See Table 5 for more information about typical current consumption of each device in on state.

Table 5 Current consumption per device

Device	Typ. current consumption in on state
AUIR3242S	35 µA
LT6015	315 µA
74LVC2G74	0.1 µA

The current consumption of the 12 V SBS nextGen Demonstrator can be further reduced, if the active freewheeling circuitry is removed. To do so R1 … R6 and U1 needs to be removed and R27 needs to be placed on the board, to short Gate and Source of the Freewheeling MOSFET Q1. Figure 8 is depicting which rework is needed to change to passive freewheeling.

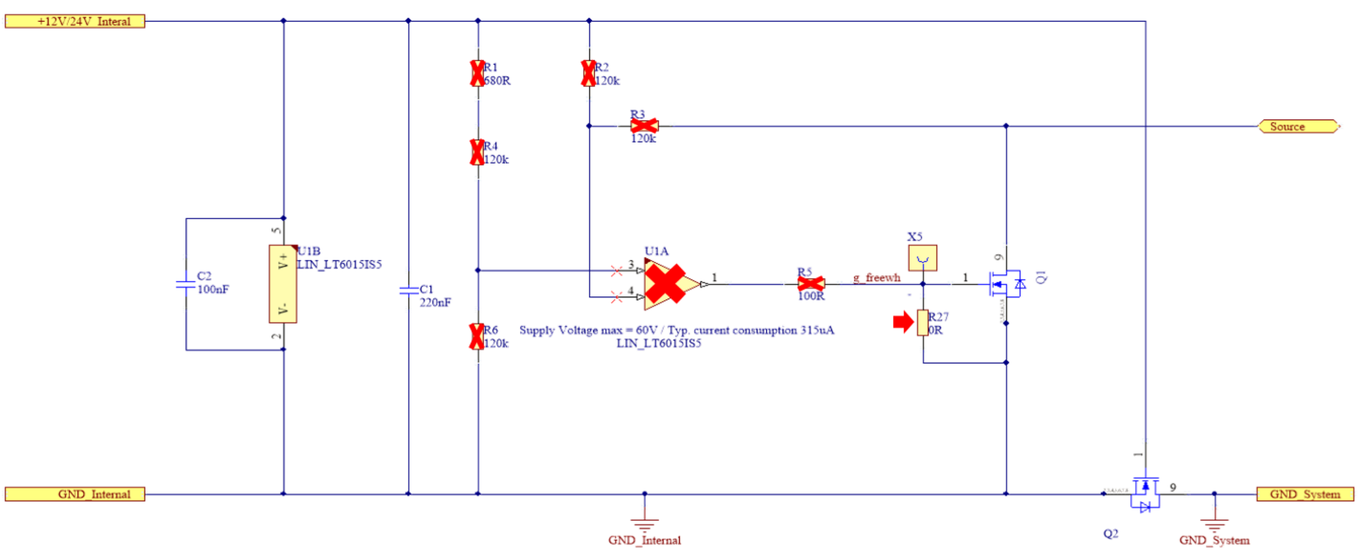


Figure 8 **Changes needed going from active to passive freewheeling**

Figure 9 is showing the difference in current consumption for both freewheeling options. For passive freewheeling the maximum current consumption in on state is about 54 µA and in off state 110 µA.

Note: *Passive freewheeling is increasing the amount of energy which is decayed inside MOSFET Q1. If this feature is assembled, the user needs to take special care about this amount of energy. Which means, inductance, switch off current or operating temperature needs to be limited. It is recommended to stay inside the SOA of the MOSFET, for more information consult the data sheet [2].*

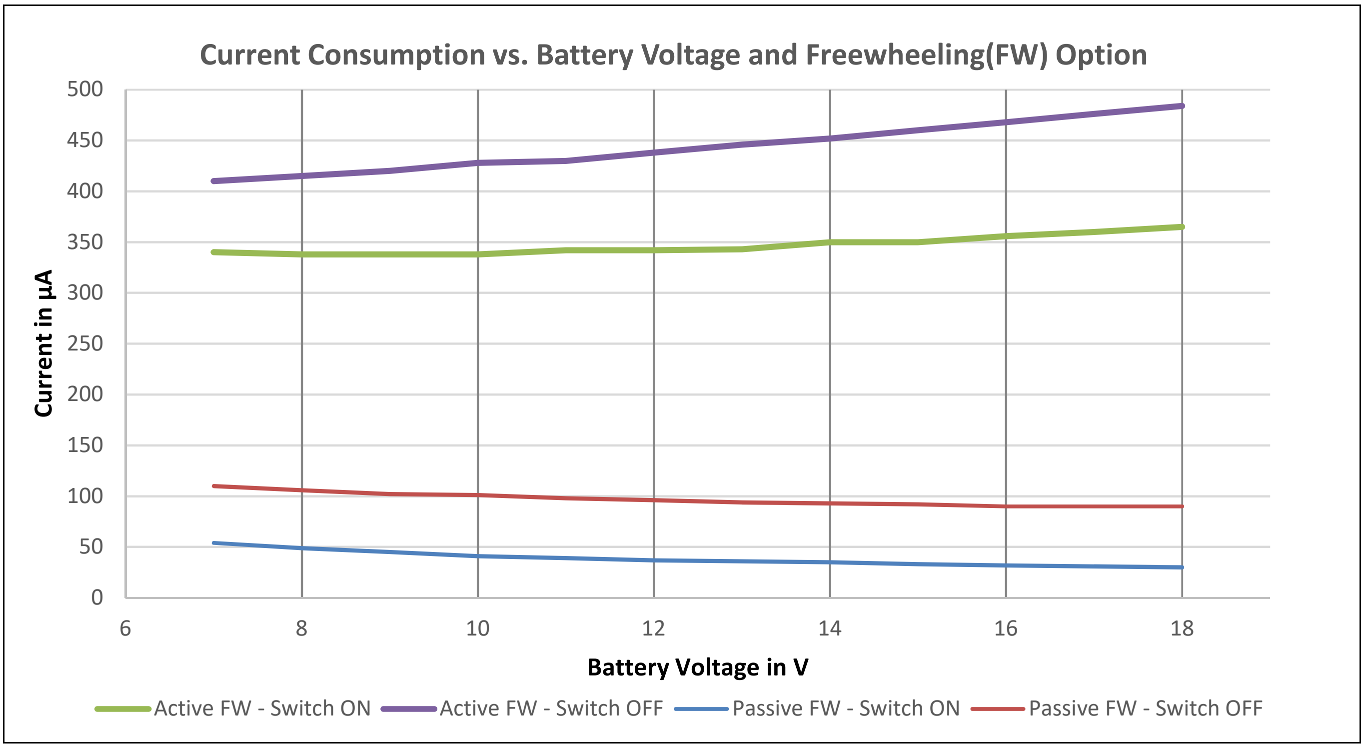


Figure 9 **Current Consumption vs. Battery Voltage**

3.2 Current Carrying Capability and Thermal behaviour

The switch is designed to handle peak currents up to 1800 A. However, due to the on-state resistance of the battery switch (160 uΩ typ. at 120°C) high currents will lead to significant power dissipation and a temperature increase in the MOSFETs. The chip can handle a maximum junction temperature of 175°C. Therefore the maximum allowable duration for high currents is limited depending on the cooling conditions. The values in Table 6 are measured for the board exposed to a small air flow velocity of approximately 30 cm/s. and a start temperature of 25°C.

Table 6 Current Carrying Capability Estimation @ 25°C Ambient Temperature, 70 mm² Cables

Current	Power Dissipation	Duration
300 A	~ 15 W	Continuous
500 A	~ 40 W	~ 15 min.
700 A	~ 80 W	~ 2 min.

The thermal measurement setup can be found in Figure 10 and Figure 11. The package temperature of each switching MOSFET was measured with a thermo couple. Also the input and output terminals, as well as the temperatures of the cables, in distance of 40 cm were measured. This was done to estimate the rate of heat flow, which can be used as a starting point for thermal simulations.

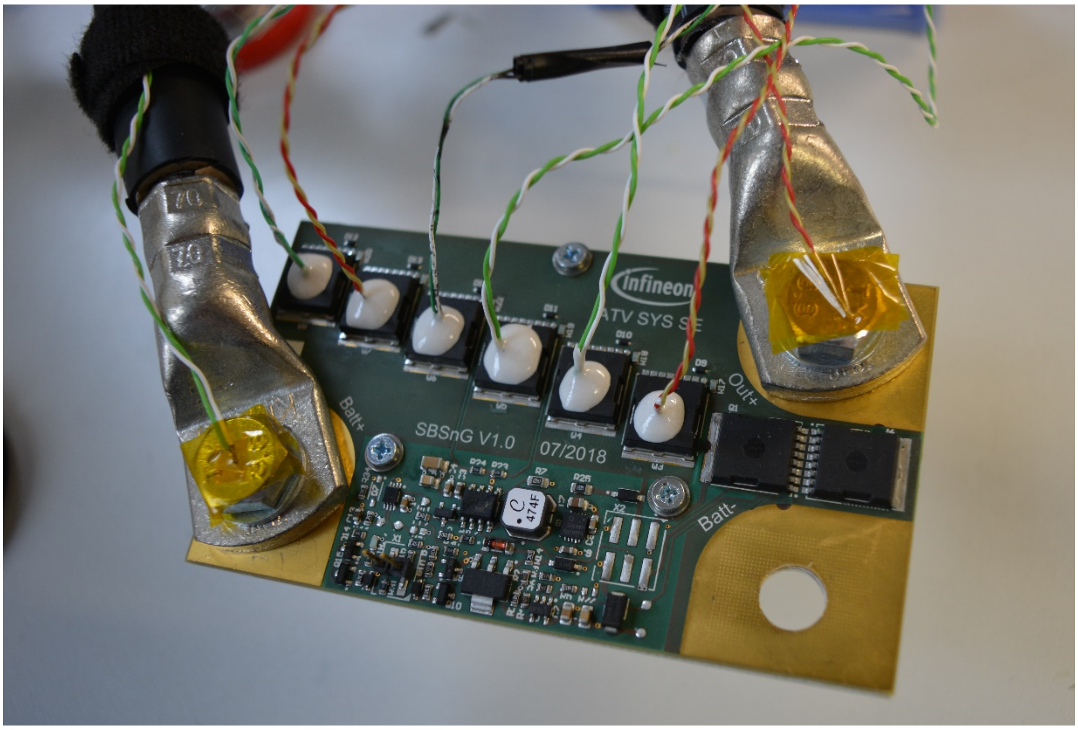


Figure 10 Temperature measurement setup

Note: Values shown in this chapter are measured under lab conditions and will vary for different cooling setups.

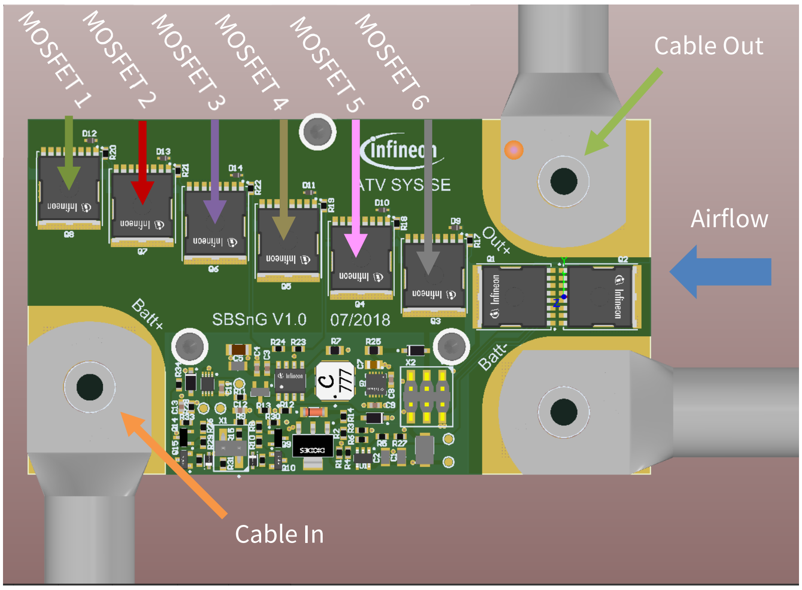


Figure 11 **Temperature measurement setup**

Results of the thermal measurments can be found in Figure 12 to Figure 14. For 300 A continuous current conduction MOSFET 3 to MOSFET 5 have around 58°C on top of the mold compound after 27 min of continuous conduction, see Figure 12 for detailed information.

