Technical Explanation SEMiX5 1200V TMLI Parallel Driver Kit

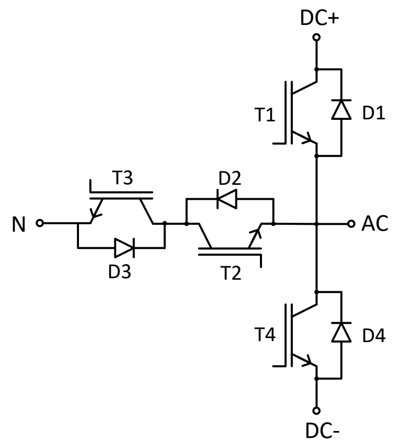
Revision:	04
Issue date:	2019-04-11
Prepared by:	Ingo Rabl
Reviewed by:	-
Approved by:	Joachim Lamp

Keyword: TMLI, IGBT driver, Application Sample, 451257, 451306

1. Introduction

SEMIKRON set up a driver kit for paralleling two SEMiX5 1200V TMLI modules for evaluation purposes. The SEMiX5 1200V TMLI Parallel Driver Kit ("driver kit") is able to operate the modules up to a DC-link voltage of 1000V (limited by insulation coordination) at a maximum switching frequency of 15kHz for the SEMiX 405 TMLI 12E4B (limited by the gate driver; i.e. higher switching frequencies with modules showing lower gate charges are possible, the limitation of the gate driver needs to be taken into account).
Two standard 2L drivers (SKYPER 42 LJ) are used to operate the two parallel 3L TMLI modules; one driver operates switches T1 and T4 (the outer switches), the other operates the inner switches T2 and T3.
The failure management of the two SKYPER 42 LJ drivers detects desaturation events at all four switch positions and also monitors the modules' built-in temperature sensors. While desaturation of the inner switches (IGBTs T2 and T3) just produces an error message sent to the user interface, desaturation of the outer switches (IGBTs T1 and T4) as well as exceeding a set sensor temperature leads to immediate safe shut-off of the outer IGBTs and 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 well balanced parallel operation and the high output power.

1.1 Features

The SEMiX5 1200V TMLI Parallel Driver Kit is designed for the SEMiX 405 TMLI 12E4B module which comes with 1200V semiconductors at the vertical and 650V semiconductors at the horizontal branch.

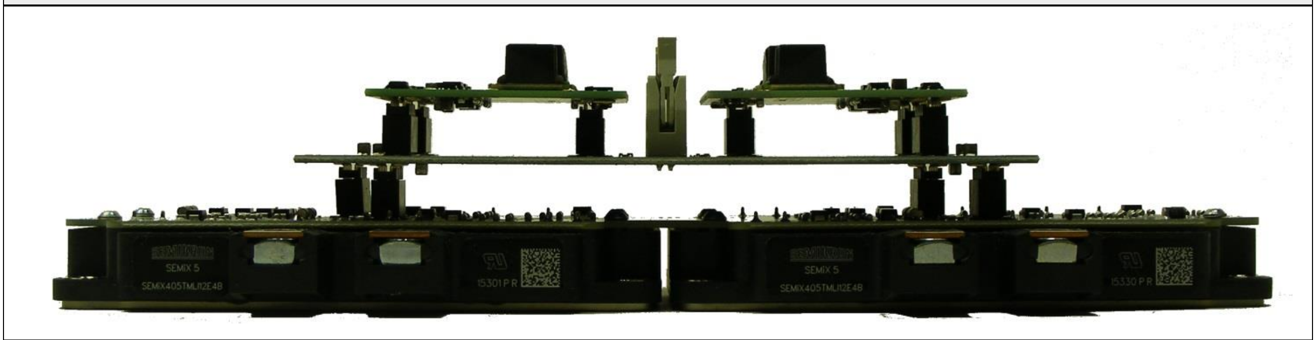
Figure 2: SEMiX5 1200V TMLI with common collector

It is the most powerful TMLI module in the SEMiX5 housing. Of course all TMLI modules (different current rating, different voltage rating) can be operated with this driver board as long as they are pin-compatible (this is valid for all SEMIKRON SEMiX5 TMLI modules) and the design limits are met (e.g. maximum DC voltage and maximum SKYPER 42 LJ output power may not be exceeded).

1.2 Hardware of the SEMiX5 1200V TMLI Parallel Driver Kit

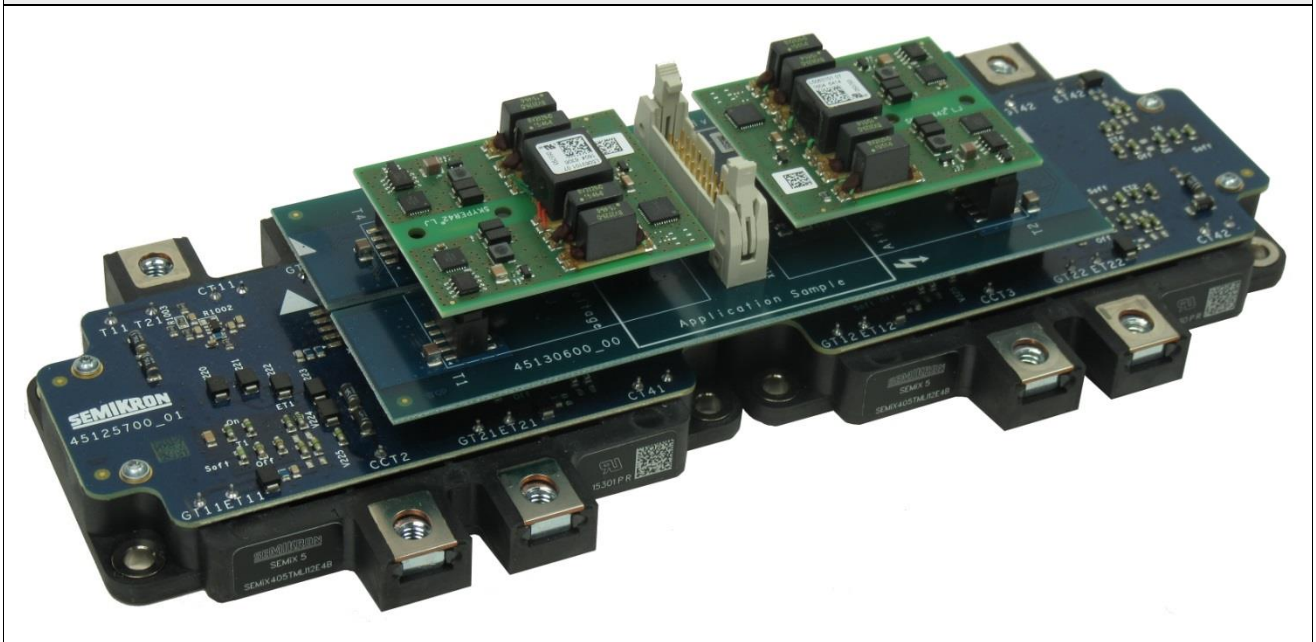
The SEMiX5 1200V TMLI Parallel Driver Kit consists of two printed circuit boards (PCBs): the larger PCB is called "2 // SEMiX5 TMLI Contact Board" ("contact board"; containing gate resistors, clamping circuitry, etc.) with item number 45125701. It contacts two SEMiX5 modules and provides sockets for the second PCB called "2 // SEMiX5 (T)MLI Driver Board" ("driver board", item number 45130601) which is plugged on top of the contact board. The driver board provides sockets for two SKYPER 42 LJ drivers and a user interface. It is required to maintain the clearance and creepage distances required for safe operation.

Figure 3: SEMiX5 1200V TMLI Parallel Driver Kit side view



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

Figure 4: SEMiX5 1200V TMLI Parallel Driver Kit bird's eye view



Depending on the power rating and the operating conditions (voltage, current, 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 both boards are available on request. For ordering the boards or the files please contact your SEMIKRON sales partner.

2. Safety Instructions

The SEMiX5 1200V TMLI Parallel Driver Kit bares risks when put in operation. Please carefully read and obey the following safety instructions to avoid harm or damage to persons or gear.

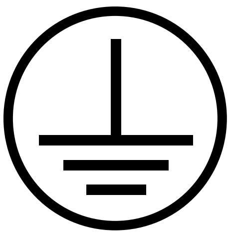
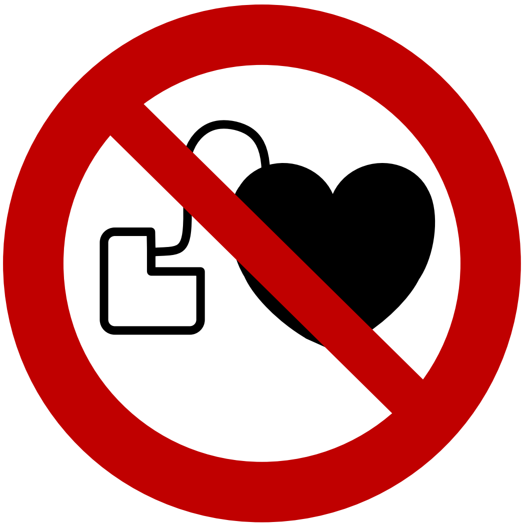
Table 1: Safety instructions	
	**In operation the SEMiX5 1200V TMLI Parallel Driver Kit inherits high voltages that are dangerous to life!** **Only qualified personnel should work with the Kit.**
	**Some parts of the SEMiX5 1200V TMLI Parallel Driver Kit or connected devices (e.g. heatsink) may reach 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 1200V TMLI Parallel Driver Kit.**

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 1200V TMLI Parallel Driver Kit.

