Technical Explanation
Board SiC Module SKYPER 42 LJ

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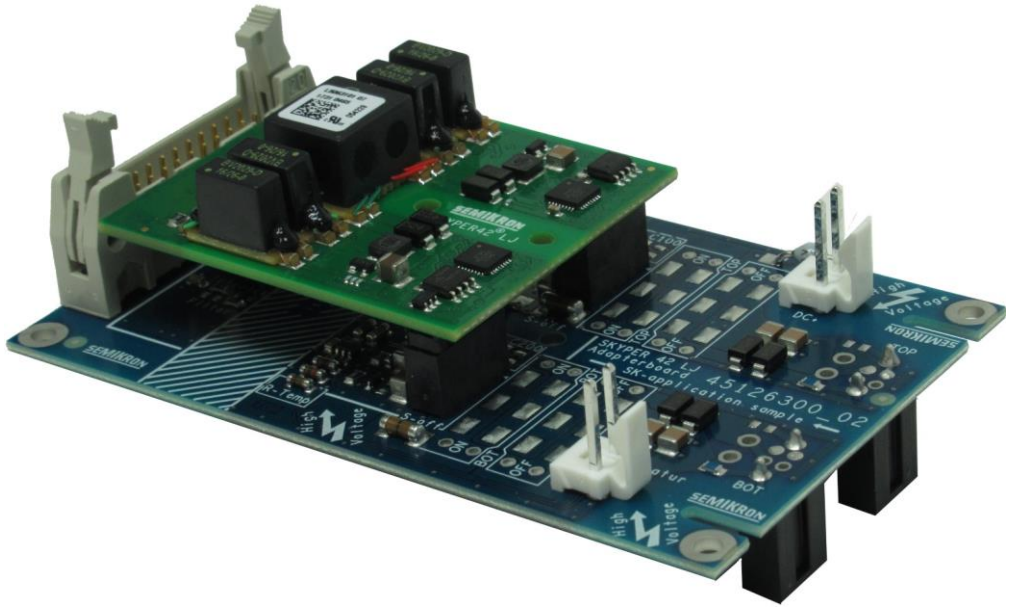
1. Introduction

SEMIKRON set up a driver board for operating SiC MOSFET modules with a SKYPER 42 LJ for evaluation purposes. The driver board can directly be contacted to 62mm modules (SEMITRANS 3), used as board-to-board connection (vertically) or can be connected by wires to any other module; here the wire-inductance needs to be checked.
The Board SiC Module SKYPER 42 LJ is able to operate a module up to a DC-link voltage of 1200V (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.
The failure management of the SKYPER 42 LJ driver detects desaturation events at both switches and also monitors a connected NTC temperature sensor. Desaturation of a switch leads to a shut-off of both switches and produces an error signal.
In case the temperature sensor exceeds a set temperature (can be set by user on the adapter board) the switches are turned off immediately and the driver produces an error signal.

By default, the interlock of the two driver channels is deactivated to allow for higher performance. However, it is possible to turn on both switches simultaneously producing a short circuit from DC+ to DC-, which could damage the device. It is necessary to implement a sufficient external interlock time in the connected control unit.

Figure 1: Board SiC Module SKYPER 42 LJ



This Application Sample is dedicated to both universities and professional development engineers. It offers an easy way to bring 2L SiC MOSFET modules in operation.
All Application Samples have been isolation tested; there is no functional routine test.

1.1 Features

The Board SiC Module SKYPER 42 LJ is designed for all SEMIKRON SiC MOSFET modules up to a chip blocking voltage of 1700V.
The gate voltages are adjusted to range between -5V (turn-off) and +18V (turn-on) by external circuitry on the Board SiC Module SKYPER 42 LJ to fit the gate voltage requirements of the MOSFETs. In that way a standard gate driver (here: SKYPER 42 LJ with a gate voltage range of -8V to +15V) can be used with SiC devices.

Figure 2: SEMITRANS 3

The driver board can directly be plugged to all SEMTRANS 3 SiC modules (62mm modules).

1.2 Hardware of the Board SiC Module SKYPER 42 LJ

The Board SiC Module SKYPER 42 LJ consists of a printed circuit board (PCB) containing gate resistors, V_{DS} diodes, etc.) with item number 45126301. It contacts the SEMITRANS 3 module directly and provides sockets for the SKYPER 42 LJ driver and a user interface.