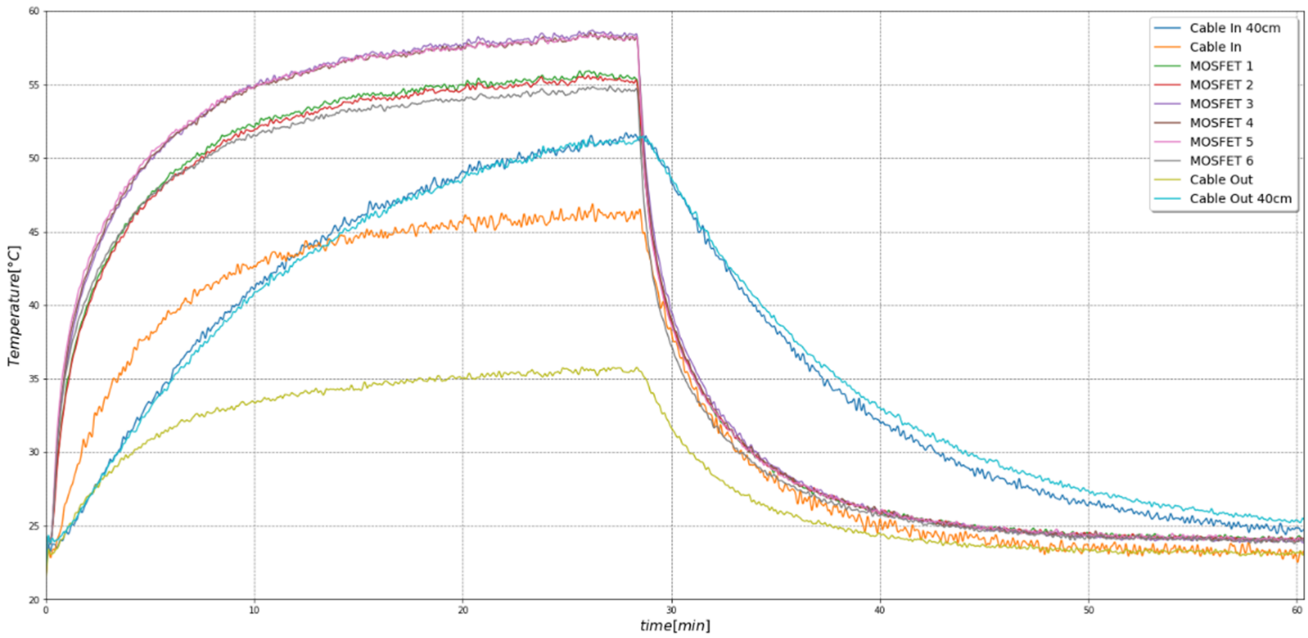


Figure 12 **Temperature measurement for 300 A and 30 cm/s airflow velocity**

Figure 13 is showing the results for 500 A continuous current conduction. The inner MOSFETs are passing the 140°C after 17 min, at that time the current conduction was stopped to prevent the switch from overheating.

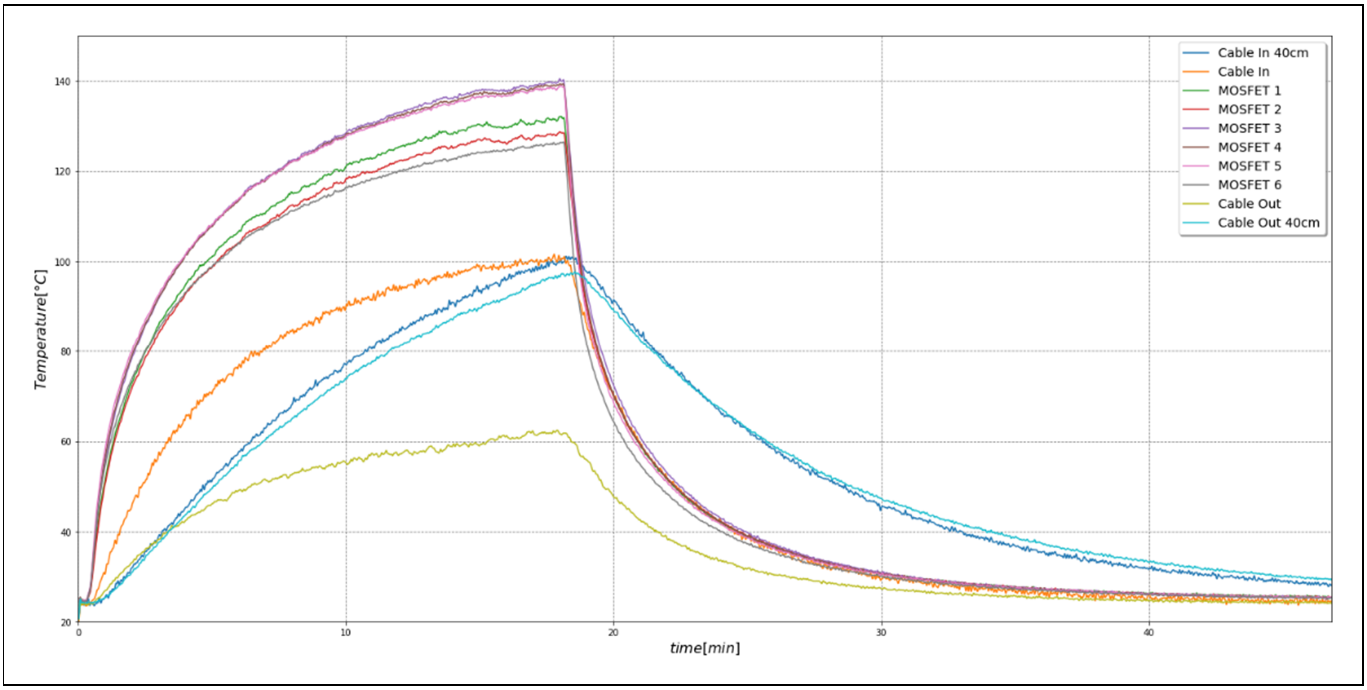


Figure 13 **Temperature measurement for 500 A and 30 cm/s airflow velocity**

Talking about 700 A continuous current conduction, the SBS nextGen was able to handle it for ~2 min.

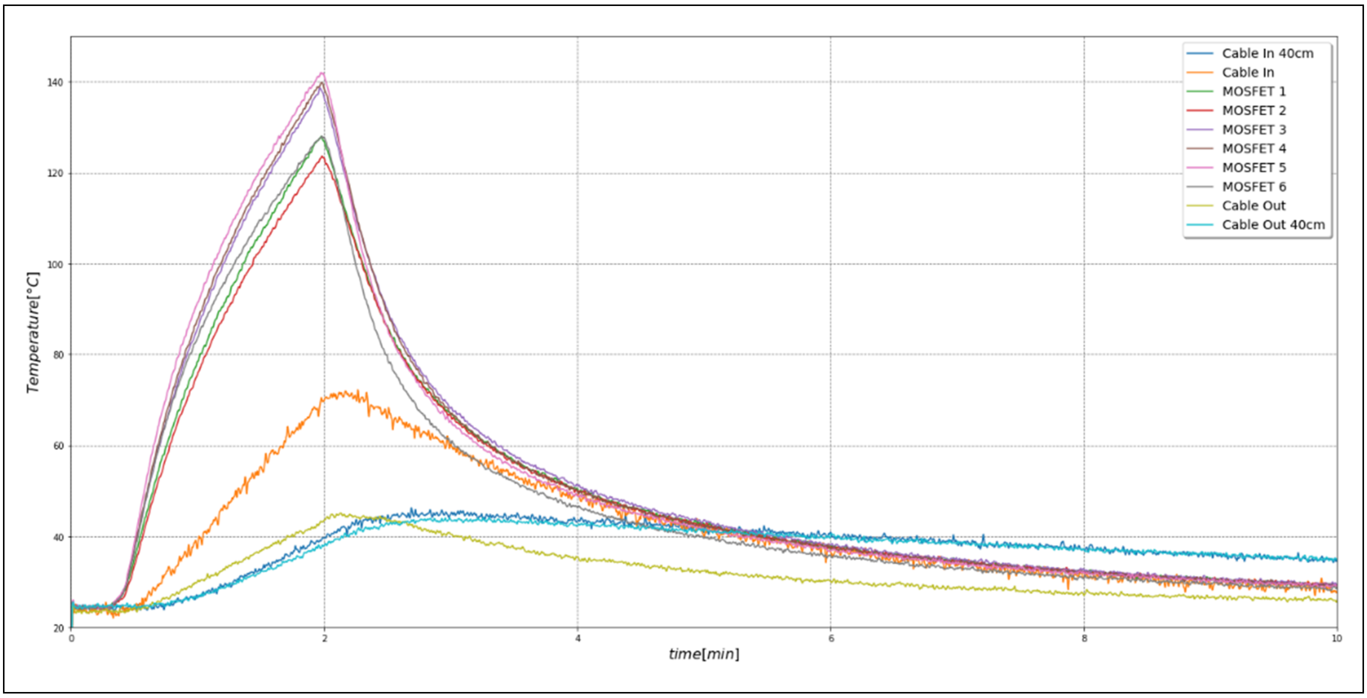


Figure 14 **Temperature measurement for 700 A and 30 cm/s airflow velocity**

4 Switching Behaviour

4.1 Setup

In contrast to relays, MOSFETs are switching much faster and cleaner. There is no bouncing of contacts and no arcing. Switching just takes microseconds instead of several milliseconds. This is a big advantage because short circuits can be switched of before high currents are flowing through the electrical system.

For the test setup, a battery voltage of 12 V and a L_{LOAD} of 6 µH was used. To create a short circuit, a separated MOSFET-Switch was used as R_{LOAD} which got triggered by the output 1 of an arbitrary waveform generator (AWG), **Output 1 AWG**. The Signal **Output 2 AWG** triggers the SBS nextGen Demonstrator and therefore breaks the circuit. Both control signals where referenced to the star point of the ground connection of the system. With the Delay between **Output 1 AWG** and **Output 2 AWG** the maximum switch off circuit current can be set.

Note: The SBS nextGen Demonstrator has no overload, overcurrent or overtemperature detection implemented, a high switch off energy could destroy the MOSFETs. It is recommended to stay inside the SOA of the MOSFETs [2]. The switch off energy is dependent on the switch off current and the intrinsic resistances and inductances of the power distribution network.

