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Technical Explanation SEMITOP E2 1200V MLI Inverter Board

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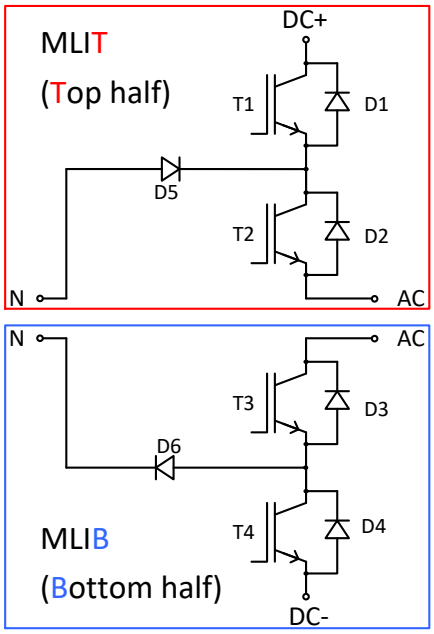
1. Introduction

SEMIKRON set up a 3-phase inverter board for operating SEMITOP E2 1200V MLI modules for evaluation purposes. The SEMITOP E2 1200V MLI Inverter Board ("inverter board") is designed to operate with three SKYPER12 (T)MLI Driver Boards (also a SEMIKRON Application Sample; Technical Explanation available), one per phase leg. 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 SEMITOP E2 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 all switches 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 – SKYPER12 (T)MLI Driver Board for detailed information on the driver boards used together with the inverter board described in this document.

Figure 1: Split MLI in SEMITOP E2

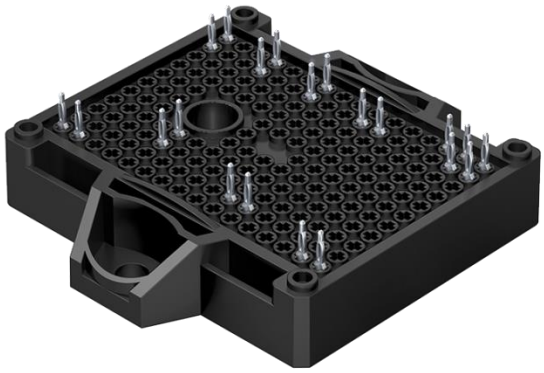


This Application Sample is dedicated to both universities and professional development engineers. It offers an easy way to set up a three phase inverter with SEMITOP E2 MLI modules and 2L drivers for a DC-link voltage up to 1500V. Performance tests can be run to prove the possibility of operation at high DC-link voltages and the high output power.

1.1 Features

The SEMITOP E2 1200V MLI Inverter Board is designed for SK150MLIT12F4TE2 (top half module) and SK150MLIB12F4TE2 (bottom half module). Both are rated 150A and come with 1200V semiconductors.

Figure 2: SEMITOP E2

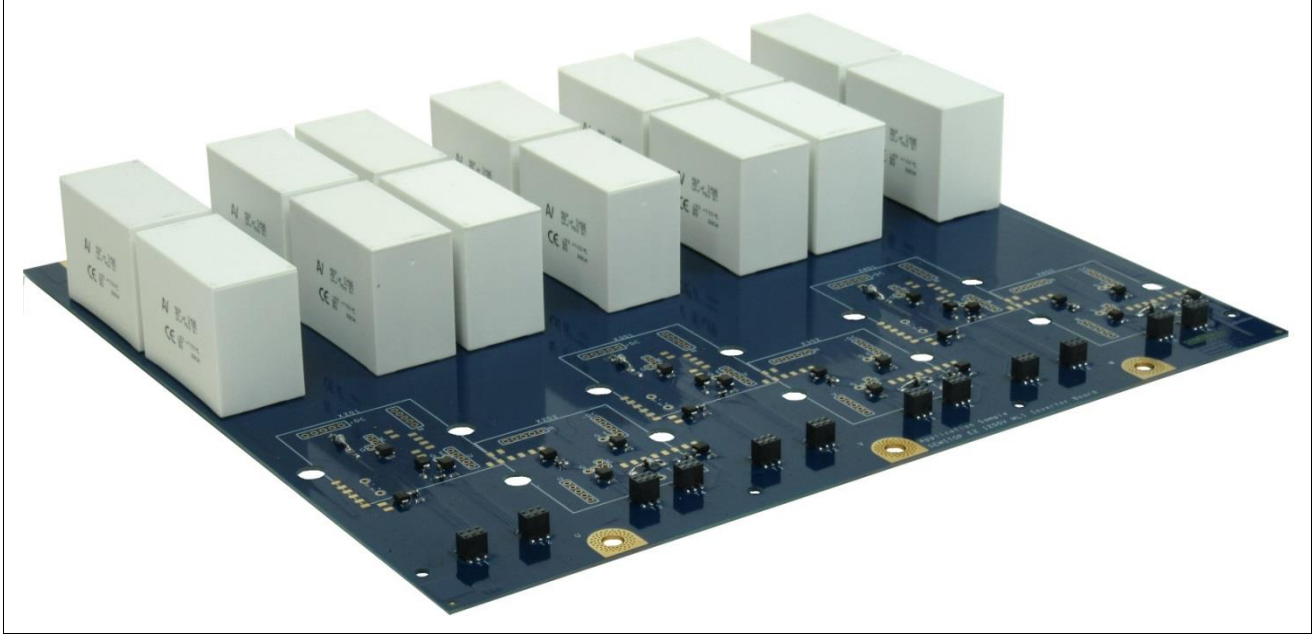


Of course all other pin compatible modules can be used as well as long as the design limits are met (e.g. maximum DC voltage and maximum driver output current may not be exceeded).

