Technical Explanation MiniSKiiP Dual Split MLI Inverter Board

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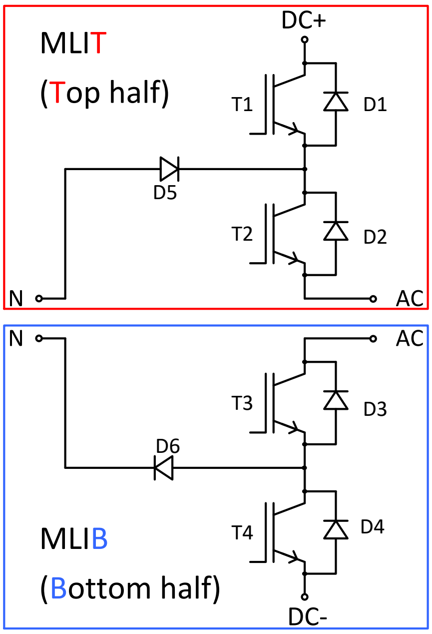
1. Introduction

SEMIKRON set up a 3-phase inverter board for operating MiniSKiiP Dual Split MLI modules for evaluation purposes. The MiniSKiiP Dual Split MLI Inverter Board ("inverter board") is designed to operate with three SKYPER12 (T)MLI Driver Boards (also a SEMIKRON Application Sample). It is designed to operate the module up to a DC-link voltage of 1500V (limited by insulation coordination) at a maximum switching frequency of 30kHz (limited by insulation coordination); i.e. higher switching frequencies are possible with a revision of the insulation coordination and the limitation of the gate driver needs to be taken into account.
Three driver boards (SKYPER 12 (T)MLI Driver Board) are mounted to the inverter board, one per phase leg. One driver operates switches T1 and T2, the other operates switches T3 and T4. The 1200V MLI phase leg is split in two MiniSkiiP Dual module housings, one inheriting switches T1, D1, T2, D2 and D5, the other housing T3, D3, T4, D4 and D6 (see Figure 1).
The inverter board provides active clamping diodes for inner IGBT (T2 and T3) and $V_{CE,desat}$ detection diodes for the outer switches T1 and T4 utilizing the driver boards' protection functionality. Further all modules have a built-in NTC sensor (six in total) which are all monitored.
Please read also the Technical Explanation [10]– SKYPER12 (T)MLI Driver Board for detailed information on the driver boards used together with the inverter board described in this document.

Figure 1: MiniSKiiP Dual Split MLI



This Application Sample is dedicated to both universities and professional development engineers. It offers an easy way to set up a three phase inverter with MiniSKiiP Dual Split MLI modules and 2L drivers for a DC-link voltage up to 1500V. Performance tests can be run to prove the possibility of operation at high DC-link voltages and high output power.

1.1 Features

The inverter Board can be used for both types of MiniSKiiP Dual Split MLI IGBT modules, SiC hybrid version and silicon version. For type designation please see chapter 6.6. The modules are rated 400A and come with 1200V semiconductors.

Figure 2: MiniSKiiP Dual Split MLI housing

The MiniSKiiP Dual Split MLI is the most powerful MLI module to build a printed-circuit-board based solar inverter.
For further information of the MiniSKiiP module see separate Technical Explanation [7] and [8]

1.2 Hardware of the MiniSKiiP Dual Split MLI Inverter Board

The inverter board consists of a printed circuit board (PCB) with item number 45145801. It provides

- DC-link capacitors
- DC input and AC output connections
- Sockets for 3 pcs. "SKYPER12 (T)MLI Driver Board" with item number 45137601 which carries gate resistors, desaturation monitoring, and driver board settings.
- Components for gate protection, desaturaton detection and active clamping.

Figure 3: MiniSKiiP Dual Split MLI Inverter Board top view

Depending on the power ratings and the operating conditions (voltage, current, and inductance of the DC-link connection) it might be necessary to adjust gate resistors, activate or deactivate active clamping sensing and trip levels of the safety circuits.
The Gerber files of the board are available on request. For ordering the board or the files please contact your SEMIKRON sales partner.
An appropriate heatsink (and mechanical support for the inverter board) needs to be provided by the user, and is described in chapter 5.

2. Safety Instructions

The MiniSKiiP Dual Split MLI Inverter Board bares risks when put in operation. Please carefully read and obey the following safety instructions to avoid harm or damage to persons or gear.

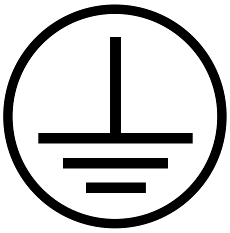
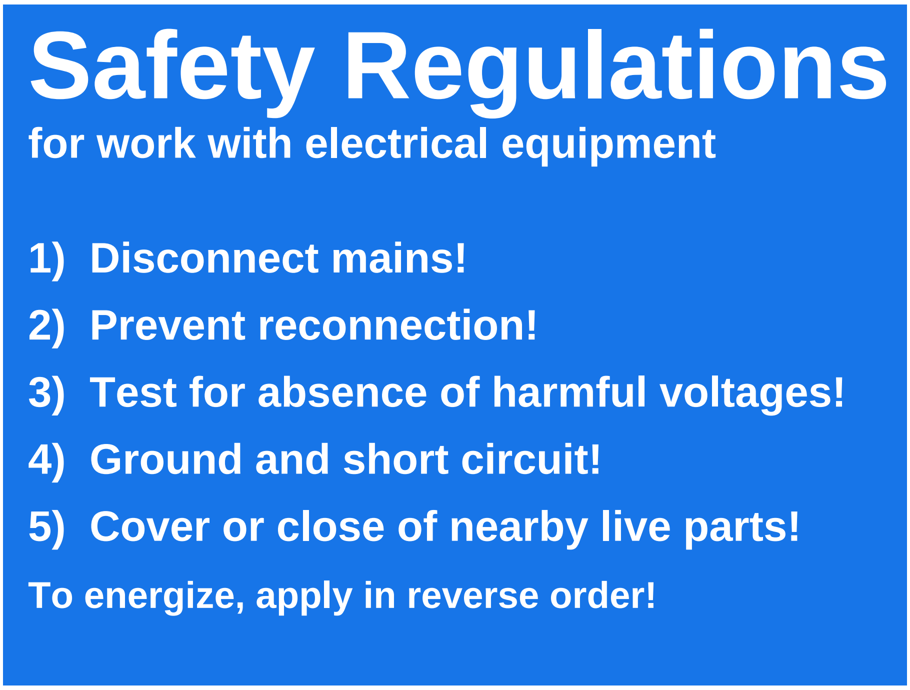
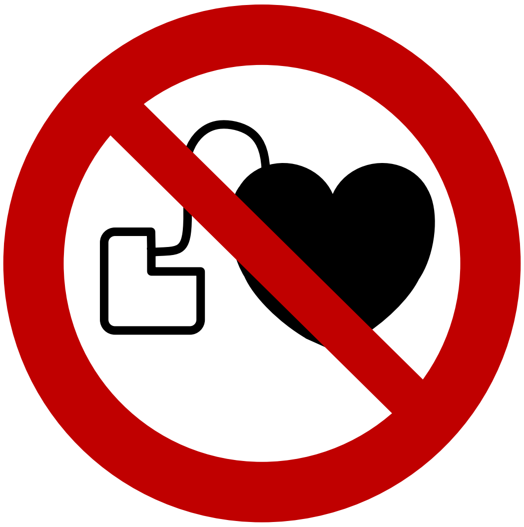
Table 1: Safety instructions	
	**In operation the MiniSKiiP Dual Split MLI Inverter Board inherits high voltages that are dangerous to life!** **Only qualified personnel should work with the Kit.**
	**Some parts of the MiniSKiiP Dual Split MLI Inverter Board or connected devices (e.g. heatsink) may reach high temperatures that might lead to burns when touched.**
	**When connected to DC-link capacitors it must be made sure that the DC-link voltage is reduced to values below 30V before touching the system.**
	**Insulation coordination and testing has been performed regarding a PE connection of one potential. It is mandatory to provide a PE connection with sufficient cross section when operating the MiniSKiiP Dual Split MLI Inverter Board.**

Table 2: Safety regulations for work with electrical equipment



Please follow the safety regulations for working safe with the MiniSKiiP Dual Split MLI Inverter Board.

