# Technical Explanation
# Board 1
# SKYPER 12 R

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|---|---|
| Revision: | 00 |
| Issue date: | 2019-06-05 |
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Keyword: 2L, 3L, IGBT driver, Application Sample, 451528

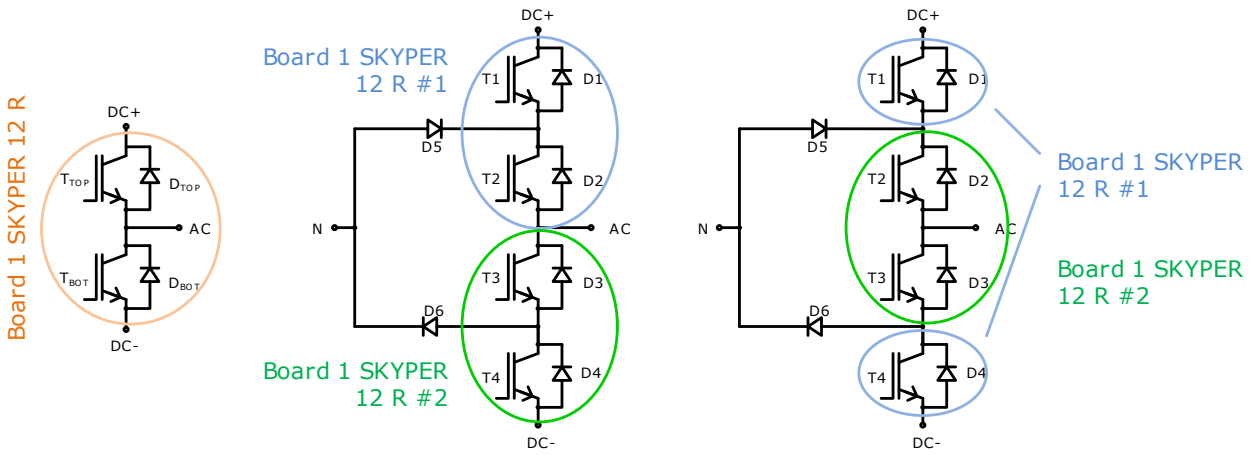


## 1. Introduction

SEMIKRON set up a general-purpose driver board for operating 2L modules or any combination of switches up to a DC-link voltage of 1500V for evaluation purposes. The Board 1 SKYPER 12 R ("driver board") is designed to be operated with a wide range of IGBT modules. It is meant to operate the module up to a DC-link voltage of 1500V (limited by insulation coordination and the allowed operating voltage of the used driver: SKYPER 12 R or SKYPER 12 PV R) 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 12 R driver is able to detect desaturation events at both channels (TOP and BOT) and can also monitor the module's built-in temperature sensor (NTC). In case the built-in temperature sensor exceeds a set temperature (can be set by user) the BOT channel switch is turned off immediately and the driver produces an error signal.
In standard configuration, desaturation of any switch turns off both channels of the driver and produces an error signal. Further, the interlock time between the two channels is activated, a digital filter is applied to the input PWM signals and the driver can be forced to switch off both channels by receiving an external error signal. All of these mentioned features can be configured by the user.

**Figure 1: Example configurations with Board 1 SKYPER 12 R**




This Application Sample is dedicated to both universities and professional development engineers. It offers an easy way to set up high power inverters or complex topologies using standard 2L gate drivers. Performance tests can be run to prove the possibility of operation at high DC-link voltages and high output power.

