Technical Explanation Board SKiM4 MLI/TMLI

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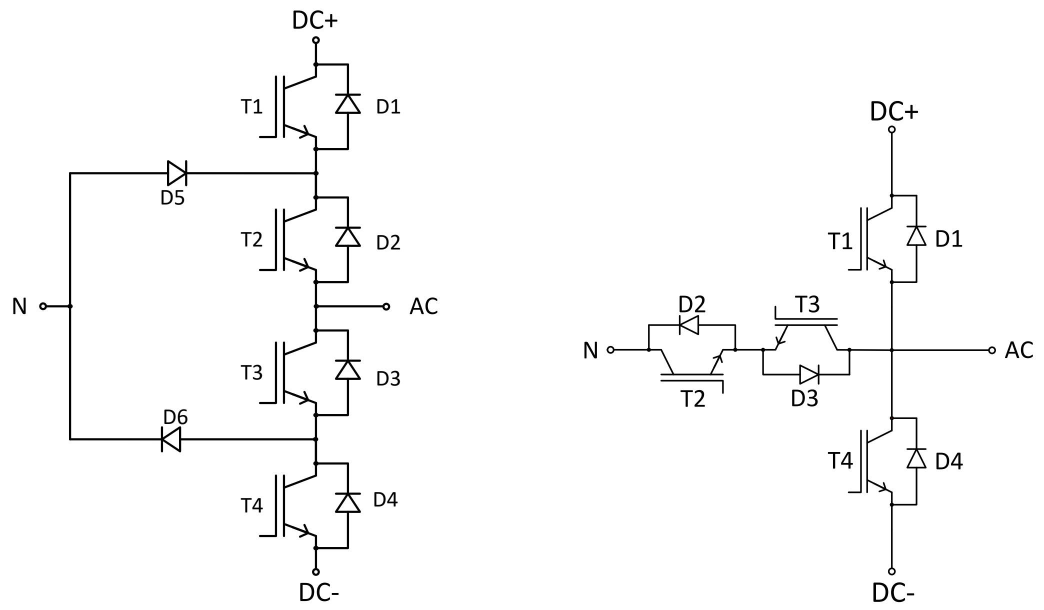
1. Introduction

SEMIKRON set up driver boards for SKiM4 MLI and SKiM4 TMLI modules for evaluation purposes. The SKiM4 driver boards are able to operate the modules up to a DC-link voltage of 1500V (MLI) respectively 1200V (TMLI) at a maximum switching frequency of 20kHz for SKiM 301 MLI 12E4 and SKiM 601 TMLI 12E4B which are the most powerful modules available.
Two standard 2L drivers (SKYPER 42 LJ) are used to operate the 3L TMLI module; 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.

Figure 1: MLI (left) and TMLI (common emitter; right)

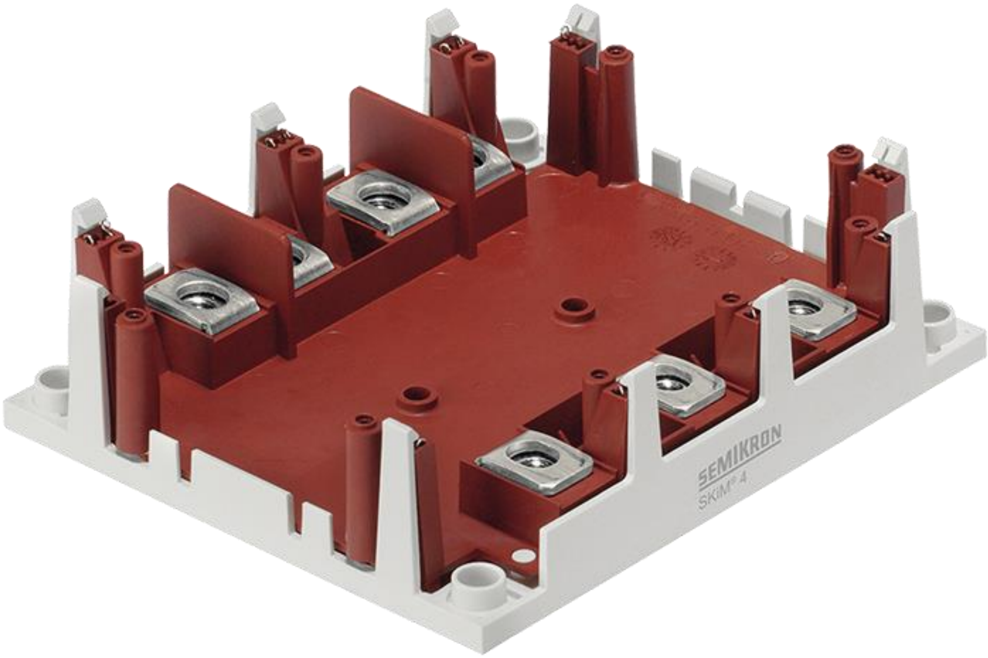


This Application Sample is dedicated to both universities and professional development engineers. It offers an easy way to set up high power inverters with standard MLI modules and 2L drivers.
All Application Samples have been isolation tested; there is no functional routine test.

1.1 Features

The SKiM4 driver boards are designed for the SKiM4 MLI modules with 650V or 1200V semiconductors at all switch positions ("Board SKIM4 MLI") respectively SKiM4 TMLI modules with 1200V semiconductors at the vertical and 650V semiconductors at the horizontal branch ("Board SKiM4 TMLI"). All SKiM4 MLI/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 SKiM4 modules) and the design limits are met (e.g. maximum DC voltage and maximum SKYPER 42 LJ output power may not be exceeded). Please note that MLI modules may only be operated with the Board SKiM4 MLI and TMLI modules may only be operated with the Board SKiM4 TMLI in order to avoid malfunction or damage.