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


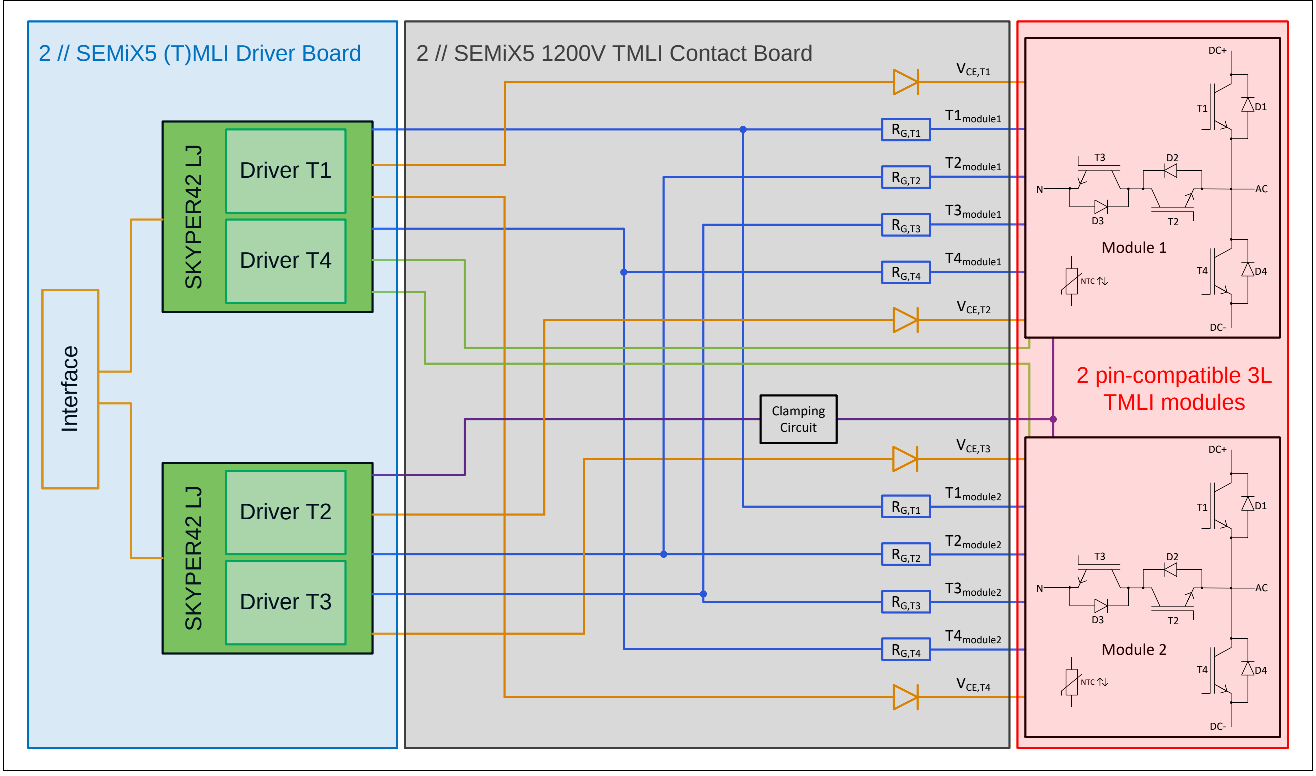
Operating the Application Sample may go along with electromagnetic fields which may disturb cardiac devices.
People with cardiac devices shall not operate the device.

3. Technical Data

3.1 Driver Kit block diagram

The electrical block diagram in Figure 5 shows three parts: the blue marked part is the driver part with sockets for the two SKYPER 42 LJ drivers, the grey marked part is the contact board with gate resistors, clamping and V_{CE} sensing circuitry. The red part symbolizes the two parallel 3-level modules.

Figure 5: SEMiX5 1200V TMLI Parallel Driver Kit block diagram



3.2 Electrical and mechanical characteristics

With regard to the requirement specification the SEMiX5 1200V TMLI Parallel Driver Kit allows for operation within the following boundaries:

- Max. DC-link voltage — V_{DC} = 1000V in total, max. 500V per individual DC-link half
- Max. AC voltage — V_{AC} = 400V_{RMS} (line-to-line)
- Max. switching frequency — f_{sw} = 15kHz (see chapter 6.5 for further information)
- Ambient temperature — T_a = 0°C…40°C (see chapter 6.6 for further information)
- CTI rating of AppS PCBs — > 175

Neglecting the above mentioned boundaries may lead to malfunction or damage of the SEMiX5 1200V TMLI Parallel Driver Kit.

An electrical insulation is implemented between the user interface (primary side) and the high voltage connections (secondary side) by using the SKYPER 42 LJ's separation. The creepage and clearance distance on the driver board is 27mm between primary and secondary side. The clearance distance is reduced to 10.75mm when the driver board it is plugged to the contact board.
The overall responsibility for a proper insulation coordination remains with the user.

Please note that further restrictions of the used driver (e.g. SKYPER 42 LJ) may apply. According information can be found in the technical documentation of the particular driver (e.g. Technical Explanations on the SEMIKRON website [1]).

The contact board is 260.7mm long and 63mm wide, the driver board is 154.7mm long and 67mm wide. The total height including SKYPER 42 LJ drivers and excluding the modules is 43mm.

To prevent driver board and the SKYPER 42 LJ drivers from loosening from each other contact board and driver board come with mounting holes for dual lock support posts (positions circled red in Figure 6 and

Figure 7). SEMIKRON recommends nylon support posts from Richco with item no. DLMSPM-8-01. Please find further information in the technical explanation of SKYPER 42 LJ [1].
The contact board can be mounted to the modules in two steps. First the board needs to be fixed to the modules by using eight self-tapping screws (type: "EJOT PT WN1451 K25x10" or "EJOT Delta PT WN5451 K25x10"). Secondly the modules' pins need to be soldered to the board although the SEMiX5 TMLI comes with press-fit contacts. That is due to the fact that soldering does not require a pressing tool which makes things easier for this Application Sample.

Figure 6: 2 // SEMiX5 1200V TMLI Contact Board ("contact board")

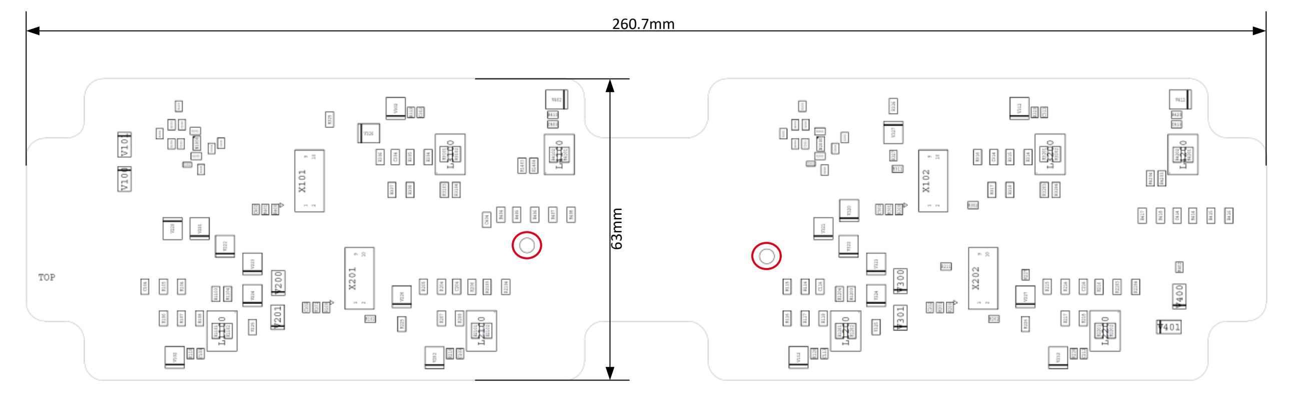
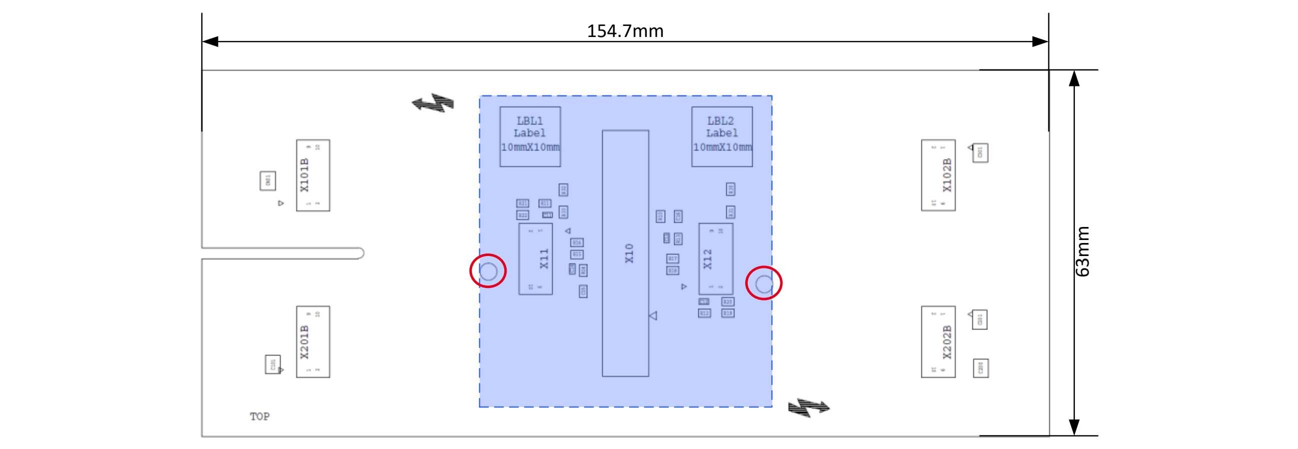


