Technical Explanation
SEMiX5 TMLI Driver Board®

SEMIKRON DANFOSS

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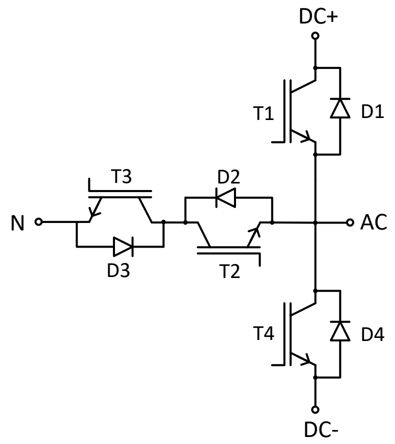
1. Introduction

Semikron Danfoss set up a driver board for operating a SEMiX5 TMLI module for evaluation purposes. The SEMiX5 TMLI SKYPER12 Driver Board ("driver board") is able 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. Both voltage ratings of TMLI modules (1700V/1200V or 1200V/650V) can be operated with the driver board.
Two standard 2L drivers (SKYPER12) are used to operate the 3L TMLI module; one driver operates switches T1 and T2, the other operates switches T3 and T4.
The failure management of the two SKYPER12 drivers detects desaturation events at the outer switches (IGBTs T1 and T4) and also monitors the module's built-in temperature sensor. While desaturation of the outer switches (IGBTs T1 and T4) leads to a shut-off of the outer IGBTs and produces an error signal, the inner switches (IGBTs T2 and T3) are not monitored.
In case the built-in temperature sensor exceeds a set temperature (can be set by user) the outer IGBTs are turned off immediately and the driver produces an error signal.
Additionally, an active clamping is implemented for protection of the inner switches (IGBTs T2 and T3) to add a maximum amount of safety to the device.

Figure 1: TMLI (common collector)



This Application Sample is dedicated to both universities and professional development engineers. It offers an easy way to set up high power inverters with standard TMLI modules and 2L drivers. Performance tests can be run to prove the possibility of operation at high DC-link voltages and the high output power.
All Application Samples have been isolation tested; there is no functional routine test.

1.1 Features

The SEMiX5 TMLI SKYPER12 Driver Board is designed for all SEMiX5 TMLI modules with either 1700V/1200V (vertical/horizontal branch) or 1200V/650V.

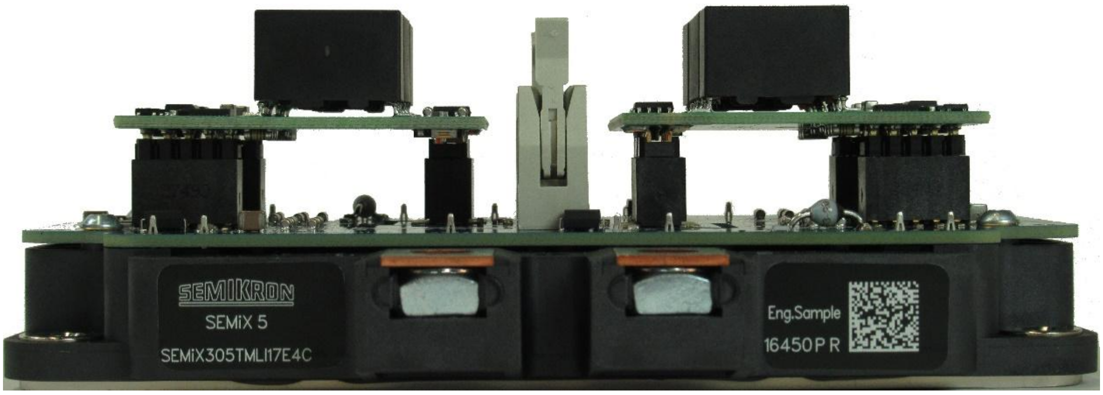
Figure 2: SEMiX5 TMLI

All pin-compatible SEMiX5 TMLI modules (different current rating, different voltage rating) can be operated with this driver board as long as they meet the design limits (e.g. maximum DC voltage and maximum SKYPER12 output power may not be exceeded).

1.2 Hardware of the SEMiX5 TMLI SKYPER12 Driver Board

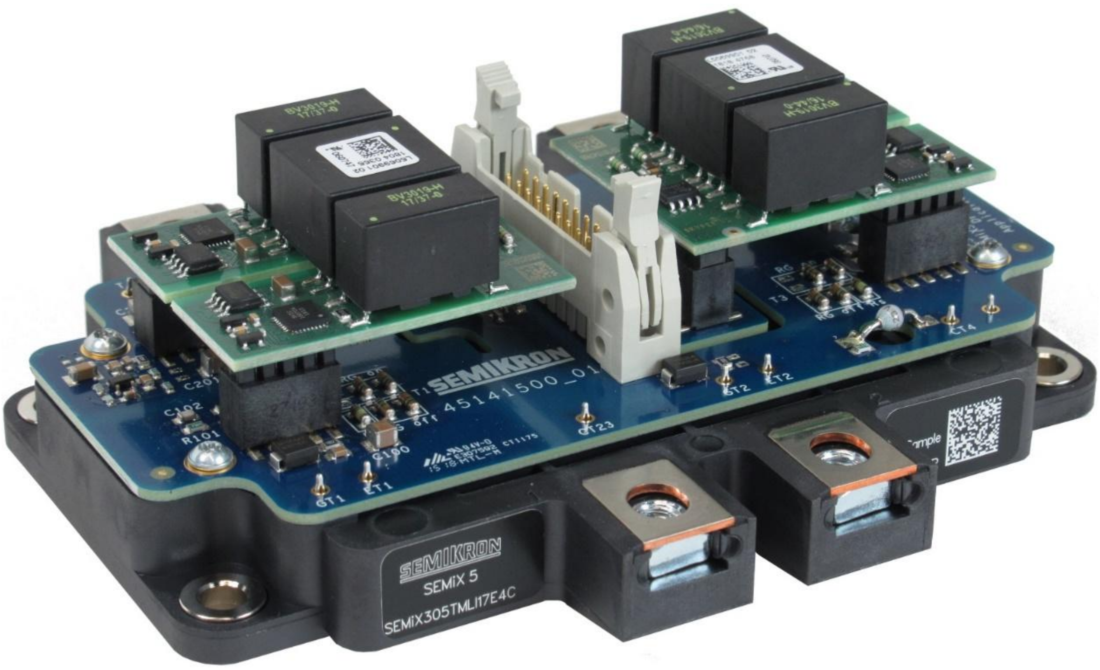
The SEMiX5 TMLI SKYPER12 Driver Board consists of a printed circuit board (PCB): it is called "SEMiX5 TMLI / SKYPER12 Driver Board" ("driver board"; containing gate resistors, clamping circuitry, etc.) with item number 45141501. It contacts the SEMiX5 module and provides sockets for the SKYPER12 drivers and a user interface.