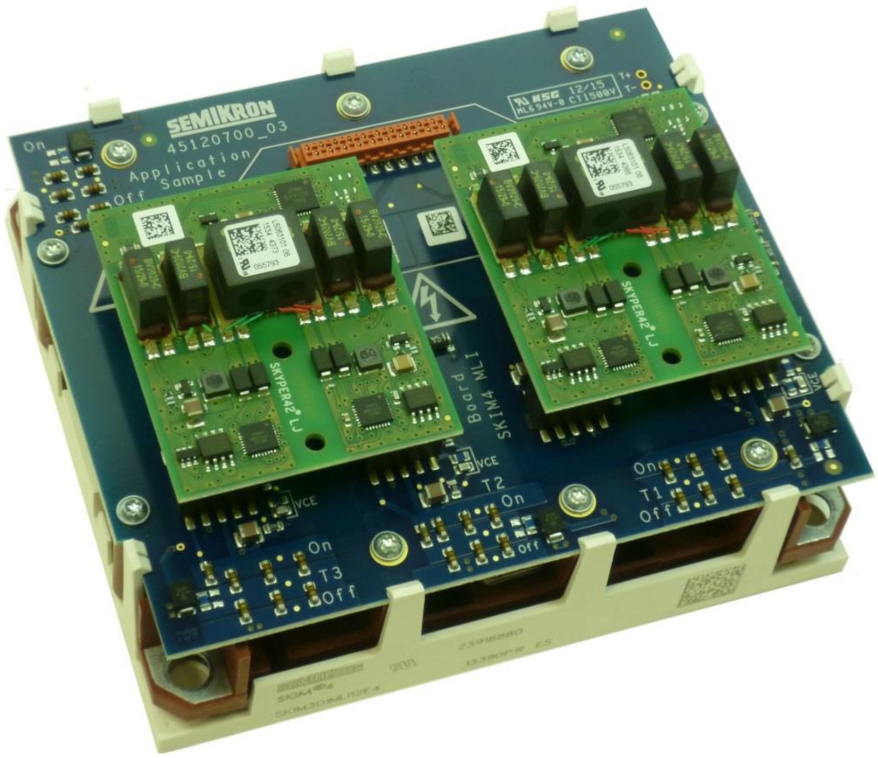
Figure 2: SKiM4



1.2 Hardware of the Board SKiM4 MLI/TMLI

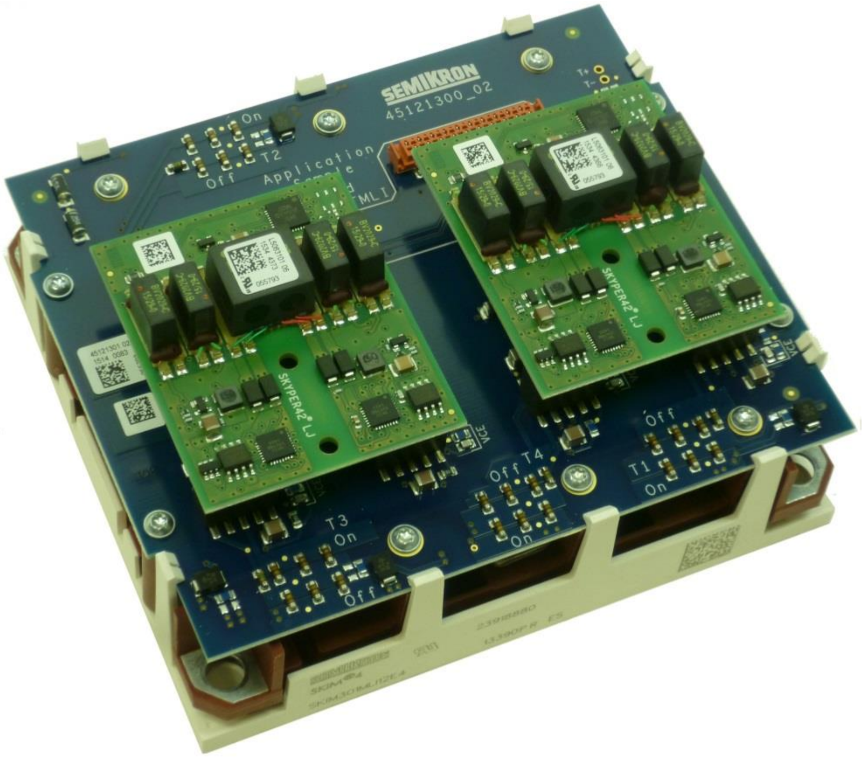
The SKiM4 MLI/TMLI driver boards consist of one printed circuit board (PCB) each; the PCB is directly mounted onto the SKiM4 module (item number 45120701 for MLI and 45121301 for TMLI). The PCBs provide sockets for two SKYPER 42 LJ drivers and a user interface.

Figure 3: SKiM4 MLI driver board



The SKiM4 modules (voltage / current rating, MLI / TMLI) may be chosen according to the desired application.

Figure 4: SKiM4 TMLI driver board



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 Board SKiM4 MLI / TMLI bares risks when put in operation. Please carefully read and obey the following safety instructions to avoid harm or damage to persons or gear.