Table 3: No access for people with active implanted cardiac devices!



Operating the Application Sample may go along with electromagnetic fields which may disturb cardiac devices.
People with cardiac devices shall not operate the device.

Please make sure to always use the appropriate personal safety equipment when working with the Application Sample.

3. Technical Data

3.1 Inverter board block diagram

The electrical block diagram in Figure 4 shows two parts: the blue marked part represents the three driver boards required to operate the inverter. The red part represents the power modules of the three phase legs which together with the grey part (the DC-link) forms the MiniSKiiP Dual Split MLI Inverter Board.

Figure 4: MiniSKiiP Dual Split MLI Inverter Board block diagram

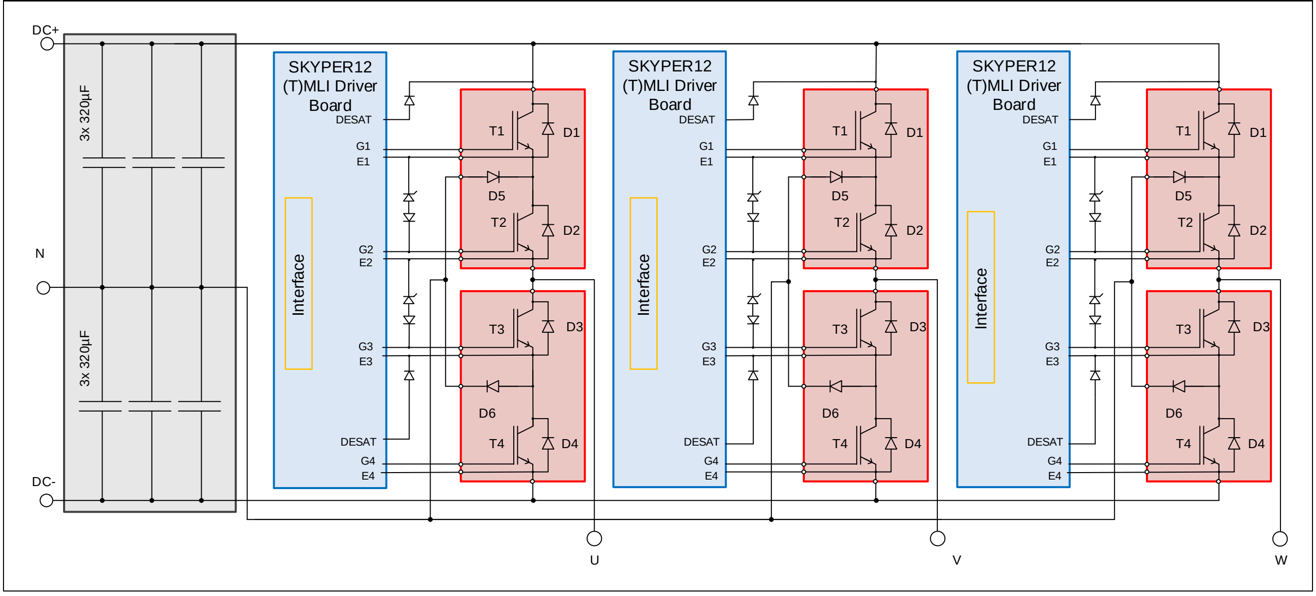
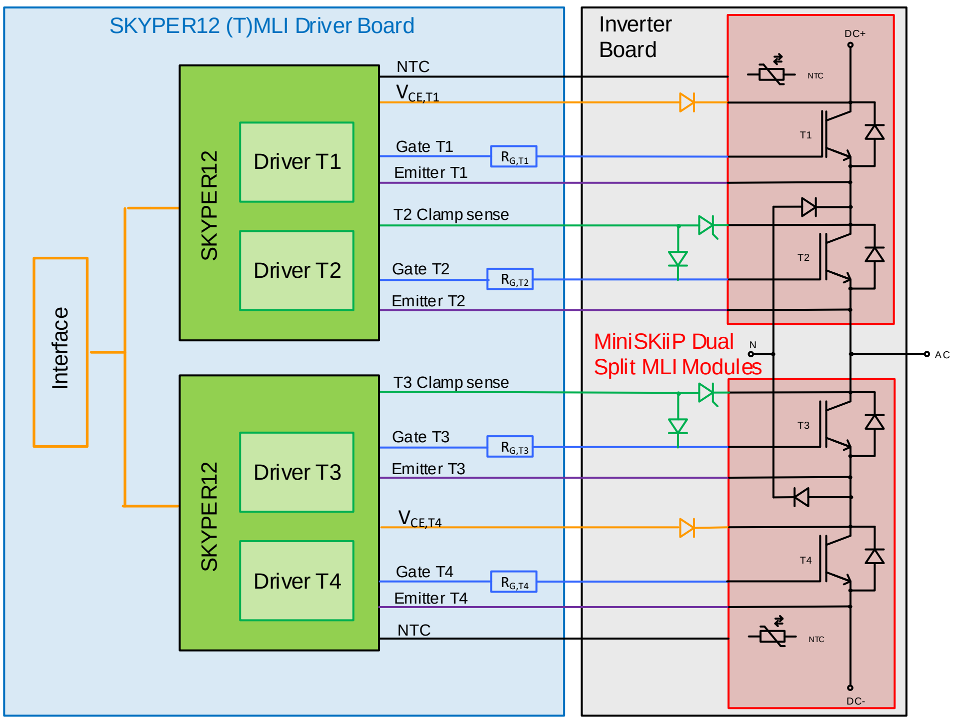


Figure 5 shows the block diagram of a single phase without DC-link. One SKYPER 12 (T)MLI Driver Board with two SKYPER12 driver cores to drive the IGBT of one phase leg. One driver operates IGBT T1 and T2, the second operates IGBT T3 and T4.