1.2 Hardware of the SEMITOP E2 1200V MLI Inverter Board

The SEMITOP E2 1200V MLI Inverter Board consists of a printed circuit board (PCB): it is called "SEMITOP E2 1200V MLI Inverter Board" with item number 45137501. It provides sockets for three SKYPER12 (T)MLI Driver Boards, six slots for the power modules (three top half modules and three bottom half modules), DC and AC terminals.

Figure 3: SKYPER12 (T)MLI Driver 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 (see also chapter 3.2).

2. Safety Instructions

The SEMITOP E2 1200V 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

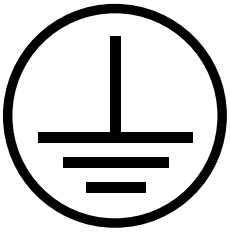
	**In operation the SEMITOP E2 1200V MLI Inverter Board inherits high voltages that are dangerous to life!** **Only qualified personnel should work with the Kit.**
	**Some parts of the SEMITOP E2 1200V MLI Inverter Board or connected devices (e.g. heatsink) may reach high temperatures that might lead 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 SEMITOP E2 1200V MLI Inverter Board.**

Table 2: Safety regulations for work with electrical equipment

Safety Regulations

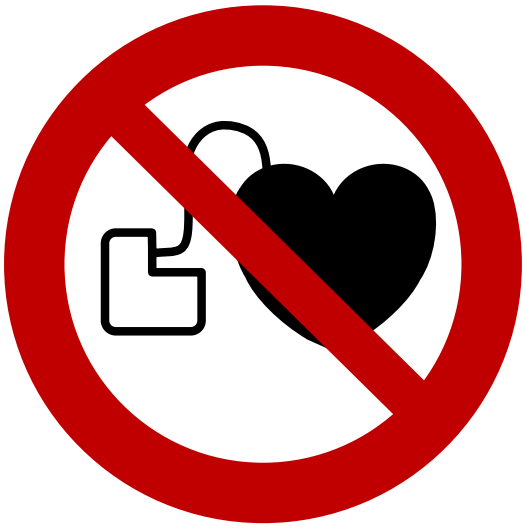
for work with electrical equipment

1) Disconnect mains!
2) Prevent reconnection!
3) Test for absence of harmful voltages!
4) Ground and short circuit!
5) Cover or close of nearby live parts!

To energize, apply in reverse order!

Please follow the safety regulations for working safe with the SEMITOP E2 1200V 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.

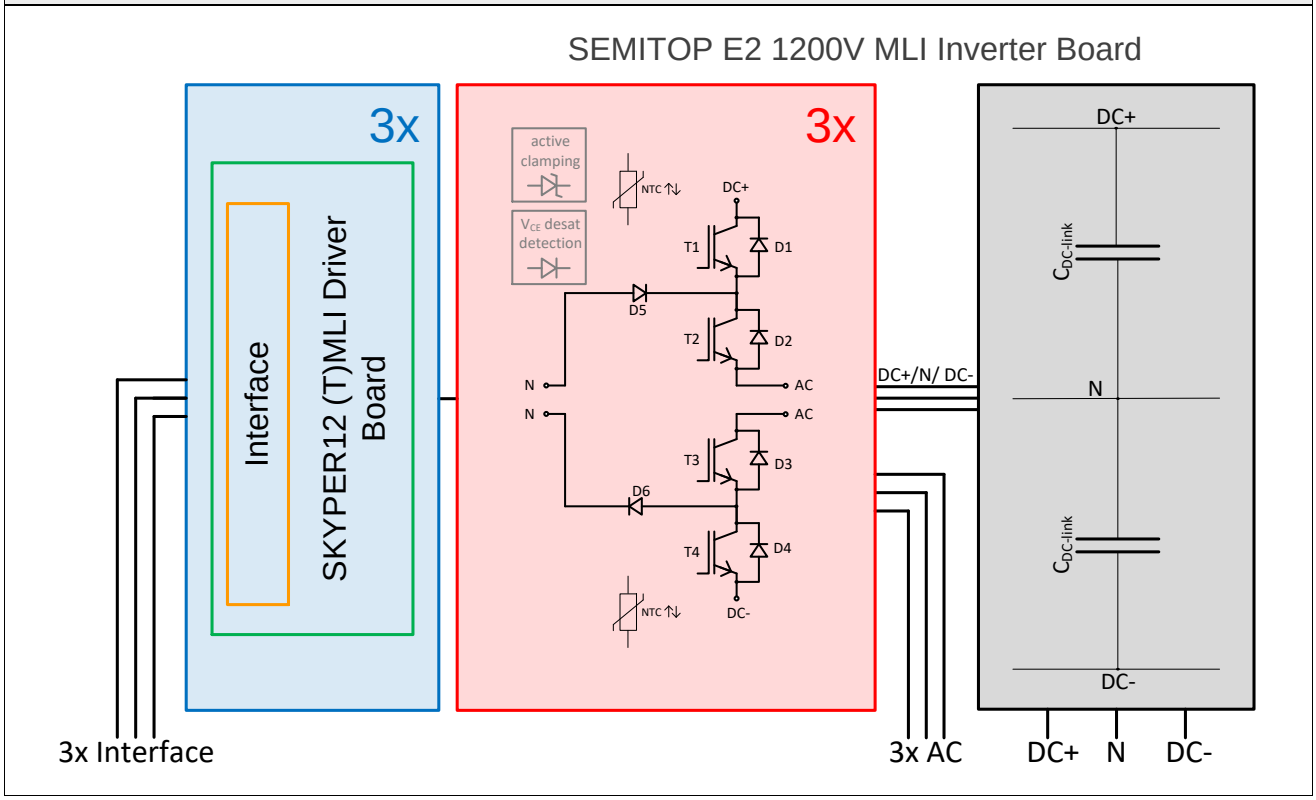
Please make sure to always use the appropriate personal safety equipment when working with the Application Sample.