Figure 3: Board SiC Module SKYPER 42 LJ

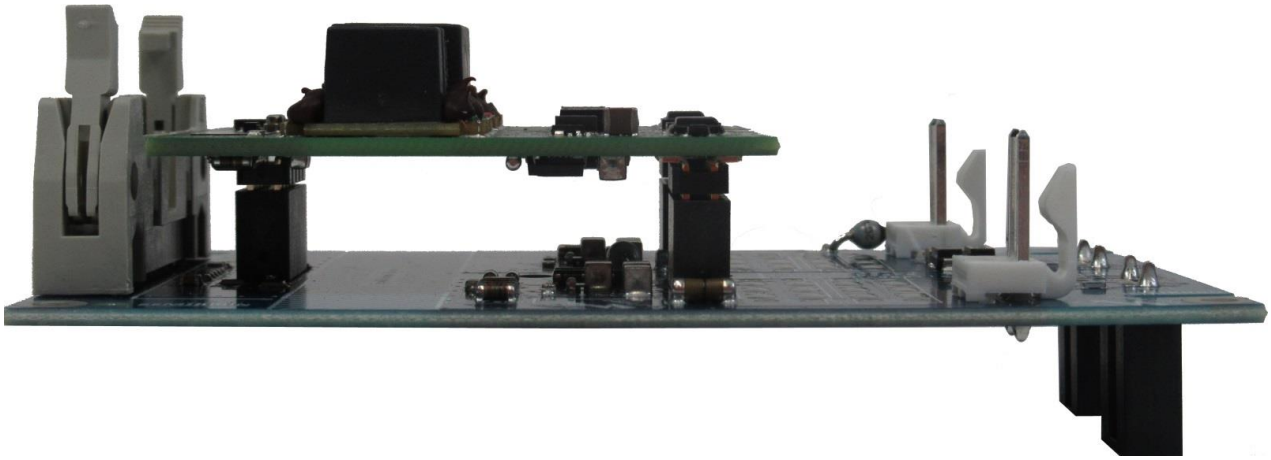
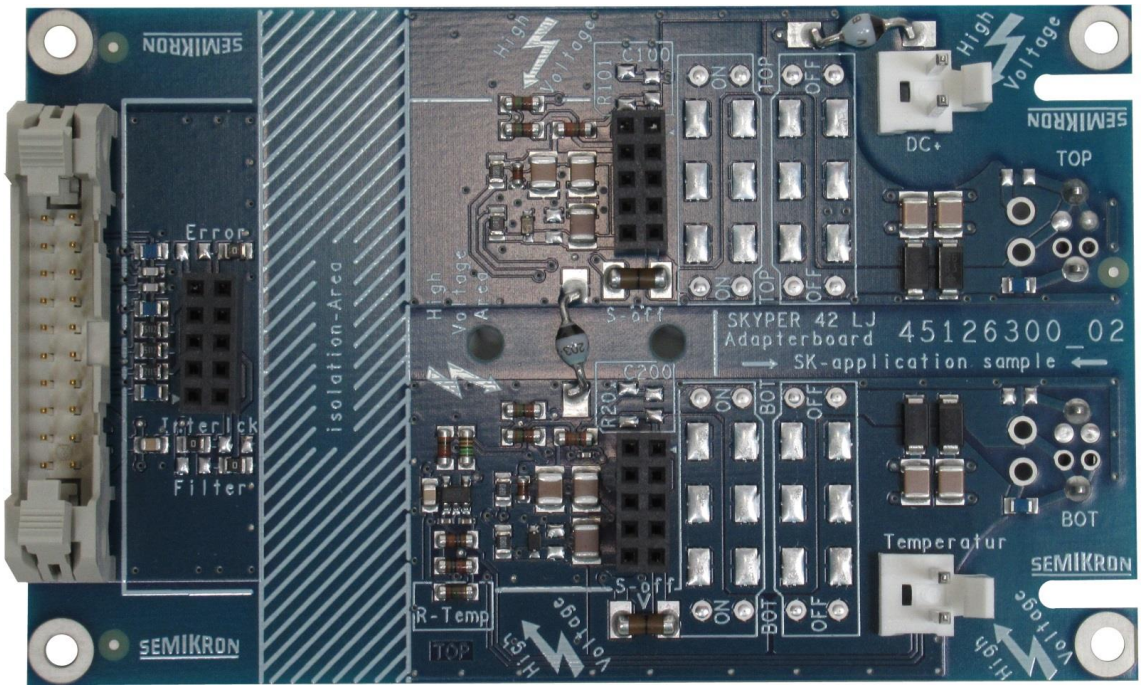


Figure 4: Board SiC Module SKYPER 42 LJ



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 sales partner.

2. Safety Instructions

The Board SiC Module SKYPER 42 LJ 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

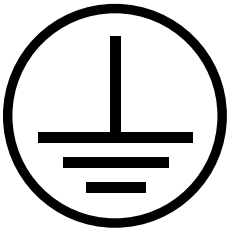
	**In operation, the Board SiC Module SKYPER 42 LJ inherits high voltages that are dangerous to life!** **Only qualified personnel should work with the Kit.**
	**Some parts of the Board SiC Module SKYPER 42 LJ or connected devices (e.g. heatsink) may reach high temperatures that might lead to burns when 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 SiC Module SKYPER 42 LJ.**

Table 2: Safety regulations for work with electrical equipment

Safety Regulations

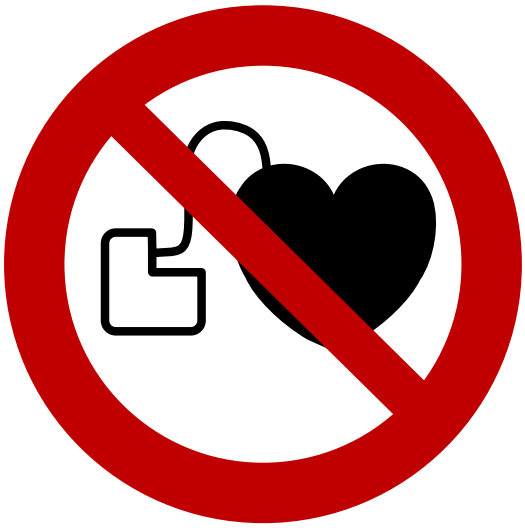
for work with electrical equipment

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 SiC Module SKYPER 42 LJ.