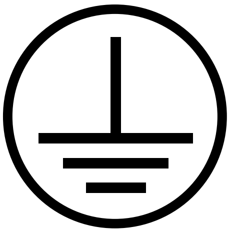
Table 1: Safety instructions	
	**In operation the Board SKiM4 MLI / TMLI inherits high voltages that are dangerous to life!** **Only qualified personnel should work with the Kit.**
	**Some parts of the Board SKiM4 MLI / TMLI or connected devices (e.g. heatsink) may reach high temperatures that might 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 Board SKiM4 MLI / TMLI.**

Table 2: Safety regulations for work with electrical equipment

Safety Regulations

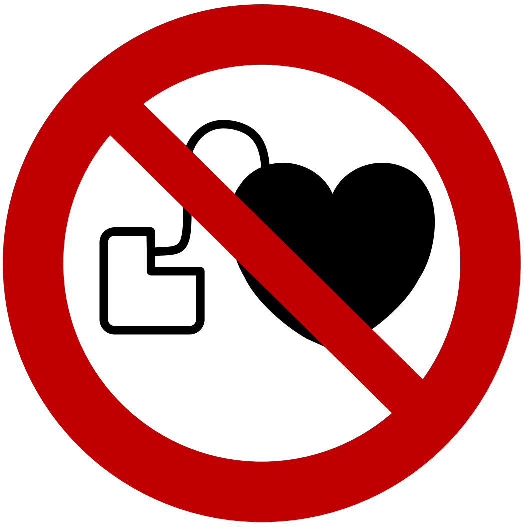
for work with electrical equipment

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 Board SKiM4 MLI/TMLI.

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 Board SKiM4 MLI / TMLI block diagram

The electrical block diagrams in Figure 5 and Figure 6 show two parts: the blue marked part is the driver part with gate resistors, clamping circuitry and sockets for the SKYPER 42 LJ drivers. The red part symbolizes the 3-level modules.

Figure 5: Board SKiM4 MLI block diagram

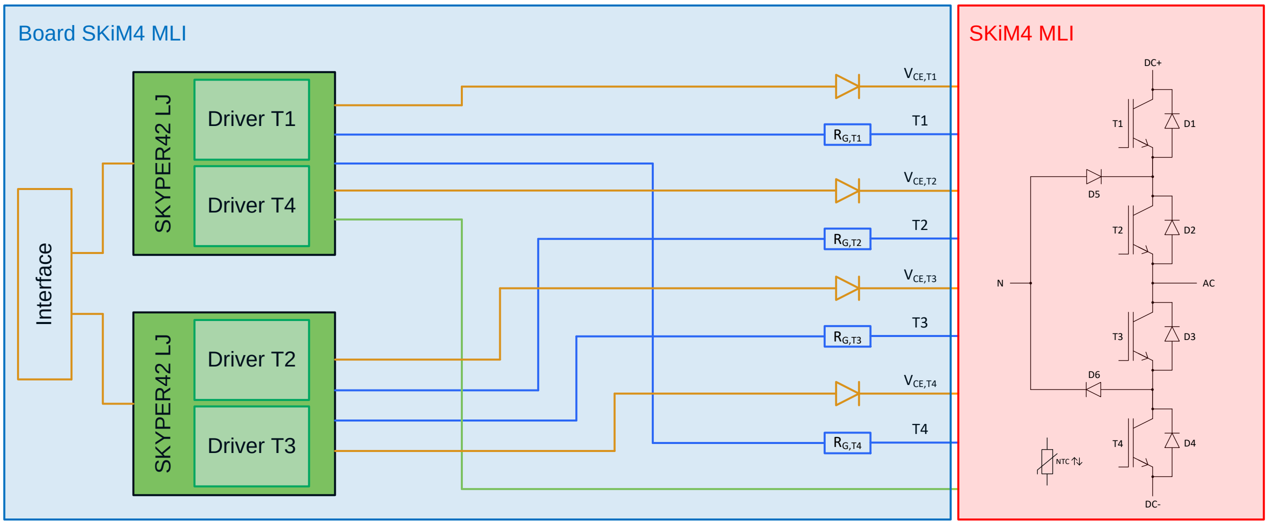
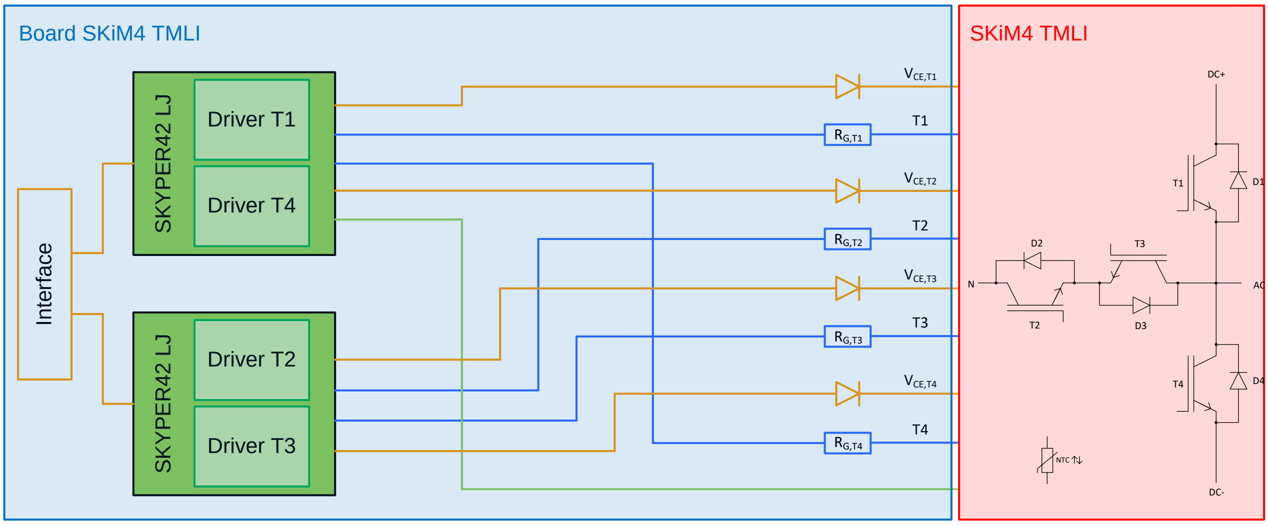