Figure 7: 2 // SEMiX5 (T)MLI Driver Board ("driver board")



The blue marked area in Figure 7 indicates the primary side with the user interface socket. The insulation is provided by the galvanic insulation of the SKYPER 42 LJ drivers. All area besides the blue marking and the entire contact board (Figure 6) may be considered as high voltage area (secondary side).

3.3 Integrated functions

The Driver Kit has some integrated safety functions to protect the device from certain harmful conditions.

3.3.1 Thermal protection

The modules' built-in NTC temperature sensors are monitored. At a pre-defined temperature (to be defined by the user by adjusting a resistor) a secondary-side error triggers the error-input of the SKYPER 42 LJ responsible for IGBTs T1 and T4. IGBTs T1 and T4 are switched off immediately and the error is transmitted from secondary side (high voltage) to primary side (PELV) by the driver. On the primary side an error is set and the user can react accordingly.

3.3.2 Short circuit protection

A shoot-through from DC+ to DC- by applying incorrect PWM pattern is prohibited by the interlock function between T1 and T4: it is not possible to turn on both IGBTs at the same time. The interlock time is 2µs.

3.3.3 Desaturation detection

The voltage drop across the outer IGBTs T1 and T4 is measured while conducting. As soon as the voltage rises 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 is set according to the technical explanation of the SKYPER42 LJ driver [6] with a resistor (R_{CE}) and a capacitor (C_{CE}) in 0805 housing. The position 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 8 (for T1 and T4) and in Figure 9 (for T2 and T3).
At the inner IGBTs T2 and T3 an error message is generated by the driver as well and the user shall react accordingly. However, the driver does not turn off the desaturated IGBTs T2 and T3 by itself; this must be done by the user.

3.3.4 Active clamping at T2 and T3

Additionally to the desaturation detection at the inner switches T2 and T3 an active clamping is implemented for those IGBTs. 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 SKYPER 42 LJ is switched off in order not to work against the active clamping.

3.4 Board description

As explained before the Application Kit consists of two PCBs. On both boards several components are meant to be changed by the user, i.e. an adaptation to the application conditions.
The changeable components of the contact board are marked with different coloured frames in Figure 8 and Figure 9; function and possible values are explained in chapters 3.4.1 to 3.4.4.

Figure 8: Left half of the contact board; user-changeable components are framed

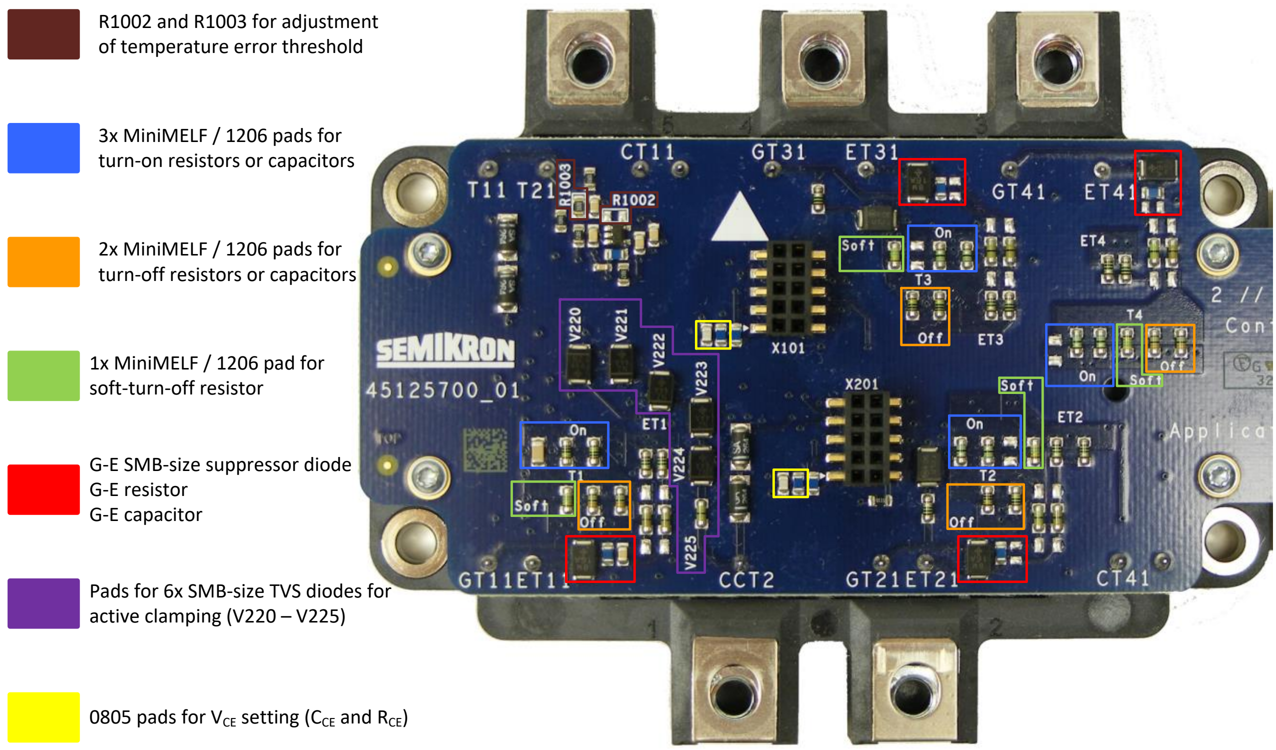
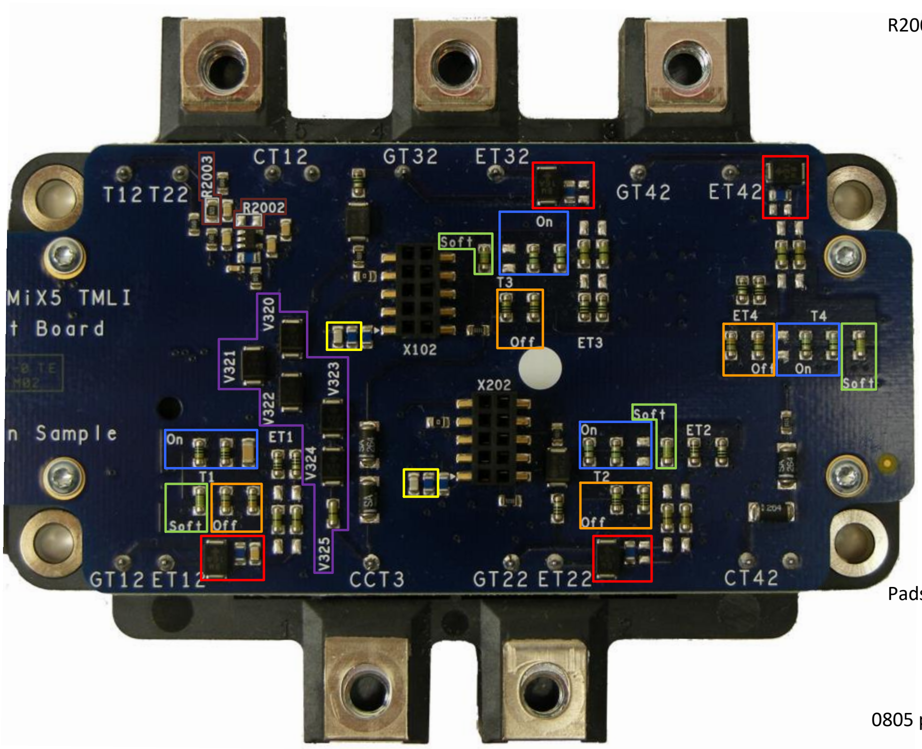


Figure 9: Right half of the contact board; user-changeable components are framed



R2002 and R2003 for adjustment of temperature error threshold

3x MiniMELF / 1206 pads for turn-on resistors or capacitors

2x MiniMELF / 1206 pads for turn-off resistors or capacitors

1x MiniMELF / 1206 pad for soft-turn-off resistor

G-E SMB-size suppressor diode
G-E resistor
G-E capacitor

Pads for 6x SMB-size TVS diodes for active clamping (V320 – V325)

0805 pads for V_{CE} setting (C_{CE} and R_{CE})

The components that can be changed by the user on the driver board are marked with different coloured frames in Figure 10. Function and possible values are explained in chapters 3.4.5 to 3.4.6.