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 SEMITOP E2 1200V MLI Inverter Board.

Figure 4: SEMITOP E2 1200V MLI Inverter Board block diagram



3.2 Electrical and mechanical characteristics

With regard to the requirement specification the SEMITOP E2 1200V 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 5.5 for further information)
- CTI rating of AppS PCBs > 175

Neglecting the above mentioned boundaries may lead to malfunction or damage of the SEMITOP E2 1200V MLI Inverter Board.

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

The inverter board is 300mm long and 330mm wide. Including SEMITOP E2 modules the total height is 60mm.

Figure 5: SEMITOP E2 1200V MLI Inverter Board ("inverter board"), top side

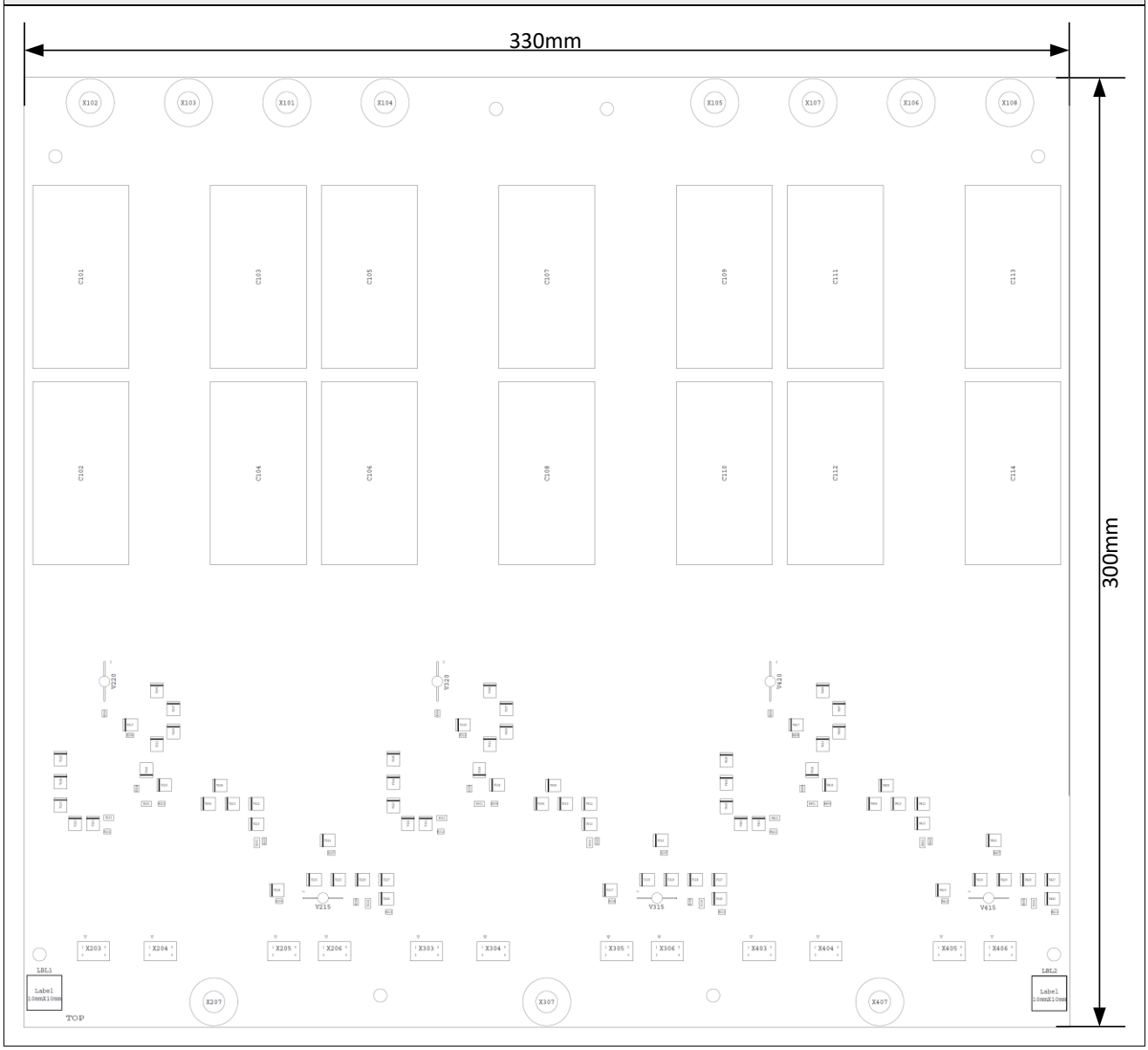
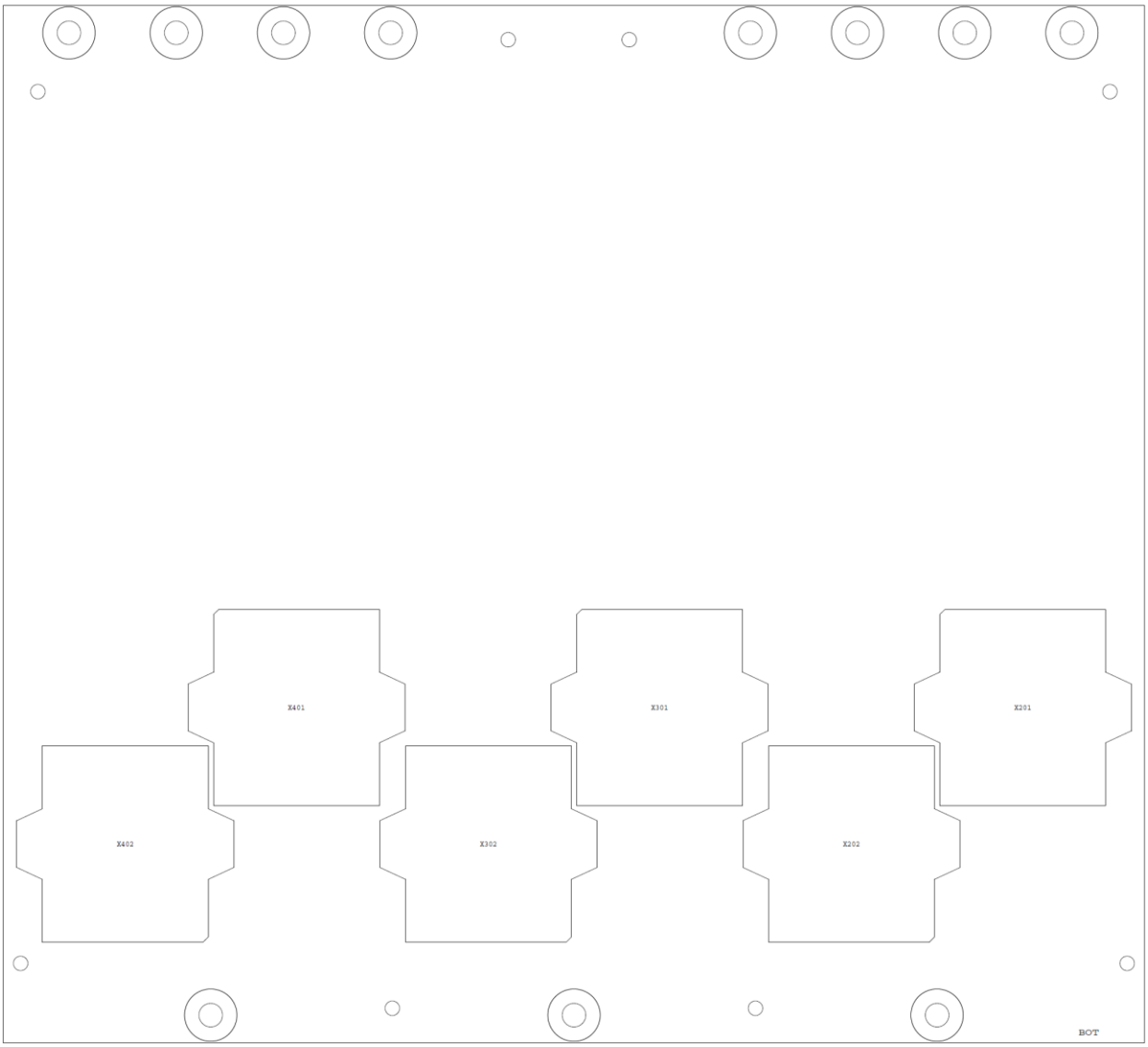


