

Description and Application Manual for 1SD312F2 SCALE High-Voltage IGBT Drivers

These plug-and-play, compact, high-performance, single-channel drivers for 4.5kV IGBTs support 2-level, 3-level and multi-level converters.

Abstract

The intelligent gate drivers of the 1SD312F2 SCALE plug-and-play driver series are compact single-channel drivers for 4.5kV high-voltage IGBTs. They were designed specifically for the precise and reliable driving and optimal protection of 4.5kV IGBT modules.

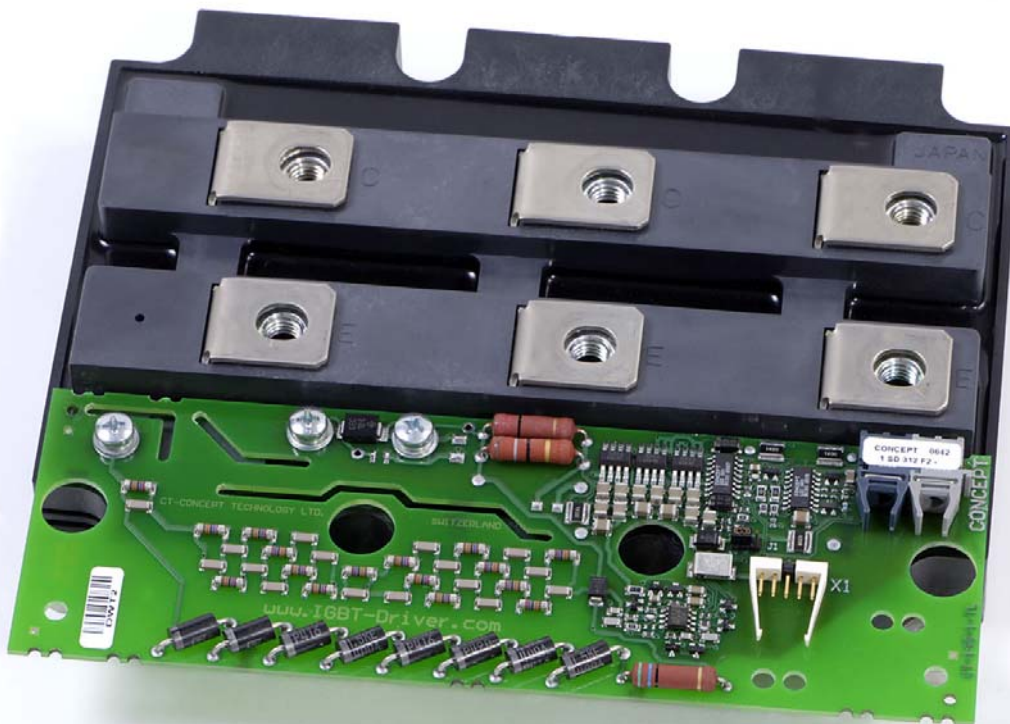


Fig. 1 SCALE driver 1SD312F2 screwed onto a 900A/4500V IGBT module

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Important Note on Technical Information

SCALE plug-and-play drivers are available in several versions in order to satisfy the particular requirements of different IGBT types.

This brief paper covers the general functionality of 1SD312F2 SCALE plug-and-play drivers. For detailed technical data of a specific driver, please refer to the corresponding data sheet.

A list of available SCALE plug-and-play drivers, detailed technical data and application notes may be viewed on the Internet at:

www.IGBT-Driver.com/go/plug-and-play

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The Seven Steps to Success

The following abstract points out the easy way to design megawatt converters by using superior SCALE plug-and-play technology:

1. Calculate the power dissipation of the IGBT modules

First choose the IGBT module suited to your application and determine its particular on-state and switching losses. This data is used to approximate the size of the required heat sink.

Since high-voltage IGBTs have relatively high switching losses, the switching frequency should be limited as much as possible.