Figure 3: SEMiX5 TMLI SKYPER12 Driver Board side view



The SEMiX5 TMLI module may be chosen according to the desired current and voltage rating.

Figure 4: SEMiX5 TMLI SKYPER12 Driver Board bird's eye 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, clamping voltage 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 Danfoss sales partner.

2. Safety Instructions

The SEMiX5 TMLI SKYPER12 Driver 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

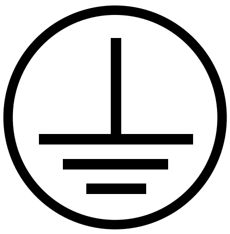
	**In operation, the SEMiX5 TMLI SKYPER12 Driver Board inherits high voltages that are dangerous to life! Only qualified personnel should work with the Kit.**
	**Some parts of the SEMiX5 TMLI SKYPER12 Driver Board or connected devices (e.g. heatsink) may reach high temperatures that might lead to burns 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 SEMiX5 TMLI SKYPER12 Driver Board.**

Table 2: Safety regulations for work with electrical equipment

Safety Regulations

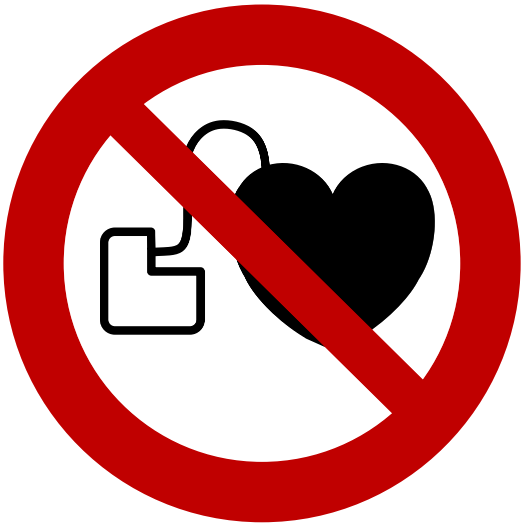
for work with electrical equipment

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 SEMiX5 TMLI SKYPER12 Driver Board.

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



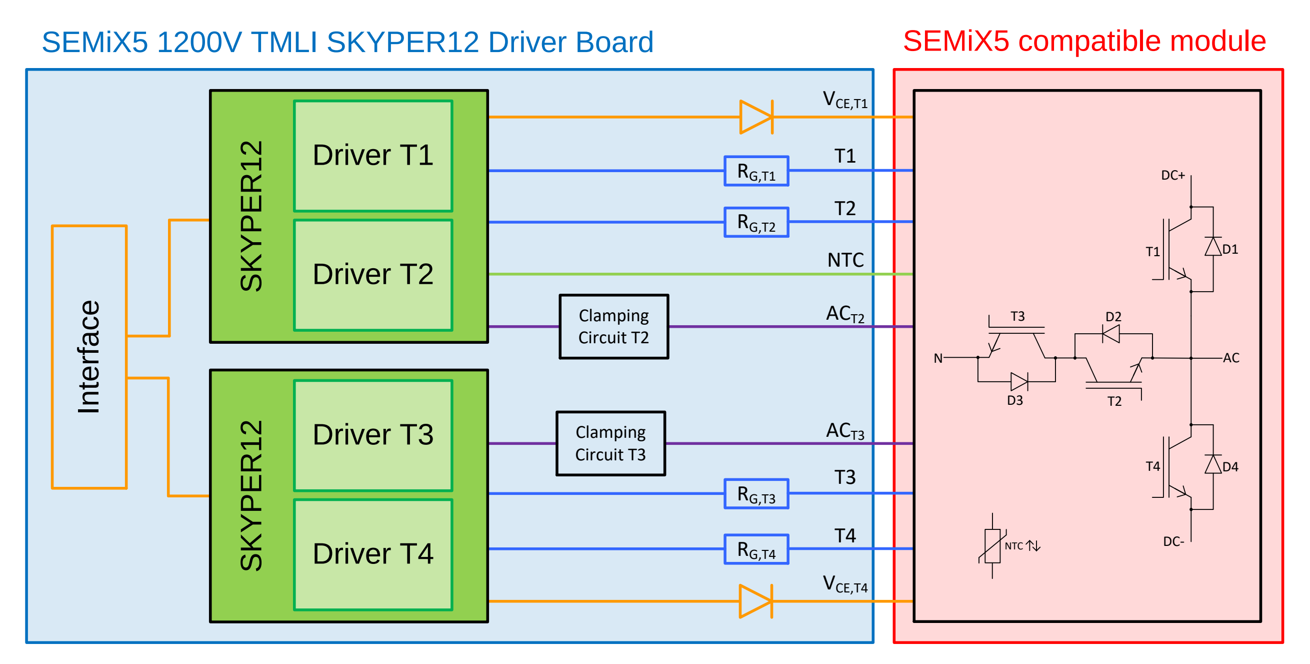
Operating the Application Sample may go along with electromagnetic fields which may disturb cardiac devices. People with cardiac devices shall not operate the device.

3. Technical Data

3.1 Driver Board block diagram

The electrical block diagram in Figure 5 shows two parts: the blue marked part is the driver PCB with sockets for the two SKYPER12 drivers (green), gate resistors, clamping and V_{CE} sensing circuitry. The red part symbolizes the 3-level module.

Figure 5: SEMiX5 TMLI SKYPER12 Driver Board block diagram



3.2 Electrical and mechanical characteristics

With regard to the requirement specification, the SEMiX5 TMLI SKYPER12 Driver Board allows for operation within the following boundaries:

- ⇨ Max. DC-link voltage — V_{DC} = 1350V in total, max. 675V per individual DC-link half
- ⇨ Max. AC voltage — V_{AC} = 900V_{RMS} (line-to-line)
- ⇨ Max. switching frequency — f_{sw} = 30kHz (see chapter 5.5 for further information)
- ⇨ Ambient temperature — T_a = 0°C…40°C (see chapter 5.6 for further information)
- ⇨ CTI rating of AppS PCBs — > 175

Neglecting the above-mentioned boundaries may lead to malfunction or damage of the SEMiX5 TMLI SKYPER12 Driver Board.

An electrical insulation is implemented between the user interface (primary side) and the high voltage connections (secondary side) by using the SKYPER12's separation. The creepage distance on the driver board is 13.5mm and the clearance distance is 7.2mm between primary and secondary side.
The overall responsibility for a proper insulation coordination remains with the user.