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



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

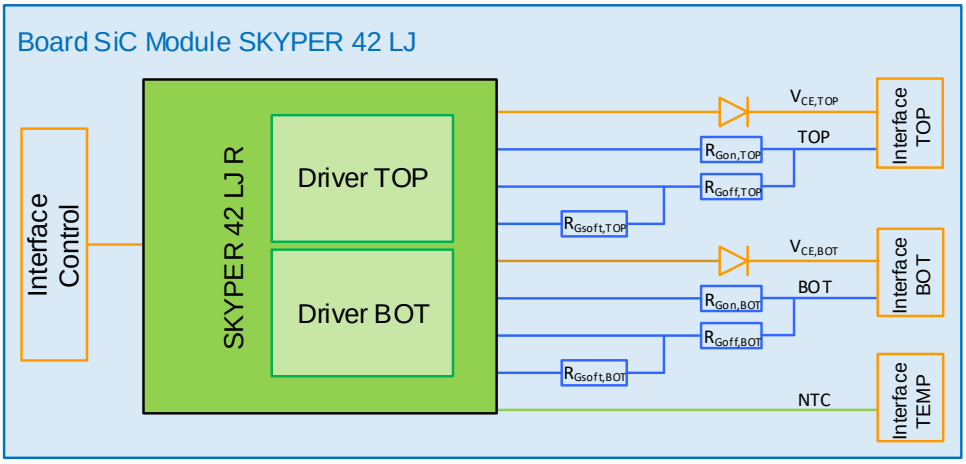
Please make sure to always use the appropriate personal safety equipment when working with the Application Sample.

3. Technical Data

3.1 Driver Board block diagram

The electrical block diagram in Figure 5 shows the driver PCB (marked blue) with sockets for the SKYPER 42 LJ driver (green), gate resistors, clamping and V_{DS} sensing circuitry.

Figure 5: Board SiC Module SKYPER 42 LJ block diagram



3.2 Electrical and mechanical characteristics

With regard to the requirement specification, the Board SiC Module SKYPER 42 LJ allows for operation within the following boundaries:

- ⇨ Max. DC-link voltage V_{DC} = 1200V
- ⇨ Max. AC voltage V_{AC} = 690V_{RMS} (line-to-line)
- ⇨ Max. switching frequency f_{sw} = 30kHz (see chapter 5.3 for further information)
- ⇨ Ambient temperature T_a = 0°C…40°C (see chapter 5.4 for further information)
- ⇨ IP rating IP 00

Neglecting the above-mentioned boundaries may lead to malfunction or damage of the Board SiC Module SKYPER 42 LJ.

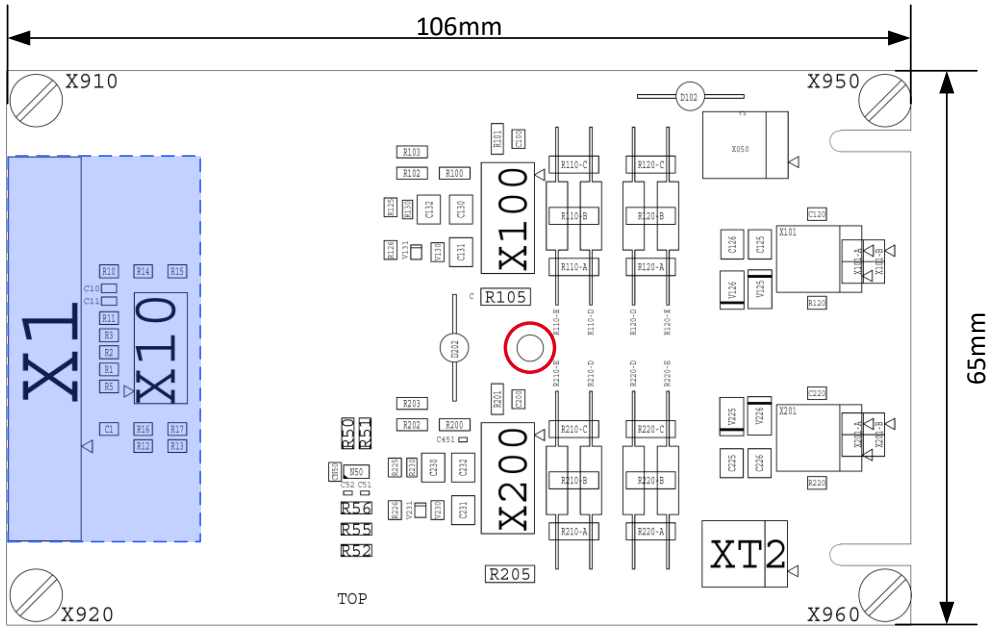
An electrical insulation is implemented between the user interface (primary side) and the high voltage connections (secondary side) by using the SKYPER 42 LJ's separation. The creepage and clearance distances on the driver board are 12.2mm between primary and secondary side.
Please note that mounting posts (to be placed at X910, X920, X950 and X960, see Figure 6), if made from electrically conducting material violate the creepage and clearance distances.
The overall responsibility for a proper insulation coordination remains with the user.