Figure 6: Board SKiM4 TMLI block diagram



3.2 Electrical and mechanical characteristics

With regard to the requirement specification the Board SKiM4 MLI / TMLI allows for operation within the following boundaries:

- Max. DC-link voltage — V_{DC} = 1500V (1200V) in total, max. 750V (600V) per individual DC-link half for MLI (TMLI)
- Max. AC voltage — V_{AC} = 1000V_{RMS} (690V_{RMS}) line-to-line for MLI (TMLI)
- Max. switching frequency — f_{sw} = 20kHz (see chapter 5.4 for further information)
- Ambient temperature — T_a = 0°C…40°C (see chapter 5.5 for further information)
- CTI rating of AppS PCBs — > 175

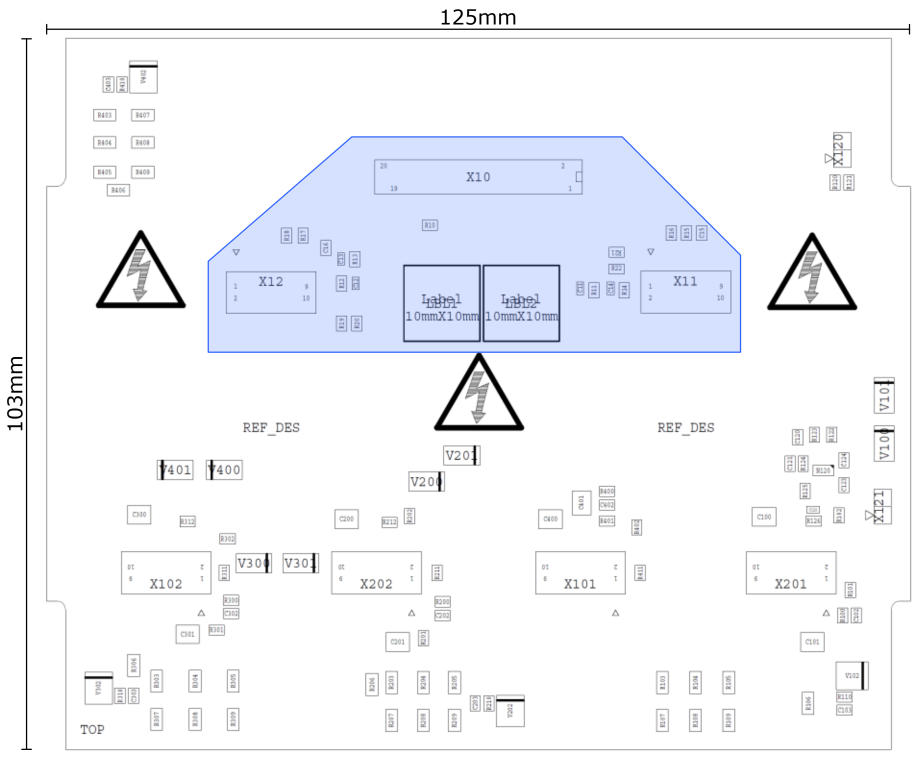
Neglecting the above mentioned boundaries may lead to malfunction or damage of the Board SKiM4 MLI / TMLI.
An electrical insulation is implemented between the user interface (primary side) and the high voltage connections (secondary side) by using the SKYPER 42 LJ’s separation. The creepage and clearance distance on the driver board is 15.1mm (MLI), respectively 12.2mm (TMLI) 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. 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 boards are 125mm long and 103mm wide.

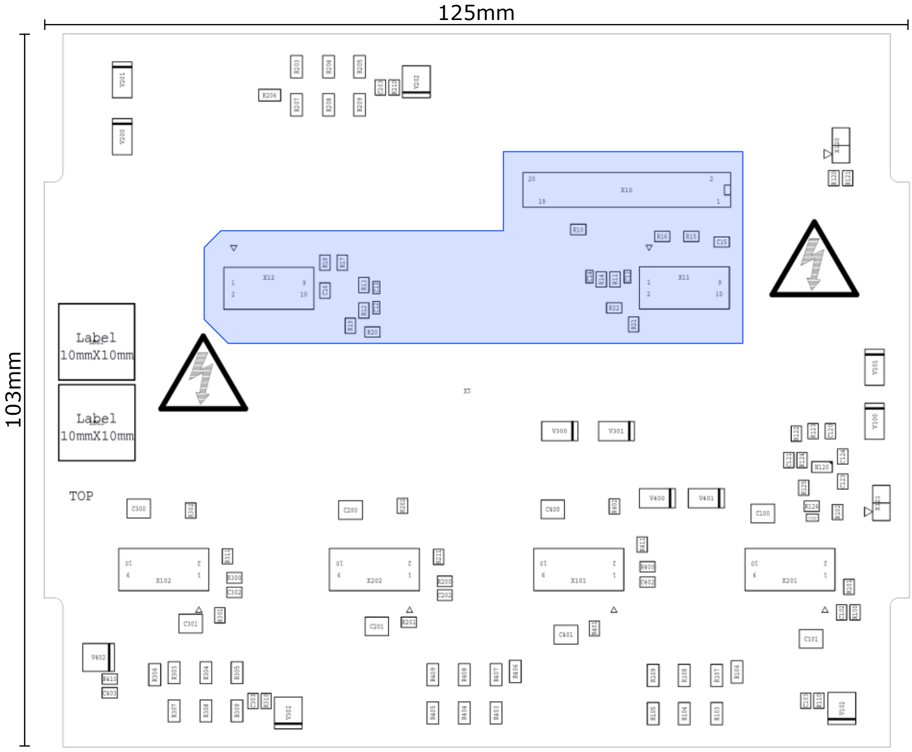
To prevent driver board and the SKYPER 42 LJ drivers from loosening from each other contact board and driver board come with mounting holes for dual lock support posts. SEMIKRON recommends nylon support posts from Richco with item no. DLMSPM-8-01. Please find further information in the technical explanation of SKYPER 42 LJ [6].