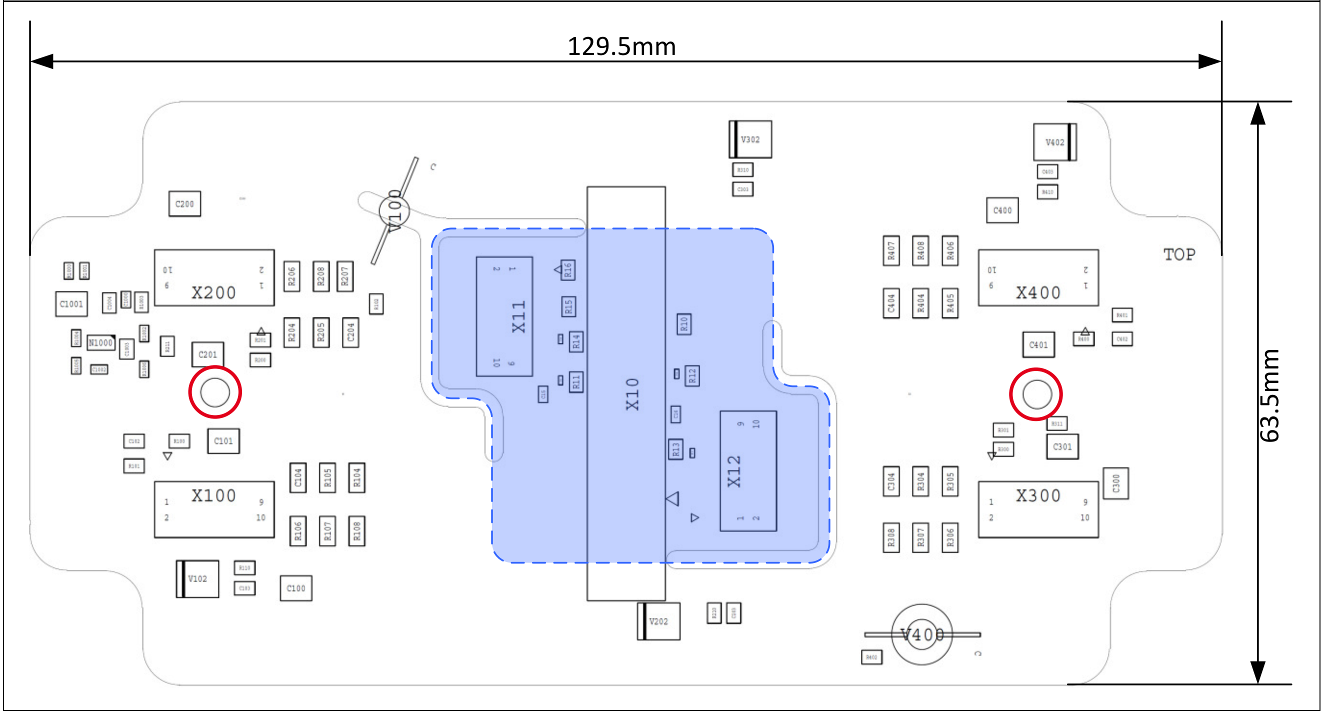
Please note that further restrictions of the used driver (e.g. SKYPER12) may apply. According information can be found in the technical documentation of the particular driver (e.g. Technical Explanations on the Semikron Danfoss website [1]).

The driver board is 129.5mm long and 63.5mm wide. Including SKYPER12 drivers, it adds a total height to the modules of 28.5mm.

To prevent the driver board and the SKYPER12 drivers from loosening from each other mounting holes for dual lock support posts are available (positions circled red in Figure 6). Please find further information in the technical explanation of SKYPER12 [5].
The driver board can be mounted to the SEMiX5 module in two steps. First, the board needs to be fixed to the module by using four self-tapping screws (type: "EJOT PT WN1451 K25x10" or "EJOT Delta PT WN5451 K25x10"). Secondly, the module's pins need to be soldered to the board although the SEMiX5 TMLI comes

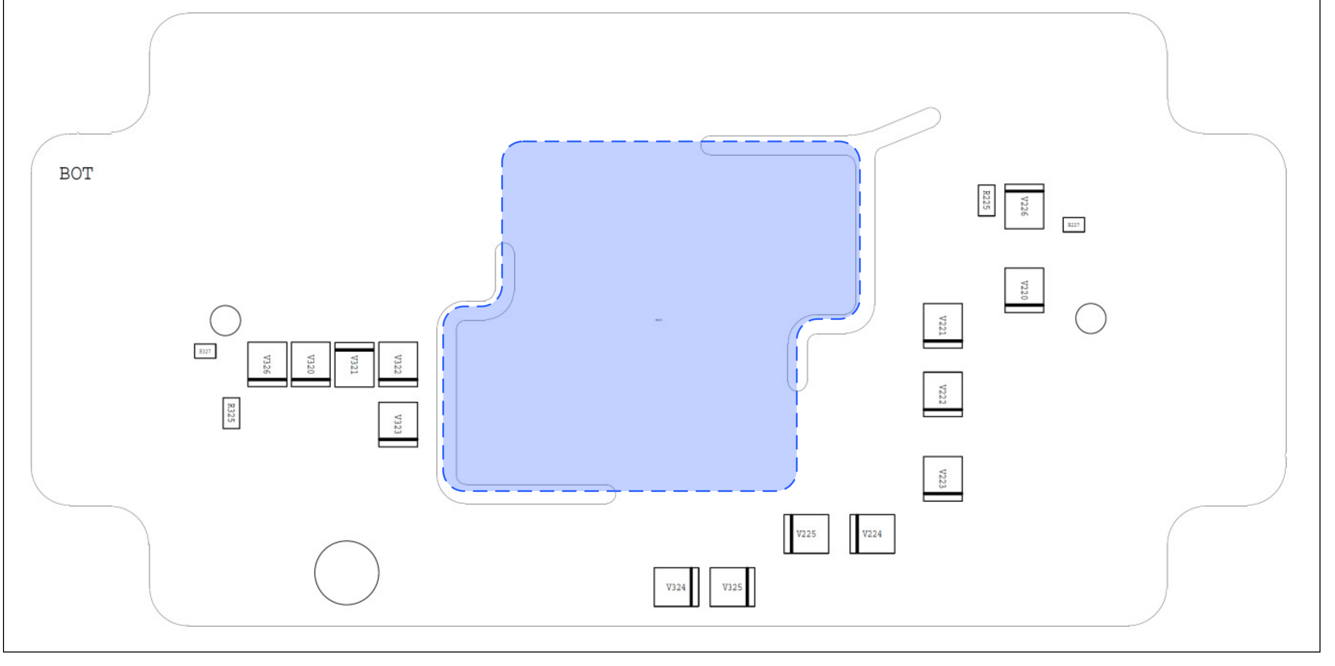
with press-fit contacts. That is because soldering does not require a pressing tool, which makes things easier for this Application Sample.