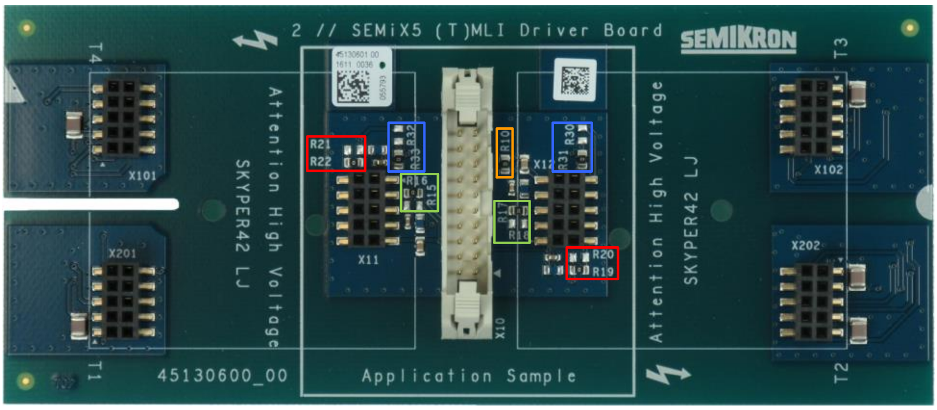
Figure 10: User-changeable components on the driver board

R10, interconnection of error outputs of the two SKYPER 42 LJ drivers

R15 – R18, configuration of error handling of the two SKYPER 42 LJ drivers

R19 – R22, configuration of interlock time of the two SKYPER 42 LJ drivers

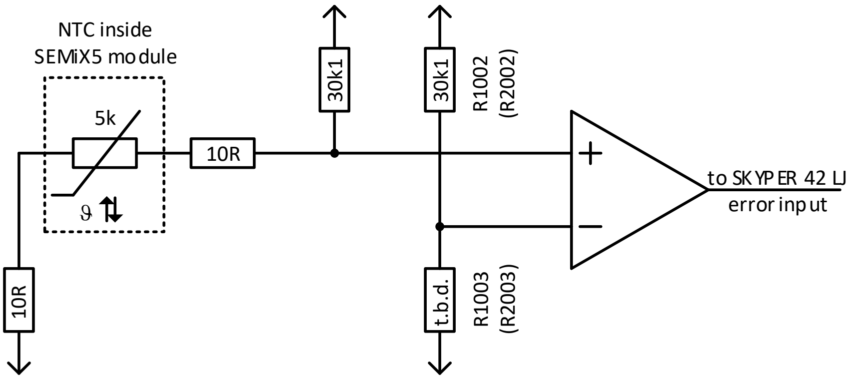
R30 – R33, configuration of input pulse filtering of the two SKYPER 42 LJ drivers



3.4.1 Adjustment of temperature error threshold (contact board)

A thermal overload can be detected by evaluating the modules' built-in NTC sensors. In case a thermal overload is detected the comparator shown in Figure 11 pulls the SKYPER's error input to GND and so the driver can communicate an error message.
The resistors R1003 (framed brown in Figure 8) and R2003 (framed brown in Figure 9) can be used for adjusting the error temperature threshold.

Figure 11: Schematic of NTC evaluation



The standard values for R1002, R1003, R2002 and R2003 are shown in Figure 11: the thermal overload detection is deactivated by leaving R1002 and R2002 unpopulated.
An error is detected, when the voltage at the negative input of the comparator is greater than the voltage at the positive input. The resistance of the NTC at a desired shut-off temperature can be taken from the diagram in Figure 12. With this resistance value the value of R1002 (R2002) can be calculated.
The current through R1002 and R1003 (R2002 and R2003) should not exceed 3mA. Chip resistors with the size 0805 can be used for R1002, R1003, R2002 and R2003.

Figure 12: SEMiX5 TMLI NTC characteristic (excerpt)

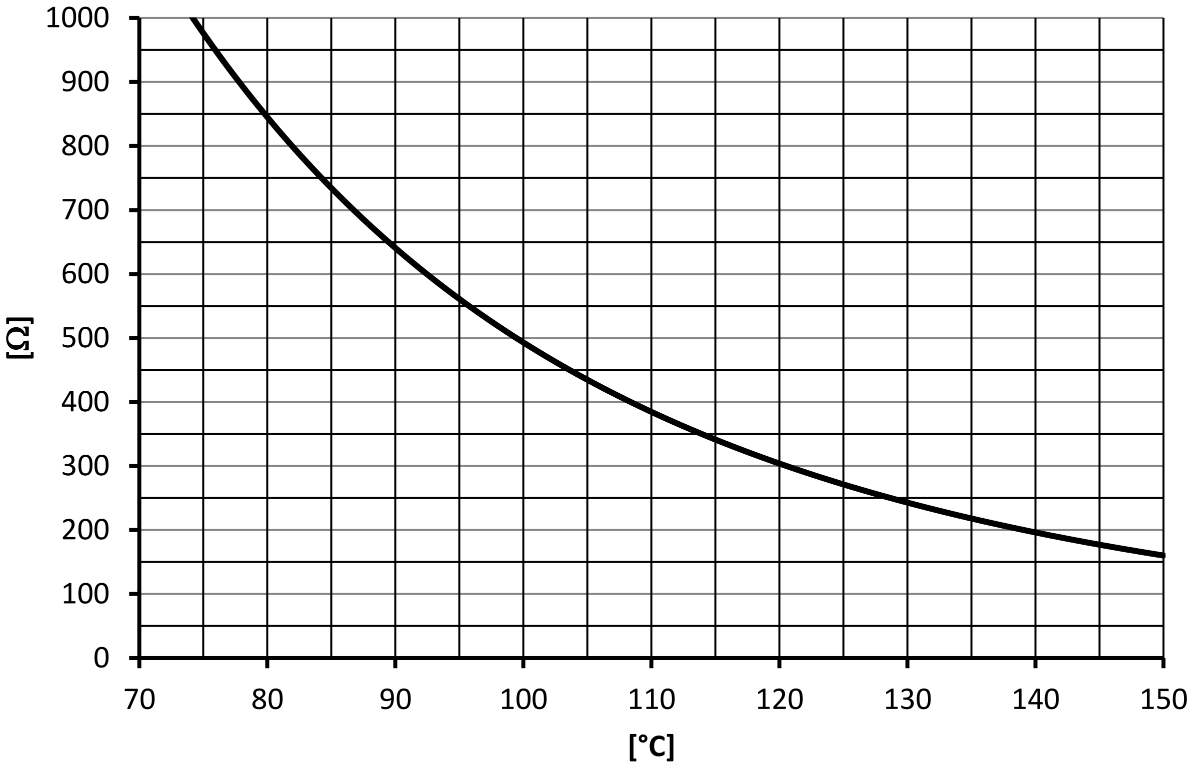
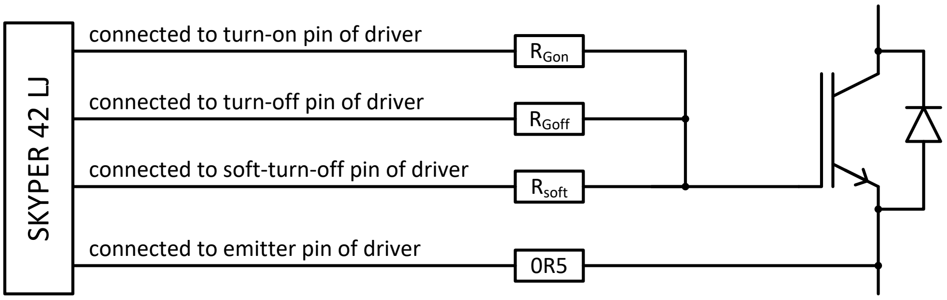


Figure 12 shows an excerpt of the SEMiX5 NTC characteristic which includes the most interesting temperature range between 70°C and 150°C. The full characteristic can be found in the Technical Explanations or can be calculated from the formula given in the SEMiX5 datasheets [1].