Figure 7: Dimensions of Board SKiM4 MLI



The driver boards can be mounted to the modules in two steps. First the particular board needs to be fixed on the module by pressing it to the white plastic hooks until it snaps.
Secondly the boards are mounted to the module using ten self-tapping screws of the type “EJOT PT WN1452 K30x8”. The screw head may be chosen by the user. Further information on the mounting process can be found in the technical explanation of SKiM4 [1].

Figure 8: Dimensions of Board SKiM4 TMLI



The blue marked area in Figure 7 and Figure 8 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 driver board (Figure 7 and Figure 8) may be considered as high voltage area (secondary side).

3.3 Integrated functions

The Board SKiM4 MLI / TMLI have some integrated safety functions to protect the device from certain harmful conditions.

3.3.1 Thermal protection

The module's built-in NTC temperature sensor is monitored. At a pre-defined temperature (to be defined by the user by adjusting a resistor; standard setting is 115°C) 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 drops across the outer IGBTs T1 and T4 is 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 SKYPER42 LJ driver [6] 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 solid purple in Figure 9 and in Figure 10.
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.

3.4 Board description

On both boards several components are meant to be changed by the user to achieve an adaptation to the application conditions.
The changeable components of the contact board are marked with different coloured frames in Figure 9 and Figure 10; function and possible values are explained in chapters 3.4.1 to 3.4.6.

Figure 9: Board SKiM4 MLI; user-changeable components are framed

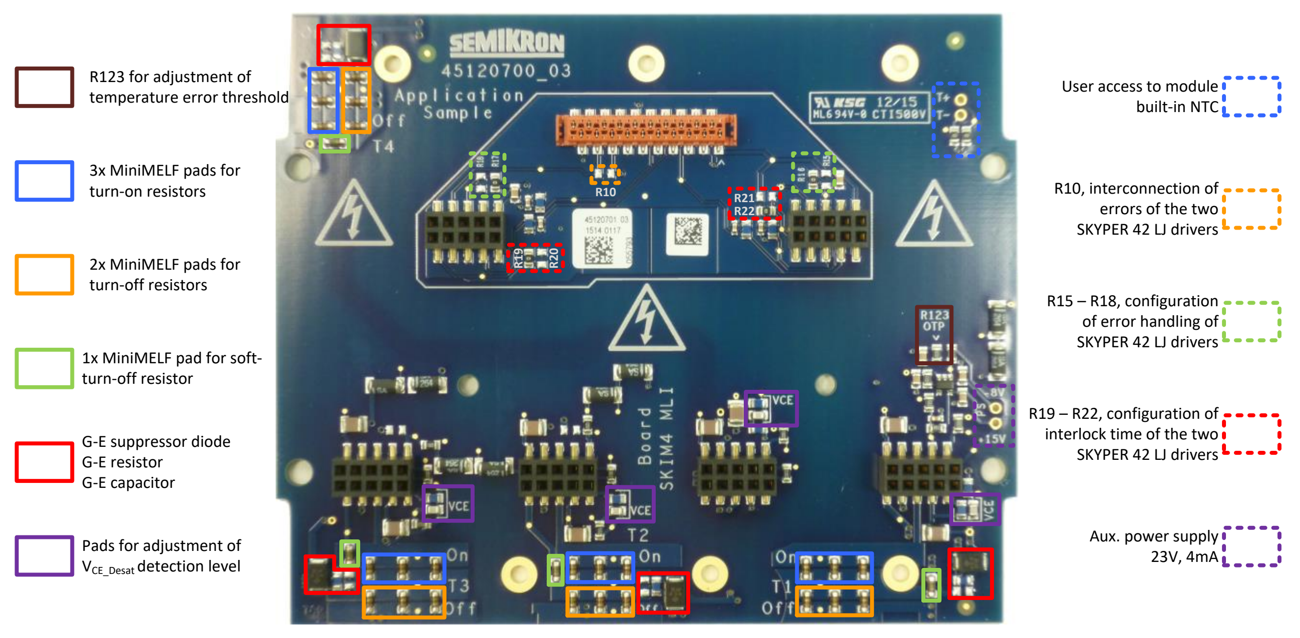
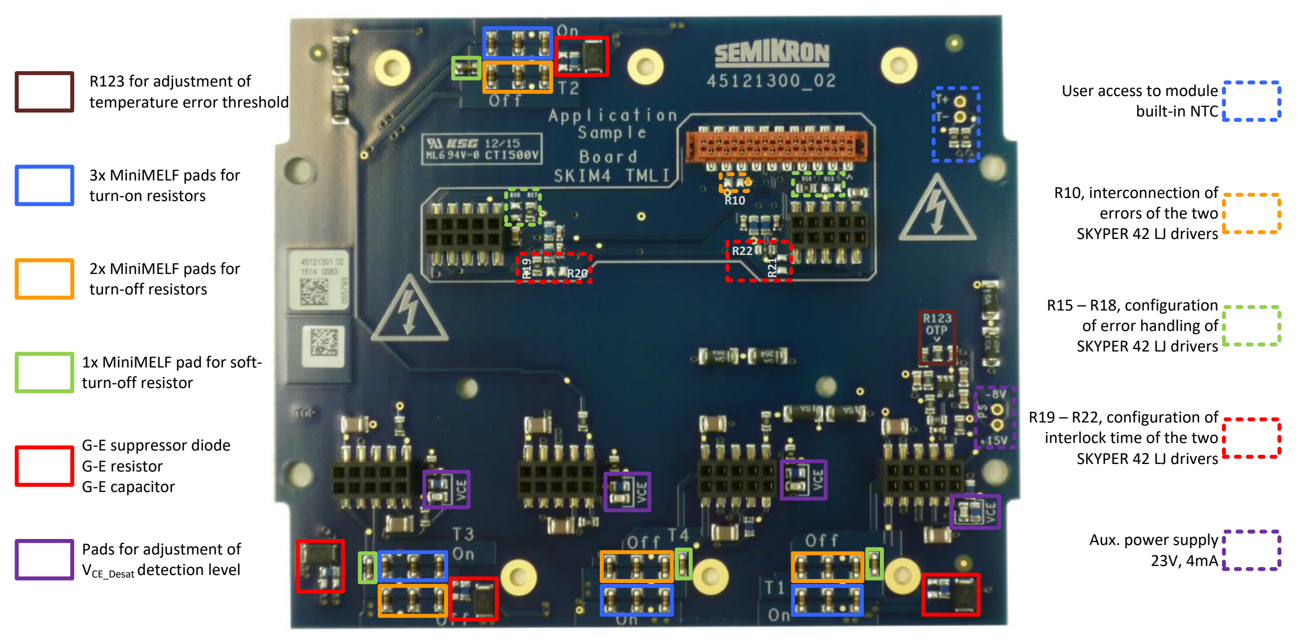