Please note that further restrictions of the used driver (SKYPER 42 LJ R) 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 driver board is 106mm long and 65mm wide. Including SKYPER 42 LJ driver, the total height is 42mm.

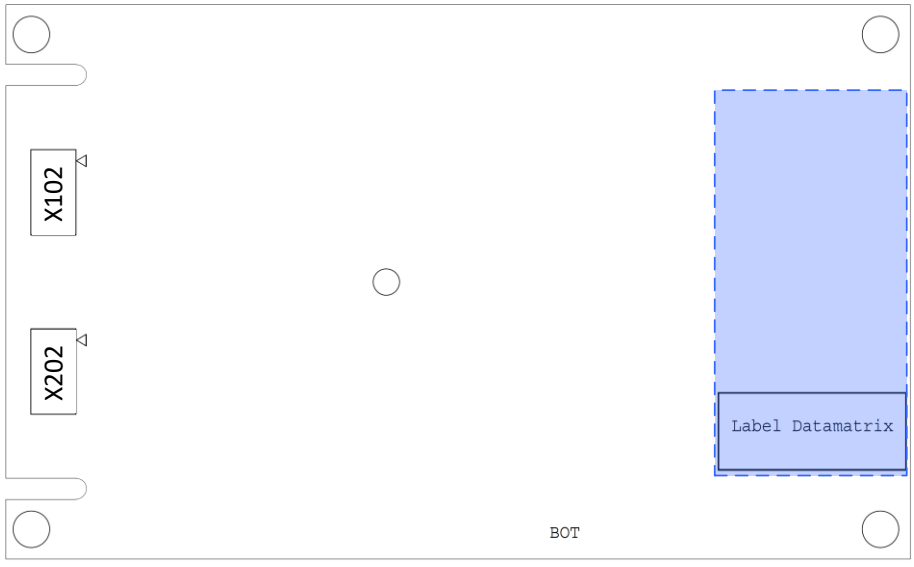
To prevent the driver board and the SKYPER 42 LJ driver from loosening from each other mounting holes for dual lock support posts are available (positions circled red in Figure 6). Please find further information in the technical explanation of SKYPER 42 LJ [5].
The driver board can be connected to a SEMITRANS 3 module by simply pressing it onto the SEMTRANS3 gate and source pins. It can be used with any other module by soldering wires to both driver board and module.

Figure 6: Board SiC Module SKYPER 42 LJ ("driver board"), top side



The blue marked area in Figure 6 and Figure 7 indicate the primary side with the user interface socket. The insulation is provided by the galvanic insulation of the SKYPER 42 LJ driver 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: Board SiC Module SKYPER 42 LJ ("driver board"), bottom side



The plugs X102 and X202 (see Figure 7) on the bottom side contact directly to a SEMITRANS 3 module.

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

SEMIKRON's standard NTC temperature sensor can be monitored by the error input of the driver's BOT channel.

At a pre-defined temperature (to be defined by the user by adjusting a resistor) the BOT switch is turned 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.

3.3.2 Desaturation detection

The voltage drop across each switch can be 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 switch using the soft-turn-off gate resistor. 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.
Information on the forward voltage drop threshold (V_{DSStat}) and the blanking time (t_{Blank}) for the desaturation detection can be found in the Technical Explanation of the SKYPER 42 LJ driver [5].
The forward voltage drop threshold and the blanking time for the desaturation detection is set with a resistor (R_{DS}) and a capacitor (C_{DS}) in 0805 housing according to the following formulas which differ slightly from these shown in the Technical Explanation of the SKYPER 42 LJ driver [5]:

$$V_{DSStat} = 15V \cdot \frac{R_{DS}}{30.1k\Omega + R_{DS}} + 3V$$

$$t_{Blank} = -C_{DS} \cdot \frac{30.1k\Omega \cdot R_{DS}}{30.1k\Omega + R_{DS}} \cdot \ln\left(\frac{10V/15V \cdot (30.1k\Omega + R_{DS}) - R_{DS}}{30.1k\Omega}\right)$$

$$V_{CE(IN)} = \frac{30.1k\Omega \cdot R_{DS}}{30.1k\Omega \cdot R_{DS} + (30.1k\Omega + R_{DS}) \cdot 3k\Omega} \cdot \left[V_{CE} + \left(V_{D\_VCE} - 1.505V\right) \cdot 30.1k\Omega \cdot R_{DS}\right] + 3V$$