Figure 6: SEMiX5 TMLI SKYPER12 Driver Board ("driver board"), top side



The blue marked area in Figure 6 and Figure 7 indicates the primary side with the user interface socket. The insulation is provided by the galvanic insulation of the SKYPER12 drivers and the insulation gap on the driver board. All area besides the blue marking may be considered as high voltage area (secondary side).

Figure 7: SEMiX5 TMLI SKYPER12 Driver Board ("driver board"), bottom side



3.3 Integrated functions

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

3.3.1 Thermal protection

The SEMiX5 module's built-in NTC temperature sensor is monitored by the error input of IGBT T2. At a pre-defined temperature (to be defined by the user by adjusting a resistor) T2 is switched off immediately and the error is transmitted from secondary side (high voltage) to primary side (low voltage) by the driver. On the primary side, an error is set, and the user can react accordingly. The thermal protection is deactivated by default.

ATTENTION: Turning off T2 without respect to the actual switching state might harm the device!

3.3.2 Desaturation detection

The voltage drops across the outer IGBTs T1 and T4 are measured while conducting. As soon as the voltages rise above a pre-defined value (that correlates to very high current of a desaturation event) an error message is generated by the driver, which the user shall react to. The driver automatically turns off the particular IGBT using the soft-turn-off gate resistor. The forward voltage drop threshold and the blanking time for the desaturation detection are set according to the Technical Explanation of the SKYPER12 driver [5] with a resistor (R_{CE}) and a capacitor (C_{CE}) in 0805 housing. The positions of R_{CE} and C_{CE} can be mixed up as they are connected in parallel. R_{CE} and C_{CE} are framed yellow in Figure 9.

The inner IGBTs T2 and T3 do not have a desaturation detection.

3.3.3 Active clamping at T2 and T3

The inner switches T2 and T3 may be protected versus over voltage by active clamping. The clamping circuit's protection level shall be chosen to a value that does not affect the device in normal operation. At the same time, the level should be low enough not to exceed the blocking voltage of the inner semiconductors.

When active clamping comes in action, the output stage of the SKYPER12 is switched off in order not to work against the active clamping.

Chapter 5.7 shows the electrical limits of the board that can be reached without using active clamping. By default active clamping diodes are not equipped.

3.4 Board description

Several components are meant to be changed by the user, i.e. an adaptation to the application conditions. The changeable components of the driver board are marked with different coloured frames in Figure 9 and Figure 8; function and possible values are explained in chapters 3.4.1 to 3.4.4.

Figure 8: Bottom side of the driver board; user-changeable components are framed

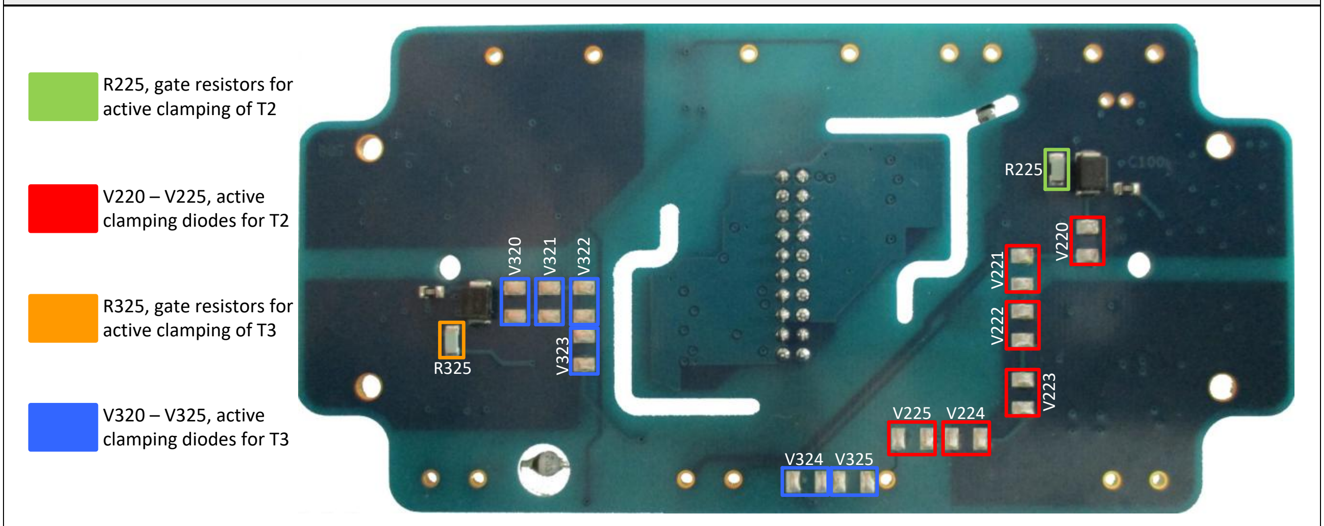
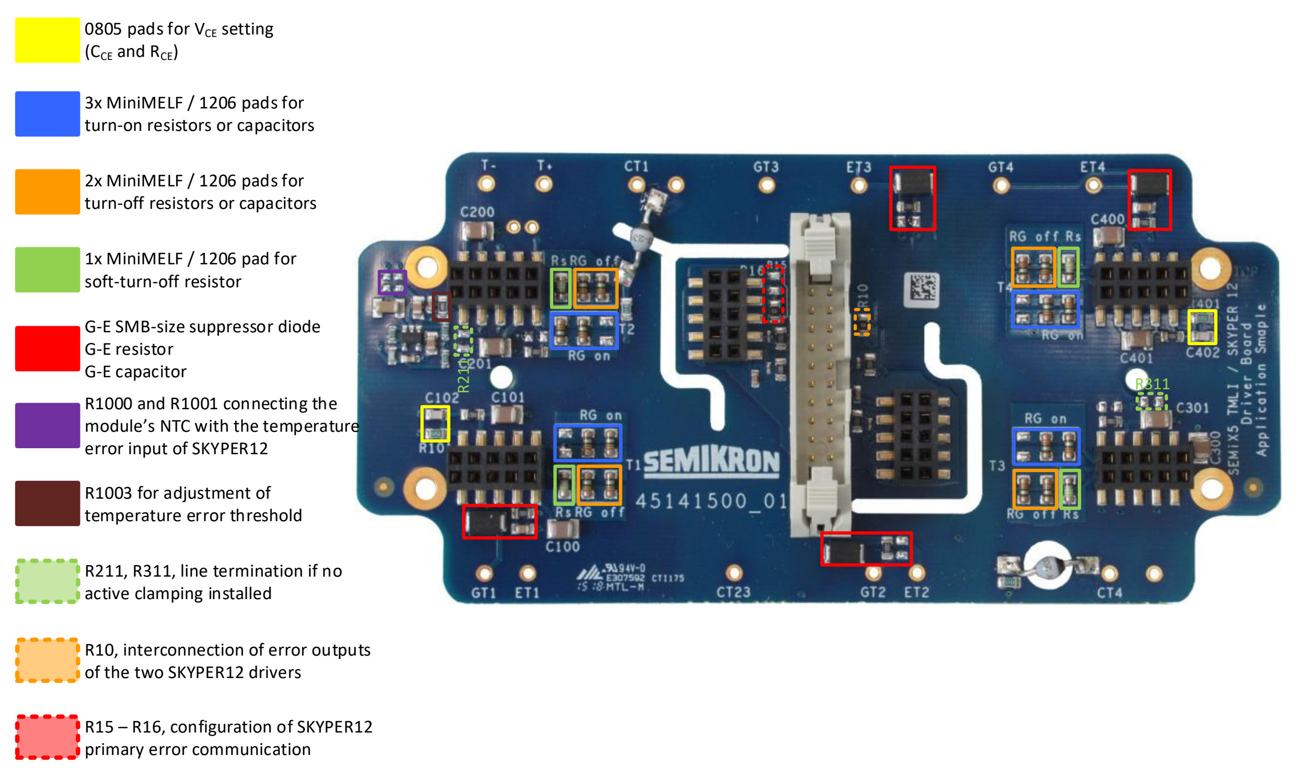