3.4.2 Gate resistors (contact board)

What is called gate resistor in this document for the sake of convenience is realized by three resistors on the contact board. The SKYPER 42 LJ offers separate connections for turn-on (R_{Gon}), turn-off (R_{Goff}) and soft-turn-off (R_{soft}), see Figure 13. 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.
An additional resistor between driver and the emitters of the paralleled modules reduces oscillations during switching.

Figure 13: Schematic of gate resistor arrangement



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

The contact board offers three pads per IGBT (framed blue in Figure 8and 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 6.3 or further information.

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

The contact board offers two pads per IGBT (framed orange in Figure 8 and 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 6.3 for further information.

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

The contact board offers one pad per IGBT (framed green in Figure 8 and Figure 9) taking a MiniMELF or 1206 sized component. The resistor value needs 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 6.3 for further information.

3.4.3 Gate-Emitter (GE) components (contact board)

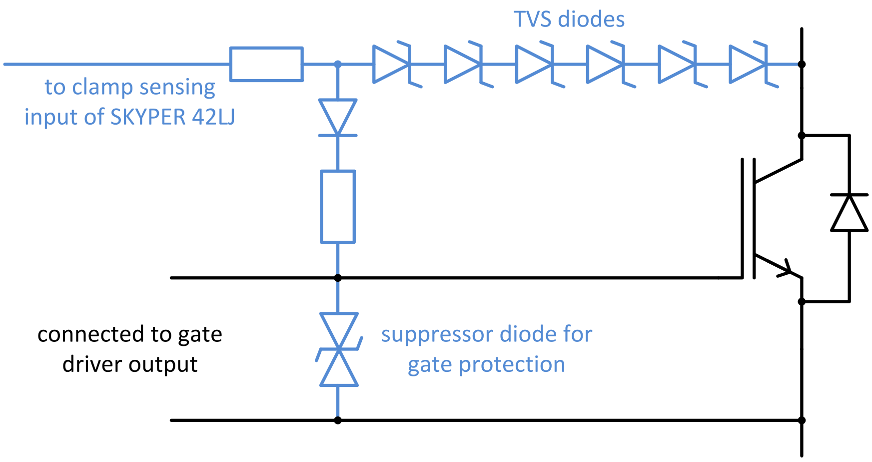
For every IGBT the contact board offers one pad sized SMB and two pads sized 0805 (framed red in Figure 8 and Figure 9). SEMIKRON recommends to use one of the 0805 sized pads for placing a 10kΩ resistor and the SMB sized pad for placing a 15V bidirectional breakdown-diode for gate protection. The additional 0805 sized pad may be used for a GE capacitor if required.

3.4.4 Active clamping (contact board)

Figure 14 shows the schematic of the active clamping used in the Application Sample. The contact board offers six pads sized SMB (framed purple; V220-V225 in Figure 8 and V320-V325 in Figure 9) for placing TVS diodes (transient voltage suppressor diodes). Additional to the TVS diodes a resistor limits the current charging the gate and a suppressor diode protects the gate from two 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 diode is connected to the clamping input of the SKYPER 42 LJ 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 don't work against each other.

Figure 14: Schematic of active clamping



Please refer to chapter 6.4 for further information.

3.4.5 Error management of driver T1/T4 and driver T2/T3 (driver board)

Error interaction of outer and inner IGBT drivers

The 0805 sized R10 (framed orange in Figure 10) 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 SKYPER 42 LJ 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 recommends to equip R10 with 0Ω. Please refer to chapter 6.2 for detailed information.

Error handling of outer and inner IGBT drivers

The 0805 sized resistors R15-R18 (framed green in Figure 10) may be equipped as shown in Table 4 and Table 5. While R15 and R16 set the error handling for the driver of T1 and T4, R17 and R18 set the error handling for the driver of T2 and T3.
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 (error handling setup for T1 and T4)

R15	0Ω	not equipped
R16	not equipped	0Ω
Function ➔	The particular driver generates an error signal when a secondary side error occurs, but the concerned IGBTs are not turned off. The driver does not react to an external error signal; it stays in the previous state until it is turned off by PWM (in case of a previous error, the soft-turn-off resistor is used). A continuous error signal prevents the driver from turning on.	The particular driver generates an error signal and immediately turns off the concerned IGBTs using the soft-turn-off resistors when a secondary side error occurs. In case an external error signal is applied the driver turns off the two IGBTs. A continuous error signal prevents the driver from turning on. ⇨ **Default setup (recommended)**

Table 5: Functional table for R17 – R18 (error handling setup for T2 and T3)		
R17	0Ω	not equipped
R18	not equipped	0Ω
Function ➔	The particular driver generates an error signal when a secondary side error occurs, but the concerned IGBTs are not turned off. The driver does not react to an external error signal; it stays in the previous state until it is turned off by PWM (in case of a previous error, the soft-turn-off resistor is used). A continuous error signal prevents the driver from turning on. ⇨ **Default setup (recommended)**	The particular driver generates an error signal and immediately turns off the concerned IGBTs using the soft-turn-off resistors when a secondary side error occurs. In case an external error signal is applied the driver turns off the two IGBTs. A continuous error signal prevents the driver from turning on.

3.4.6 Interlock time of driver T1/T4 and driver T2/T3 (driver board)

The 0805 sized resistors R19-R22 (framed red in Figure 10) may be equipped as shown in Table 6 and Table 7. R19 and R20 set the interlock function for the driver of T2 and T3, R21 and R22 set the interlock time for the driver of T1 and T4.
Any other combination (e.g. all resistors 0Ω or all resistors not connected) will lead to malfunction and may damage the system.

Table 6: Functional table for R19 – R20 (interlock setup for T2 and T3)		
R19	0Ω	not equipped
R20	not equipped	0Ω
Function ➔	The interlock time between T2 and T3 is set to 0. That means that both IGBTs may be switched on at the same time. ⇨ **Default setup (recommended)**	The interlock time between T2 and T3 is activated and set to 2µs. That means that one IGBT may be switched on 2µs after the other IGBT switched off. The two IGBTs cannot be turned on at the same time.

Table 7: Functional table for R21 – R22 (interlock setup for T1 and T4)		
R21	0Ω	not equipped
R22	not equipped	0Ω
Function ➔	The interlock time between T1 and T4 is set to 0. That means that both IGBTs may be switched on at the same time.	The interlock time between T1 and T4 is activated and set to 2µs. That means that one IGBT may be switched on 2µs after the other IGBT switched off. The two IGBTs cannot be turned on at the same time. ⇨ **Default setup (recommended)**

3.4.7 Input pulse filtering driver T1/T4 and driver T2/T3 (driver board)

The 0805 sized resistors R30-R33 (framed blue in Figure 10) may be equipped as shown in Table 6 and Table 7. R30 and R31 set the input pulse filtering function for the driver of T2 and T3, R32 and R33 set the input pulse filtering for the driver of T1 and T4.
Any other combination (e.g. all resistors 0Ω or all resistors not connected) will lead to malfunction and may damage the system.

Table 8: Functional table for R30 – R31 (interlock setup for T2 and T3)		
R30	0Ω	not equipped
R31	not equipped	0Ω
Function ➔	The input pulse filtering is set to digital operation. The filter time is 375ns, delay time typically 0.7µs and the jitter 30ns with very low tolerances over the whole temperature range.	The input pulse filtering is set to analogue operation. The filter time is 180ns, delay time typically 0.4µs and the jitter 2.5ns. ⇨ **Default setup (recommended)**

Table 9: Functional table for R32 – R33 (interlock setup for T1 and T4)		
R32	0Ω	not equipped
R33	not equipped	0Ω
Function ➔	The input pulse filtering is set to digital operation. The filter time is 375ns, delay time typically 0.7µs and the jitter 30ns with very low tolerances over the whole temperature range.	The input pulse filtering is set to analogue operation. The filter time is 180ns, delay time typically 0.4µs and the jitter 2.5ns. ⇨ **Default setup (recommended)**

4. User Interface

4.1 Contact board interface

The contact board connects to two SEMiX5 1200V TMLI (or compatible) modules on the bottom side and to the driver board on the top side.

4.1.1 Module interface

The pinout of a SEMiX5 TMLI module is shown in Figure 15 and explained in Table 10. All modules that are pin-compatible may be used with the driver kit.