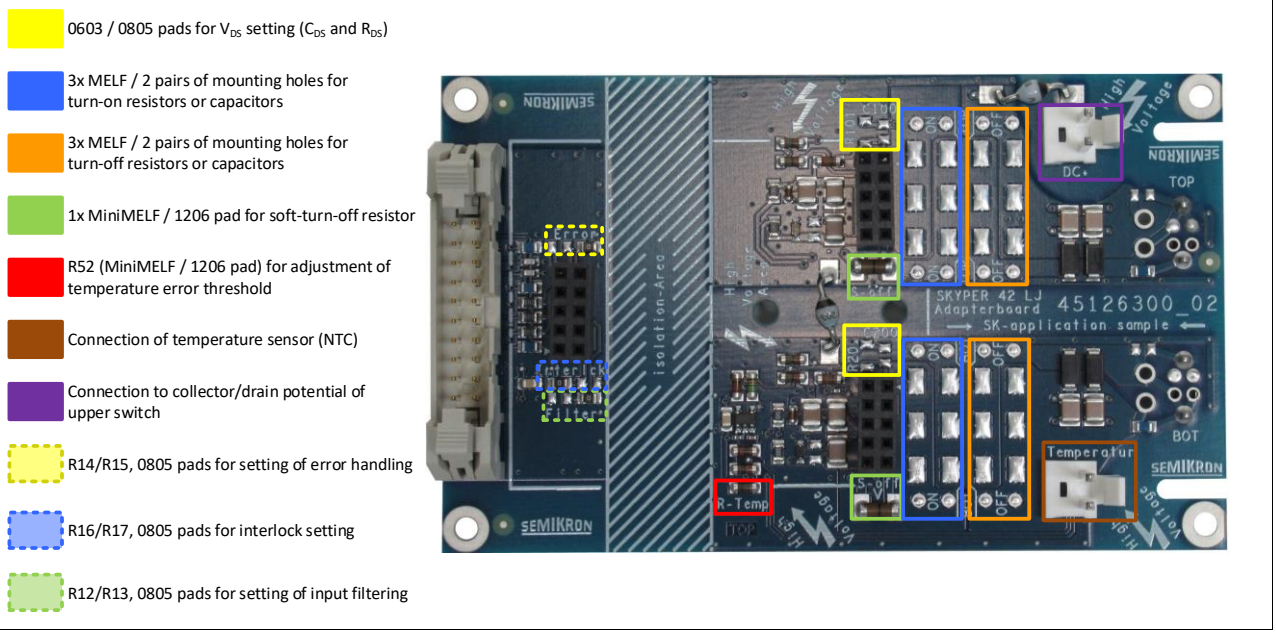
The voltages V_{DSStat} and $V_{CE(IN)}$ refer to Pin 2 of X102 (TOP switch) respectively Pin 1 of X202 (BOT switch).

The position of R_{DS} and C_{DS} can be mixed up as they are connected in parallel. R_{DS} and C_{DS} are framed yellow in Figure 8.
Please note that desaturation detection cannot be deactivated. For that reason the collector/drain potential of the upper (TOP) switch must be connected to X050 (framed purple in Figure 8, both pins are connected in parallel).

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 8; function and possible values are explained in chapters 3.4.1 to 3.4.5.

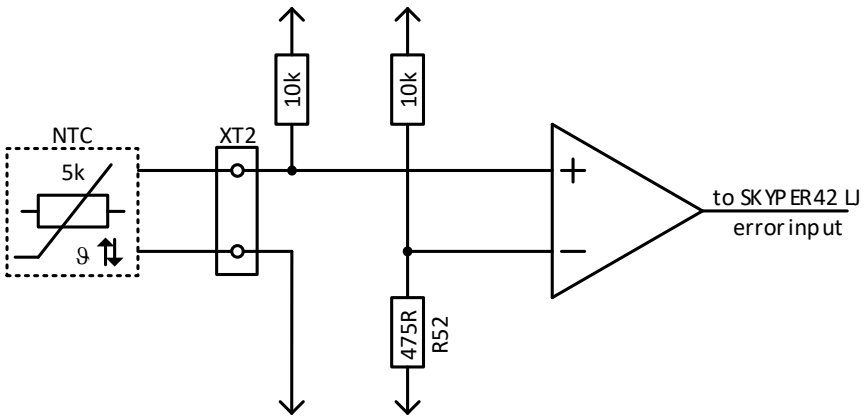
Figure 8: Top side of the driver board; user-changeable components are framed



3.4.1 Adjustment of temperature error threshold

A thermal overload can be detected by evaluating a SEMIKRON module's built-in, or an external NTC sensor. In case a thermal overload is detected, the comparator shown in Figure 9 pulls the SKYPER's error input to GND and so the driver can communicate an error message.
The resistor R52 (framed red in Figure 8) can be used for adjusting the error temperature threshold.

Figure 9: Schematic of NTC evaluation



The standard value for R52 is 475Ω (refers to 100°C): the thermal overload detection is deactivated by not connecting the NTC-plug XT2 (framed brown in Figure 8).
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 10; R52 needs to be chosen to that value. A MiniMELF or 1206 sized chip resistor can be used for R52.