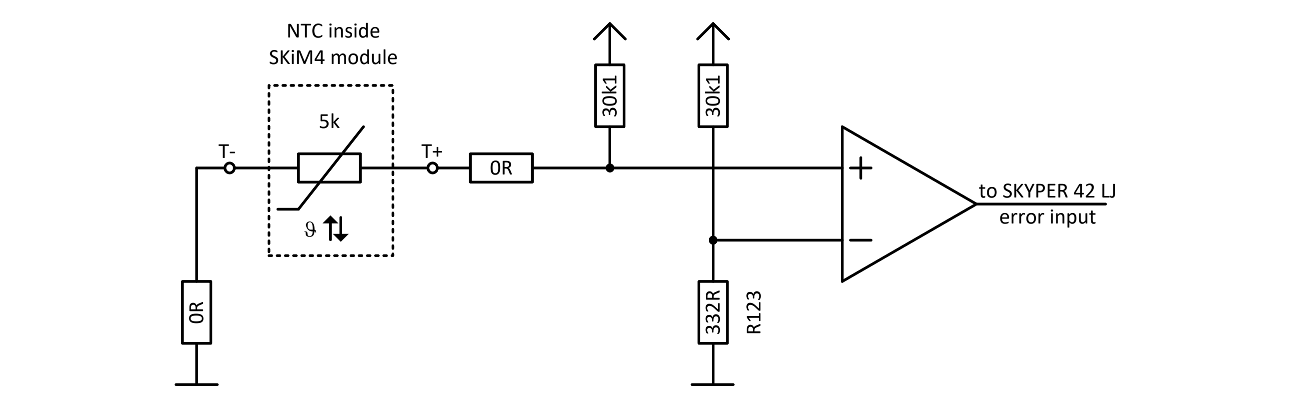
Figure 10: Board SKiM4 TMLI; user-changeable components are framed



3.4.1 Adjustment of temperature error threshold

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 resistor R123 (framed brown in Figure 9 and Figure 10) can be used for adjusting the error temperature threshold.

Figure 11: Schematic of NTC evaluation



The standard value for R123 is 332Ω which refers to a temperature threshold of approximately 115°C. The thermal overload detection is deactivated by removing the two 0Ω resistors shown in Figure 11.

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 R123 can be calculated.

Chip resistors with the size 0805 can be used for R123 and the two 0Ω jumpers.

Figure 12: SKiM4 MLI / TMLI NTC characteristic (excerpt)