Figure 15: SEMiX5 1200V TMLI interface

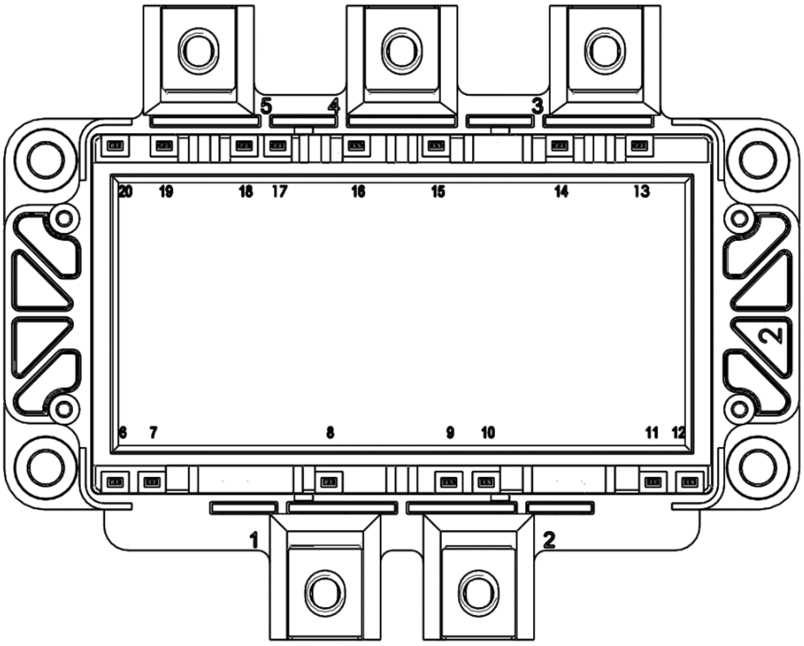


Table 10: SEMiX5 1200V TMLI pin description

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].

4.1.2 Contact/driver board interface

The driver board is connected to the contact board by four 10-pin plugs named X101, X102, X201 and X202. The pin descriptions are given in Table 11 to Table 14.

Table 11: X101 pin description

Pin	Signal name	Description
1	VCE_CFG_T4	V_{CE} reference
2	VCE_IN_T4	Input of V_{CE} monitoring
3	T4_15P	Stabilized +15V output power supply
4	ERROR_T4	External secondary side error input (detects thermal overload at sensor of module 1)
5	IGBT_ON_T4	Switch-on signal IGBT T4
6	IGBT_OFF_T4	Switch-off signal IGBT T4
7	EMITTER_T4	GND for power supply and digital signals
8	EMITTER_T4	GND for power supply and digital signals
9	IGBT_SOFT_T4	Soft switch-off signal IGBT T4
10	T4_8N	Stabilized -8V output power supply

Table 12: X102 pin description

Pin	Signal name	Description
1	VCE_CFG_T3	V_{CE} reference
2	VCE_IN_T3	Input of V_{CE} monitoring
3	T3_15P	Stabilized +15V output power supply
4	ERROR_T3	Connected to +15V; no error detection
5	IGBT_ON_T3	Switch-on signal IGBT T3
6	IGBT_OFF_T3	Switch-off signal IGBT T3
7	IGBT_CL_T3	Connected to active clamping
8	EMITTER_T3	GND for power supply and digital signals
9	IGBT_SOFT_T3	Soft switch-off signal IGBT T3
10	T3_8N	Stabilized -8V output power supply

Table 13: X201 pin description		
Pin	**Signal name**	**Description**
1	VCE_CFG_T1	V_{CE} reference
2	VCE_IN_T1	Input of V_{CE} monitoring
3	T1_15P	Stabilized +15V output power supply
4	ERROR_T1	External secondary side error input (detects thermal overload at sensor of module 2)
5	IGBT_ON_T1	Switch-on signal IGBT T1
6	IGBT_OFF_T1	Switch-off signal IGBT T1
7	EMITTER_T1	GND for power supply and digital signals
8	EMITTER_T1	GND for power supply and digital signals
9	IGBT_SOFT_T1	Soft switch-off signal IGBT T1
10	T1_8N	Stabilized -8V output power supply

Table 14: X202 pin description		
Pin	**Signal name**	**Description**
1	VCE_CFG_T2	V_{CE} reference
2	VCE_IN_T2	Input of V_{CE} monitoring
3	T2_15P	Stabilized +15V output power supply
4	ERROR_T2	Connected to +15V; no error detection
5	IGBT_ON_T2	Switch-on signal IGBT T2
6	IGBT_OFF_T2	Switch-off signal IGBT T2
7	IGBT_CL_T2	Connected to active clamping
8	EMITTER_T2	GND for power supply and digital signals
9	IGBT_SOFT_T2	Soft switch-off signal IGBT T2
10	T2_8N	Stabilized -8V output power supply

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 15.

Table 15: 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/T4	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 T2/T3	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. Mechanical Stack Setup

All electrical tests have been made with a mechanical stack consisting of chassis, heatsink, DC-link (capacitors and busbars), fans and a very simple AC-busbar. This stack represents one possibility how the SEMiX5 1200V TMLI Parallel Driver Kit can be utilized. On several points improvements can be achieved, and on other points simplifications have been made. An optimization process remains to the user.
The mechanical stack or drawings of it can be made available on request.

Figure 16: Block diagram of the complete SEMiX5 1200V TMLI stack

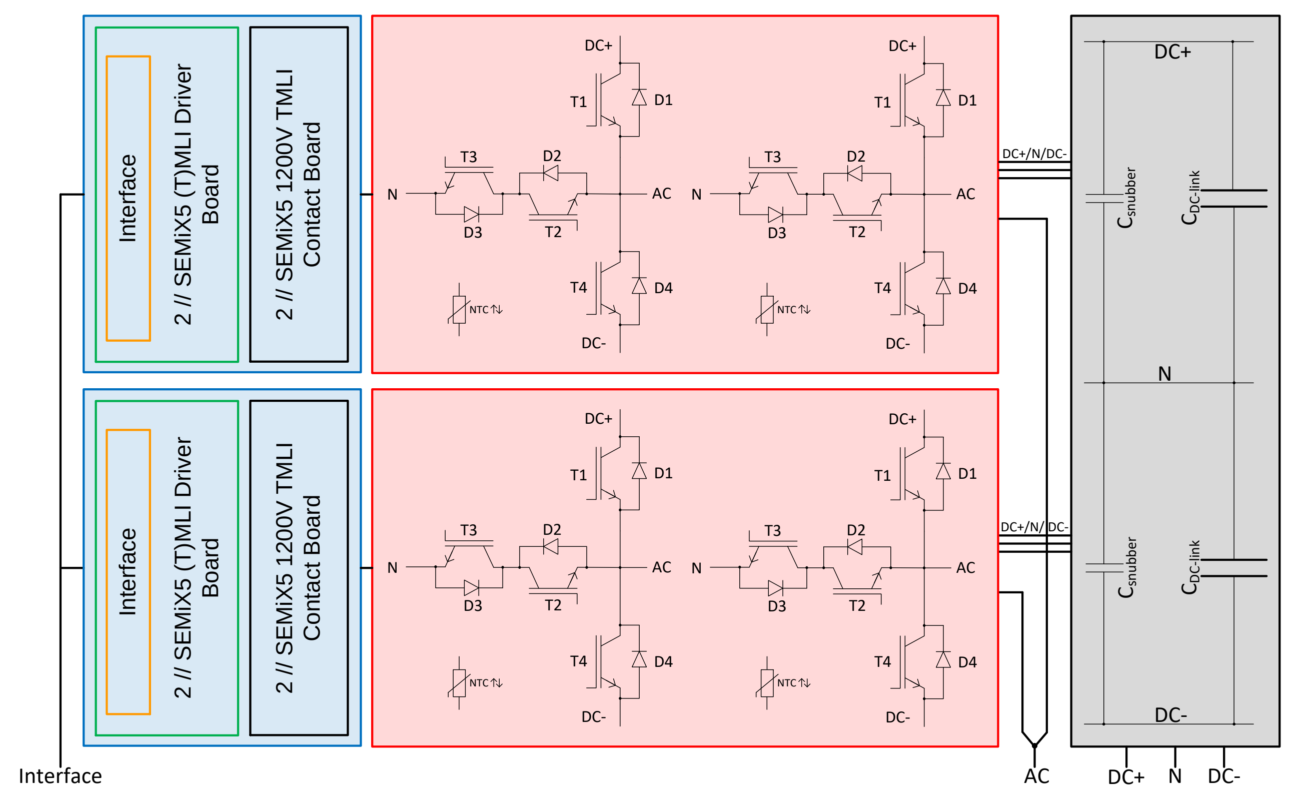


Figure 16 shows the block diagram of the stack shown in Figure 17: two pairs of modules are connected in parallel to increase the total output power. Due to a better scalability there is no 3-fold or even 4-fold parallel driver available.