Figure 10: SEMIKRON NTC characteristic (excerpt)

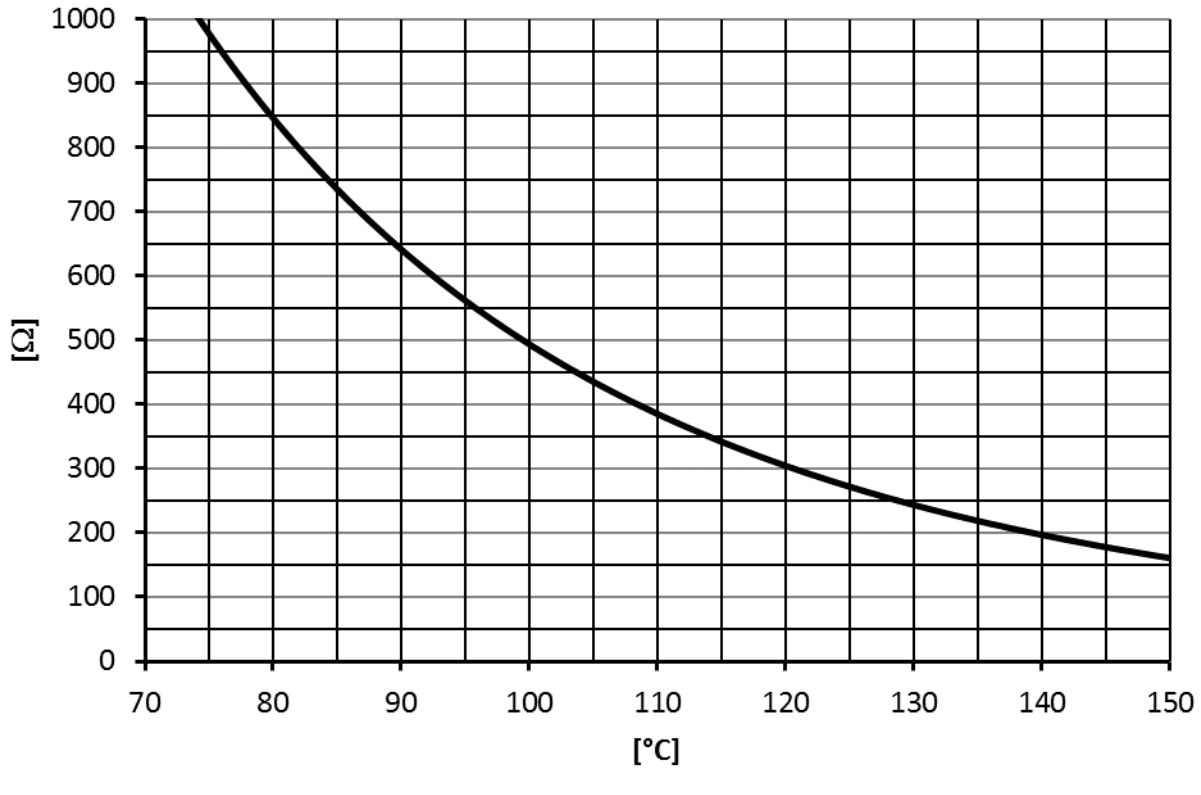
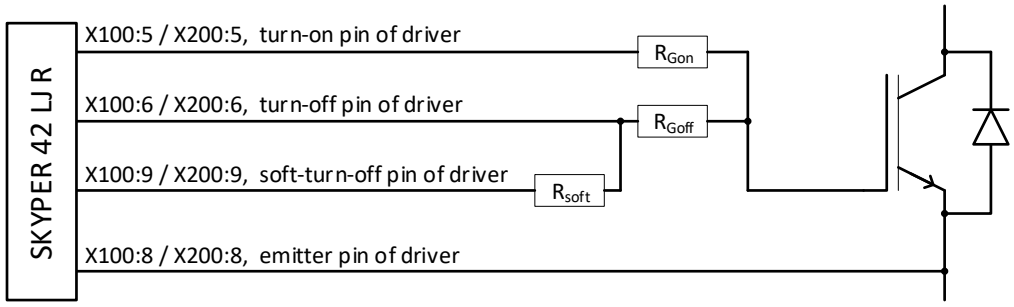


Figure 10 shows an excerpt of the SEMIKRON standard modules' NTC characteristic, which includes the most interesting temperature range between 70°C and 150°C. The full characteristic can be found in the Technical Explanation of the used module's datasheet or can be calculated from the formula given in the particular 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 SKYPER 42 LJ offers separate connections for turn-on (R_{Gon}), turn-off (R_{Goff}) and soft-turn-off (R_{soft}), see Figure 11. 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 11: Schematic of gate resistor arrangement



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

The driver board offers three pads per switch (framed blue in Figure 8) taking MELF sized components. There are also drill holes for two wired 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 5.2 for further information.