Figure 5: Single phase leg block diagram (without DC-link)



3.2 Electrical and mechanical characteristics

With regard to the requirement specification the MiniSKiiP Dual Split MLI Inverter Board allows for operation within the following boundaries:

- Max. DC-link voltage V_{DC} = 1500V in total, max. 750V per individual DC-link half
- Max. AC voltage V_{AC} = 1000V_{RMS} (line-to-line)
- Ambient temperature T_a = 0°C...40°C (see chapter 6.5 for further information)

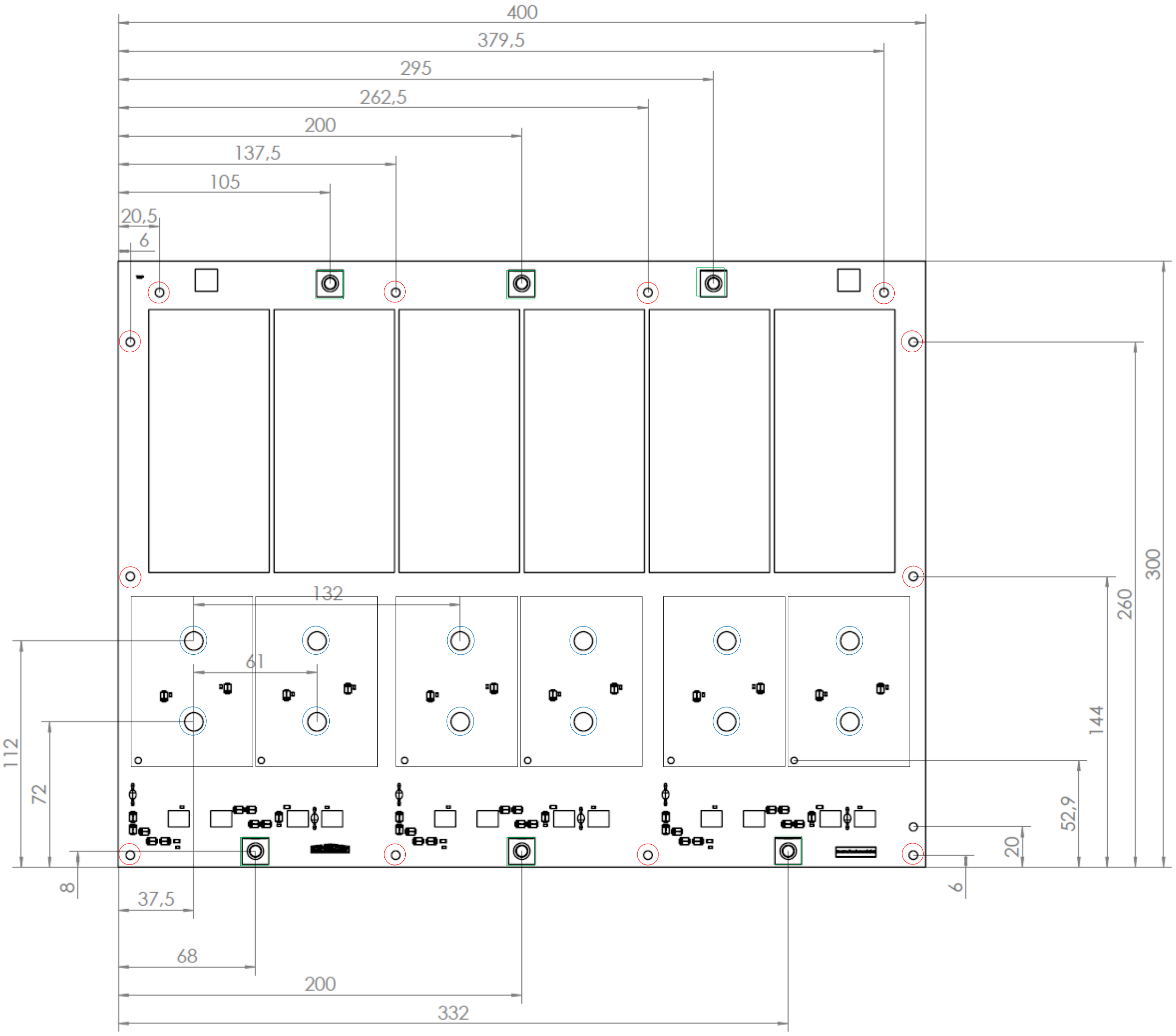
Neglecting the above mentioned boundaries may lead to malfunction or damage of the MiniSKiiP Dual Split MLI Inverter Board.

The overall responsibility for a proper insulation coordination remains with the user.

The inverter board is 400mm long and 300mm wide. Including MiniSKiiP Dual and without heat sink the total height of the inverter board is 81mm.

The user needs to provide a heatsink and a mechanical support for the inverter board, see chapter 5. All red circled holes have a diameter of 4.3mm to take M4 supporting posts. The positions of the M4 mounting screws for the modules are marked with blue circles. Green rectangles are the screw connections for the DC-link (DC+, M, DC-) and AC output (U, V, W).
The support posts must be able to isolate the DC-link voltage from the heatsink, i.e. no metal posts may be used.

Figure 6: MiniSKiiP Dual Split MLI Inverter Board mounting holes and power terminals



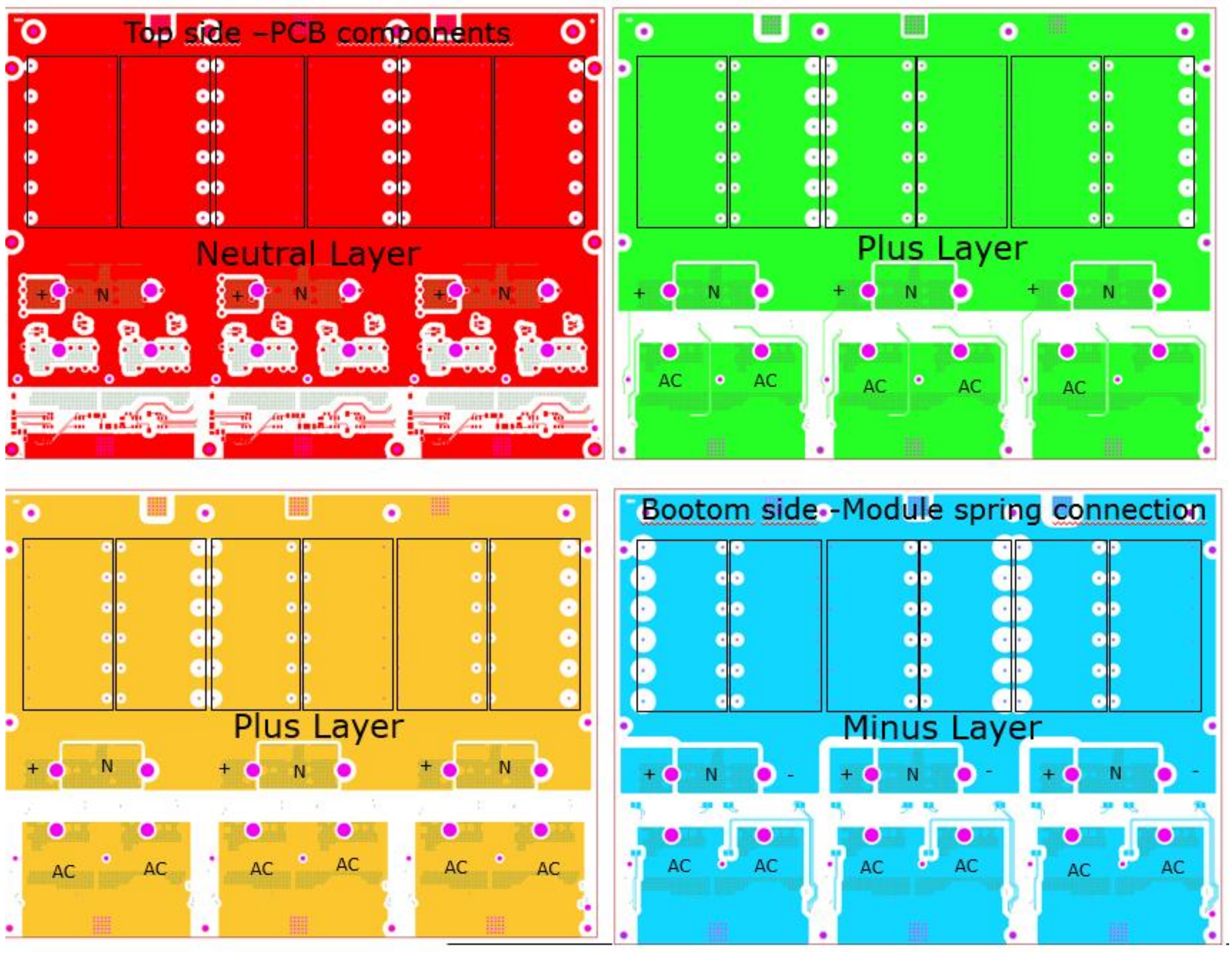
3.3 PCB design

The PCB is composed of 4 layers.