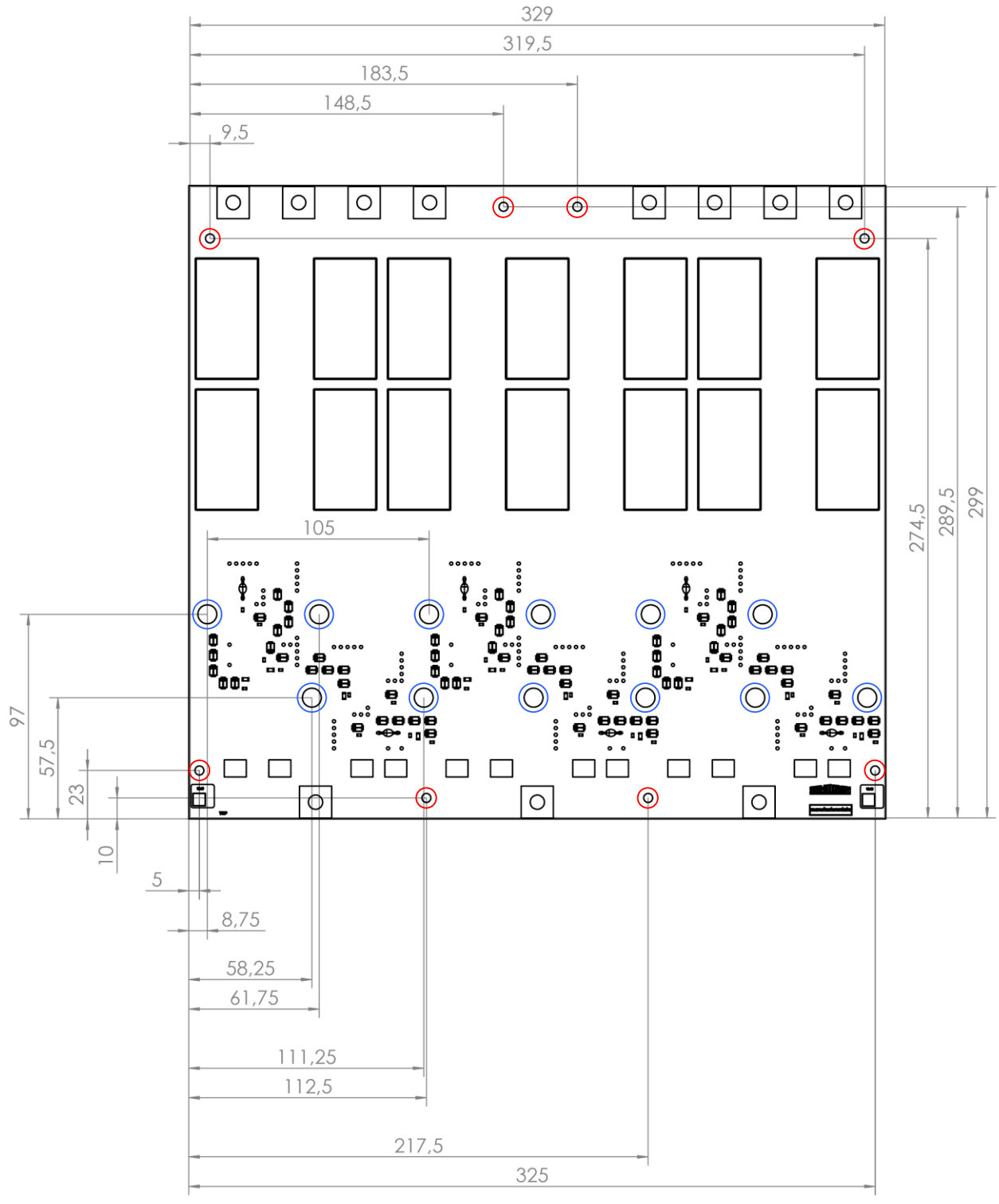
Figure 5 shows the top side of the inverter board. Here the diodes for the active clamping circuit are located.
The SEMITOP E2 power semiconductor modules are mounted on the bottom side of the inverter board (Figure 6).