5.1 Setup and stack assembly

The completely assembled stack is shown in Figure 18. The lid covers the DC-link and the modules. The AC connection is mounted on top of the fan box. Both can easily be disassembled to try out different designs.
Removing the lid allows for a top view (see Figure 17) on the 610mm wide and 570mm long stack (415mm without fan box). The total height including lid is 215mm. The heatsink offers enough space for two SEMiX5 1200V TMLI Parallel Driver Kits. Those can be connected in parallel as in the photo; a simple 20-pin ribbon cable with two plugs with a one-to-one pin assignment is good for paralleling the two driver boards. The stack can also be changed into an H-bridge configuration by using different AC-busbars.
The modules need to be assembled as described in the Mounting Instruction SEMiX®5 – rev12 [7]. For the tests at SEMIKRON 75µm of the thermal paste Wacker P12 have been applied to the modules and they have been fastened with 4.5Nm torque. The torque for the busbars has also been chosen to 4.5Nm.
It is essential to have a PE connection to the stack's chassis; any part of the chassis may be used to establish that connection. As SEMIKRON does not know in which way the chassis is used at the customer there is no dedicated PE connection point. In regards of safety this connection must be made before applying dangerous voltages.

Figure 17: SEMiX5 stack top view (lid removed)

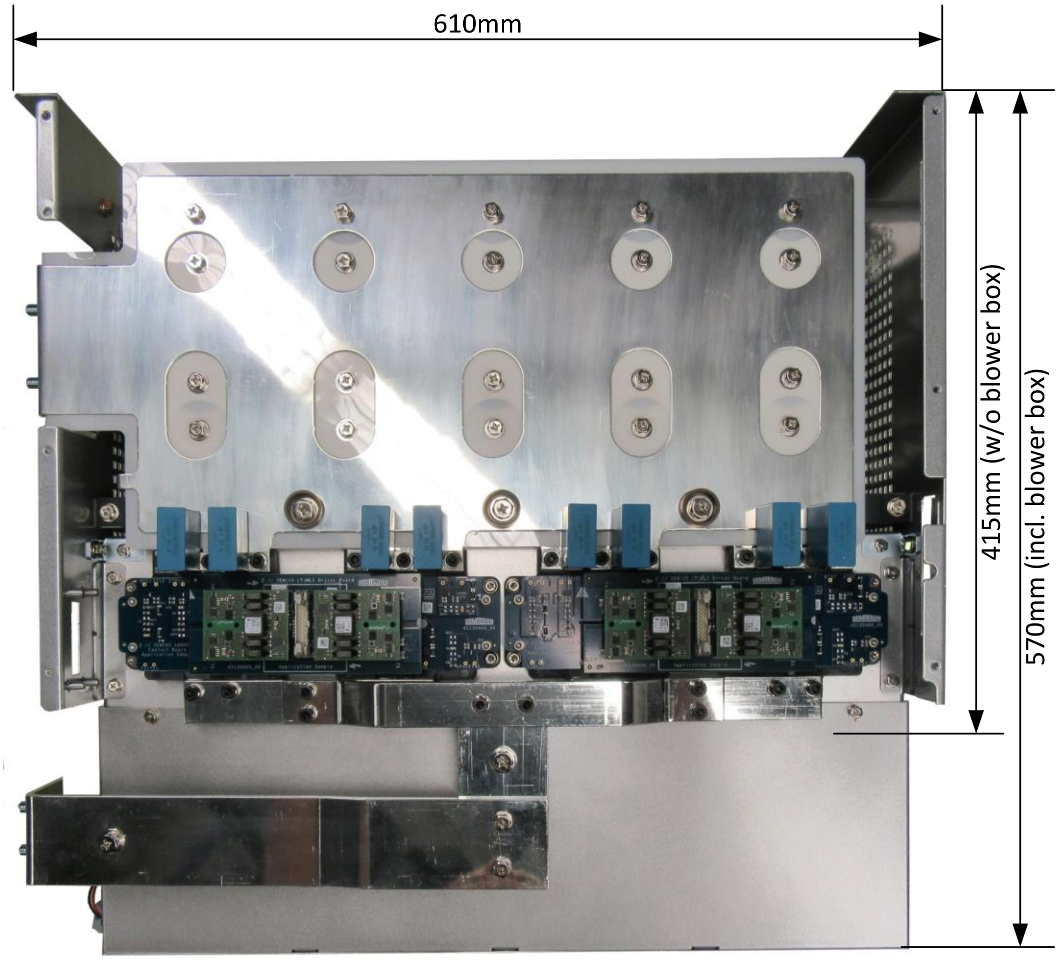


Figure 18: SEMiX5 stack front view

5.2 DC-link

The DC-link consists of 10 film capacitors with 420µF each at a voltage rating of 900V. The voltage rating is chosen higher than necessary for the SEMiX 1200V TMLI Driver Kit because it is a general purpose stack that can be used with all kinds of SEMiX5 3L modules. The amount of capacitors is determined by ripple current load of a three phase system; each one-phase stack comes with one third these capacitors.

Figure 19: SEMiX5 stack back view with DC-link capacitors and discharge resistors

To provide a low stray inductance the DC+, N and DC- layers are designed in a way that they overlap as much as possible. Only close to the modules' power terminals overlapping is no longer possible due to insulation restrictions. Figure 19 shows the capacitors; marked in red are the discharge resistors. **These resistors are only a fall-back solution with a very long discharge time (≥10 minutes)**.

Figure 20: SEMiX5 stack side view with DC-link, AC and fan supply connectors

Also the DC connection of several stacks for setting up a multi-phase system uses a very low inductive busbar design. The three potentials overlap as much as possible (see Figure 20 and Figure 21). This low-inductive connection is necessary to keep oscillation between the split DC-link capacitor banks as low as possible. The laminated busbar adds a stray inductance of approx. 7nH.

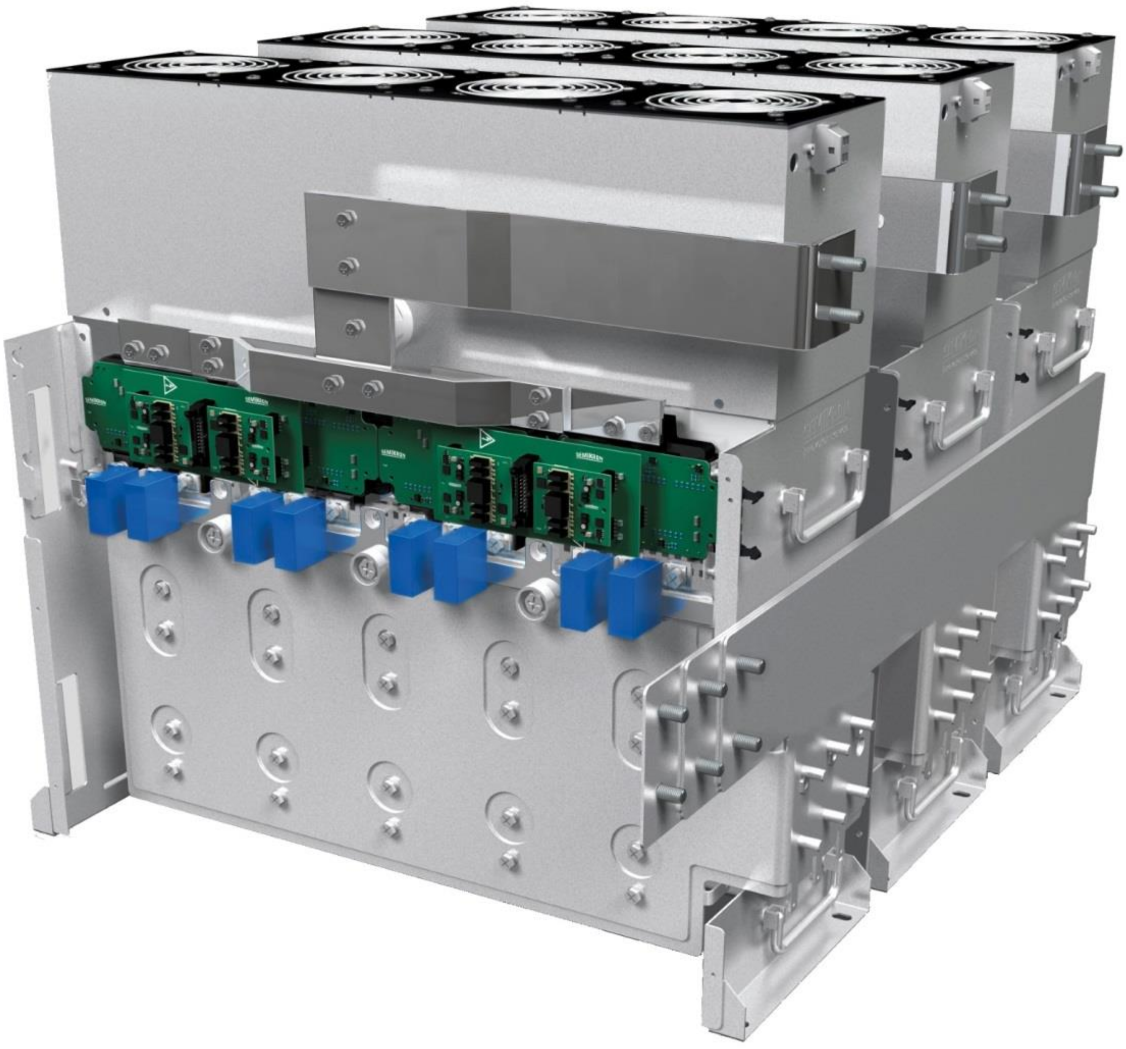
5.3 AC connection

The AC busbar shown in Figure 17 and Figure 18 is an example how it could be designed. All tests at SEMIKRON have been performed with this specimen but other designs are possible and may be even better. The optimization of the AC busbar remains to the user.
There is only one restriction when both module pairs per stack are operated in parallel: the AC connection of the modules of one pair should be as short as possible while the interconnection of the two pairs should have some inductance. This can be achieved by not directly connecting the two pairs (e.g. by using a flat copper bar across all four modules' AC terminals).