2. Choose a suitable SCALE plug-and-play driver

When applying SCALE plug-and-play drivers, you should note that they are specifically adapted to a particular type of IGBT module.

Therefore, the type designation of SCALE plug-and-play drivers includes the type designation of the corresponding IGBT module. **These drivers are not valid for IGBT modules other than those specified. Incorrect use may cause failure.**

3. Design the power stack

When designing a power stack, minimize the parasitic inductances. As a rule, a total DC-link inductance of about 50...200 nH should be achievable with reasonable effort.

SCALE plug-and-play drivers are specified and optimized to operate under such conditions. As a result, the dynamic behavior of the IGBTs is superior to that obtainable under straightforward gate driving.

To speed up your startup with SCALE plug-and-play drivers, CONCEPT offers ready-to-use evaluation systems; see page **Fehler! Textmarke nicht definiert.**

4. Attach the drivers to the IGBT modules

The driver can be easily mounted onto an IGBT module by using the three screws enclosed.



Fig. 2 SCALE 4.5kV plug-and-play driver and the required tool



Any handling of IGBT modules or drivers is subject to the general specifications for protecting electrostatic-sensitive devices according to international standard IEC 747-1, Chapter IX or European standard EN 100015 (i.e. the workplace, tools, etc. must comply with these standards).

If these specifications are ignored, both IGBTs and drivers may be damaged.

5. Select the operating mode

Jumper J1 sets the operating mode according to the specific topology of the power converter. For details, see the paragraph "operating mode" on page 13.

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6. Perform the functional tests of the drivers

Attach the driver to the fiber-optic links and to the power supply. Check the gate voltage. For the off-state, the nominal gate voltage is -15V . For the on-state, i.e. with light entering the fiber-optic receiver, the nominal gate voltage is $+15\text{V}$. Furthermore, check the input current consumption of the driver without a drive signal and at the nominal command-signal frequency.

It is recommended that these tests be performed before installation, as the gate terminals may otherwise not be accessible.

7. Set-up and test the power stack

Before starting up the system, you are recommended to check each IGBT module separately under power-cycling conditions. It is usually sufficient to apply the single or double-pulse technique.

Even if only single IGBTs are tested, all the system's gate drivers must be supplied with energy. All the other IGBTs can then be kept in the off-state by applying negative gate voltages, which is particularly important when switching the IGBTs under test.

The short-circuit behavior can now also be verified.

After this step, the system is ready to start under real-world load conditions. This allows the thermal behavior of the whole arrangement to be determined.

The system must now be re-qualified over the entire specified range of temperature and load conditions.



CAUTION: Handling all high-voltage equipment involves risk to life.

Strict compliance with the respective safety regulations is mandatory!

What is a SCALE Plug-and-Play Driver?

SCALE plug-and-play drivers are based on the sophisticated SCALE driver chipset. This is a set of application-specific integrated circuits (ASICs) which covers all the main functions required to design intelligent gate drivers.

"**SCALE**" stands for **S**caleable, **C**ompact, **A**ll-purpose, **L**ow-cost and **E**asy-to-use

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Here is a concise listing of the most outstanding properties of SCALE drivers.

For further information about the SCALE driver chipset, refer to: "Description and Application Manual for SCALE Drivers" /3/

<p>Your Benefit: The Application Advantages of SCALE Plug-and-Play Drivers</p>
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Plug-and-play

These drivers are completely matched in the factory to the corresponding IGBT module (plug-and-play solution). The user has no need to make any further adjustments apart from mounting the driver onto the module, fixing it in place and connecting the power supply unit.

Reliable operation

1SD312F2 SCALE plug-and-play drivers were developed specifically for the precise and reliable driving and protection of high-power, high-voltage IGBT modules.

Gate driving with a bipolar control voltage (typically $\pm 15V$) allows reliable operation of IGBT modules with high interference immunity.

SCALE plug-and-play drivers feature an active clamping function which is the most reliable and effective way of protecting the costly IGBTs against overvoltage at turn-off, particularly during conditions of overload and short circuit.