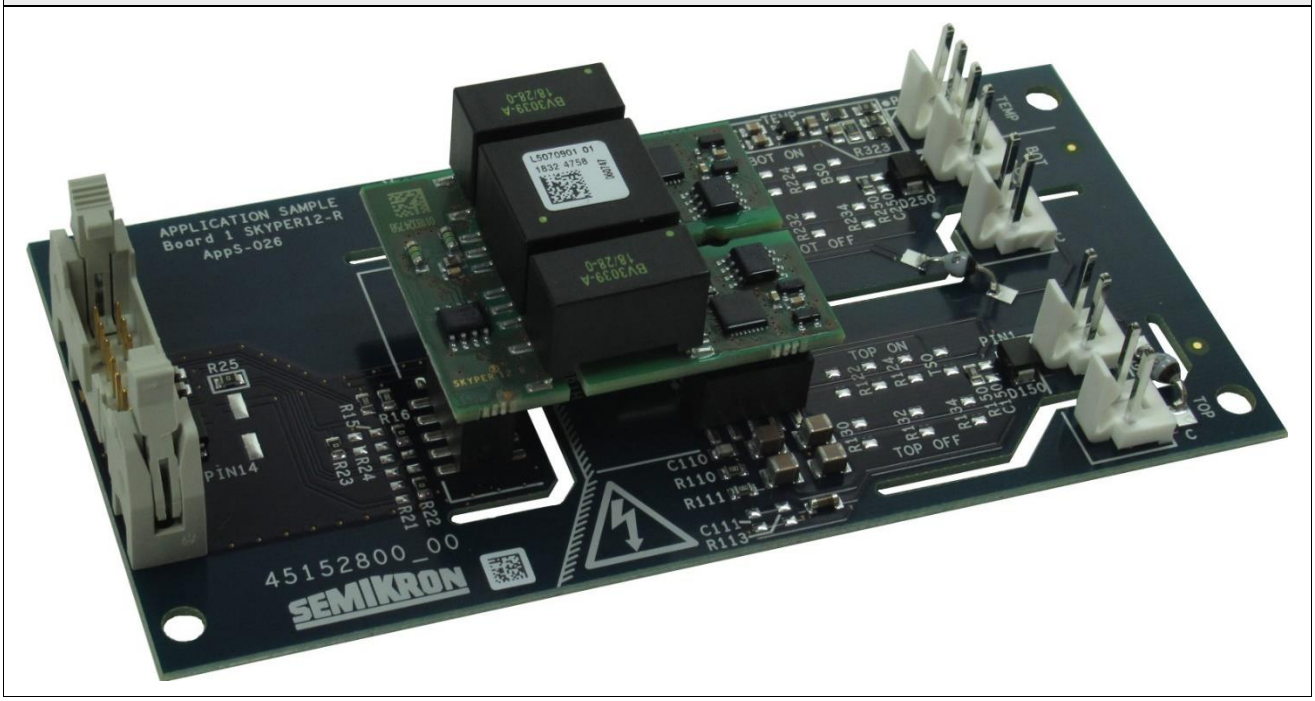
### 1.1 Features

The Board 1 SKYPER 12 R is designed as general-purpose 2L driver board that can be contacted to a variety of IGBT modules. Several driver boards can be combined and used for more complex topologies like 3L NPC (see Figure 1).
As long as the boundaries of the board are not exceeded (e.g. maximum DC-link voltage, switching frequency, etc.) the driver board can be used in any configuration.

### 1.2 Hardware of the Board 1 SKYPER 12 R

The Board 1 SKYPER 12 R consists of a printed circuit board (PCB): it is called "Board 1 SKYPER 12 R" with item number 45152801. It provides plugs for two IGBT switches on the one hand and sockets for the SKYPER 12 R driver and a user interface on the other. SKYPER 12 R and SKYPER 12 PV R can be used alternatively; the main difference is the allowed DC-link voltage (please find more information in [6] and [7]). All electronics on the Board 1 SKYPER 12 R behave the same and the explanations in this document are valid for both drivers.

**Figure 2: Board 1 SKYPER 12 R top view**




Depending on the power ratings of the used IGBT module and the operating conditions (voltage, current, inductance of the DC-link connection) gate resistors need to be chosen and equipped, and trip levels of the safety circuits need to be adjusted.
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 1 SKYPER 12 R 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**

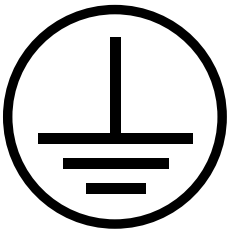
| | |
|---|---|
|  | **In operation, the Board 1 SKYPER 12 R inherits high voltages that are dangerous to life!**<br>**Only qualified personnel should work with the Kit.** |
|  | **Some parts of the Board 1 SKYPER 12 R or connected devices (e.g. heatsink) may reach high temperatures that might lead to 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 1 SKYPER 12 R.** |

**Table 2: Safety regulations for work with electrical equipment**

# Safety Regulations

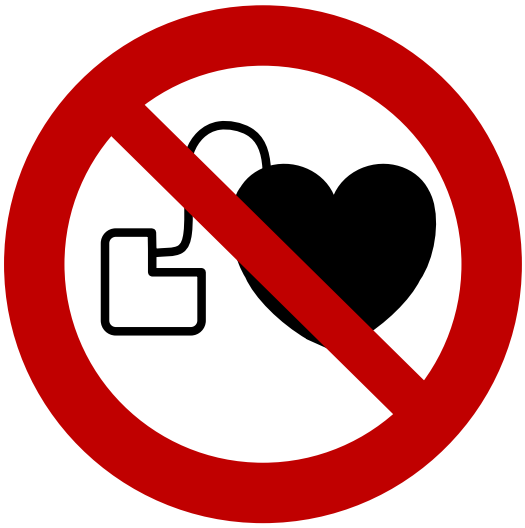
## for work with electrical equipment

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 1 SKYPER 12 R.