- Total thickness: 2.0mm
- Copper layer thickness: 105µm each
- Material: FR4, TG150
- Insulation between layer: 0.51mm, 0.56mm, 0.51mm
- CTI > 600
- Surface: Chemical NiAu

The PCB top side layer has DC-link middle point potential ("N") because of the easier insulation coordination to the MiniSKiiP lid.

Figure 7: MiniSKiiP Dual Split MLI Inverter Board, PCB layers



3.4 Integrated functions

The inverter board has some integrated safety functions to protect the power module from certain harmful conditions.

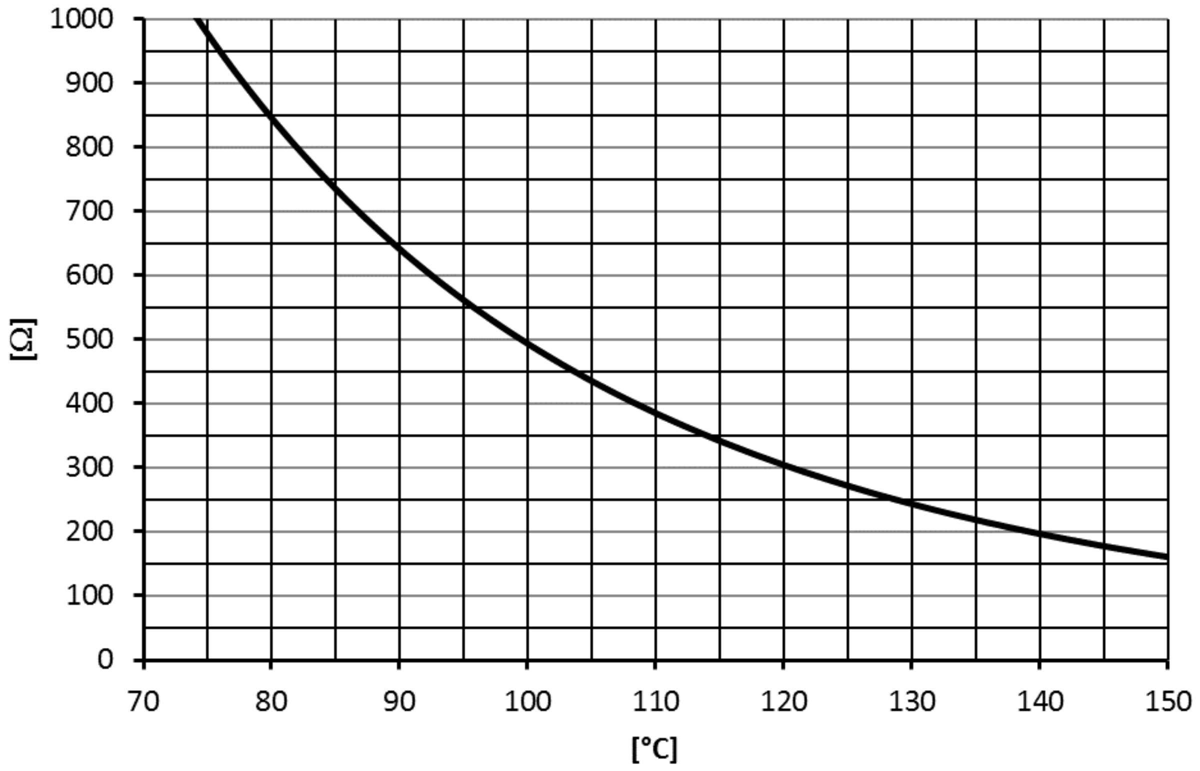
3.4.1 Gate protection

For gate protection purposes the inverter board is by default equipped with a 10kΩ resistor and a bidirectional 15V TVS diode between gate and emitter connection of every IGBT. Thus the ESD sensitive gates are protected even if no driver board is plugged to the inverter board. The 10kOhm resistor shall ensure that the IGBT is kept off when the driver board is not supplied or not plugged.

3.4.2 Thermal overload protection

Each MiniSKiiP module has a built-in temperature sensor. The measured temperature can in first estimated be considered as heat sink temperature. The temperature sensor of the TOP module (T1, T2) is connected to the secondary side error input of driver stage T1. The temperature sensor of the BOT module (T3, T4) is connected to the secondary side error input of driver stage T4. In case of thermal overload the IGBT switches off and an error is set. The temperature threshold level can be set on SEMIKRON's SKYPER12 (T)MLI Driver Board. Please see the technical explanation.
Figure 8 shows an excerpt of the NTC characteristic which includes the most interesting temperature range between 70°C and 150°C.

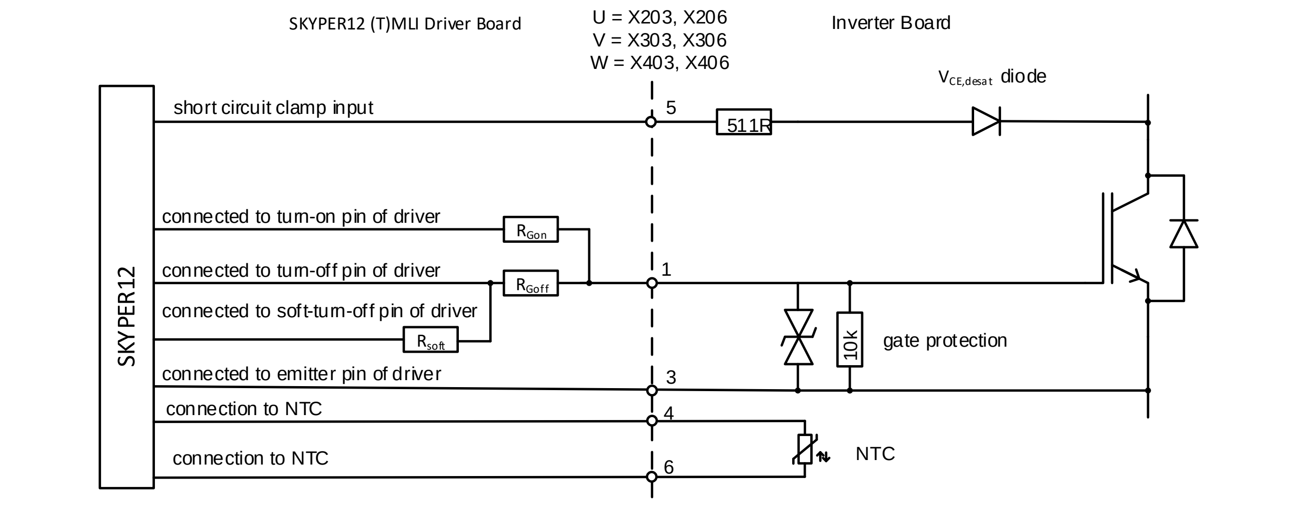
Figure 8: MiniSKiiP Dual Split MLI NTC characteristic (excerpt)



3.4.3 Short circuit protection

IGBTs T1 and T4 are equipped with $V_{CE,desat}$ diodes for short circuit protection. This diodes are located close to each collector on the inverter board. In case of a desaturation event the particular IGBT is switched off with soft-turn-off gate resistor and an error is set from the driver board. The error switches off all IGBTs in case of desaturation T1 or T4. SEMIKRON's SKYPER12 (T)MLI Driver Board supports desaturation detection. V_{CE} threshold levels and blanking times are set on the driver board.