Figure 6: SEMITOP E2 1200V MLI Inverter Board ("inverter board"), bottom side



The user needs to provide a heatsink and a mechanical support for the inverter board. The drill holes that need to be made are marked in Figure 7. The red circled holes have a diameter of 4.3mm to take M4 supporting posts. The blue circled holes have a diameter of 9mm; through these holes the M4 screws for mounting the modules can be reached.
The support posts must be able to isolate the DC-link voltage from the heatsink, i.e. no metal posts may be used.

Figure 7: SEMITOP E2 1200V MLI Inverter Board drill holes for mounting



3.3 Integrated functions

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

3.3.1 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.

3.3.2 $V_{CE,desat}$ diodes

In order to detect desaturation events a diode between collector and the particular driver stage is required. This diode is located close to each collector on the power board. $V_{CE,desat}$ detection, however, is only possible, when the driver supports this functionality. SEMIKRON's SKYPER12 (T)MLI Driver Board supports desaturation detection.

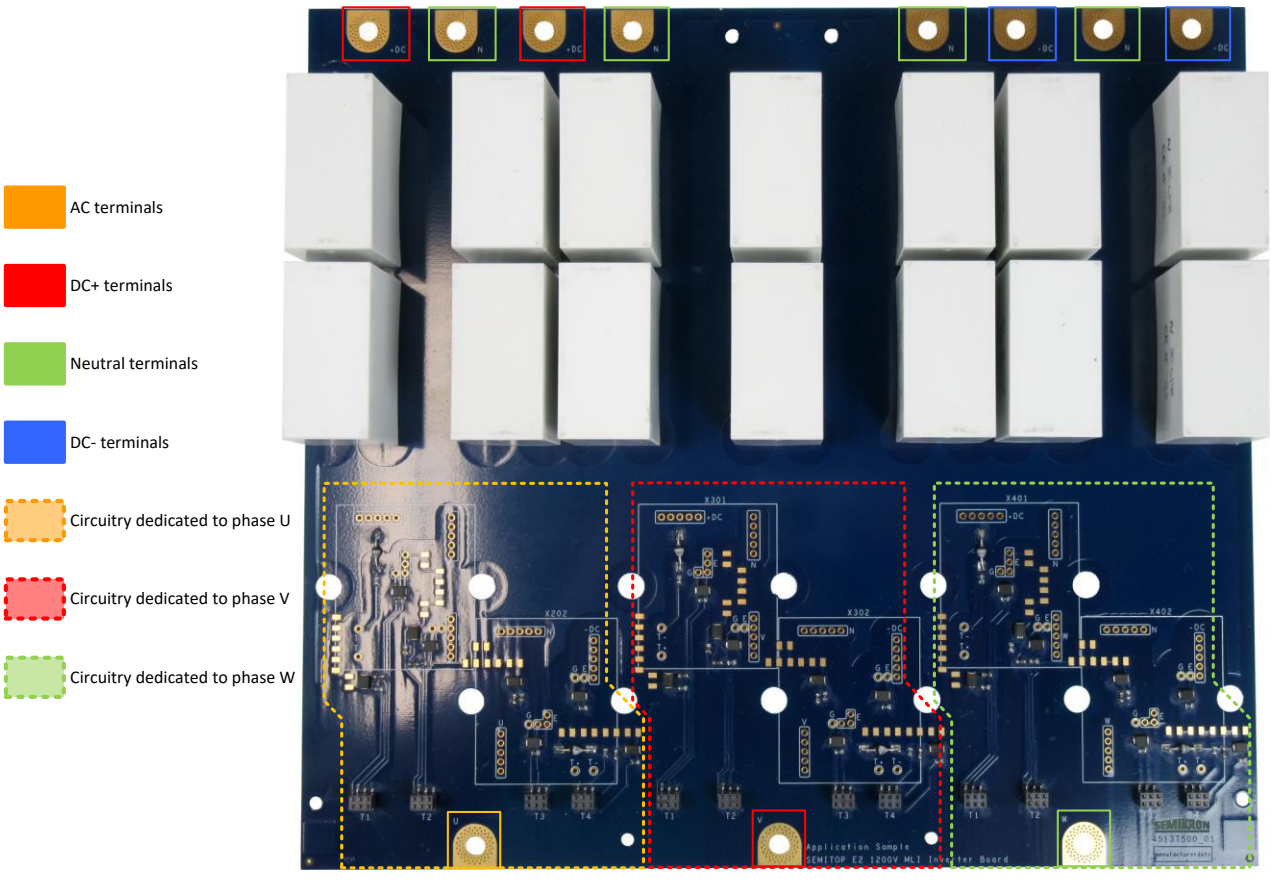
3.3.3 Active clamping