**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.

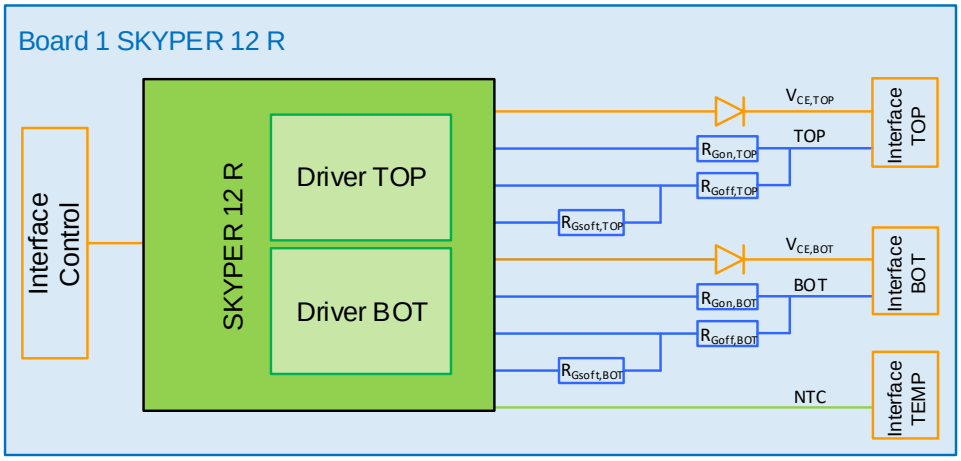
**Please make sure to always use the appropriate personal safety equipment when working with the Application Sample.**

# 3. Technical Data

## 3.1 Driver Board block diagram

The electrical block diagram in Figure 3 shows two parts: the green device represents the SKYPER 12 R which is plugged to the blue marked PCB. The PCB comes with sockets for the SKYPER 12 R driver, gate resistors, and $V_{CE}$ sensing circuitry.

**Figure 3: Board 1 SKYPER 12 R block diagram**




## 3.2 Electrical and mechanical characteristics

With regard to the requirement specification the Board 1 SKYPER 12 R allows for operation within the following boundaries:

- ⇨ Max. DC-link voltage $V_{DC}$ = 1500V (with SKYPER 12 PV R)
- ⇨ Max. AC voltage $V_{AC}$ = 1000$V_{RMS}$ (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)
- ⇨ CTI rating of AppS PCBs > 175

Neglecting the above mentioned boundaries may lead to malfunction or damage of the Board 1 SKYPER 12 R.

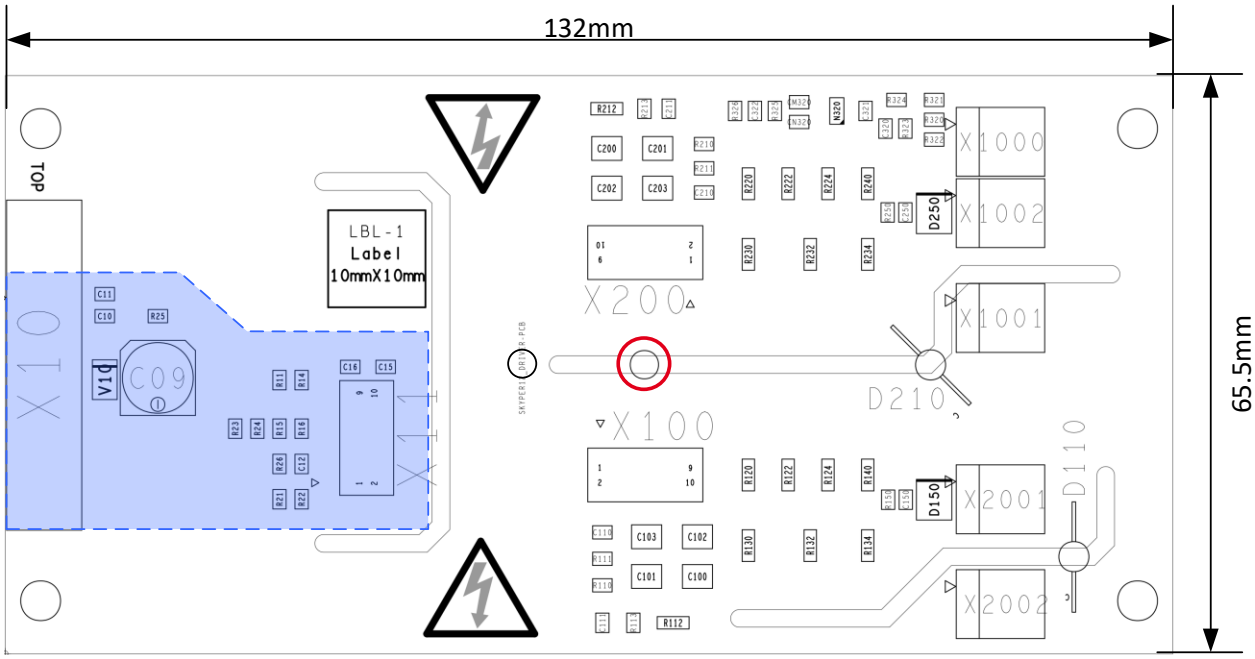
An electrical insulation is implemented between the user interface (primary side) and the high voltage connections (secondary side) by using the SKYPER 12 R's separation. The creepage distance on the driver board is 30mm between primary and secondary side, the clearance distance is 18mm.
**The overall responsibility for a proper insulation coordination remains with the user.**