Figure 9: Short circuit protection for IGBT T1 and T4 and temperature protection



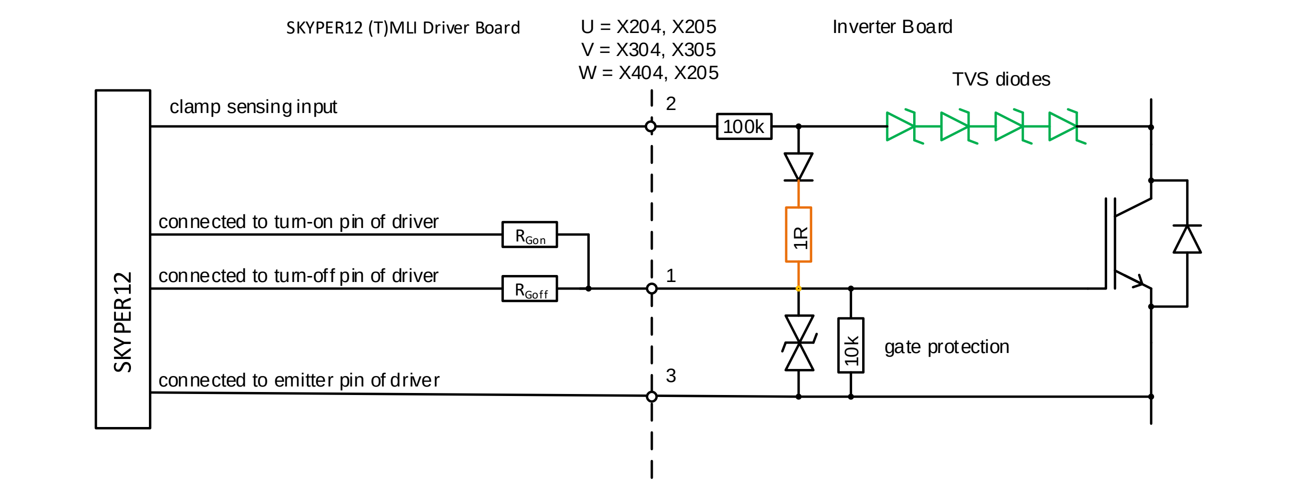
Short circuits phase to phase are monitored since the outer IGBTs (T1 and T4) are always in the short circuit loop. Phase to DC-link short circuits are not detected in all cases since only the inner IGBTs (T2 and T3) may conduct. However, a short circuit of an inner IGBT is rather unlikely, because it would require a defective semiconductor module or a defective PCB.
Phase to ground (chassis) short circuits are not detected either due to the same reason. However, the short circuit current in this case is low when the DC-link is grounded via resistor. The described protection in this inverter board covers the relevant application related cases and is a good compromise between effort and level of protection

3.4.4 Active clamping

IGBT T2 and T3 are equipped with circuitry to provide an operative active clamping protection. The active clamping protects the IGBT for too high peak voltage when switching off high currents or when switching off the inner IGBT prior to the outer IGBT. This case can occur when T1 respectively T4 are desaturating and T2, respectively T3, is switched off because of the set error from desaturation detection. A feedback pin from the active clamping to the driver is provided to be able to turn off the output stage of the driver in order not to work against the active clamping (this functionality is available with the SKYPER12 (T)MLI Driver Board).

Figure 10 shows the schematic of the active clamping circuit as it is realized on the inverter board. Four SMB sized TVS diodes are used to set the maximum peak voltage (marked green in Figure 10). The orange resistor limits the current charging the gate when the active clamping is in operation. This part is equipped by default with a 1Ohm MiniMELF resistor.

Figure 10: Schematic of active clamping for IGBT T2 and T3



3.5 Inverter Board description

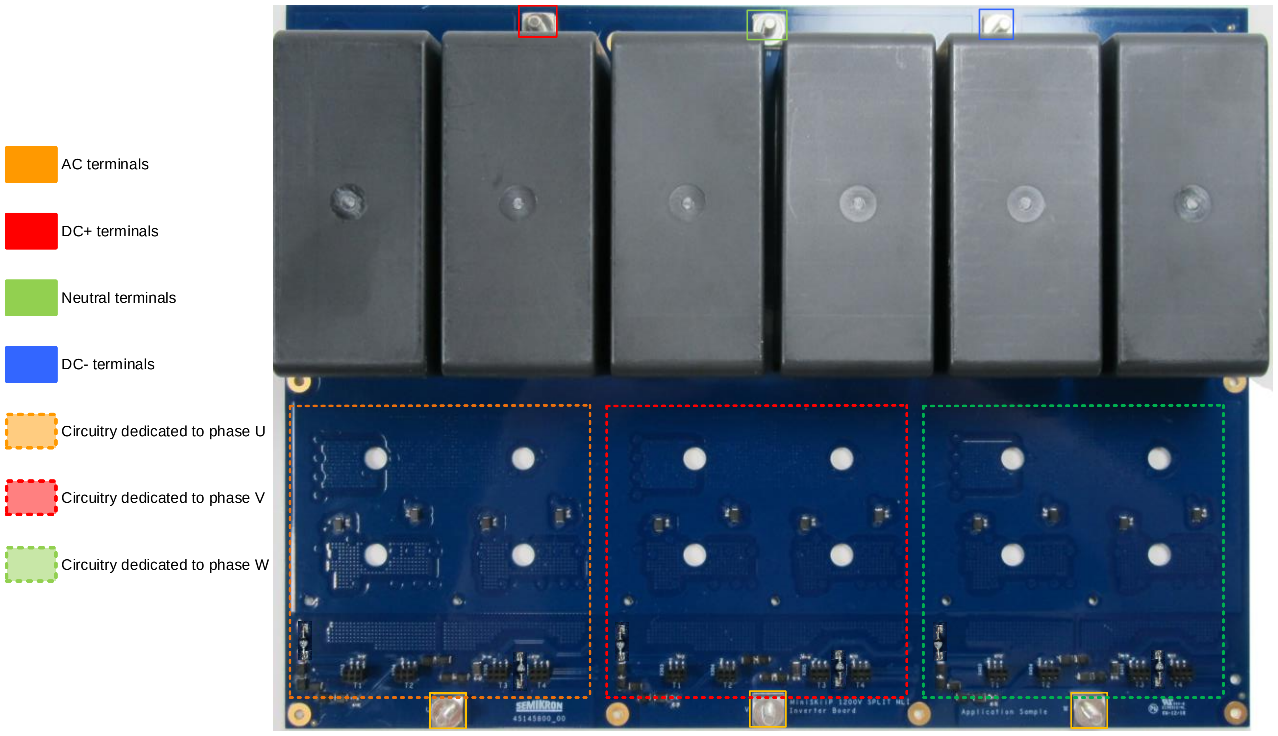
Polypropylene capacitors are used to build the DC-link.
Supplier and type: Vishay MKP1848C73280YY5.
6pcs. each 320µF; total capacitance: 2* 960µF (DC+/N and N/DC-)
V_{DC}=800V@85°C
I_{RMS}=55A
Capacitor Size: (l x w x h) 130mm x 57,5mm x 65mm

The inverter board is designed to be operated with three SKYPER12 (T)MLI Driver Boards. The driver board can be connected to the inverter board via four 6-pin plugs.