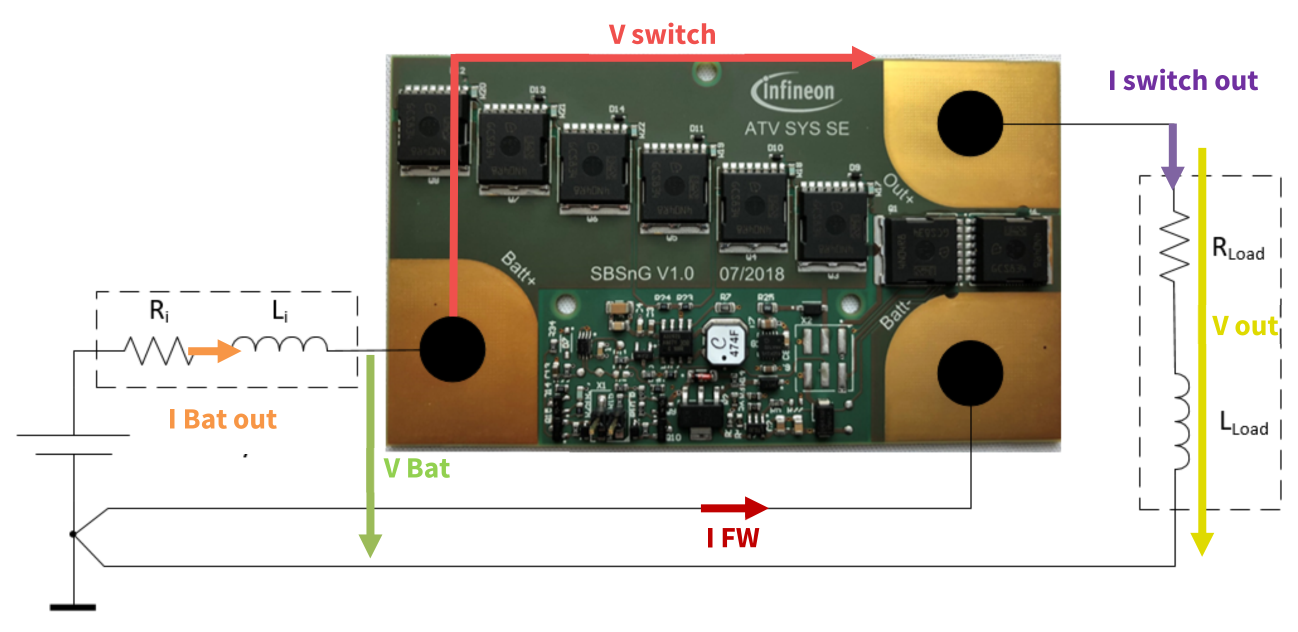


Figure 15 Measured Voltages and Currents

Figure 15 explains where the measurement probes are connected in the setup.The following waveforms in Figure 16 show the switching behaviour of the SBS nextGen Demonstrator with the AUIR3242S driver. [3]

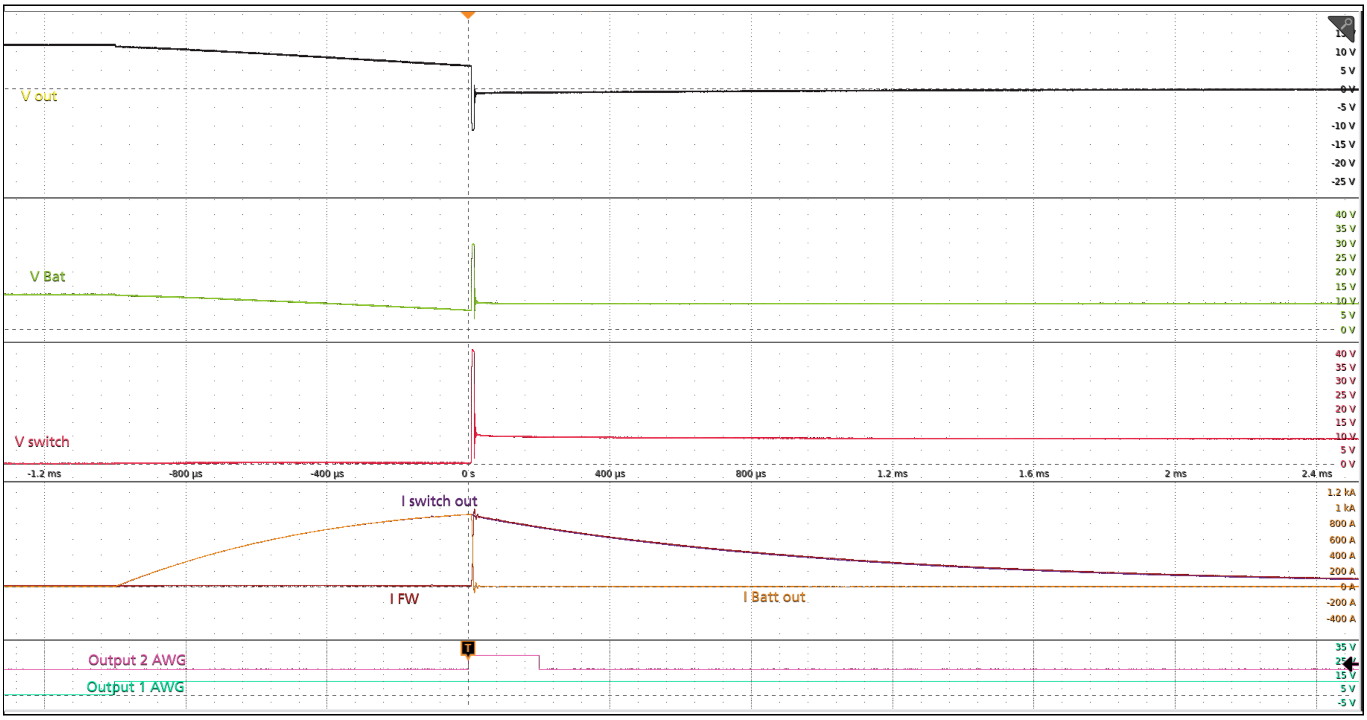


Figure 16 Switch Timing – On and Off 4 ms horizontal timespan

4.2 Basic switching behaviour

Please note that **V switch** shows the drain source voltage across the MOSFETs, so a small voltage means the switch is on (conducting) and a high voltage means the switch is off (blocking).

The delay between the occurrence of the short (Rise of **Output 1 AWG**) and the break of the circuit (Rise of **Output 2 AWG**) is responsible for the rise of the current going through the Switch. As soon as the short of the circuit occurs, the rise of the current can be approximated by the step-response of a RL-Network.

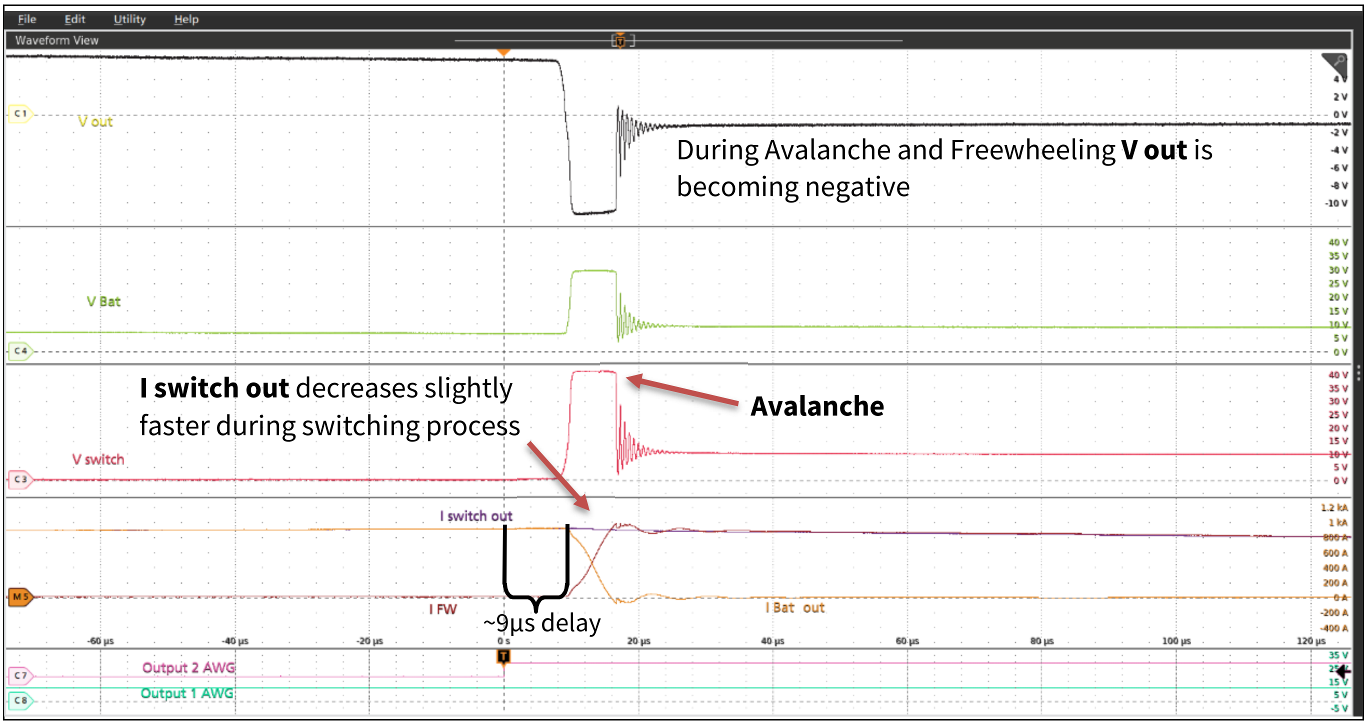
$$i_L(t) = \frac{U_{Bat}}{R_i+R_{Load}}\left(1-e^{-\frac{t}{\tau}}\right) \text{ with } \tau = \frac{L_i+L_{Load}}{R_i+R_{Load}}$$

Equation 1

As you can see in Figure 16 the SBS nextGen Demonstrator was blocked at about 900 A. The maximum current going through the switch is limited to $i_{max} = \frac{U_{Bat}}{R_i+R_{Load}}$. For this specific system configuration (R_{LOAD}, L_{LOAD}) it takes approximately 3.5 ms for the 900 A to reduce to zero.

The delay between the input signal **Output 2 AWG** and the SBS nextGen Demonstrator actually breaking the circuit is caused by the input circuitry (~9 µs), see Figure 17.

When the SBS nextGen Demonstrator switches off, the current coming from the Battery (**I Bat out**) decreases rapidly. Therefore the current going through the freewheeling diodes (**I FW**) increases, as L_{LOAD} keeps pushing current through the electrical system. The rise of **I FW** is almost identical to the fall of **I Bat out** and only limited by the parasitic inductance and resistance between the “Batt-“ terminal of the SBS nextGen Demonstrator and the negativ terminal of the battery. As a result, **I switch out** decreases slightly faster during the switching process as shown in Figure 17. Afterwards **I switch out** decreases the same way as **I FW** does.



During Avalanche and Freewheeling **V out** is becoming negative

I switch out decreases slightly faster during switching process

Avalanche

~9µs delay

Figure 17 Switch Timing – On and Off 200 µs timespan

Figure 17 shows that after triggering the switch **V out** reaches about -13 V due to the inductance of the load L_{LOAD}. When the current flow through L_{LOAD} is interrupted it induces a voltage that pulls **V out** below ground potential. The same happens to **V Bat** with the induced voltage across L_i pulling **V Bat** to about 30 V. As a result the voltage across the SBS nextGen Demonstrator (**V switch**) rises to 43 V.

The energy stored in L_{LOAD} is released by the MOSFET used as active free wheeling diode. Energy stored in L_i gets released by the avalanche breakdown of the six MOSFETs. This happens when **V switch** reaches the avalanche breakdown voltage of the MOSFETs, which is about (1.2 … 1.5) x V_{BRDSS}. V_{BRDSS} is the drain-source breakdown voltage of the MOSFET [1]. In this case the V_{BRDSS} is between 48 V and 60 V respectively, which is higher than the measured voltage of 43 V. An explanation for that can be found in Figure 18. **V switch** was measured between input terminal "Batt+" and output terminal "Out+", during the switch off event the internal PCB Inductances are working against the V_{BRDSS}. If it is measured directly at the MOSFET Terminal V_{BRDSS} of ~48 V can be seen.