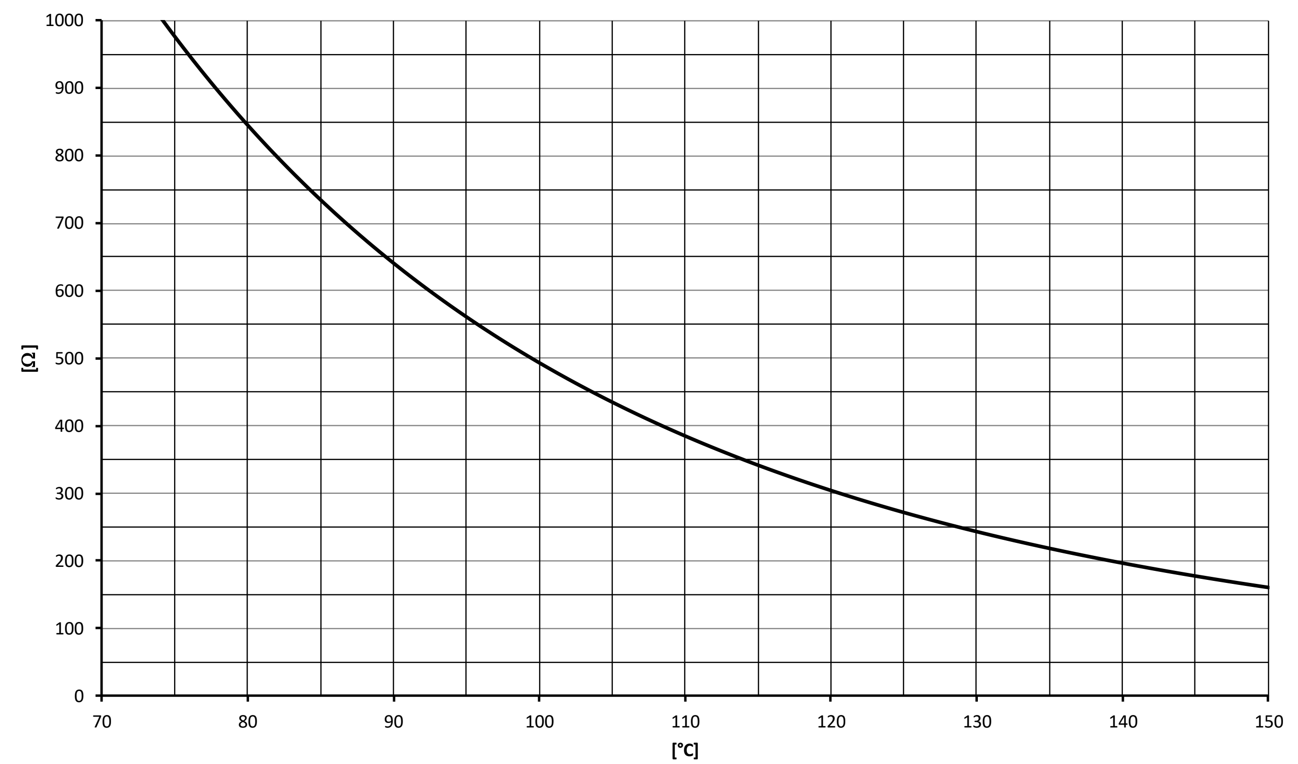
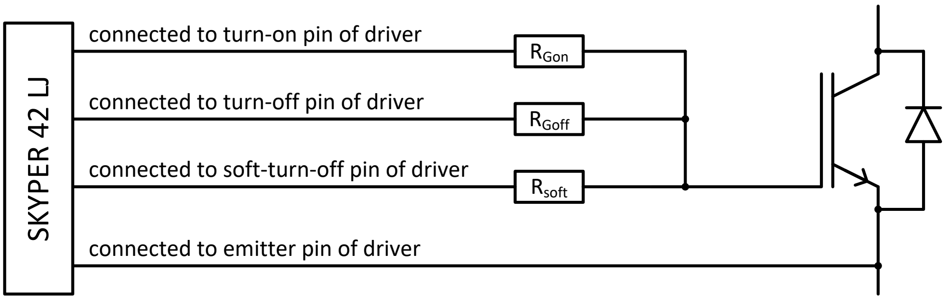


Figure 12 shows an excerpt of the SKiM4 MLI/TMLI NTC characteristic which includes the most interesting temperature range between 70°C and 150°C. The full characteristic can be found in the Technical Explanations or can be calculated from the formula given in the SKiM4 MLI/TMLI datasheets [1].

3.4.2 Gate resistors

Three resistors on the contact board realize what is called gate resistor in this document for the sake of convenience. 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.

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 9 and Figure 10) 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 5.3.2 for further information.

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

The contact board offers two pads per IGBT (framed orange in Figure 9 and Figure 10) 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 5.3.2 for further information.

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

The contact board offers one pad per IGBT (framed green in Figure 9 and Figure 10) 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 5.3.2 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 and Figure 10). 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 $V_{CE,Desat}$ components

For every IGBT the boards offers two pads sized 0805 (framed purple in Figure 9 and Figure 10) for adjusting the $V_{CE,Desat}$ detection level. The standard values are 10kΩ and 820pF for the outer IGBTs T1 and

T4 and 15kΩ and 820pF for the inner IGBTs T2 and T3. With these values the detection at the outer switches is more sensitive and it can be made sure that the inner switches will not detect an error before the outer switches.
For further information please refer to the technical explanation of SKYPER 42 LJ [1].

3.4.5 Error management of driver T1/T4 and driver T2/T3

Error interaction of outer and inner IGBT drivers

The 0805 sized R10 (framed dotted-orange in Figure 9 and 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 5.2 for detailed information.

Error handling of outer and inner IGBT drivers

The 0805 sized resistors R15-R18 (framed dotted-green in Figure 9 and 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

The 0805 sized resistors R19-R22 (framed dotted-red in Figure 9 and 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 equipped) 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)**

4. User Interface

4.1 Module interface

The pinout of a SKiM4 MLI and SKiM4 TMLI module is shown in Figure 14 and explained in Table 8. All modules that are pin-compatible may be used with the driver board.