On the top side the inverter board is equipped with components for active clamping and desaturation detection. This components are meant to be changed by the user, i.e. an adaptation to the application conditions.

The connections to DC supply and AC output are marked in Figure 11; it also shows three dotted frames (orange, red and green) which mark three congruent areas (for different phase legs). One of those is picked exemplarily and explained in detail in Figure 12

Figure 11: Top side of the inverter board; DC and AC connections

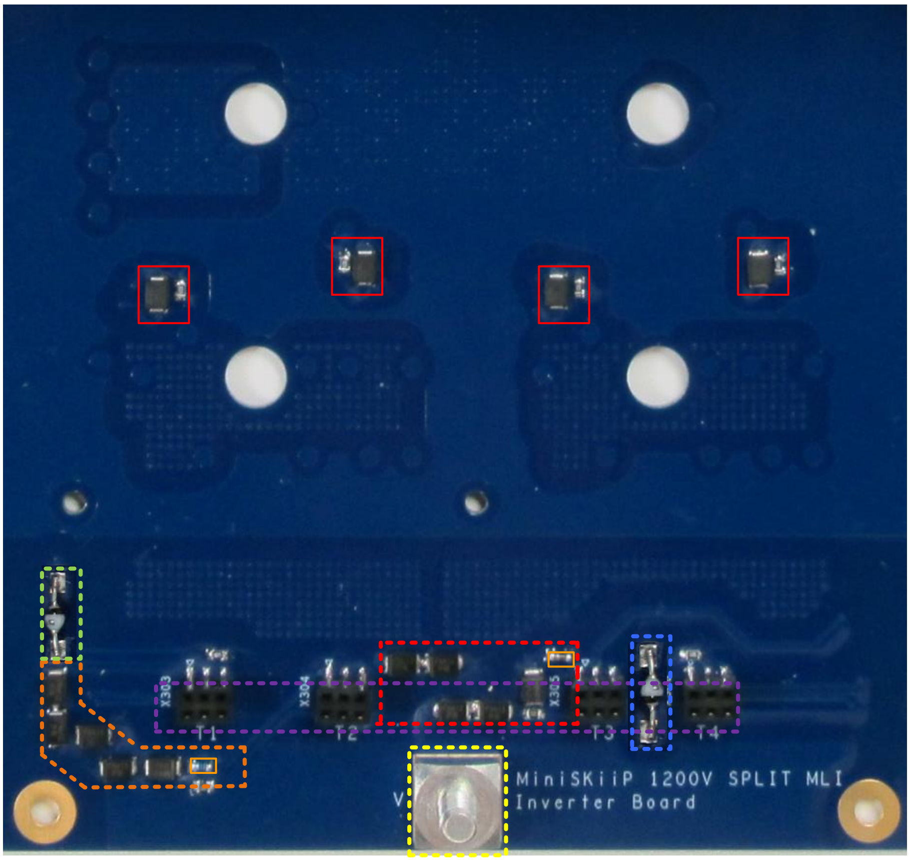


The components that can be changed by the user on the inverter board are marked with different coloured frames in Figure 12. The positions are shown for phase V exemplarily. For phase U, phase V and phase W the positions of all parts are congruent.

Figure 12 shows also the position where the SEMIKRON SKYPER12 (T)MLI Driver Board can be plugged to the inverter board (dotted purple frame).

Figure 12: Top side of the inverter board

- 1x MiniMELF / 1206 pad for active clamping turn-off resistor
- G-E SMB-size suppressor diode G-E resistor
- Pads for 4x SMB-size TVS diodes for active clamping
- Plugs for driver board
- V_{CE} desat diode to T1
- Active clamping circuitry to T2
- Active clamping circuitry to T3
- V_{CE} desat diode to T4
- AC terminal



3.6 SKYPER12 (T)MLI Driver Board

Three SKYPER12 (T)MLI Driver Boards are used to operate the IGBTs.. The driver boards (see separate Technical Explanation for further information [10]) consist of two SKYPER12 driver cores each. One for IGBTs T1 and T2 and the second for IGBTs T3 and T4.

Figure 13: SKYPER12 (T)MLI Driver Board top view

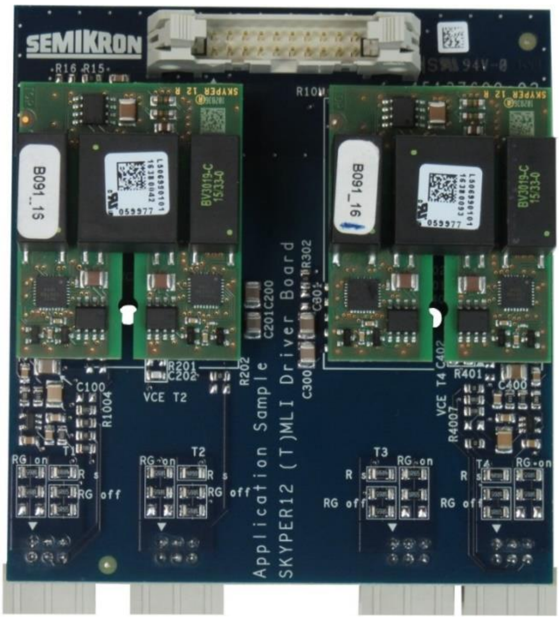


Table 4 shows the values which were used for SEMIKRON testing. It is up to the customer to optimize user-changeable values according to the particular operation and do the necessary tests with these changes.

Table 4: Part values for SEMIKRON tests (SiC and Si version)

Part	Resulting value for T1 and T4	Resulting value for T2 and T3	Description
R_{Gon}	0.81Ω		Gate resistor settings
R_{Goff}	1.62Ω		
R_{Soft}	30Ω	Not equipped	
R_{GE}	10kΩ	Not equipped	Setting of blanking time and desaturation threshold
C_{GE}	820pF	820pF	
R15/R16	Not equipped / 0Ω		Switch off on error
R10	0Ω		Interconnection of error outputs of the two SKYPER12 drivers
C105, C405	Not equipped		VCE detection input capacitor not needed
R202, R302	0Ω		Disable VCE detection on IGBT T2 and T3
$R_{temp,threshold}$	332Ω		Temperature threshold 105°C
Active Clamping	none	4x SMBJ170	Mounted on inverter board.

With this setting of R15/R16 the IGBT T2 is switched off in case of error from IGBT T1. Respectively IGBT T3 is switched off in case of error from IGBT T4.
The interconnection of the SKYPER12 error outputs (setting of R10=0Ω) causes IGBT T3 and T4 to switch off in case of error from IGBT T1. Respectively IGBT T1 and T2 are switched off in case of error T4.
This means that in case of one error all IGBT are switched off.