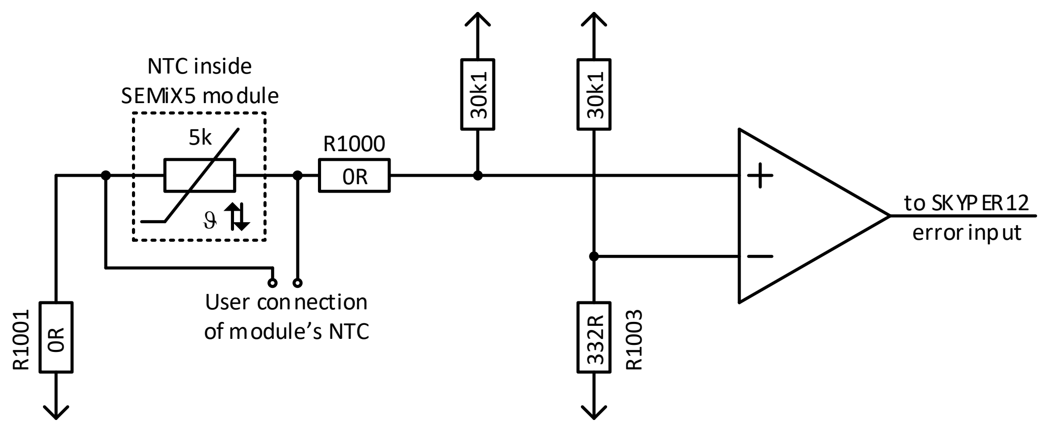
Figure 9: Top side of the driver board; user-changeable components are framed



3.4.1 Adjustment of temperature error threshold

A thermal overload can be detected by evaluating the SEMiX5 module's built-in NTC sensor. In case a thermal overload is detected, the comparator shown in Figure 10 pulls the SKYPER's error input to GND and so the driver can communicate an error message.
The resistor R1003 (framed brown in Figure 9) can be used for adjusting the error temperature threshold.

Figure 10: Schematic of NTC evaluation



The standard value for R1003 is 332Ω (refers to 115°C): the thermal overload detection is deactivated by leaving R1000 and/or R1001 unpopulated.
An error is detected, when the voltage at the inverting input of the comparator is greater than the voltage at the non-inverting input. The resistance of the NTC at a desired shut-off temperature can be taken from the diagram in Figure 11; R1003 needs to be chosen to that value. A chip resistor with the size 0805 can be used for R1003.
ATTENTION: Due to layout restrictions the built-in thermal overload detection turns off T2 (an inner IGBT). As long as the adjacent outer IGBT is not turned off this procedure closes the

recommended commutation path for the turn-off of the outer IGBT. It would then commutate to the diode on the opposite position with a much higher commutation inductance and hence voltage overshoot. This overshoot might lead to destruction of the device.
For that reason, the thermal shut-down is deactivated by default by unpopulated resistors R1000 and R1001.
It is possible to use a separate, user-specific thermal detection; in that case the resistors R1000 and R1001 must be removed.

Figure 11: SEMiX5 NTC characteristic (excerpt)

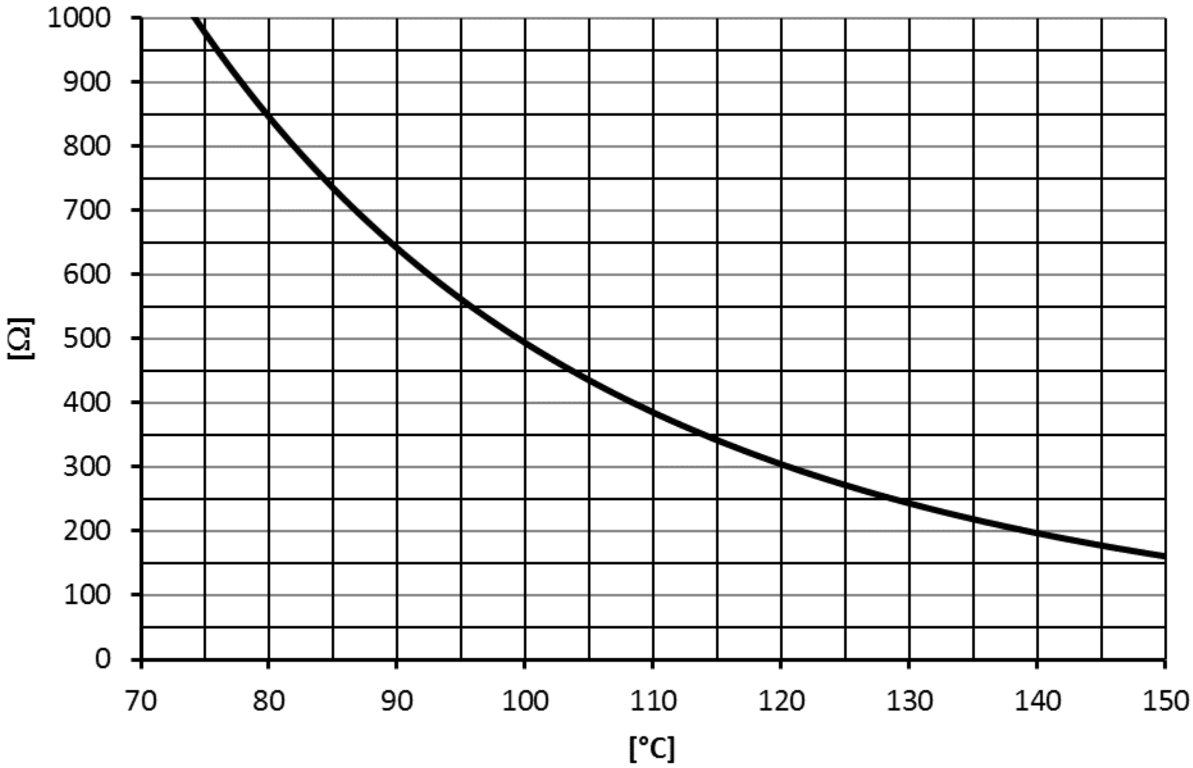
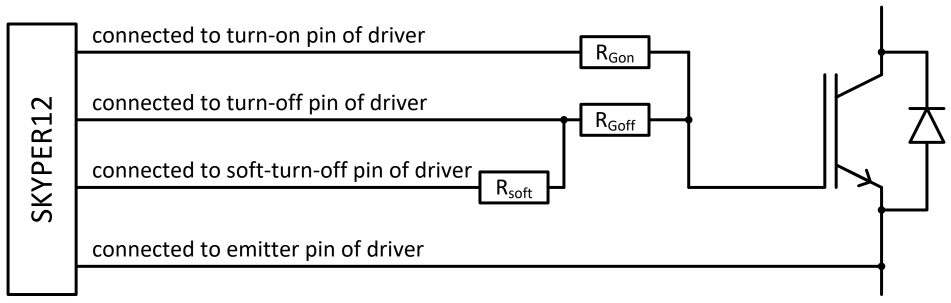