**Please note that further restrictions of the used driver (SKYPER 12 R / SKYPER 12 PV 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 132mm long and 65.5mm wide. Including SKYPER 12 R driver the total height is 30mm.

To prevent driver board and the SKYPER 12 R drivers from loosening from each other mounting holes for dual lock support posts are available (positions circled red in Figure 4). Please find further information in the technical explanation of SKYPER 12 R [6].
The blue marked area in Figure 4 indicates the primary side with the user interface socket. The insulation is provided by the galvanic insulation of the SKYPER 12 R 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 4: Board 1 SKYPER 12 R ("driver board"), top side**




### 3.3 Integrated functions

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

#### 3.3.1 Thermal protection

SEMIKRON's standard NTC temperature sensors 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 IGBT is switched off immediately and the error is transmitted from secondary side (high voltage) to primary side (low voltage) by the driver. On the primary side an error is set and the user can react accordingly. See also chapter 3.4.1.

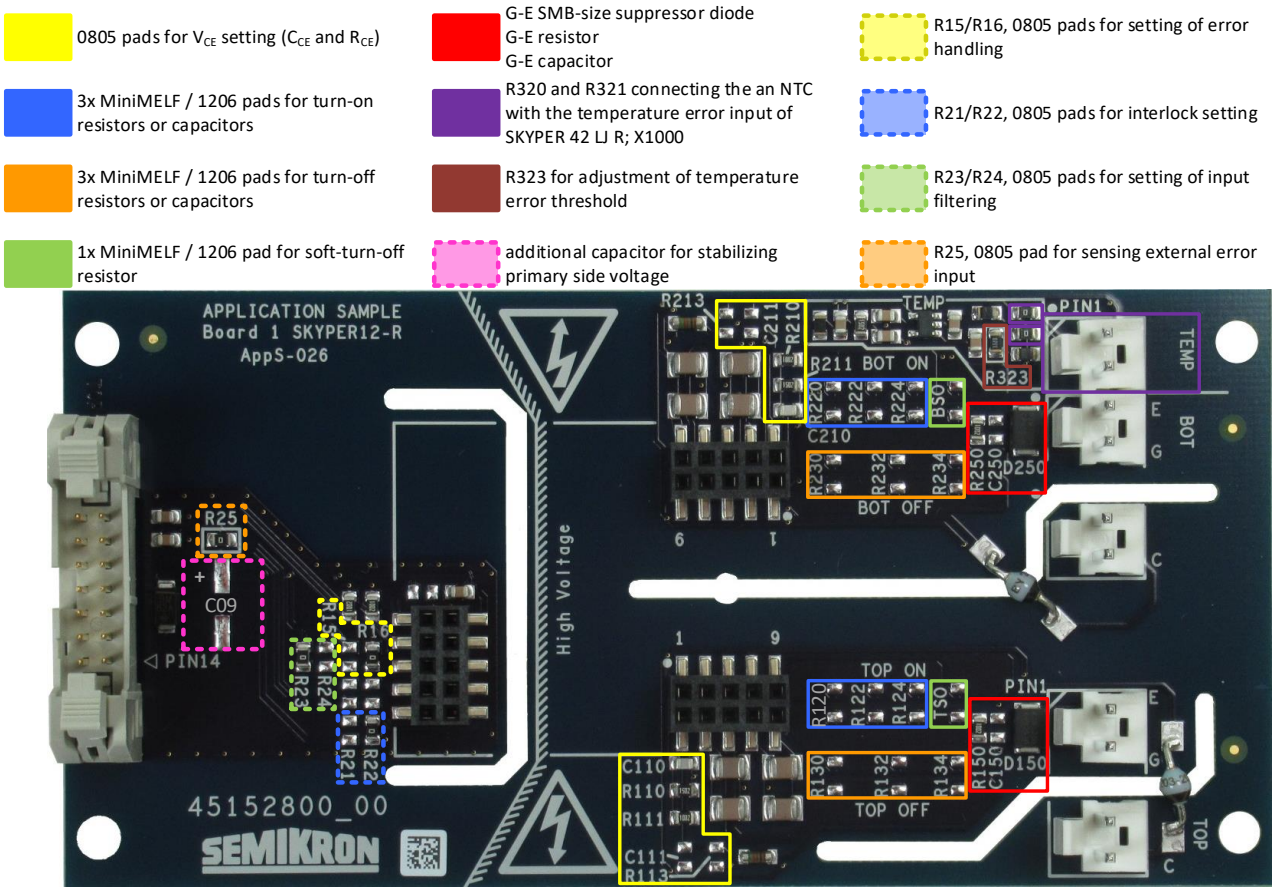
#### 3.3.2 Desaturation detection

The voltage drop across each IGBT 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 IGBT 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.