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

The driver board offers three pads per switch (framed orange in Figure 8) taking MELF sized components. There are also drill holes for two wired 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 5.2 for further information.

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

The driver board offers one pad per switch (framed green in Figure 8) taking a MELF 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 5.2 for further information.

3.4.3 Error management of SKYPER 42 LJ driver

The 0805 sized resistors R14-R15 (framed dotted yellow in Figure 8) may be equipped as shown in Table 4. R14 and R15 set the error communication of the SKYPER 42 LJ driver's 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 R14 – R15		
R14	0Ω	not equipped
R15	not equipped	0Ω
Function ➔	The particular driver generates an error signal when a secondary side error occurs, but the concerned transistor is 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 transistor using the soft-turn-off resistor when a secondary side error occurs. In case an external error signal is applied the driver turns off the transistor. A continuous error signal prevents the driver from turning on. ⇨ **Default setup (recommended)**

Find further information on the error handling in the Technical Explanation of the SKYPER 42 LJ [5].

3.4.4 Interlock setting of SKYPER 42 LJ driver

The 0805 sized R16 and R17 (framed dotted blue in Figure 8) offer the opportunity to turn on or off the interlock functionality of the driver. Equipping R16 with a 0Ω jumper disables interlock, i.e. both channels of the driver may be turned on simultaneously.
An interlock time of 2µs can be used by equipping R22 with a 0Ω jumper.

Table 5: Functional table for R16 – R17		
R16	0Ω	not equipped
R17	not equipped	0Ω
Function ➔	Interlock functionality is turned off; both channels of the SKYPER 42 LJ may be turned on simultaneously. ⇨ **Default setup**	Interlock functionality is active and set to 2µs.

Find further information on the interlock setting in the Technical Explanation of the SKYPER 42 LJ [5].

3.4.5 Input filter setting of SKYPER 42 LJ driver

The 0805 sized R12 and R13 (framed dotted green in Figure 8) offer the opportunity to choose between analogue and digital filtering of the PWM input signal. Equipping R12 with a 0Ω jumper activates analogue filtering. Equipping R13 with a 0Ω jumper activates digital filtering.

Table 6: Functional table for R12 – R13		
R12	not equipped	0Ω
R13	0Ω	not equipped
Function ➔	Digital filtering of the PWM input signals is activated. ⇨ **Default setup**	Analogue filtering of the input signal is activated.

Find further information on the input filtering in the Technical Explanation of the SKYPER 42 LJ [5].

4. User Interface

4.1 Module interface

The Board SiC Module SKYPER 42 LJ can be plugged directly to suitable SEMITRANS 3 modules as shown in Figure 12. The plugs X102 and X202 are placed on the bottom side of the driver board (see Figure 12). The pin description is given in Table 7 and Table 8.
Please note that plugging the board to the module in any other way (e.g. directly over the module) will lead to destruction of the driver board.