All required circuitry to provide an operative active clamping protection of the four IGBTs per phase leg is located on the inverter board. By default the TVS diodes that limit the maximum voltage across each IGBT are not equipped as the correct value depends on the precise operating conditions (e.g. DC voltage). 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).

3.4 Board description

Several 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 8; 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 9.

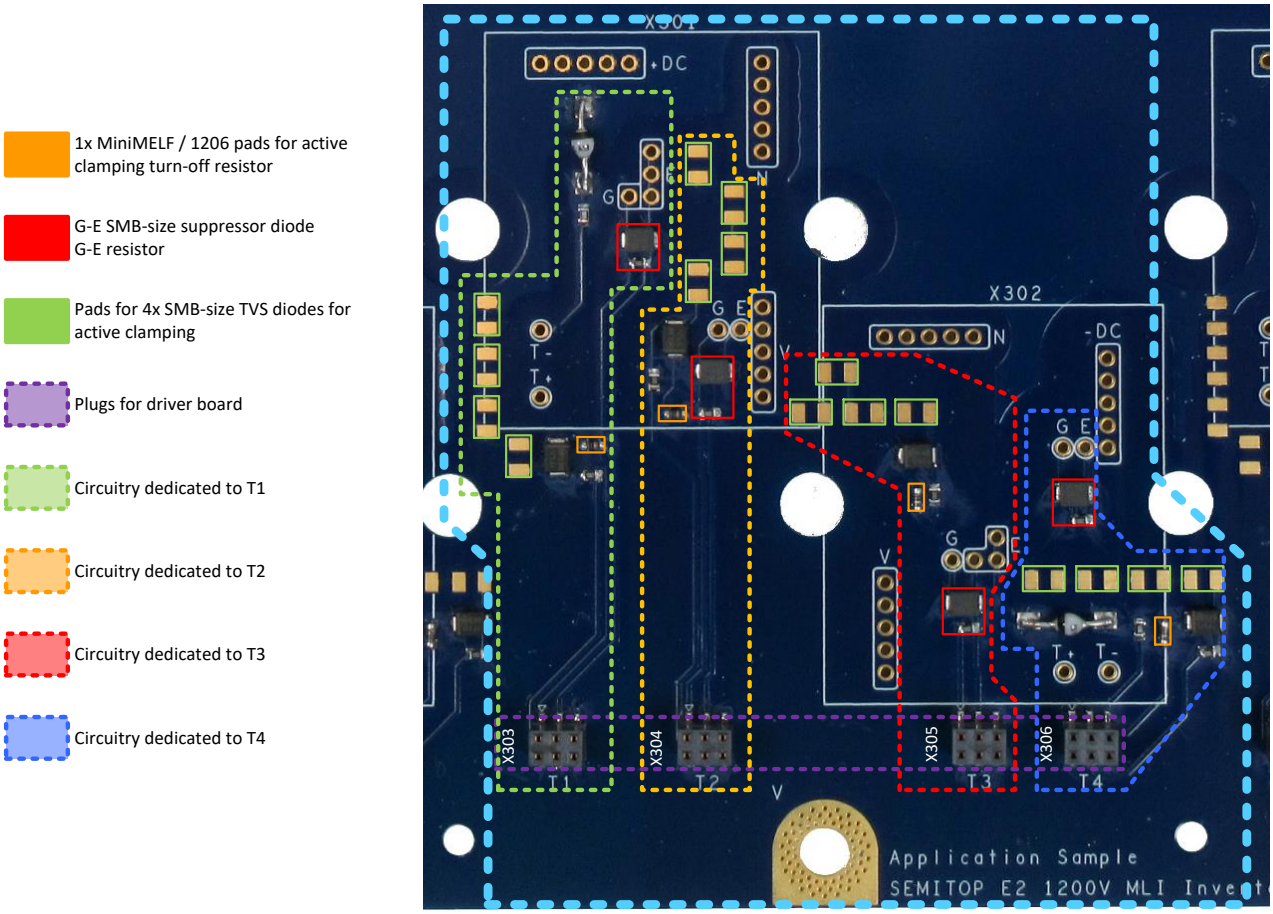
Figure 8: Top side of the inverter board; DC and AC connections



The components that can be changed by the user on the inverter board are marked with different coloured frames in Figure 8. Figure 9 shows the positions exemplarily at phase V (the light blue dotted frame in

Figure 9 represents the orange, red and green dotted frames in Figure 8). The positions of all parts are congruent for phase U, phase V and phase W and only the leading digit in the part number is increased by one from phase U to phase V and by one from phase V to phase W. Example: X**2**01 ⇒ upper half module phase U; X**3**01 ⇒ upper half module phase V, X**4**01 ⇒ upper half module phase W.
Figure 9 shows also the position where the SEMIKRON SKYPER12 (T)MLI Driver Board can be plugged to the inverter board (dotted purple frame).
Function and possible values are explained in chapters 3.4.1 to 3.4.3.