Figure 11 shows an excerpt of the SEMiX5 NTC characteristic, which includes the most interesting temperature range between 70°C and 150°C. The full characteristic can be found in the Technical Explanation of SEMiX5 or can be calculated from the formula given in the SEMiX5 datasheets [1].

3.4.2 Gate resistors

One or more chips on the driver board realize what is called gate resistor in this document for the sake of convenience. The SKYPER12 offers separate connections for turn-on (R_{Gon}), turn-off (R_{Goff}) and soft-turn-off (R_{soft}), see Figure 12. R_{Gon} is used for every turn-on process, R_{Goff} for every turn-off action. In case of an error, the driver uses R_{soft} instead of the standard R_{Goff}. All resistor positions must be populated for proper operation.

Figure 12: Schematic of gate resistor arrangement



Turn-on resistor (R_{Gon}) / capacitor

The driver board offers three pads per IGBT (framed blue in Figure 9) taking MiniMELF or 1206 sized components. Resistor/capacitor values need to be chosen according to the particular application (DC-link voltage, DC-link inductance, switching frequency, switching losses, etc.) so there is no general recommendation.
It is necessary to calculate the power losses of the gate resistor in order not to overload and damage it.
Please refer to chapter 5.3 for further information.

Turn-off resistor (R_{Goff}) / capacitor

The driver board offers two pads per IGBT (framed orange in Figure 9) taking MiniMELF or 1206 sized components. Resistor/capacitor values need to be chosen according to the particular application (DC-link voltage, DC-link inductance, switching frequency, switching losses, etc.) so there is no general recommendation.
It is necessary to calculate the power losses of the gate resistor in order not to overload and damage it.
Please refer to chapter 5.3 for further information.

Soft-turn-off resistor (R_{soft})

The driver board offers one pad per IGBT (framed green in Figure 9) taking a MiniMELF or 1206 sized component. The resistor values need to be chosen according to the particular application (DC-link voltage, DC-link inductance, switching frequency, switching losses, etc.) so there is no general recommendation.
It is recommended to calculate the power losses of the gate resistor in order not to overload and damage it.
Please refer to chapter 5.3 for further information.

3.4.3 Gate-Emitter (GE) components

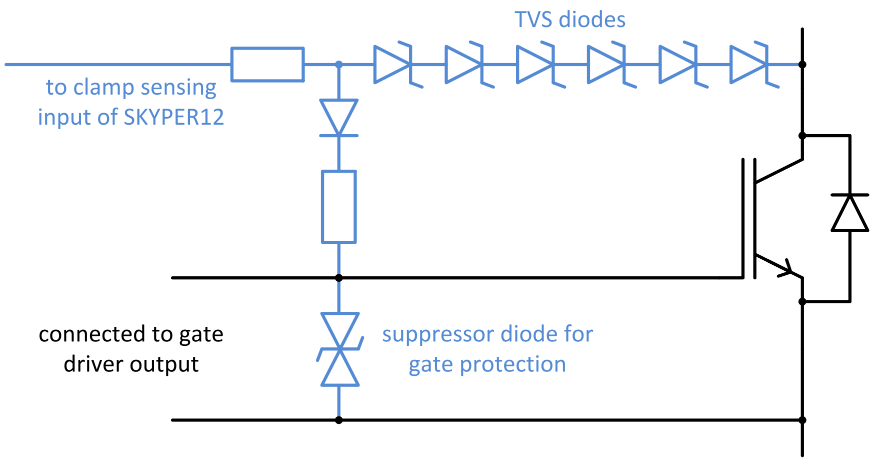
For every IGBT the contact board offers one pad sized SMB, and two pads sized 0805 (framed red in Figure 9). Semikron Danfoss recommends using one of the 0805 sized pads for placing a 10kΩ resistor and the SMB sized pad for placing a 15V TVS diode for gate protection. The additional 0805 sized pad may be used for a GE capacitor if required.

3.4.4 Active clamping (bottom side)

Figure 13 shows the schematic of the active clamping used in the Application Sample. The driver board offers six pads sized SMB (V220-V225 framed red and V320-V325 framed blue in Figure 8) for placing TVS diodes (transient voltage suppressor diodes). Additional to the TVS diodes a resistor (R225 framed green and R325 framed orange in Figure 8) limits the current charging the gate and a suppressor diode protects the gate from too high voltages (as described in 3.4.3). A standard diode prevents the driver from feeding into the collector in standard operation. Further, the chain of TVS diodes is connected to the clamping input of the SKYPER12 via a resistor. In case of a clamping event the driver stage is disconnected from the gate so that the gate charging effect of the active clamping and the driver do not work against each other.

In case TVS diodes shall not be placed resistors R211 and R311 (framed dotted green in Figure 9) need to be equipped with 0Ω.

Figure 13: Schematic of active clamping



Please refer to chapter 5.4 for further information.

3.4.5 Error management of SKYPER12 drivers

Error interaction of the two SKYPER12 drivers

The 0805 sized R10 (framed dotted orange in Figure 9) on the driver board may either be left open or equipped with a 0Ω jumper. In case of 0Ω the error outputs/inputs of the two SKYPER12 drivers are connected. In case R10 is not connected, an error output of one driver would not be communicated to the error input of the other driver immediately. Semikron Danfoss recommends equipping R10 with 0Ω. Please refer to chapter 5.2 for detailed information.