Figure 12: Board SiC Module SKYPER 42 LJ / SEMITRANS 3 interface

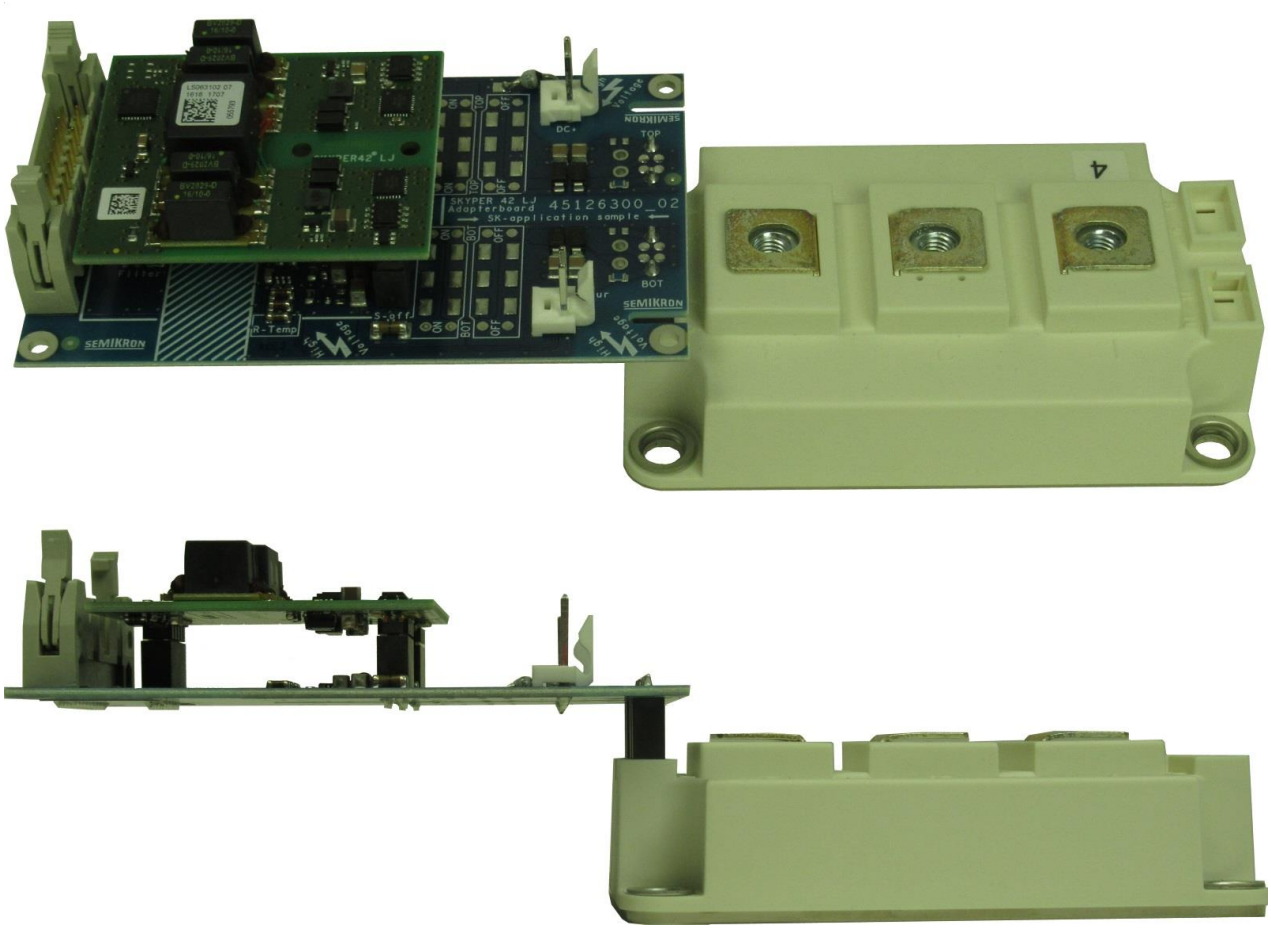


Table 7: X102 pin description

Pin	Description
1	Gate TOP switch
2	Emitter / Source TOP switch

Table 8: X202 pin description

Pin	Description
1	Emitter / Source BOT switch
2	Gate BOT switch

4.2 User interface

The user interface is the 20-pin connector X1 located in the middle on the left edge of the driver board (see Figure 8). The pin description is given in Table 9.

Table 9: X1 pin description

Pin	Signal name	Description	Voltage level
1	IF_PWR_VP	Driver supply voltage	$15V_{DC}$±4%, max. 0.5A, pins 1, 3 and 5 must be connected
2	GND	Ground	0V, all ground pins must be connected
3	IF_PWR_VP	Driver supply voltage	$15V_{DC}$±4%, max. 0.5A, pins 1, 3 and 5 must be connected
4	GND	Ground	0V, all ground pins must be connected
5	IF_PWR_VP	Driver supply voltage	$15V_{DC}$±4%, max. 0.5A, pins 1, 3 and 5 must be connected
6	GND	Ground	0V, all ground pins must be connected
7	RESERVED	Reserved	Do not connect
8	GND	Ground	0V, all ground pins must be connected
9	IF_CMN_NHALT	Error input/output	Error=0V / ready-for-operation=15V (Pull-Up to 15V on user-side; $R_{pull-up}$=1.8kΩ..10kΩ)
10	RESERVED	Reserved	Do not connect
11	RESERVED	Reserved	Do not connect
12	GND	Ground	0V, all ground pins must be connected
13	GND	Ground	0V, all ground pins must be connected
14	GND	Ground	0V, all ground pins must be connected
15	IF_CMN_TOP	PWM pattern TOP switch	Off=0V / On=15V; R_{in}=10kΩ / 1nF
16	IF_CMN_BOT	PWM pattern BOT switch	Off=0V / On=15V; R_{in}=10kΩ / 1nF
17	RESERVED	Reserved	Do not connect
18	GND	Ground	0V, all ground pins must be connected
19	GND	Ground	0V, all ground pins must be connected
20	GND	Ground	0V, all ground pins must be connected

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 Error treatment

If a desaturation event occurs, the desaturated transistor 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. This is important especially if the error management of the SKYPER 42 LJ is configured to produce a warning only (see Table 4).

5.2 Design limits gate resistors

5.2.1 Minimum gate resistor

The minimum gate resistor is determined by the maximum difference of the driver output voltages during switching; it turns from -5V to +18V or back, so the voltage difference is 23V. The peak current SKYPER 42 LJ 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 SKYPER 42 LJ.

5.2.2 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.
Further information about the power rating and correct choice of gate resistors can be found in Application Note AN-7003 [3].

5.3 Design limits switching frequency

The used modules, their gate charge and the output power of the SKYPER 42 LJ driver 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-7004 [4].

5.4 Design limits ambient temperature

The Board SiC Module SKYPER 42 LJ 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.

5.5 SEMIKRON assembly

The Board SiC Module SKYPER 42 LJ has passed isolation and partial discharge tests. The isolation test voltage was set to 3200V_{AC} for 1s.

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.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
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[5] J. Krapp, "Technical Explanation SKYPER®42 LJ – rev11", SEMIKRON Technical Explanation, 2017

IMPORTANT INFORMATION AND WARNINGS

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