Figure 9: Top side of the driver board; user-changeable components are framed



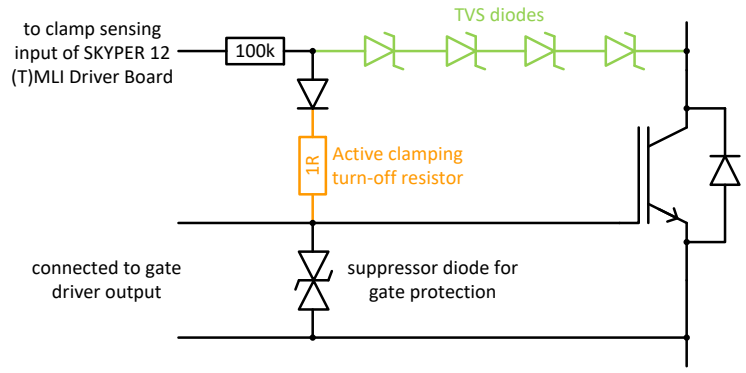
3.4.1 Plugs for driver board adaptation

The inverter board is designed to be operated with three SKYPER12 (T)MLI Driver Boards (see separate Technical Explanation for further information [1]). The driver board can be connected to the inverter board via four 6-pin plugs (framed dotted purple in Figure 9).

3.4.2 Active clamping

Figure 10 shows the schematic of the active clamping circuit as it is realized on the inverter board. The orange resistor represents the turn-off resistor which limits the current charging the gate when the active clamping is in operation. It can be found in Figure 9 framed solid orange. These parts are equipped by default with 1Ω MiniMELF resistors.
The four SMB sized pads per switch for the TVS diodes (marked green in Figure 10, framed solid green in Figure 9) are unpopulated by default. If the TVS diodes are not installed (no active clamping functionality) it is necessary to deactivate the clamp sensing input of the SKYPER12 (T)MLI Driver Board if it is in use with the inverter board (see also [1]).

Figure 10: Schematic of active clamping

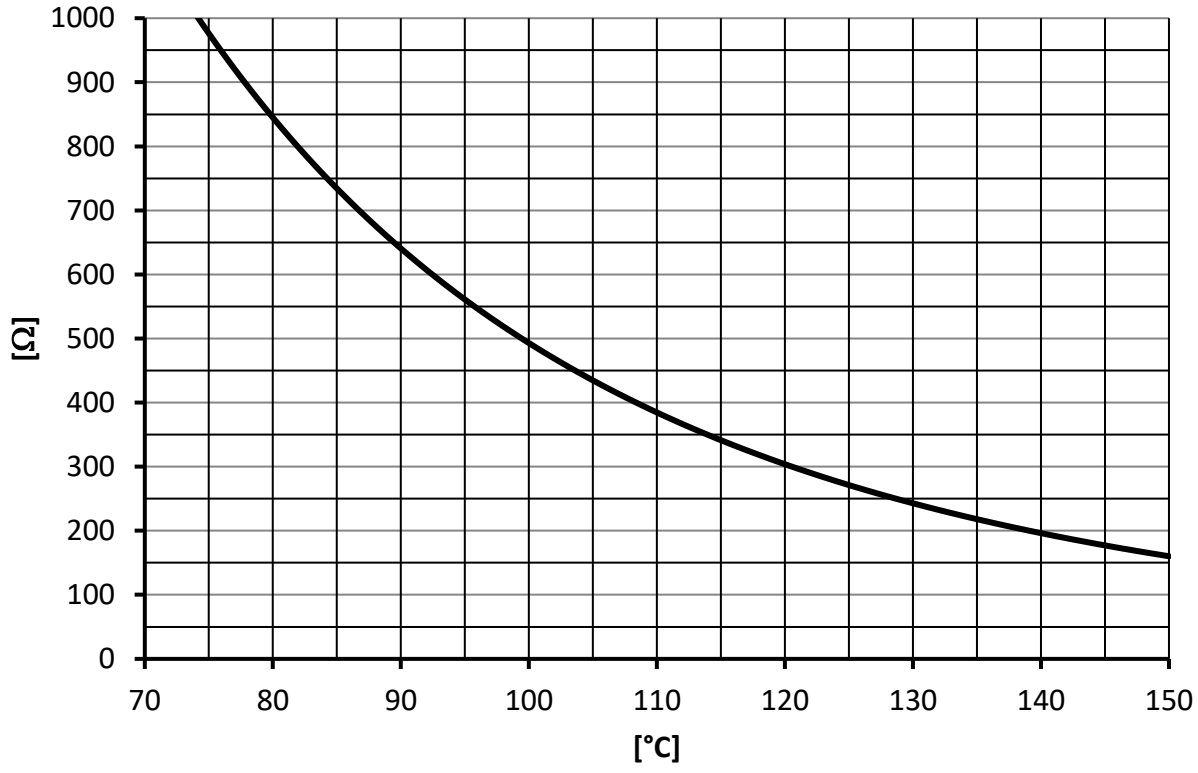


Please refer to chapter 5.3 for further information.