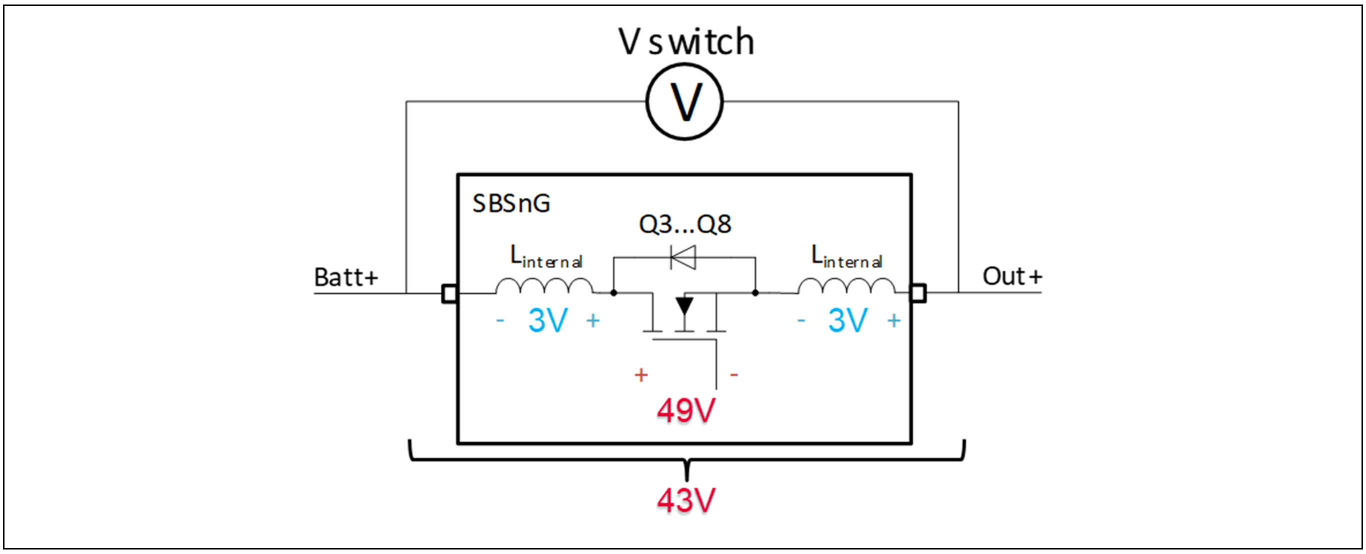


Figure 18 Parasitic switch inductaces are lowering the measured V switch voltage.

4.3 Approximation of avalanche losses

The avalanche of the MOSFETs occurs when the SBS nextGen Demonstrator breaks the circuit and L_i keeps pushing the current trought the switch and therefore the voltage across L_i rises and exceeds the breakdown voltage V_{BRDSS}. As **V Switch** stays almost constant during avalanche and the rise- and fall-time is negligible relative to the length of the pulse, **V Switch** can be described as a simple voltage pulse. Therefore the circuitry during the avalanche can be approximated as shown in Figure 19.

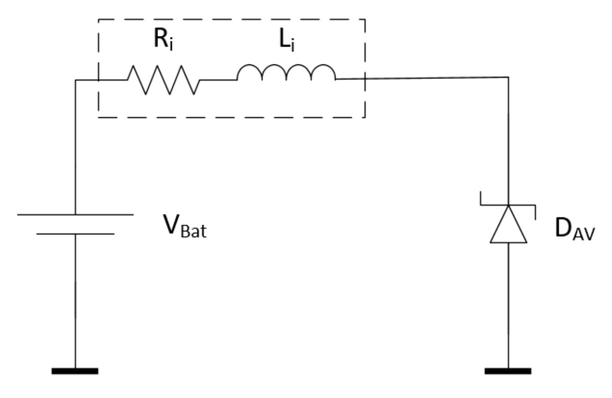


Figure 19 Approximated circuitry during avalanche breakdown

The clamping voltage of D_{AV} is the avalanche breakdown voltage (V_{AV}) of the switching MOSFETs. V_{AV} can be assumed as 1.3 x V_{BRDSS}. However for all the latest OptiMOS^{TM} families V_{DS} spikes during avalanche should not exceed 1.2 x V_{BRDSS} [1]. As the diode clamps the voltage to V_{AV} during avalanche we can, in first approximation, replace the diode with a constant voltage source and get a linear differential system. By solving the differential equation we get the current as a function of time.

$$i(t) = e^{-\frac{t}{\tau_{Bat}}}\left(I_0 - \frac{V_{Bat} - V_{AV}}{R_i}\right) + \frac{V_{Bat} - V_{AV}}{R_i}$$

Equation 2

To obtain the avalanche breakdown losses we subtract the energy losses of the resistor from the total stored energy (Equation 3).

$$E_{AV} = E_{Total} - E_R = L_i \cdot {I_0}^2 \cdot \left(\frac{1}{2} \cdot \frac{V_{AV}}{V_{AV} - V_{Bat}} - \frac{1}{3} \cdot \ln\left(1 - \frac{R_i \cdot I_0}{V_{Bat} - V_{AV}}\right)\right)$$

Equation 3

Note: *The given equations above are only a rough approximation and should only be used for a first estimation.*

4.3.1 Example calculation for the SBS nextGen

As example calculation the initial avalanche current I_0= 900 A, the internal battery resistance R_i=5 mΩ and the internal inductance L_i=100 nH can be used. V_{AV} is approximately 1.2* V_{BRDSS}, where V_{BRDSS} = 40 V for the IPLU300N04S4-R8. By using Equation 3 we can estimate the avalanche energy.

$$E_{AV} = E_{Total} - E_R = 100nH \cdot (900A)^2 \cdot \left(\frac{1}{2} \cdot \frac{48V}{48V - 12V} - \frac{1}{3} \cdot \ln\left(1 - \frac{5m\Omega \cdot 900A}{12V - 48V}\right)\right) = 50{,}8mJ$$

Equation 4

When assumed that the complete avalanche energy is absorbed by all six MOSFETs equally, the maximum avalanche energy can be extrapolated from the avalanche energy graph of the datasheet [2] and multiplied by six, for six parallelized MOSFETs.

Note: *Due to the production distribution of V_{BRDSS} and temperature differences of the MOSFET dies the avalanche energy may not be spread equaly among all MOSFETs.*

4.3.2 Simulated Safe Operating Areas at different Battery Configurations

Equation 3 shows that the avalanche energy is a function of the internal resistance, inductance of the battery, the battery voltage, the avalanche breakdownvoltage of the MOSFETs and the current going through the SBS nextGen Demonstrator. As these parameters are different in every application, it is not possible to estimate a single absolute maximum rating. Different battery configurations need to be taken into account. Additionally, the limits for the maximum avalanche energy are strongly dependend on the junction temperature of the MOSFETs. Therefore multiple safe operating area plots based on simulation results are provided below. The simulations are done for lab conditions, at 25°C junction temperature.

Note: *The results below are restricted to lab conditions. It is recommended to stay inside the SOA of the MOSFET [2]. For additional information or help with your specific application, please get in contact with Infineon Technologies AG.*

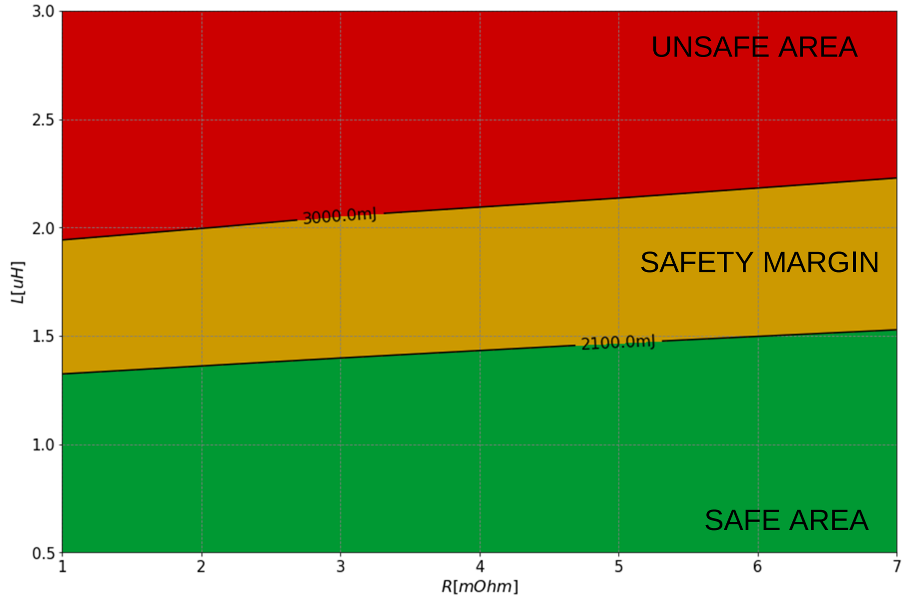


Figure 20 SOA for 12 V, Current = 1500 A, Limit = 6*500mJ, T_j=25°C, limit extracted from Datasheet [2]

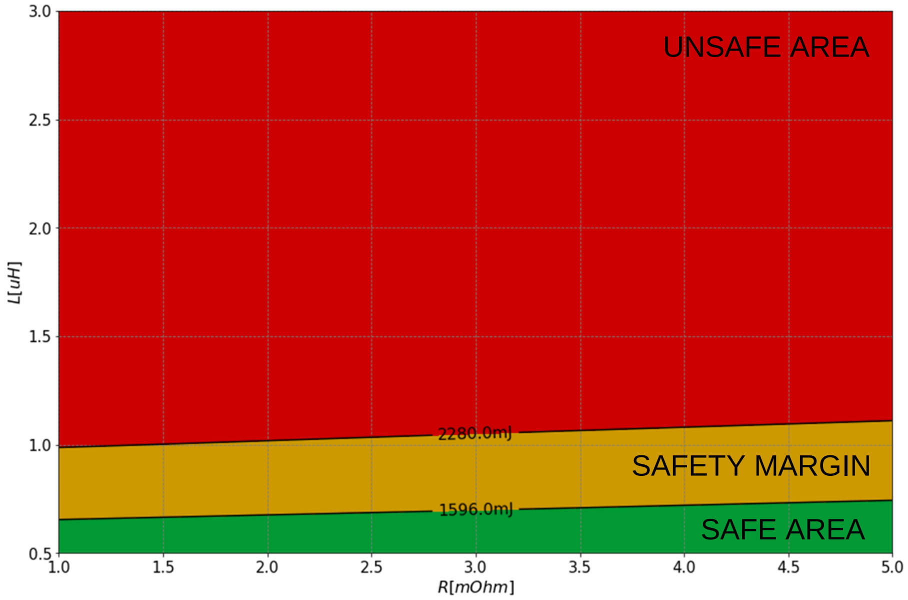


Figure 21 SOA for 12 V, Current = 1800 A, Limit = 6*380mJ, T_j=25°C, limit extracted from Datasheet [2]