With the above mentioned values the inverter board was tested up to 1500V_{DC}. It can also withstand soft and hard short circuits.

4. User Interface

4.1 Driver board interface

The connection between inverter board and driver board is established via twelve 6-pin plugs:

Phase U	T1: X203	T2: X204	T3: X205	T4: X206
Phase V	T1: X303	T2: X304	T3: X305	T4: X306
Phase W	T1: X403	T2: X404	T3: X405	T4: X406

Plugs **X**xx**3** and **X**xx**6** show the same pinout as well as plugs **X**xx**4** and **X**xx**5**. The pinouts are explained in Table 5 and Table 6.

Table 5: Xxx**3 (X**xx**6) on inverter board interface to driver board**

Pin	Description
1	Gate potential of T1 (T4)
2	not connected
3	Emitter potential of T1 (T4)
4	Pin T+ of MiniSKiiP module's NTC sensor T1 (T4)
5	$V_{CE,desat}$ detection of T1 (T4)
6	Pin T- of MiniSKiiP module's NTC sensor T1 (T4)

Table 6: Xxx**4 (X**xx**5) on inverter board interface to driver board**

Pin	Description
1	Gate potential of T2 (T3)
2	Active Clamping sense of T2 (T3)
3	Emitter potential of T2 (T3)
4	not connected
5	not connected
6	not connected

4.2 DC and AC interface

The DC and AC interfaces are realized by PCB contact areas where cable shoes can be directly mounted by using an M6 screw.
The cable shoes may not exceed the size of the pressfit shanks' areas in order not to reduce insulation distances.

Connector supplier and type: Würth Connector Pressfit No. 746 109 8. Threaded Shank M6, RM2,54

5. Mechanical Stack Setup

All electrical tests have been made with a mechanical stack consisting of the inverter board, SKYPER12 (T)MLI Driver Board, heat sink and fans. The inverter has been tested up to 200KVA output power using SiC module and radial fan for heat sink cooling. The semiconductors are optimized for solar inverter operation with positive power factor between 0.85 and 1.
Figure 14 shows the stack setup from the heat sink side. The user needs to provide a mechanical support for the inverter board on the heat sink with stand offs.

Stack Setup
Weight: 12.2kg w/o fan
Dimension: (l x w x h) 405mm x 300mm x 175mm w/o driver board and 210mm including driver board

For further information of the MiniSKiiP module mounting see separate Mounting Instruction [9]

Figure 14: MiniSkiiP Dual Split MLI stack setup

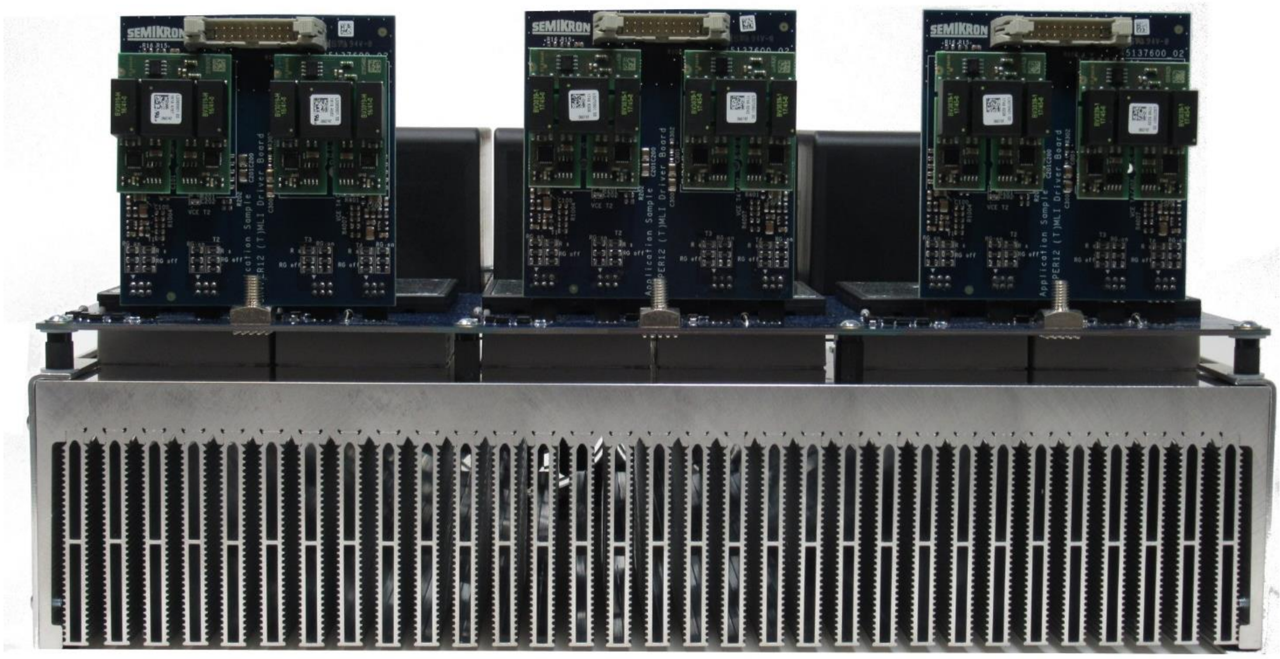


Figure 15 shows the ventilation of the stack with 4pcs. axial fans. For higher air flow a single powerful radial fan can be used.

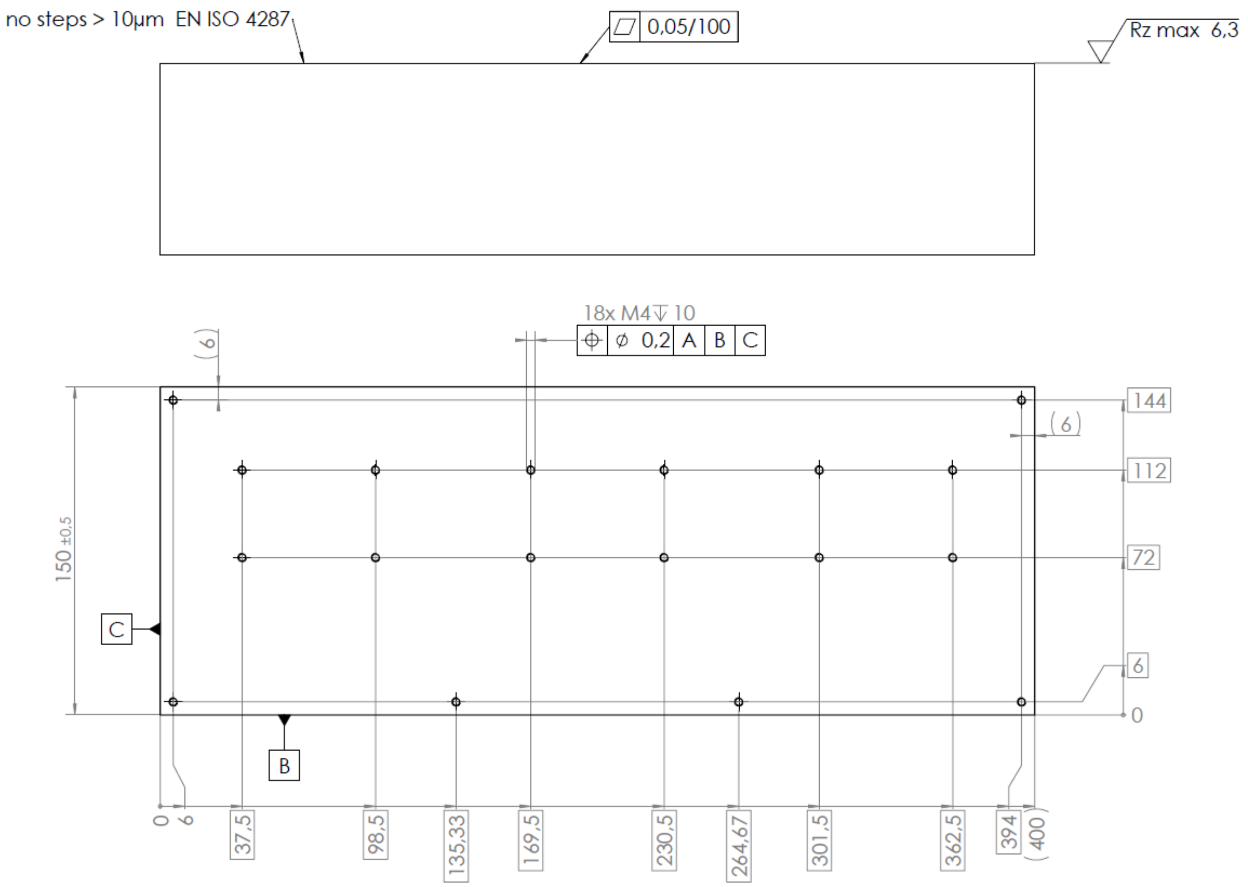
Figure 15: MiniSkiiP Dual Split MLI stack ventilation with axial fans