Error communication of SKYPER12 drivers' channels

The 0805 sized resistors R15-R16 (framed dotted red in Figure 9) may be equipped as shown in Table 4. R15 and R16 set the error communication of the two SKYPER12 drivers' channels.
Any other combination (e.g. all resistors 0Ω or all resistors not connected) will lead to malfunction and may damage the system.

Table 4: Functional table for R15 – R16

R15	0Ω	not equipped
R16	not equipped	0Ω
Function ➔	The secondary side producing an error turns off the particular IGBT and communicates the error to the primary side. At the primary side the error is communicated to the user interface, but the second channel of the driver is not affected (will not turn off due to the error; this is in the user's responsibility). ⇨ **Default setup (recommended)**	The secondary side producing an error turns off the particular IGBT and communicates the error to the primary side. At the primary side the error is communicated to the user interface and the second channel of the driver which will turn of the second IGBT as well.

4. User Interface

4.1 Module interface

The pinout of a SEMiX5 TMLI module is shown in Figure 14 and explained in Table 5. All pin-compatible SEMiX5 TMLI modules may be used with the driver board.

Figure 14: SEMiX5 TMLI interface

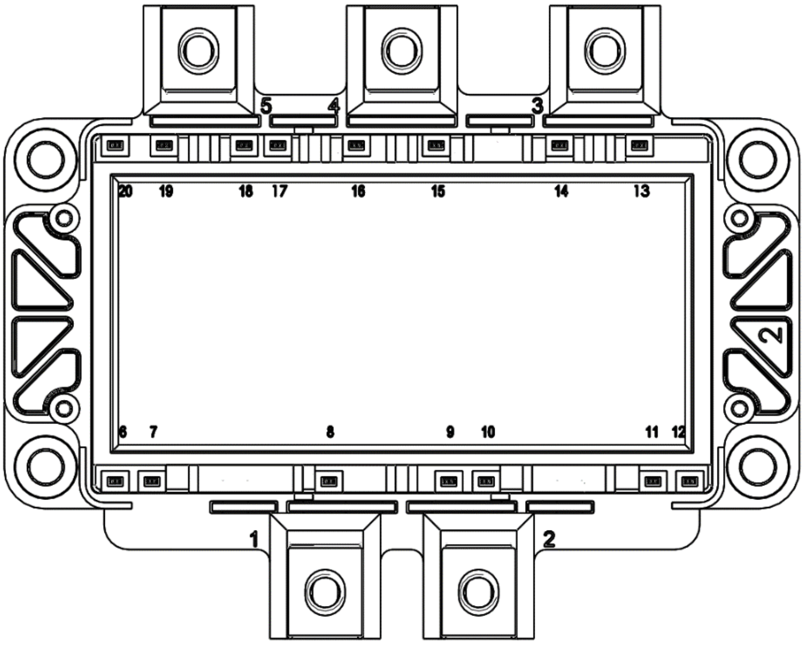


Table 5: SEMiX5 1200V TMLI pin description

Pin	Description	Pin	Description
1	AC terminal	11	Collector IGBT T4
2	AC terminal	12	not connected
3	DC- terminal	13	Emitter IGBT T4
4	N terminal	14	Gate IGBT T4
5	DC+ terminal	15	Emitter IGBT T3
6	Gate IGBT T1	16	Gate IGBT T3
7	Emitter IGBT T1	17	not connected
8	Common collector IGBTs T2 and T3	18	Collector IGBT T1
9	Gate IGBT T2	19	NTC temperature sensor
10	Emitter IGBT T2	20	NTC temperature sensor

Further information about module mounting, etc. may be found in the module datasheets and the SEMiX5 Technical Explanation [1].

4.2 User interface

The user interface is the 20-pin connector X10 located in the middle of the driver board. The pin description is given in Table 6.

Table 6: X10 pin description

Pin	Signal name	Description	Voltage level
1	IF_PWR_VP	Driver supply voltage	$15V_{DC}$±4%, max. 0.5A
2	IF_PWR_VP	Driver supply voltage	
3	GND	Ground	0V
4	GND	Ground	0V
5	GND	Ground	0V
6	IF_CMN_T1	PWM pattern IGBT T1	Off=0V / On=15V; R_{in}=10kΩ / 1nF
7	GND	Ground	0V
8	IF_CMN_T2	PWM pattern IGBT T2	Off=0V / On=15V; R_{in}=10kΩ / 1nF
9	GND	Ground	0V
10	IF_CMN_T3	PWM pattern IGBT T3	Off=0V / On=15V; R_{in}=10kΩ / 1nF
11	GND	Ground	0V
12	IF_CMN_T4	PWM pattern IGBT T4	Off=0V / On=15V; R_{in}=10kΩ / 1nF
13	GND	Ground	0V
14	GND	Ground	0V
15	IF_CMN_NERR_1	Error input/output T1/T2	Error=0V / ready-for-operation=15V (Pull-Up to 15V on user-side; $R_{pull-up}$=1.8kΩ..10kΩ)
16	GND	Ground	0V
17	IF_CMN_NERR_2	Error input/output T3/T4	Error=0V / ready-for-operation=15V (Pull-Up to 15V on user-side; $R_{pull-up}$=1.8kΩ..10kΩ)
18	GND	Ground	0V
19	GND	Ground	0V
20	GND	Ground	0V

5. Restrictions and Requirements

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

5.1 Switching pattern of TMLI modules

A detailed explanation of the TMLI switching pattern is given in the Semikron Danfoss Application Note AN 11-001 [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).

In case all IGBTs are turned off simultaneously, a current through T1 would not commutate to T2 but to D4 instead. As this commutation loop inherits a higher inductance a higher voltage overshoot would happen at the turning-off of the IGBT (here: T1). If the voltage applied to T1 exceeded the blocking voltage, T1 would be destroyed.

5.2 Error treatment

If a desaturation event occurs, the desaturated IGBT must be turned off within maximum short circuit pulse duration (t_{psc}; stated in the semiconductor module datasheet), otherwise it might be destroyed by this extreme overload. The correct turn-off sequence is recommended to be maintained to prevent the commutating semiconductors from overvoltage.

The user needs to react appropriately to error messages sent from the driver board: the correct switching pattern is recommended and a switch-off time below t_{psc} is mandatory to avoid damage.

5.2.1 Secondary side error at T1 (T4)

In case a secondary side error (e.g. desaturation) occurs at T1 (T4) the error signal is communicated to the driver's primary side and an error message is produced and sent to the user interface using pin 15 (pin 17) of X10 (see Table 6). At the same time T1 (T4) is turned off using the soft-turn-off resistor and stays off as long as the error signal is active.

The second channel of the faulty driver needs to be turned off by the user (latest with the next regular PWM turn-off signal). As long as the error signal is active it cannot be turned on.