3.4.3 Plugs for driver board adaptation

The SEMITOP E2 modules that can be operated with the inverter board have a built-in NTC temperature sensor. Figure 11 shows an excerpt of the NTC characteristic which includes the most interesting temperature range between 70°C and 150°C. The full characteristic can be found in the Technical Explanations of SEMITOP E or can be calculated from the formula given in the SEMITOP E2 datasheets [1].

Figure 11: SEMITOP E2 NTC characteristic (excerpt)



4. User Interface

4.1 Driver board interface

The connection between inverter board and driver board is established by X203, X204, X205 and X206 for phase U, X303, X304, X305 and X306 for phase V and X403, X404, X405 and X406 for phase W.
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 4 and Table 5.

Table 4: Xxx**3 (X**xx**6) on inverter board interface to driver board**

Pin	Description
1	Gate potential of T1 (T4)
2	Active Clamping sense of T1 (T4)
3	Emitter potential of T1 (T4)
4	Pin T+ of SEMITOP E2 module's NTC sensor T1 (T4)
5	$V_{CE,desat}$ detection of T1 (T4)
6	Pin T- of SEMITOP E2 module's NTC sensor T1 (T4)

Table 5: 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	$V_{CE,desat}$ detection of T2 (T3)
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. A washer with the same size as the PCB contact area allows for a planar contact between cable shoe and inverter board.
The cable shoes may not exceed the size of the DC contact areas in order not to reduce insulation distances.

5. 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.

5.1 Switching pattern of (T)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.
This sequence is recommended to be maintained at any time, even and especially in case of emergency shut-down (e.g. because of over current or desaturation).

5.2 Error treatment

The inverter board provides active clamping functionality only. In case desaturation events or thermal overloads take place, the connected driver needs to react accordingly. All required functionality for an extensive error management is integrated in the SKYPER12 (T)MLI Driver Board. SEMIKRON recommends using this driver board for proper and save operation.
If other driving equipment shall be used it must be made sure that the aforementioned events are treated correctly.

5.3 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.

5.4 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].

5.5 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.

5.6 SEMIKRON assembly

SEMIKRON has tested the Application Sample with three SKYPER12 (T)MLI Driver Boards utilizing not optimized forced air cooled heatsink. All results shown are valid for the particular revisions shown in Table 6 only.

Table 6: Part revisions for SEMIKRON tests	
Part	**Revision**
SEMITOP E2 1200V MLI Inverter Board	45137501_04
SKYPER 12	L5069901
SKYPER12 (T)MLI Driver Board	45137601_02
SK150MLIT12F4TE2	Datecode: 17010P R
SK150MLIB12F4TE2	Datecode: 17010P R

Variable part values have been chosen according to Table 7.

Table 7: Part values for SEMIKRON tests		
Part	**Resulting value for T1 and T4**	**Resulting value for T2 and T3**
R_{Gon}	1.65Ω	1.65Ω
R_{Goff}	1.65Ω	1.65Ω
R_{Soft}	5.1Ω	5.1Ω
Active Clamping	4x 170V (i.e. four TVS diodes with a nominal breakdown voltage of 170V)	4x 170V (i.e. four TVS diodes with a nominal breakdown voltage of 170V)
R_{CE}	7.5kΩ	n.c.
C_{CE}	820pF	820pF
$R_{temp,threshold}$	332Ω	

With the above mentioned values an absolute maximum operation up to $1500V_{DC}$ and $75A_{RMS}$ is possible at all power factor values at a maximum ambient temperature of 40°C.
It can also withstand soft and hard short circuits, when the active clamping circuits are adjusted to come into action at V_{CE}=1000..1100V.
The SEMITOP E2 1200V MLI Inverter Board has passed isolation and partial discharge tests.

It is up to the customer to optimize user-changeable values according to the particular operation and do the necessary tests with these changes.

Symbols and Terms

Letter Symbol	Term
3L	Three level
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-
n.c.	not connected
NTC	Temperature sensor with negative temperature coefficient
PELV	Protective Extra Low Voltage
PWM	Pulse Width Modulation
R_{Gint}	Internal gate resistance
R_{Goff}	External gate series resistor at switch-off
R_{Gon}	External gate series resistor at switch-on
RMS	Root Mean Square
SELV	Safety Extra Low Voltage
T_a	Ambient temperature
T_j	Junction temperature
TNPC	T-type Neutral Point Clamped
TVS	Transient voltage suppressor
V_{CE}	Collector-emitter 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

[1] www.SEMIKRON.com
[2] A. Wintrich, U. Nicolai, W. Tursky, T. Reimann, "Application Manual Power Semiconductors", 2nd edition, ISLE Verlag 2015, ISBN 978-3-938843-83-3
[3] I. Staudt, "3L NPC & TNPC Topology", SEMIKRON Application Note, AN-11001 - rev05, 2015
[4] M. Hermwille, "Gate Resistor – Principles and Applications", SEMIKRON Application Note, AN-7003 - rev00, 2007
[5] M. Hermwille, "IGBT Driver Calculation", SEMIKRON Application Note, AN-7004 - rev00, 2007
[6] J. Krapp, "Technical Explanation SKYPER®12 – rev5", SEMIKRON Technical Explanation, 2017
[7] R. Agostini, "Technical Explanation SEMITOP® – rev5", SEMIKRON Technical Explanation, 2017

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