5.4 Cooling

The design of this Application Sample requires a cooling air flow through the capacitors towards the heatsink (i.e. from bottom to top side in Figure 21) so that the DC-link is placed in the airflow of the "cool" air. That is because capacitors' lifetimes are strongly dependant on their temperature. As SEMIKRON does not know how the user will operate the stack a simple box with four 120mm fans has been designed and mounted to the stack to provide a basic cooling. Although knowing that hot air flowing through the fans will significantly reduce their lifetime it is possible to operate the Application Sample in a laboratory environment for testing purposes where fan lifetime is not crucial.
In case this design shall be used as a first step SEMIKRON strongly recommends to use a different blower design.
During the tests SEMIKRON used fans that deliver a volume flow of approx. 1000m³/h. Any kind of fan can be used; it is in the user's responsibility to check for proper cooling performance and lifetime criteria.

Figure 21: SEMiX5 stacks in three-phase system connection



6. Restrictions and Requirements

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

6.1 Switching pattern of TMLI modules

A detailed explanation of the TMLI switching pattern is given in the SEMIKRON Application Note AN11001 [3]. Summed up always an inner IGBT (T2 or T3) may 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 IGBT (here: T1). If the voltage applied to T1 exceeded the blocking voltage T1 would be destroyed.
If switching off all IGBTs simultaneously is recommended it must be made sure that the voltages across the semiconductors do never exceed the blocking voltages.

6.2 Error treatment

If a desaturation event occurs, the desaturated IGBT must be turned off within 10µs, otherwise it might be destroyed by this extreme overload. The correct turn-of sequence (inner IGBT first, outer IGBT afterwards) is recommended to be maintained to prevent the commutating semiconductors from overvoltage.
The user can influence the error management by equipping or not connecting R10 on the driver board; SEMIKRON recommends to equip R10 with 0Ω. For an error at T1 (T4) it makes no difference if it is equipped or not, but in case of an error at T2 (T3) the turn-off sequence is faster. The error treatments are described below.
In any case the user needs to react appropriately to error messages sent from the driver kit: the correct switching pattern is recommended and a switch-off time below 10µs is mandatory to avoid damage.

6.2.1 Secondary error at T1 (T4)

In case a secondary side error (e.g. desaturation) occurs at an outer IGBT (T1 or 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 of X10 (see Table 15). At the same time the particular IGBT (T1 or T4) is turned off using the soft-turn-off resistor.

- When resistor R10 on the driver board is equipped with 0Ω the error message from driver of T1 and T4 is sent to the error input of the driver of T2 and T3. This error message at the input prevents the driver from turning on as long as the error message is active. If IGBTs T2 or T3 are in on-state when the error message is received by the error input, however, the IGBTs are not turned off as long as the PWM signal of T2 (T3) is active. As soon as the PWM signal turns off the IGBTs are turned off and stays in off-state as long as the error message is active.
- Not connecting R10 does not make a difference: the error message from driver of T1 and T4 will not be sent to driver of T2 and T3 and the correct and in-time shut-off needs to be ensured by the user.

6.2.2 Secondary side error at T2 (T3)

In case a secondary side error (e.g. desaturation) occurs at an inner IGBT (T2 or T3) 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 17 of X10 (see Table 15).
In order to maintain the correct turn-off sequence the inner IGBTs are not turned off automatically.

- When resistor R10 on the driver board is equipped with 0Ω the error message from driver of T2 and T3 is sent to the error input of the driver of T1 and T4 indicating an immediate turn-off of T1 and T4.
- When resistor R10 on the driver board is not connected the error message from driver of T2 and T3 is not sent to the error input of the driver of T1 and T4. It is in the responsibility of the user to take care of switching off the short circuit within 10µs using the correct turn-off sequence.

In both cases the IGBTs T2 or T3 are switched off with the next regular PWM turn-off. The IGBT which detected the error is switched off using the soft-turn-off resistor, the IGBT without error is turned off using the standard resistors.

6.2.3 Error treatment in paralleled driver kits

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

6.2.4 Error treatment in 3-phase systems

In 3-phase systems there is no direct connection of the driver kits' error signals. This connection must be provided by the user; either by a hardware connection of the particular error lines or by routing the error messages and appropriate handling on the controller side. Please note that time is critical when an error occurs and therefore error treatment shall be performed using fast hardware.

6.3 Design limits gate resistors

6.3.1 Minimum gate resistor

The minimum gate resistor is determined by the maximum voltage change of the driver during switching; it turns from -8V to +15V or back, so the voltage change is 23V. The peak current SKYPER 42 LJ is capable of driving 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 two modules (that can be found in the module datasheet), the emitter resistors (0.5Ω per module) and the gate-turn-on or gate-turn-off resistors R_{Gon} and R_{Goff}. The gate resistors per module can be calculated according to:

$R_{Gon,min} = R_{Goff,min} = 1.8\Omega - R_{Gint}$ (with SEMiX 405 TMLI 12E4B and 0.5Ω emitter resistance)

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 per module to avoid damage to the SKYPER 42 LJ.

6.3.2 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 AN7003.

6.4 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 recommends to use 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 contact 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.

6.5 Design limits switching frequency

The used modules, their gate charge and the power of the SKYPER 42 LJ drivers determine the maximum switching frequency. Further information on calculating the switching frequency limit can be found in Application Note AN7004.

6.6 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.

6.7 SEMIKRON assembly

SEMIKRON has tested the Application Sample as it is shown in the photos above. All results shown are valid for the particular revisions shown in Table 16 only.

Table 16: Part revisions for SEMIKRON tests

Part	Revision
SKYPER42 LJ	L5063101_07
2 // SEMiX5 TMLI Contact Board	45125701_05
2 // SEMiX5 (T)MLI Driver Board	45130601_00
SEMiX 405 TMLI 12E4B	Datecode: 16143P R

Variable part values have been chosen according to Table 17.

Table 17: Part values for SEMIKRON tests

Part	Resulting value for T1 and T4	Resulting value for T2 and T3
R_{Gon}	1.65Ω	0.5Ω
R_{Goff}	1.65Ω	5Ω
R_{Soft}	1.65Ω	5Ω
C_{GE}	10nF	-
Active Clamping	-	4x 100V + 1x 75V (i.e. five TVS diodes with a nominal breakdown voltage of 100V respectively 75V)
R_{CE}	10kΩ (R101, R401)	15kΩ (R201, R301)
C_{CE}	820pF (C102, C402)	820pF (C202, C302)
$R_{temp,threshold}$	250Ω (R1003, R2003)	

With the above mentioned values and additional 680µF snubber capacitors (SEMIKRON specific snubber capacitor; EPCOS Code: B32656-S0684-+504) from DC+ to N and N to DC- at every module an absolute maximum operation up to 900V_{DC} and 1000A_{RMS} is possible at all power factor values at a maximum ambient temperature of 40°C. At these conditions the heatsink temperature exceeds 100°C and the junction temperatures are around 145°C.
It can also withstand soft and hard short circuits, when the active clamping circuits at IGBTs T2 and T3 are adjusted to come into action at V_{CE}=600..630V.
The SEMiX5 1200V TMLI Parallel Driver Kit excluding the stack has passed isolation and partial discharge tests.

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
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, AN11001 - rev05, 2015
[4] M. Hermville, "Gate Resistor – Principles and Applications", SEMIKRON Application Note, AN7003 - rev00, 2007
[5] M. Hermville, "IGBT Driver Calculation", SEMIKRON Application Note, AN7004 - rev00, 2007
[6] J. Krapp, "Technical Explanations SKYPER®42 – rev11", SEMIKRON Technical Explanation, 2017
[7] M. Santoro, A. De Medici, "Mounting Instruction SEMiX®5 – rev14", SEMIKRON Mounting Instruction, 2017

IMPORTANT INFORMATION AND WARNINGS

SEMIKRON INTERNATIONAL GmbH
Sigmundstrasse 200, 90431 Nuremberg, Germany
Tel: +49 911 6559 6663, Fax: +49 911 6559 262
sales@semikron.com, www.semikron.com