- When resistor R10 on the driver board is equipped with 0Ω the error message from driver of T1/T2 (T3/T4) is sent to the error input of the driver of T3/T4 (T1/T2). There, it does also not turn off IGBTs automatically; this must be done by the user (either as reaction to the error or with the next regular PWM turn-off signal). It prevents turned-off IGBTs from being turned on as long as the error message is active.
- Not connecting R10 means that one driver's error does not prevent the other driver from turning on the IGBTs. The correct and in-time shut-off needs to be ensured by the user.

5.2.2 Secondary side error at T2 (T3)

While T3 does not detect any external secondary side errors, the module's built-in temperature sensor is connected to T2. At the thermal threshold an error input is produced at T2 and it will turn off immediately. An error message is communicated to the driver's primary side and to the user interface using pin 15 of X10 (see Table 6). T2 stays off as long as the error signal is active.

T1 needs to be turned off by the user (latest with the next regular PWM turn-off signal). As long as the error signal is active it cannot be turned on.

- When resistor R10 on the driver board is equipped with 0Ω the error message from driver of T1/T2 is sent to the error input of the driver of T3/T4. There, it does not turn off T3 and T4 automatically; this must be done by the user (either as reaction to the error or with the next regular PWM turn-off signal). It prevents T3 and T4 from being turned on as long as the error message is active.
- Not connecting R10 means that the error of T1/T2's driver does not prevent the other driver from turning on T3/T4. The correct and in-time shut-off needs to be ensured by the user.

The thermally indicated turn-off of T2 does not take into account the actual switching state of the TNPC topology; it is turned off immediately when the error occurs. In case T2 is turned off while T1 is in on-state a too high voltage might be applied to T1 at its next turn-off damaging the device.

In case R1000 and R1001 are equipped with 0Ω and the overtemperature shutdown is activated, the user must take care of the correct shut-down sequence or suitable protection measures against too high voltages across the outer IGBTs.
Please also refer to chapter 3.4.1.

5.2.3 Error treatment in paralleled driver boards

It is possible to use several driver boards in parallel to increase the inverter's output power by simply plug all parallel drivers to one controller cable. This method parallels all PWM signals and also the error messages. The errors of one driver board would be communicated to the other drivers of one phase leg leading to the error handling as described above.

5.2.4 Error treatment in 3-phase systems

In 3-phase systems, there is no direct connection of the driver boards' error signals. This connection must be provided by the user. Please note that time is critical when an error occurs and therefore error treatment shall be performed using fast hardware.

5.3 Design limits gate resistors

5.3.1 Minimum gate resistor

The minimum gate resistor is determined by the maximum difference of the driver output voltages during switching; it turns from -8V to +15V or back, so the voltage difference is 23V. The peak current SKYPER12 is capable of driving is 20A, so the minimum total gate resistor that needs to be used is 1.15Ω.
The total gate resistor consists of the internal gate resistor of the module (that can be found in the module datasheet) and the gate-turn-on or gate-turn-off resistor R_{Gon} and R_{Goff}. The minimum gate resistor can be calculated according to:

$$R_{Gon,min} = R_{Goff,min} = 1.15\Omega - R_{Gint}$$

If this value is ≤0Ω the value for R_{Gon} or R_{Goff} can be chosen to 0Ω without overpowering the driver. Otherwise, this minimum gate resistance must be used to avoid damage to the SKYPER12.

5.3.2 Power rating of the gate resistors

Depending on the ohmic value of the gate resistors also their power rating needs to be chosen sufficiently high to avoid overload.
The gate resistors need to be able to withstand high pulse load. It needs to be made sure by the user to choose suitable resistors.
Please note that 1206 sized chip resistors have a lower power and pulse load rating than MiniMELF resistors.
Further information about the power rating and correct choice of gate resistors can be found in Application Note AN 21-002 [4].

5.4 Design limits active clamping

The clamping voltage for protecting T2 and T3 can be adjusted by changing the breakdown voltage of the six SMB sized TVS diodes.
Semikron Danfoss recommends using six 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 of the six pads. This might influence the overall insulation capability of the driver board. 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. mac. DC-link voltage plus voltage overshoot in normal operation) in order not to increase the switching losses.

5.5 Design limits switching frequency

The used modules, their gate charge and the power of the SKYPER12 drivers determine the maximum switching frequency. It is limited to 30kHz by insulation coordination. Further information on calculating the switching frequency limit can be found in Application Note AN 21-002 [4].

5.6 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.

5.7 Semikron Danfoss assembly

Semikron Danfoss has tested the Application Sample as it is shown in the photos above. All results are valid for the particular revisions shown in Table 7.

Table 7: Part revisions for Semikron Danfoss tests

Part	Revision
SKYPER12	L5069901
SEMiX5 TMLI Driver Board	45141500_00
SEMiX 405 TMLI 12E4B	Datecode: 16143P R
SEMiX 305 TMLI 17E4C	Datecode: 16450P R

Variable part values have been chosen according to Table 8.

Table 8: Part values for Semikron Danfoss 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}	1.65Ω	4.99Ω
C_{GE}	-	-
Active Clamping	Active Clamping is not available for T1 and T4	-
R_{CE}	7.5kΩ (R101, R401)	-
C_{CE}	820pF (C102, C402)	-
$R_{temp,threshold}$	560Ω (R1003), thermal protection deactivated (R1000 and R1001 not equipped)	

With the above-mentioned values and additional 680nF snubber capacitors (EPCOS Code: B32656-S0684-+504) from DC+ to N and N to DC- an absolute maximum operation up to 900V_{DC} and 275A_{RMS} at f_{sw}=5kHz is possible at all power factor values at a maximum ambient temperature of 40°C with SEMiX 405 TMLI 12E4B. Using SEMiX 305 TMLI 17E4C an absolute maximum operation is possible up to 1350V_{DC} and 200A_{RMS} at 5kHz at all power factors.
The SEMiX5 TMLI SKYPER12 Driver Board has passed isolation and partial discharge tests. The isolation test voltage was set to 2550V_{AC} for 3s.

It is up to the customer to optimize gate resistor 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
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
R_{Soft}	External gate series resistor at error switch-off
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-danfoss.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. Rabl, “3L NPC & TNPC Topology”, Application Note, AN 11-001 – rev06, Semikron Danfoss, www.semikron-danfoss.com
[4] P. Drexhage, “Gate Driver Basics”, Application Note, AN 21-002 – rev02, Semikron Danfoss, www.semikron-danfoss.com
[5] A. Darmanandana, “SKYPER®12”, Technical Explanation – rev06, Semikron Danfoss, www.semikron-danfoss.com
[6] M. Santoro, “SEMiX®5”, Mounting Instruction – rev15, Semikron Danfoss, www.semikron-danfoss.com

IMPORTANT INFORMATION AND WARNINGS

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