The forward voltage drop threshold and the blanking time for the desaturation detection is set according to the Technical Explanation of the SKYPER 12 R 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 5.

### 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 5; function and possible values are explained in chapters 3.4.1 to 3.4.4.

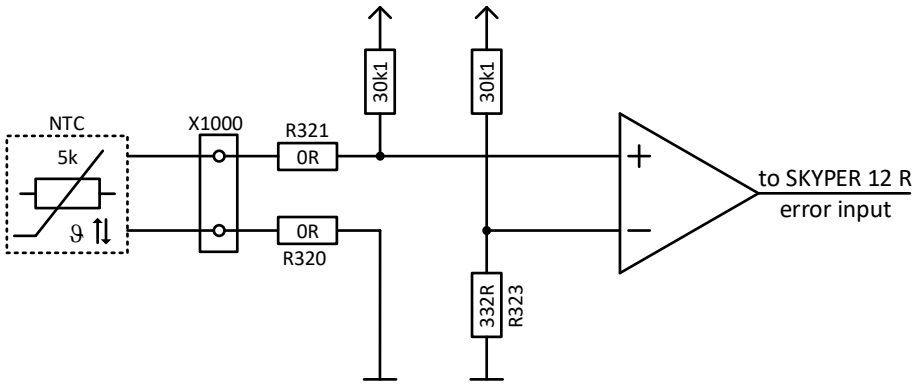
**Figure 5: Top side of the driver board; user-changeable components are framed**




### 3.4.1 Adjustment of temperature error threshold

A thermal overload can be detected by evaluating the IGBT module's built-in NTC sensor. In case a thermal overload is detected, the comparator shown in Figure 6 pulls the SKYPER 12 R's error input to GND and so the driver can communicate an error message.
The resistor R323 (framed brown in Figure 5) can be used for adjusting the error temperature threshold.

**Figure 6: Schematic of NTC evaluation**




The standard value for R323 is 332Ω (refers to 115°C): the thermal overload detection is deactivated by leaving R320 and/or R321 unpopulated or by not connecting the NTC plug X1000 (framed purple in Figure 5).
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 7; R323 needs to be chosen to that value. A chip resistor with the size 0805 can be used for R323.