5 Mechanical Dimensions

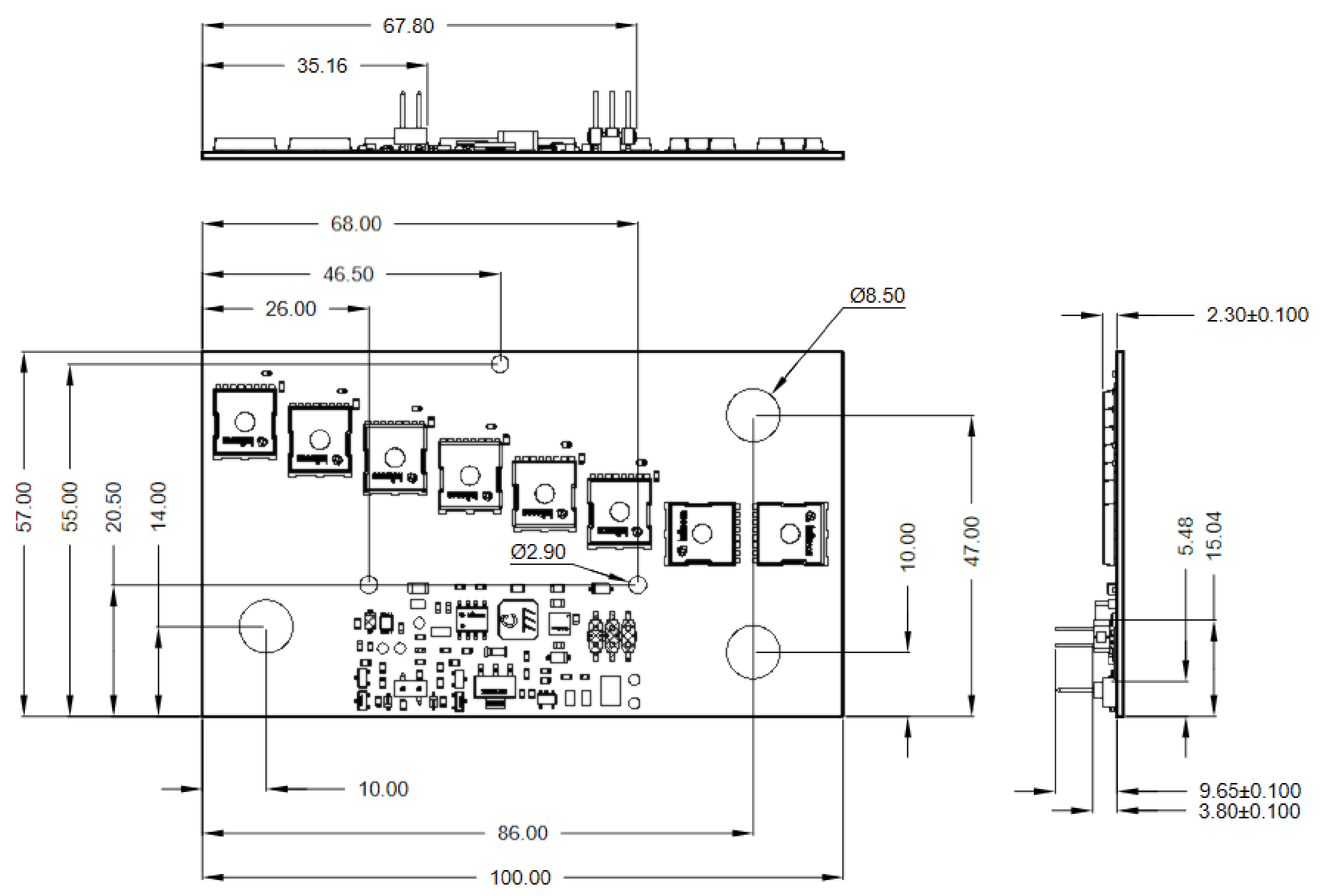


Figure 22 **Board Dimensions [mm]**

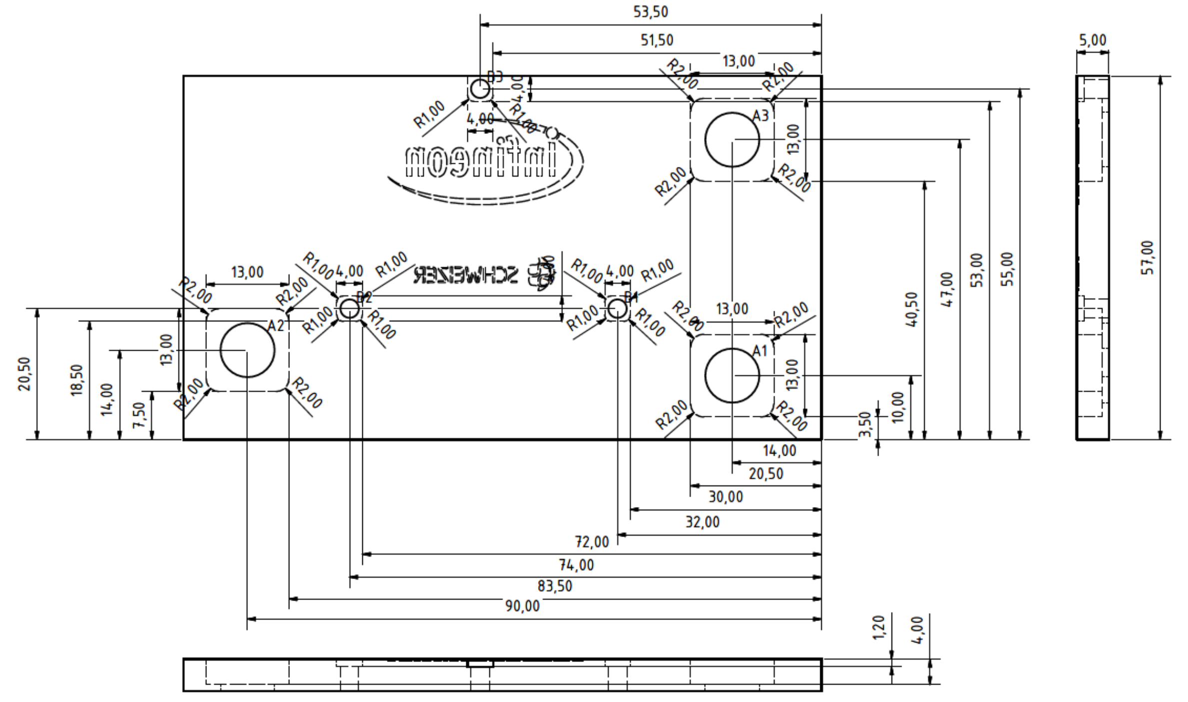


Figure 23 **PCB Holder [mm]**

6 Schematics

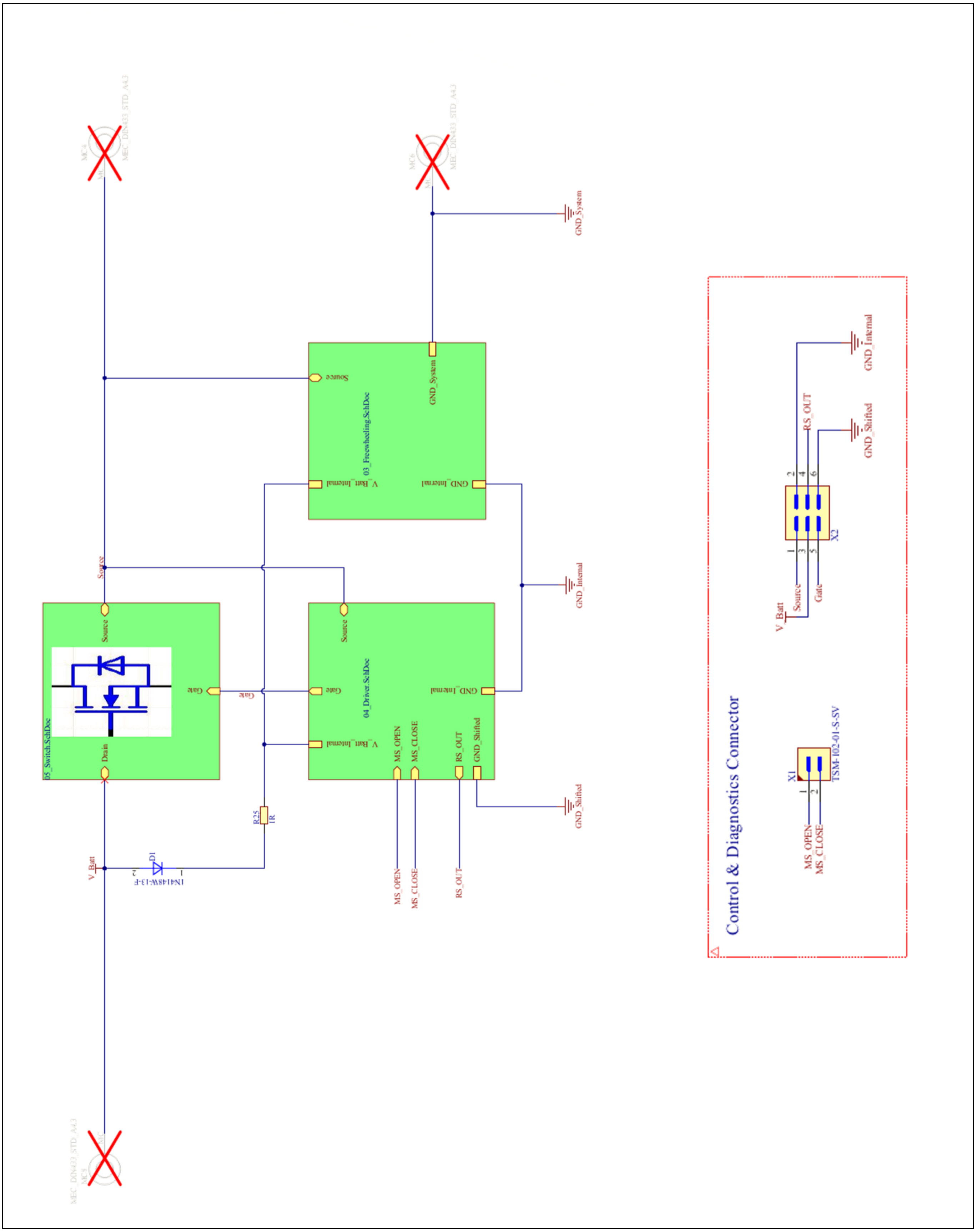


Figure 24 Top Level Schematics

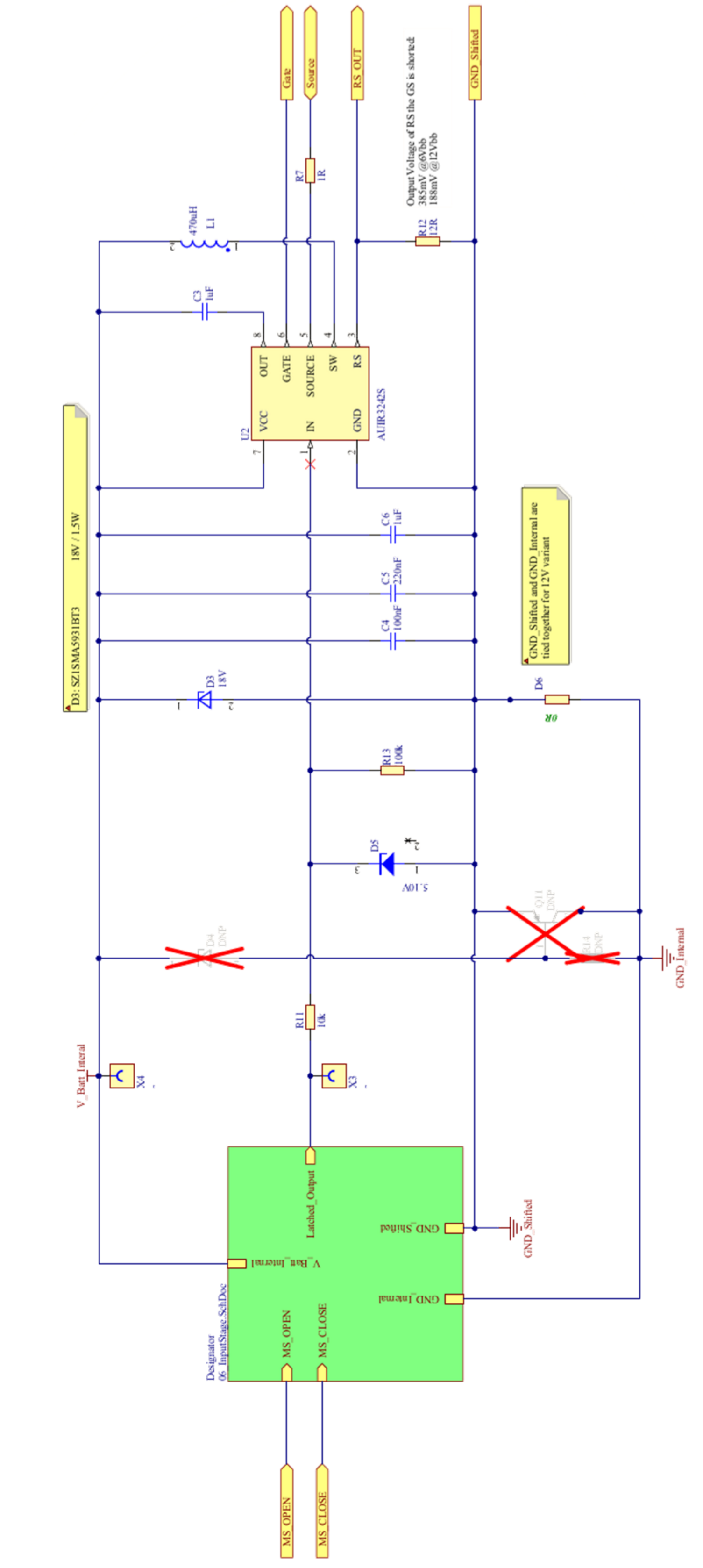


Figure 25 MOSFET Driver Circuit

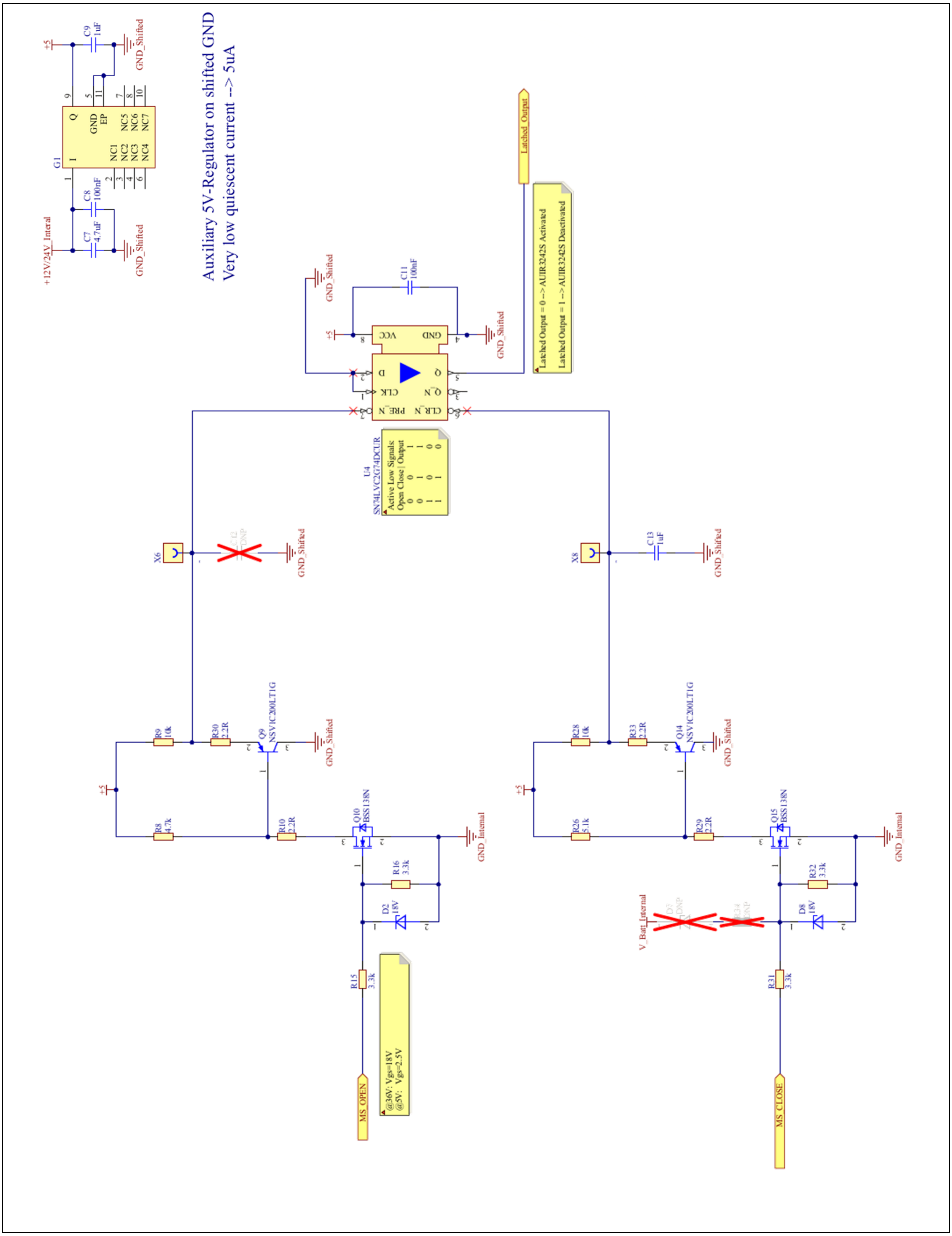


Figure 26 Input Circuitry

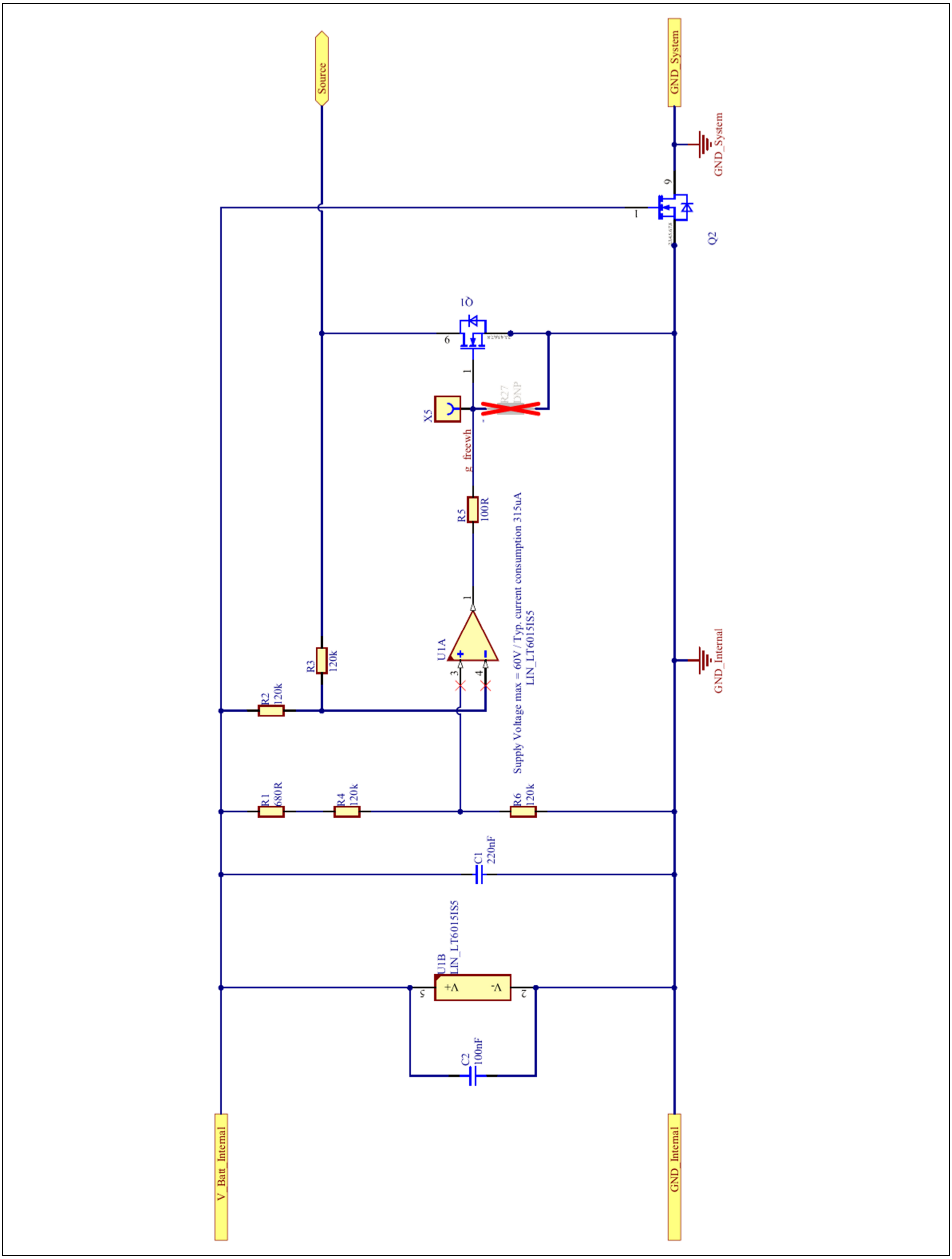


Figure 27 **Active Freewheeling Circuitry**

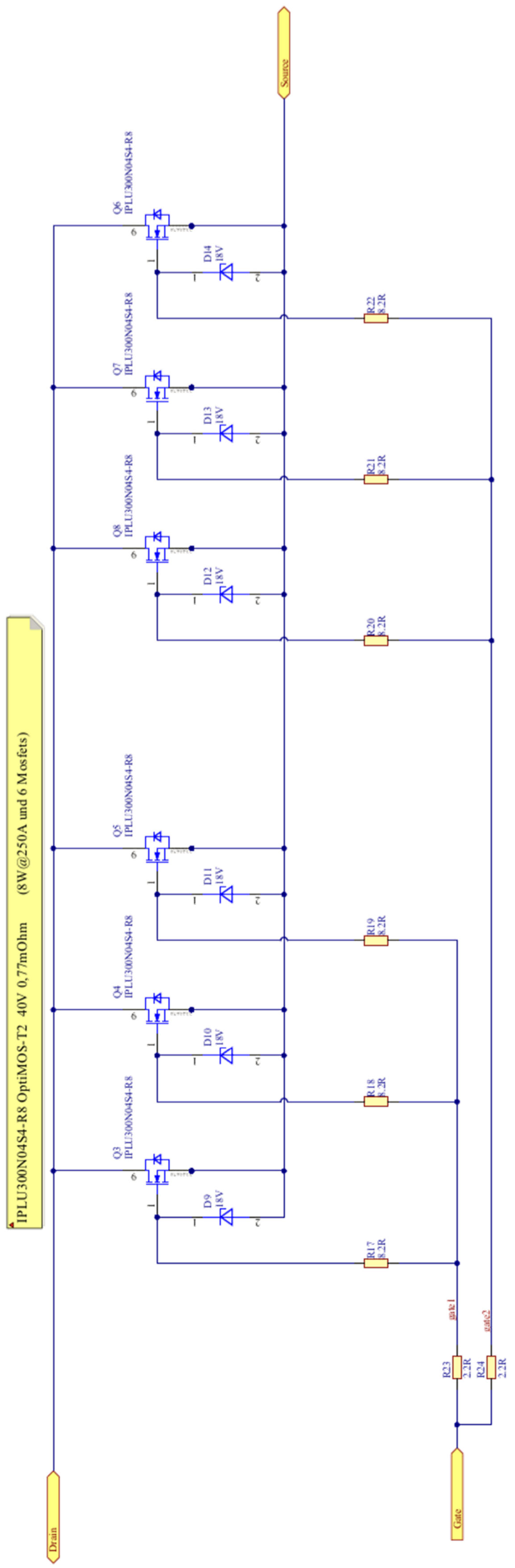


Figure 28 Power Stage

7 PCB Description

7.1 PCB Technology

The Printed Circuit Board used for the shown SBS nextGen Demonstrator is a product idea of Schweizer Electronic AG. The deployment of the Inlay Board 2.0 technology assures highest current carrying capability in conjunction with lowest thermal resistance. A superior thermal connection between the MOSFETs and the integrated power rail of the PCB allows to conduct a permanent current of up to 300A and a short-circuit current of up to 1800A. The complete feature set is visible in Table 7.