Heat sink proposal:
Supplier and type: Fischer SK461.
Dimension: (l x w x h) 400mm x 150mm x 88mm.
Weight: 4.8kg

The user may change the heat sink type and size to adapt the performance to the application conditions.

The drill holes for module and PCB fastening are given in Figure 16. Further the heat sink surface specification is given.

Figure 16: Heat sink drill hole position and surface specification



6. Restrictions and Requirements

This chapter claims some restrictions that must be paid attention to in order to avoid damage to inverter board or power semiconductor.

6.1 Switching pattern of MLI modules

A detailed explanation of the MLI switching pattern is given in the SEMIKRON Application Note AN-11001 [3]. Summed up always an inner IGBT (T2 or T3) must be switched on first, the corresponding outer IGBT (T1 or T4) after a short while, namely when the inner IGBT is entirely switched on. For switch-off this sequence must be maintained in reverse order: it must be made sure that T1 (T4) is thoroughly turned off before T2 (T3) may be switched off.

6.2 Error treatment

The SKYPER12 (T)MLI Driver Board is configured that in case of any error all IGBTs of the phase leg are switched off at the same time. So the switching pattern described in section 6.1 is not followed. This is possible because the active clamping at the inner IGBTs T2 and T3 limits the voltage across the semiconductors so it does not lead to destruction. However, active clamping means high thermal stress for the particular IGBTs and is hence meant for emergency situations only.

Short circuit
The inverter board provides short circuit detection of IGBT T1 and T4. In case of short circuit detection on T1 or T4 an error is set by the driver board and all IGBTs of the phase are switched off.

Thermal overload protection
The built-in temperature sensor of each MiniSKiiP module is supervised. The temperature trip level is set on SKYPER12 (T)MLI Driver Board. In case of exceeding the temperature trip level an error is generated and all IGBTs are switched off. The SKYPER12 secondary side failure input is used for temperature shut down.

Supply voltage
Further the SKYPER12 driver board monitors the primary and secondary supply voltage. Any error detected will set the error output and switches off all IGBTs.

6.3 Design limits active clamping

The clamping voltage for protecting the IGBTs can be adjusted by changing the breakdown voltage of the TVS diodes.
SEMIKRON recommends to use four diodes with the same breakdown voltage. Using less diodes and 0Ω jumpers instead or using diodes with different breakdown voltages influences the blocking voltage sharing across the individual pads. This might influence the overall insulation capability. Therefore the insulation capability needs to be checked in case this approach is desired.
The total breakdown voltage (sum of the breakdown voltages of all TVS diodes) must under all circumstances (tolerances of the breakdown voltage, thermal drift) be lower than the breakdown voltage of the IGBT that shall be protected.
On the other hand the clamping shall not work when just the maximum DC-link voltage is applied and the inverter is operating in normal operation (i.e. maximum DC-link voltage plus voltage overshoot in normal operation) in order not to increase the switching losses.

6.4 Design limits switching frequency

The maximum switching frequency is determined by the used modules and their gate charge and the power of the drivers. It is limited to 30kHz by insulation coordination. Further information on calculating the switching frequency limit can be found in Application Note AN-7004 [5].

6.5 Design limits ambient temperature

This Application Sample has been developed as reference design for laboratory use and tested up to 40°C accordingly.
However, it might be possible to extend the ambient temperature range; the responsibility to test and qualify this larger range remains with the user.

6.6 SEMIKRON assembly

SEMIKRON has tested the Application Sample with three SKYPER12 (T)MLI Driver Boards utilizing a not optimized forced air cooled heatsink. All results shown are valid for the particular revisions shown in Table 7 only.

Table 7: Part revisions for SEMIKRON tests

Part	No.	Remark
MiniSKiiP Dual Split MLI Inverter Board	45145801	
SKYPER 12	L5069901	Driver core
SKYPER12 (T)MLI Driver Board	45137601	
SKiiP39MLIT12F4V22	25241242P	D5 SiC diode. Hybrid module
SKiiP39MLIB12F4V22	25241243P	D6 SiC diode. Hybrid module
SKiiP39MLIT12F4V1	25241240P	D5 Si diode. Silicon module
SKiiP39MLIB12F4V1	25241241P	D6 Si diode. Silicon module

Symbols and Terms

Letter Symbol	Term
3L	Three level
C_{GE}	External gate emitter capacitance
CTI	Comparative Tracking Index
DC-	Negative potential (terminal) of a direct voltage source
DC+	Positive potential (terminal) of a direct voltage source
f_{sw}	Switching frequency
GND	Ground
IGBT	Insulated Gate Bipolar Transistor
N	Neutral potential (terminal) of a direct voltage source; midpoint between DC+ and DC-
NTC	Temperature sensor with negative temperature coefficient
PWM	Pulse Width Modulation
R_{GE}	External gate emitter resistor
R_{Gint}	Internal gate resistance
R_{Goff}	External gate series resistor at switch-off
R_{Gon}	External gate series resistor at switch-on
R_{soft}	External gate series resistor at soft-turn-off
$R_{temp,threshold}$	Resistor to set the temperature threshold
RMS	Root Mean Square
T_a	Ambient temperature
T_j	Junction temperature
TNPC	T-type Neutral Point Clamped
TVS	Transient voltage suppressor
V_{AC}	Inverter output voltage
V_{CE}	Collector-emitter voltage
$V_{CE,desat}$	Collector-emitter desaturation voltage
V_{DC}	Total supply voltage between DC+ and DC-

A detailed explanation of the terms and symbols can be found in the "Application Manual Power Semiconductors" [2]

References

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IMPORTANT INFORMATION AND WARNINGS

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