**Figure 7: SEMIKRON NTC characteristic (excerpt)**

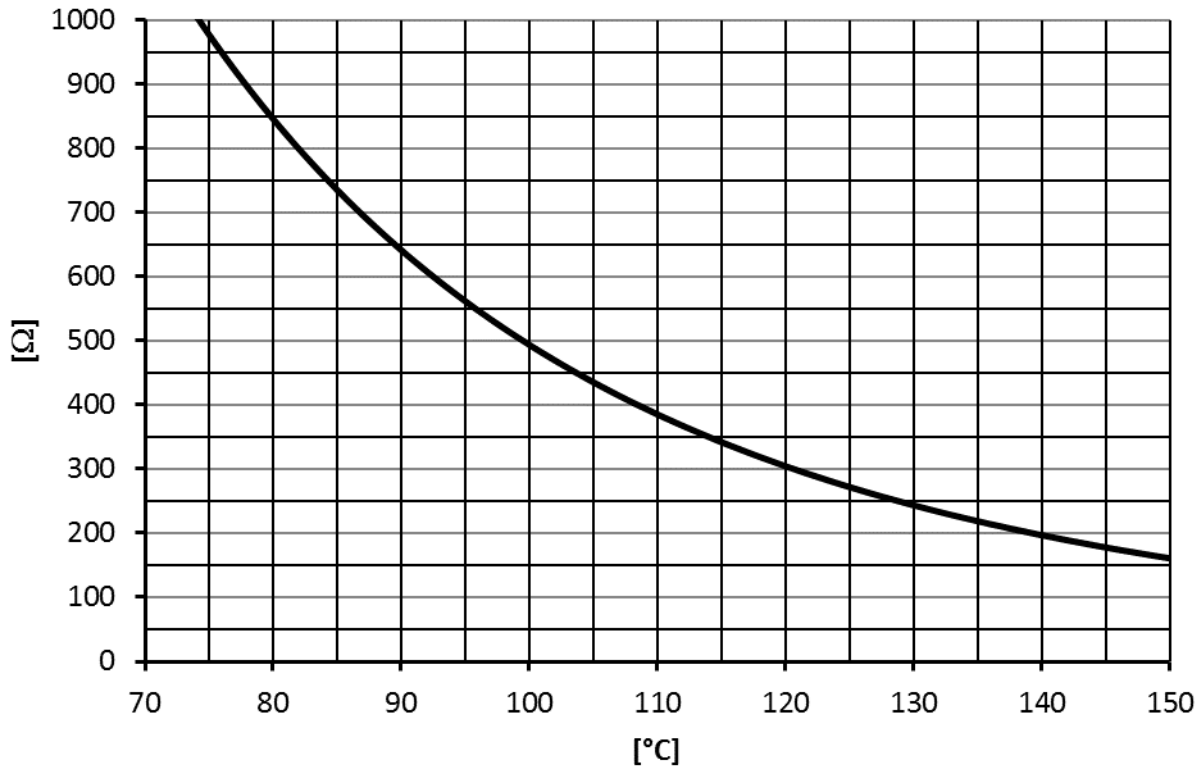
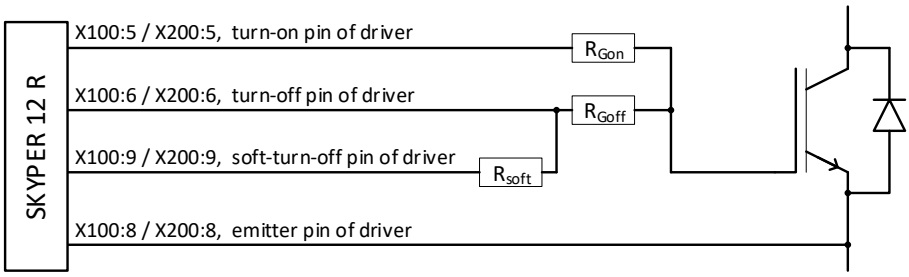



Figure 7 shows an excerpt of SEMIKRON standard modules' NTC characteristic, which includes the most interesting temperature range between 70°C and 150°C. The full characteristic can be found in the Technical Explanations or can be calculated from the formula given in the module datasheets [1].

### 3.4.2 Gate resistors / capacitors

One or more SMD resistors on the driver board realize what is called gate resistor in this document for the sake of convenience. The SKYPER 12 R offers separate connections for turn-on ($R_{Gon}$), turn-off ($R_{Goff}$) and soft-turn-off ($R_{soft}$), see Figure 8. $R_{Gon}$ is used for every turn-on event, $R_{Goff}$ 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 8: Schematic of gate resistor arrangement**



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

The driver board offers three pads per IGBT (framed blue in Figure 5) 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 5.2 for further information.

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

The driver board offers three pads per IGBT (framed orange in Figure 5) 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 5.2 for further information.

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

The driver board offers one pad per IGBT (framed green in Figure 5) taking a MiniMELF or 1206 sized component. The resistor values need to be chosen according to the particular application (DC-link voltage, DC-link inductance, switching frequency, switching losses, etc.) so there is no general recommendation.
It is recommended to calculate the power losses of the gate resistor in order not to overload and damage it.
Please refer to chapter 5.2 for further information.

### 3.4.3 $V_{CE}$ monitoring

A resistor ($R_{CE}$, R111 for TOP switch, R211 for BOT switch) and a capacitor ($C_{CE}$, C110 for TOP Switch, C210 for BOT switch) in 0805 housing are responsible for the right $V_{CE}$ detection level and the correct blanking time. By default, R111 and R211 are equipped with 15kΩ and C110 and C210 are equipped with 820pF.
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 5.

**$V_{CE}$ detection input capacitor**

In some cases it might help stabilizing the $V_{CE}$ monitoring by adding a capacitor to the $V_{CE}$ detection input at the driver to prevent spurious desaturation detection. With C111 and C211 a 0805 pad per input is available to populate such a capacitor. By default those pads are not equipped.

**Disabling $V_{CE}$ detection**

If the $V_{CE}$ detection shall not be operated, it can be deactivated by populating R113 (or top switch) and/or R213 (for BOT switch) with a 0Ω resistor to deactivate desaturation detection.
**Please note that no connection to collector potential of the particular IGBT is allowed if R113/R213 is equipped; otherwise the driver board or semiconductor may be damaged.**

Find further information on the $V_{CE}$ desaturation detection setting in the Technical Explanation of the SKYPER 12 R [6].