Table 7 Feature Set of Metal Core Board (Non-Isolated Version)

Feature	Value
Size	100.0 mm x 57.0 mm
Thickness	1.3 mm
Electrical resistance	60 µΩ
Thermal resistance (non-isolated version)	0.1 K/W
Thermal resistance (isolated version)	~ 0.2 K/W
No. of copper-filled laser vias per MOSFET	300

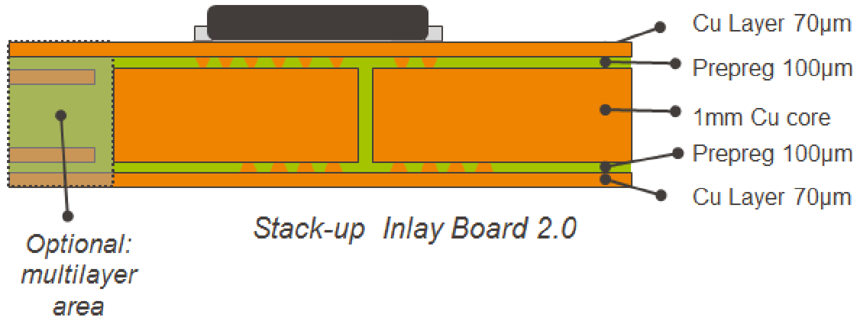


Figure 29 PCB Stackup

The PCB Stackup is shown in Figure 29. The core of the PCB is a copper plate of 1.0 mm thickness which represents the power rail for the SBS nextGen Demonstrator. This copper plate is structured by an isolation gap of 500 µm width. By means of a lamination process the isolation gap is filled with the resin from Prepreg material. This represents a safe isolation space between battery and load potential. The outer layers are consisting of 35 µm copper foils, after plating 70 µm. To ensure both a low-ohmic electrical connection from the MOSFETs to the current rail and a good heat flow to a potentially used heatsink, the PCB is provided with hundreds of copper-filled microvias in the soldering area of the MOSFET and on the back-side of the PCB. The high filling factor with dimple depths lower than 25 µm allows the designer to have the MOSFETs soldered on top of the via field without facing the risk of solder voids. During assembly it has to be made sure that solder profiles will be used which are appropriate for power PCBs with a large thermal mass. The MOSFETs are placed on the PCB so that the MOSFETs, once they are turned on, connect the two isolated parts of the PCB, see cross section in Figure 30.

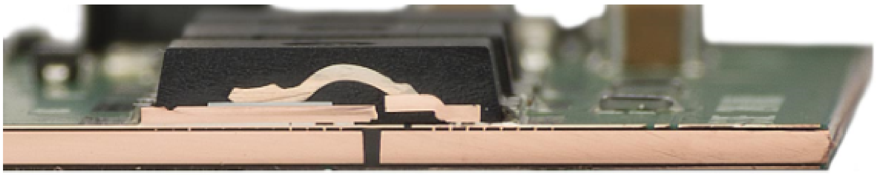


Figure 30 Cross Section

For higher logic content requirements the Inlay Board 2.0 technology can optionally accommodate an area with four or more electrical layers next to the power rails as demonstrated with the SBS nextGen Demonstrator.