Figure 14: SKiM4 interface

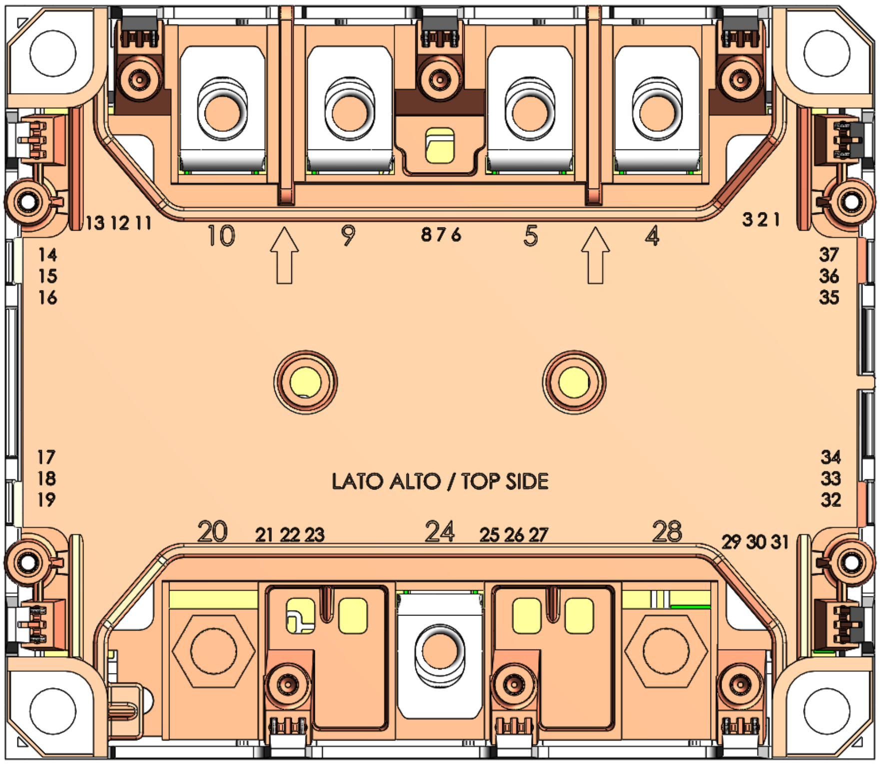


Table 8: SKiM4 MLI (TMLI) pin description					
Pin	**Description**		**Pin**	**Description**	
1	n.c.	(n.c.)	20	n.c.	(n.c.)
2	n.c.	(n.c.)	21	n.c.	(Emitter IGBT T3)
3	Collector IGBT T1	(n.c.)	22	n.c.	(n.c.)
4	DC+ terminal	(DC+ terminal)	23	n.c.	(Gate IGBT T3)
5	N terminal	(N terminal)	24	AC terminal	(AC terminal)
6	N auxiliary	(Gate IGBT T2)	25	Gate IGBT T2	(n.c.)
7	n.c.	(n.c.)	26	n.c.	(n.c.)
8	n.c.	(Emitter IGBT T2)	27	Emitter IGBT T2	(n.c.)
9	N terminal	(N terminal)	28	n.c.	(n.c.)
10	DC- terminal	(DC- terminal)	29	n.c.	(Emitter IGBT T1)
11	Emitter IGBT T4	(Collector IGBT T2)	30	n.c.	(n.c.)
12	n.c.	(n.c.)	31	n.c.	(Gate IGBT T1)
13	Gate IGBT T4	(n.c.)	32	Emitter IGBT T1	(n.c.)
14	n.c.	(n.c.)	33	n.c.	(n.c.)
15	n.c.	(n.c.)	34	Gate IGBT T1	(n.c.)
16	n.c.	(n.c.)	35	NTC sensor	(NTC sensor)
17	Emitter IGBT T3	(Emitter IGBT T4)	36	n.c.	(n.c.)
18	n.c.	(n.c.)	37	NTC sensor	(NTC sensor)
19	Gate IGBT T3	(Gate IGBT T4)	38	n.c.	(n.c.)

Further information about module mounting, etc. may be found in the module datasheets and the SKiM4 Technical Explanation [1].

4.2 Temperature sensing interface

In case the internal temperature shut-off shall be replaced by an external (user-side) temperature evaluation, the two 0Ω jumpers need to be removed; that deactivates the internal temperature error detection and disconnects the NTC sensor from the on-board circuits. The user can access the NTC directly using the solder pads T+ and T- (framed blue-dotted in Figure 9 and Figure 10).
If required the auxiliary power supply of the driver's secondary side can supply 23V at max. 4mA for the user's temperature evaluation circuit. The power supply can be found in the purple-dotted box in Figure 9 and Figure 10. **Please note that the temperature sensor and the aforementioned power supply have no protective separation from high voltage circuits!**

4.3 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 9.

Table 9: 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. 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.

5.1 Switching pattern of MLI modules

A detailed explanation of the MLI 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 must 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

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-off sequence (outer IGBT first, inner IGBT afterwards) must 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 Board SKiM4 MLI / TMLI: the correct switching pattern is recommended and a switch-off time below 10µs is mandatory to avoid damage.

5.2.1 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 9). 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.
- 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.

5.2.2 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 9).
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.

5.2.3 Error treatment in paralleled driver kits

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 methods parallels all PWM signals and also the error messages. The errors of one Board SKiM4 MLI / TMLI would be communicated to the other drivers of one phase leg leading to the error handling as describes above.

5.2.4 Error treatment in 3-phase systems

In 3-phase systems there is no direct connection of the driver' 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.

5.3 Design limits gate resistors

5.3.1 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 module (that can be found in the module datasheet) and the gate-turn-on or gate-turn-off resistors R_{Gon} and R_{Goff}. The minimum gate resistors 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 SKYPER 42 LJ.

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 AN7003 [4].

5.4 Design limits switching frequency

The used modules and 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 [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 a specific DC-link, DC-link connection and snubber capacitors. All variable parts (resistors / capacitors, e.g. R_{Gon}, R_{Goff}, etc.) are chosen to allow for immediate start of operation. These values are not suitable for optimal operation (e.g. optimized switching losses or minimized voltage overshoots). This work needs be done in the final setup.

Variable part values have been chosen according to Table 10.

Table 10: Part values for SEMIKRON tests		
Part	**Resulting value for T1 and T4**	**Resulting value for T2 and T3**
R_{Gon}	13.7Ω	13.7Ω
R_{Goff}	13.7Ω	13.7Ω
R_{Soft}	47.5Ω	47.5Ω
C_{GE}	-	-
R_{CE}	10kΩ	15kΩ
C_{CE}	820pF	820pF
$R_{temp,threshold}$	332Ω	

With the above mentioned values and additional 680µF snubber capacitors from DC+ to N and N to DC- at every module an absolute maximum operation up to 1500V_{DC} and 200A_{RMS} (@5kHz; MLI) respectively up to 1200A and 275A_{RMS} (@5kHz; TMLI) is possible at all power factor values at a maximum ambient temperature of 40°C.
The driver board has passed isolation and partial discharge tests. The isolation test voltage was set to 4kV_{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.

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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.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 Explanations SKYPER®42 – rev11", SEMIKRON Technical Explanation, 2017
[7] M. Santoro, "SKiM®4 MLI & TMLI – rev1.5", SEMIKRON Technical Explanation, 2017

IMPORTANT INFORMATION AND WARNINGS

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