### 3.4.4 Error management of SKYPER 12 R driver

The 0805 sized resistors R15-R16 (framed dotted yellow in Figure 5) may be equipped as shown in Table 4. R15 and R16 set the error communication of the two SKYPER 12 R drivers' channels.
Any other combination (e.g. all resistors 0Ω or all resistors not connected) will lead to malfunction and may damage the system.

| Table 4: Functional table for R15 – R16 | | |
|---|---|---|
| R15 | 0Ω | not equipped |
| R16 | not equipped | 0Ω |
| **Function ➔** | The secondary side producing an error turns off the particular IGBT and communicates the error to the primary side.<br>At the primary side, the error is communicated to the user interface, but the second channel of the driver is not affected (will not turn off due to the error; this is within the user's responsibility). | The secondary side producing an error turns off the particular IGBT and communicates the error to the primary side.<br>At the primary side, the error is communicated to the user interface and the second channel of the driver, which will turn off the second IGBT as well.<br>⇨ **Default setup (recommended)** |

Find further information on the error handling in the Technical Explanation of the SKYPER 12 R [6].

### 3.4.5 Interlock setting of SKYPER 12 R driver

The 0805 sized R21 and R22 (framed dotted blue in Figure 5) offer the opportunity to turn on or off the interlock functionality of the driver. Equipping R21 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 R21 – R22 | | |
|---|---|---|
| R21 | 0Ω | not equipped |
| R22 | not equipped | 0Ω |
| **Function ➔** | Interlock functionality is turned off; both channels of the SKYPER 12 R may be turned on simultaneously. | Interlock functionality is active and set to 2µs.<br>⇨ **Default setup** |

Find further information on the interlock setting in the Technical Explanation of the SKYPER 12 R [6].

### 3.4.6 Input filter setting of SKYPER 12 R driver

The 0805 sized R23 and R24 (framed dotted green in Figure 5) offer the opportunity to choose between analogue and digital filtering of the PWM input signal. Equipping R23 with a 0Ω jumper activates digital filtering. Equipping R24 with a 0Ω jumper activates analogue filtering.

| Table 6: Functional table for R23 – R24 | | |
|---|---|---|
| R23 | 0Ω | not equipped |
| R24 | not equipped | 0Ω |
| **Function ➔** | Digital filtering of the PWM input signals is activated.<br>⇨ **Default setup** | Analogue filtering of the input signal is activated. |

Find further information on the input filtering in the Technical Explanation of the SKYPER 12 R [6].

### 3.4.7 Input capacitor

The pad framed dotted pink in Figure 5 offers the opportunity to equip an electrolytic capacitor (C09) for stabilizing the input voltage. This might become necessary if the ribbon cable is rather long. Then the inductance in the cable may lead to malfunction if the driver is running at high load.
A typical value for the capacitance is 100µF.

# 4. User Interface

## 4.1 IGBT Module interface

The connection between driver board and IGBT module is established by X1001 and X1002 (BOT switch) and X2001 and X2002 (TOP switch).
The spacing of the X1001/X1002 and X2001/X2002 is chosen to fit a 5-pin plug with left-out middle pin (for insulation reasons). Of course, 2-pin plugs can be used as well.

| Table 7: X1001 on Board 1 SKYPER 12 R interface to semiconductor | |
|---|---|
| **Pin** | **Description** |
| 1 | Not connected |
| 2 | Collector potential of BOT switch |

| Table 8: X1002 on Board 1 SKYPER 12 R interface to semiconductor | |
|---|---|
| **Pin** | **Description** |
| 1 | Emitter potential of BOT switch |
| 2 | Gate potential of BOT switch |

| Table 9: X2001 on Board 1 SKYPER 12 R interface to semiconductor | |
|---|---|
| **Pin** | **Description** |
| 1 | Emitter potential of TOP switch |
| 2 | Gate potential of TOP switch |

| Table 10: X2002 on Board 1 SKYPER 12 R interface to semiconductor | |
|---|---|
| **Pin** | **Description** |
| 1 | Not connected |
| 2 | Collector potential of TOP switch |

## 4.2 NTC interface

The connection between driver board and NTC sensor is established by X1000.

| Table 11: X1000 on Board 1 SKYPER 12 R interface to NTC sensor | |
|---|---|
| **Pin** | **Description** |
| 1 | Pin TEMP_NTC |
| 2 | Pin TEMP_GND |

### 4.3 User interface

The user interface is the 14-pin connector X10 located in the middle of the driver board's low voltage side. The pin description is given in Table 12.