7.2 PCB Layout

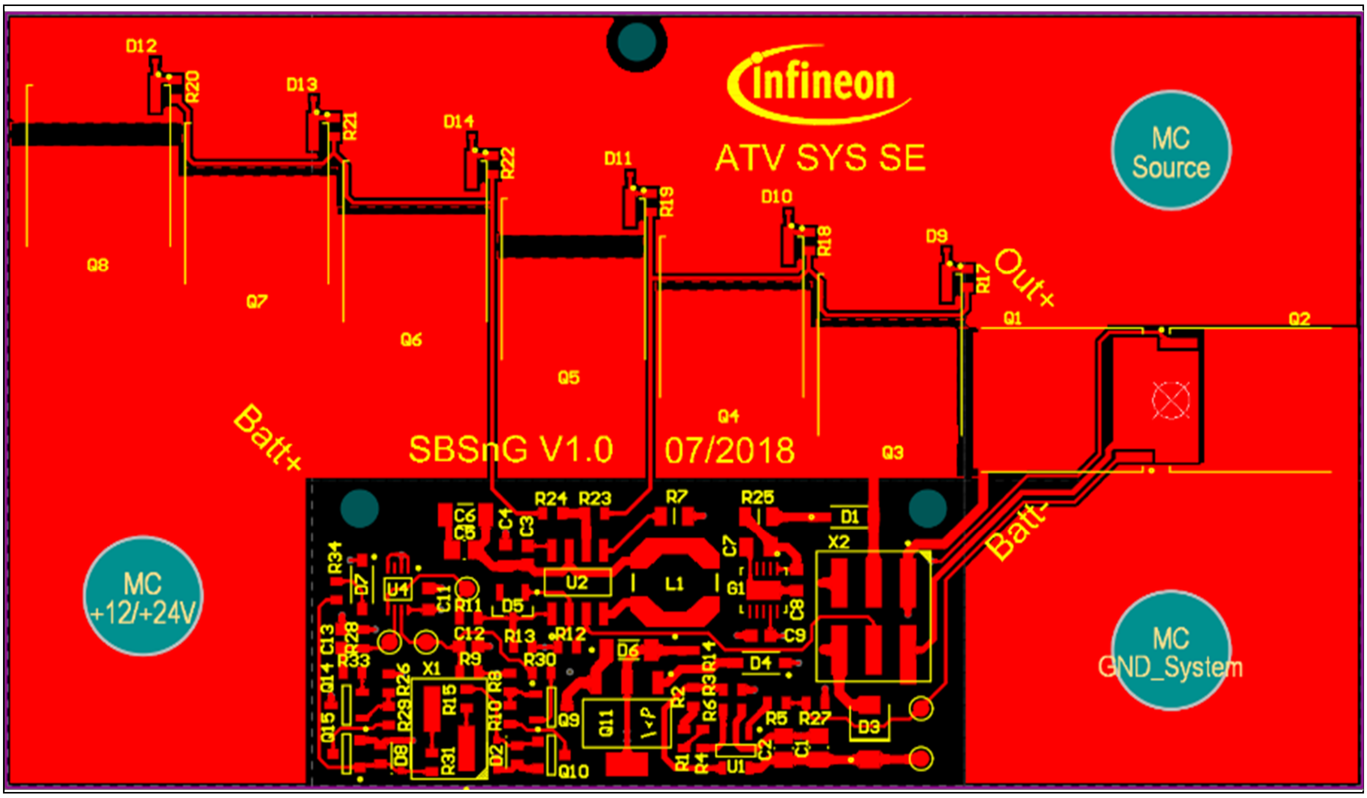


Figure 31 Top Layer

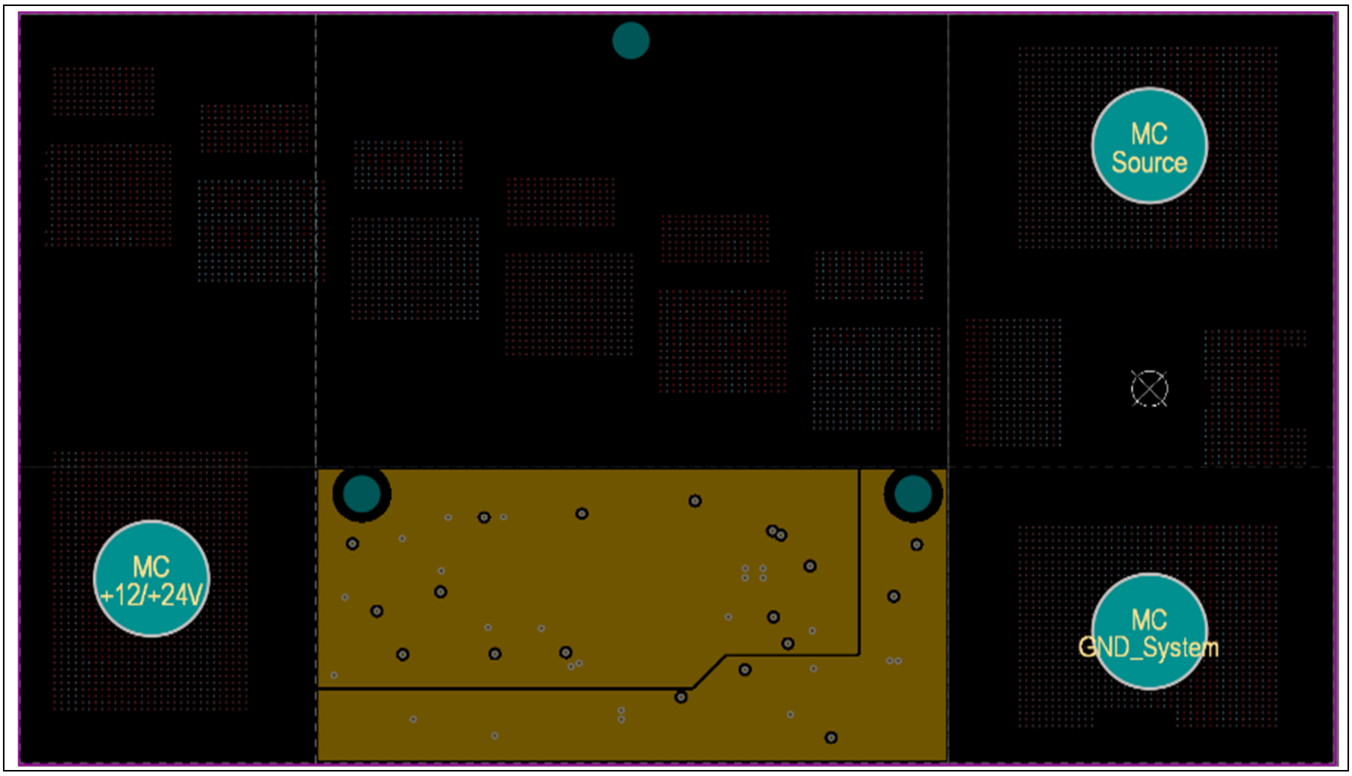


Figure 32 Logic Ground Layer

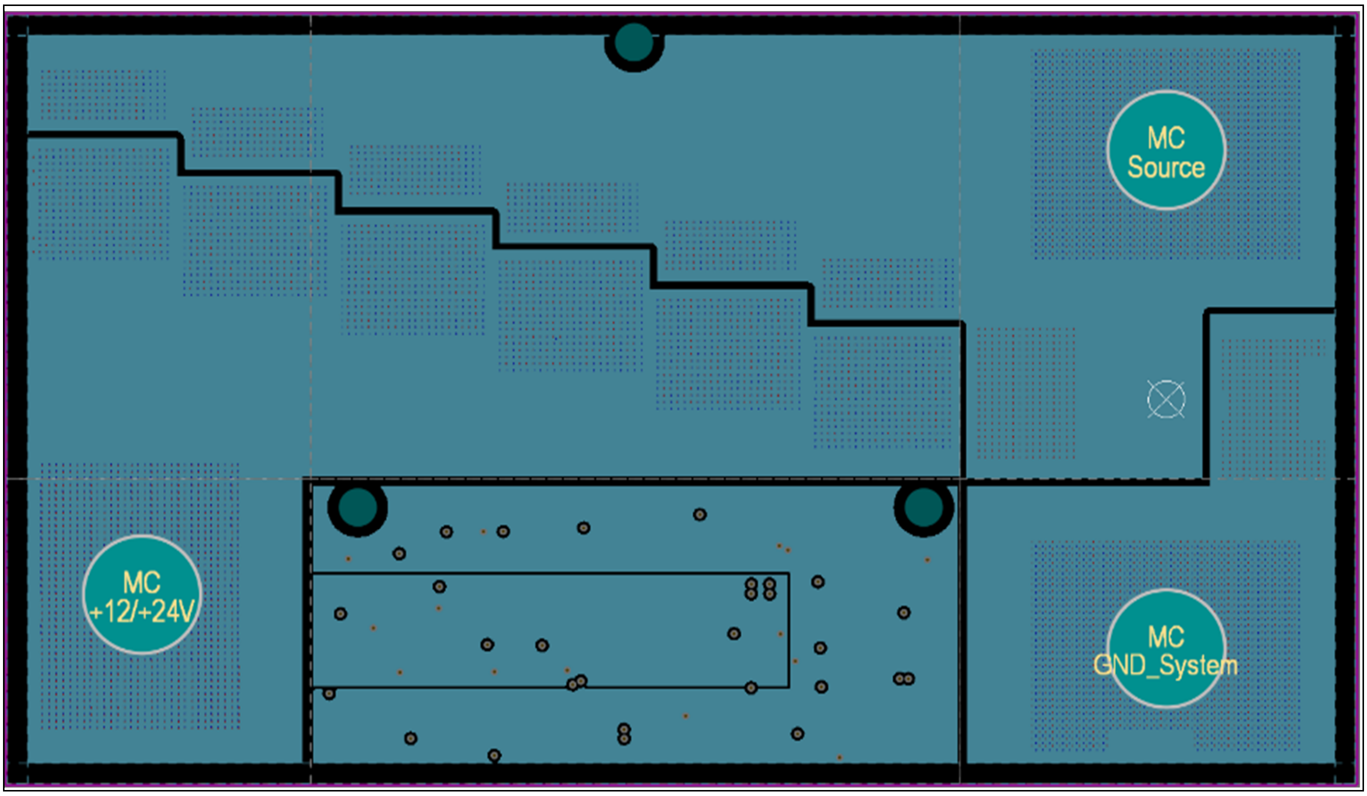


Figure 33 Power Layer

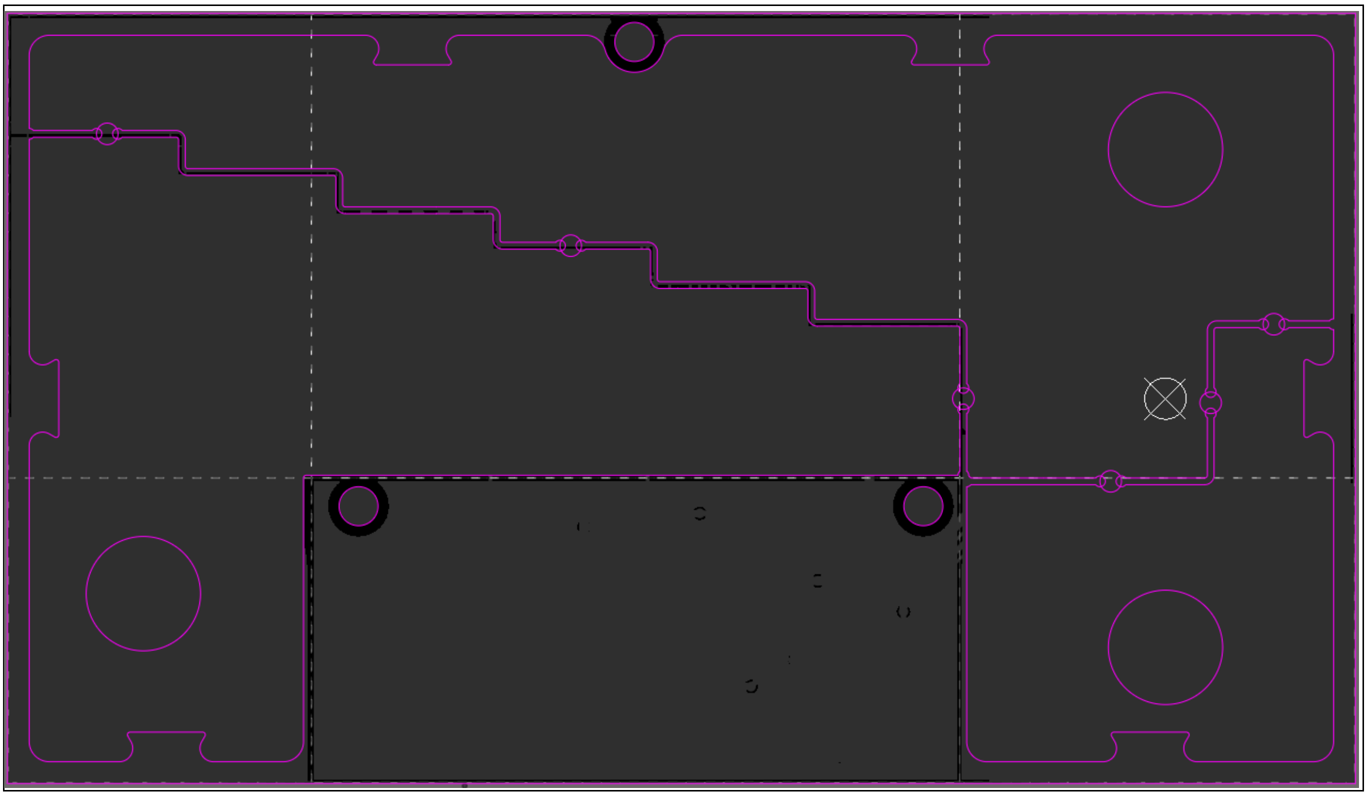


Figure 34 1mm Inlay-Design from Schweizer Electronic AG

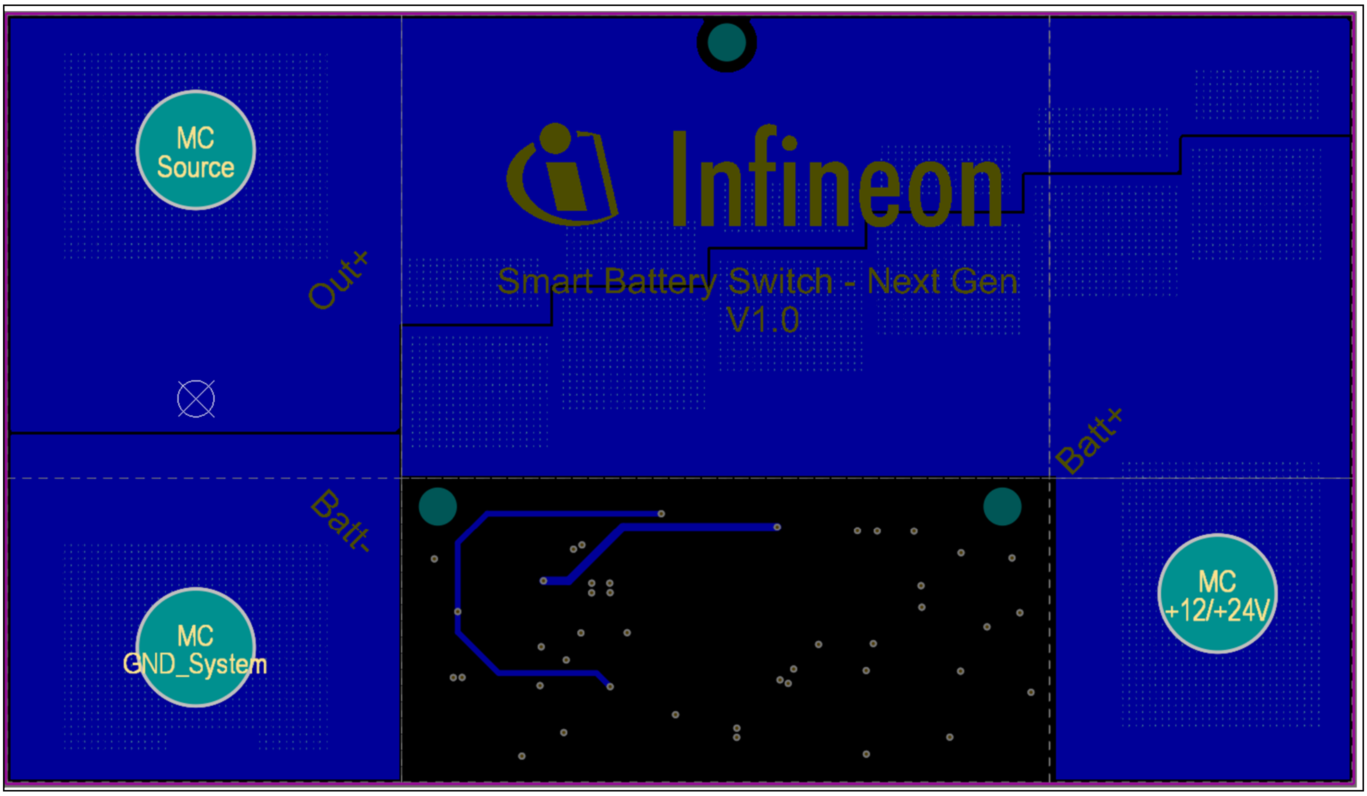


Figure 35 Bottom Layer

8 Bill Of Materials

Table 8 12V Variant

Designator	Value	Description
C1, C5	220nF/50V	Capacitor 0805 X7R 10%
C2	100nF/100V	Capacitor 0805 X7R 10%
C3, C9, C13	1uF/25V	Capacitor 0603 X7R 10%
C4, C8, C11	100nF/50V	Capacitor 0603 X7R 10%
C6	1uF/50V	Capacitor 1206 X7R 10%
C7	4.7uF/35V	Capacitor 0805 X7S 10%
D1	1N4148W-13-F	Standard Diode
D2, D8	GDZ18B-G3-08	Zener Diode, 18V, 200mW
D3	SZ1SMA5931BT3	Zener Diode, 18V, 1.5W
D5	BZX84C5V1LT1G	Zener Diode, 5.1V, 250mW
D9, D10, D11, D12, D13, D14	MM5Z18VT1G	Zener Diode, 18V, 200mW
G1	**TLS810A1LD V50**	**Ultra Low Quiescent Linear Voltage Regulator, 5V**
L1	LPS6235-474MR	Shielded Power Inductor, 470uH
Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8	**IPLU300N04S4-R8**	**OptiMOS T2 N-Channel Enhancement Power-Transistor, 40 V**
Q9, Q14	NSV1C200LT1G	100V, 2.0 A, Low VCEsat PNP Transistor
Q10, Q15	**BSS138N**	**N-Channel Small Signal Transistor**
R1	680R	Resistor 0603 75V 1%
R2, R3, R4, R6	120k	Resistor 0603 75V 1%
R5	100R	Resistor 0603 75V 1%
R7, R25	1R	Resistor 0805 150V 1%
R8	4.7k	Resistor 0603 75V 1%
R9, R11, R28	10k	Resistor 0603 75V 1%
R10, R23, R24, R29, R30, R33	2.2R	Resistor 0603 75V 1%
R12	12R	Resistor 0603 75V 1%
R13	100k	Resistor 0603 75V 1%
R15, R16, R31, R32	3.3k	Resistor 0603 75V 1%
R17, R18, R19, R20, R21, R22	8.2R	Resistor 0603 75V 1%
R26	5.1k	Resistor 0603 75V 1%
R35/D6	0R/Jumper	Resistor 1206
U1	LT6015IS5	Low Power Op Amp
U2	**AUIR3242S**	**Low Quiescent Current Back to Back MOSFET Driver**
U4	74LVC2G74	Positive Edge Triggered D-Type Flip Flop
X1	TSM-102-01-S-SV	SMT .025'' SQ Post Header, 2.54mm Pitch, 2 Pin, Vertical, Single Row
X2	TSM-103-01-L-DV	SMT .025'' SQ Post Header, 2.54mm Pitch, 6 Pins, Vertical, Double Row

9 References

[1] **Some key facts about avalanche** - Infineon Technologies AG, Version 1.0, 2017-01-9

[2] **IPLU300N04S4-R8 datasheet** - Infineon Technologies AG, Rev. 1.0, 2015-10-06

[3] **AUIR3242S datasheet** - Infineon Technologies AG, Rev. 1.0, 2018-07-26

Revision History

Major changes since the last revision

Page or Reference	Description of change
Page 4	Added some more details to Figure 3
Page 6	Clarify descriptions of connector X1 and X2
Page 15	Added Figure 18 to explain the switching event in more detail

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