**Table 12: X10 pin description**

| Pin | Signal name | Description | Voltage level |
|---|---|---|---|
| 1 | GND | Ground | 0V |
| 2 | IF_CMN_BOT | PWM pattern IGBT BOT | Off=0V / On=15V; $R_{in}$=10kΩ / 1nF |
| 3 | IF_CMN_HALT | Error output | Error=0V / ready-for-operation=15V<br>(Pull-Up to 15V on user-side; $R_{pull-up}$=1.8kΩ..10kΩ) |
| 4 | IF_CMN_TOP | PWM pattern IGBT TOP | Off=0V / On=15V; $R_{in}$=10kΩ / 1nF |
| 5 | IF_CMN_NERR | Error input | Error=0V / ready-for-operation=15V<br>(Pull-Up to 15V on user-side; $R_{pull-up}$=1.8kΩ..10kΩ) |
| 6 | reserved | Reserved pins | DO NOT CONNECT! |
| 7 | reserved | Reserved pins | DO NOT CONNECT! |
| 8 | IF_PWR_VP | Driver supply voltage | $15V_{DC}$±4%, max. 0.5A |
| 9 | IF_PWR_VP | Driver supply voltage | |
| 10 | GND | Ground | 0V |
| 11 | GND | Ground | 0V |
| 12 | reserved | Reserved pins | DO NOT CONNECT! |
| 13 | reserved | Reserved pins | DO NOT CONNECT! |
| 14 | reserved | Reserved pins | DO NOT CONNECT! |

Both driver supply voltage pins (pins 8 and 9) and at least two ground pins must be used.

## 5. Restrictions and Requirements

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

### 5.1 Error treatment

If a desaturation event occurs, the desaturated IGBT must be turned off within the maximum permitted short circuit pulse duration ($t_{psc}$; stated in the module datasheet), otherwise it might be destroyed by this overload.
In case the driver is configured to warning only (see Table 4, left column) the driver does not turn off the faulty channel autonomously; the user needs to react appropriately to error messages sent from the driver board: the correct switching pattern is recommended and a switch-off time below $t_{psc}$ is mandatory to avoid damage.

#### 5.1.1 Secondary side error with R15=0Ω

In case a secondary side error (e.g. desaturation) occurs 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 3 of X10 (see Table 12). The particular IGBT is turned off using the soft-turn-off resistor. The second channel of the driver will not be turned off; this is in the user's responsibility.

#### 5.1.2 Secondary side error with R16=0Ω

In case a secondary side error (e.g. desaturation) occurs 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 3 of X10 (see Table

12). At the same time the particular IGBT is turned off using the soft-turn-off resistor. The error is internally sent to the second channel of the SKYPER 12 R driver and turns off this IGBT as well.

#### 5.1.3 Error treatment in multi-driver-systems

In systems using more than one driver board there is no direct connection of the driver boards' error signals. This connection, if required, needs to be provided by the user. It is needed in case an error occurring at one Board 1 SKYPER 12 R shall turn off the switches connected to another Board 1 SKYPER 12 R. Whether this functionality is necessary or not needs to be decided by the user.
Interconnection of errors is done by connecting pin 3 and pin 5 of X10 of all driver boards.

### 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 -9V to +15V or back, so the voltage difference is 24V. The peak current SKYPER 12 R is capable of driving is 20A, so the minimum total gate resistor that needs to be used is 1.2Ω. 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 resistors $R_{Gon}$ and $R_{Goff}$. The gate resistors can be calculated according to:

$$R_{Gon,min} = R_{Goff,min} = 1.2\Omega - R_{Gint}$$

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 12 R.

#### 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.
Please note that 1206 sized chip resistors have a lower power and pulse load rating than MiniMELF resistors.
Further information about the power rating and correct choice of gate resistors can be found in Application Note AN-7003 [4].

### 5.3 Design limits switching frequency

The used semiconductors, their gate charge, and the power of the SKYPER 12 R drivers determine the maximum switching frequency. It is limited to 30kHz by insulation coordination. Further information on calculating the switching frequency limit can be found in Application Note AN-7004 [5].

### 5.4 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.

### 5.5 SEMIKRON assembly

The Board 1 SKYPER 12 R 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 |
|---|---|
| 2L | Two level topology |
| 3L | Three level topology |
| BOT | Lower side switch (“bottom”) in 2L configuration |
| CTI | Comparative Tracking Index |
| 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 |
| NTC | Temperature sensor with negative temperature coefficient |
| PCB | Printed Circuit Board |
| 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 |
| $R_{Soft}$ | External gate series resistor for switch-off in case of desaturation event |
| RMS | Root Mean Square |
| $T_a$ | Ambient temperature |
| $T_j$ | Junction temperature |
| TOP | Upper side switch (“top”) in 2L configuration |
| $V_{AC}$ | AC output voltage |
| $V_{CE}$ | Collector-emitter voltage |
| $V_{DC}$ | Total supply voltage between DC+ and DC- / DC-link voltage |

A detailed explanation of the terms and symbols can be found in the "Application Manual Power Semiconductors" [2]

**References**

[1] www.SEMIKRON.com
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