Electrical insulation

Control signals are applied via external fiber-optic cables. This achieves, in addition to electrical insulation, superior noise immunity even for long signal cables.

The power supply (DC/DC converter) is a separate unit.

Status feedback

A status feedback is transmitted via the fiber-optic interface and enables the host controller to monitor both the gate driver and the IGBT. Since each edge of the control

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signal is acknowledged by the interface, any malfunction of the fiber-optic links can also be detected by the host controller.

How Do SCALE Plug-and-Play Drivers Work in Detail

Overview

4.5kV SCALE plug-and-play drivers are single-channel drivers for high-voltage IGBTs. They are equipped with the usual protection functions integrated in all drivers of the SCALE driver family, including V_{ce} monitoring for short-circuit protection, operation inhibit after fault, supply under-voltage shutdown and status feedback /3/.

Outstanding features of SCALE plug-and-play drivers are: compact size, simple mounting (directly onto the IGBT module) and the active-clamping function. Active clamping is a technique designed to protect the IGBTs against overvoltage during turn-off. It is particularly relevant when turning off an IGBT in cases of high collector current or short circuit.

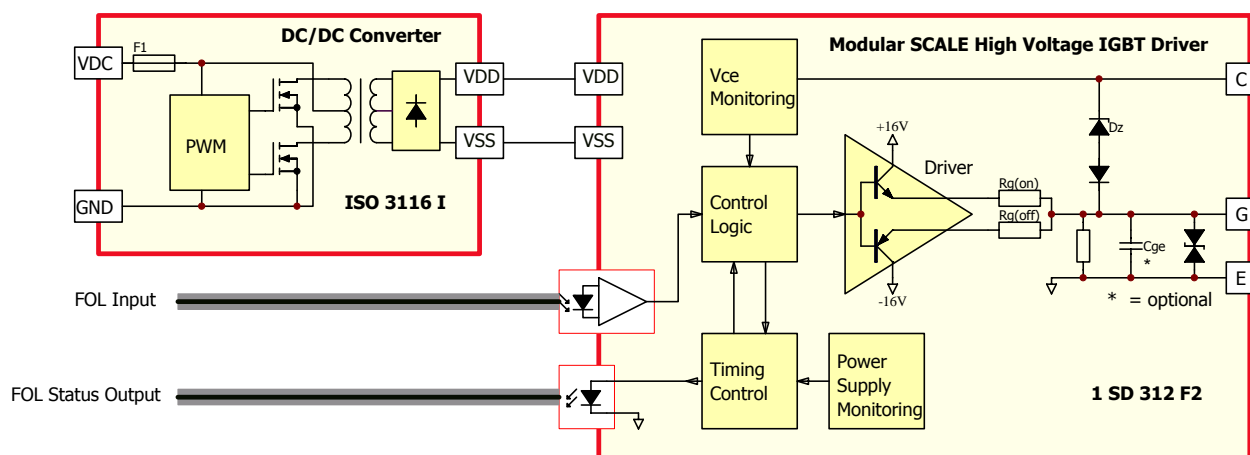


Fig. 3 Block diagram of SCALE plug-and-play driver 1SD312F2 with external DC/DC converter

Power supply and electrical insulation

In contrast to the other SCALE plug-and-play drivers (e.g. 1SD418F2 or 1SD536F2), the drivers of the 1SD312F2 family are modular in the sense that the driver card and power supply (DC/DC converter) are two separate units.

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Thanks to this modular concept, any driver unit that was developed to match a specific IGBT module can be used for any required insulation specifications. Only the separate power supply unit must be chosen or adjusted to a specific application. On the basis of this concept, the drivers for IGBTs in the voltage range from 3.3 to 6.5 kV can be implemented in 2-level, 3-level and multi-level inverter topologies.

The driver unit is mounted directly onto the IGBT module by means of three screws. The power supply unit is designed as a separate module attached close to the IGBT (see Fig. 4)

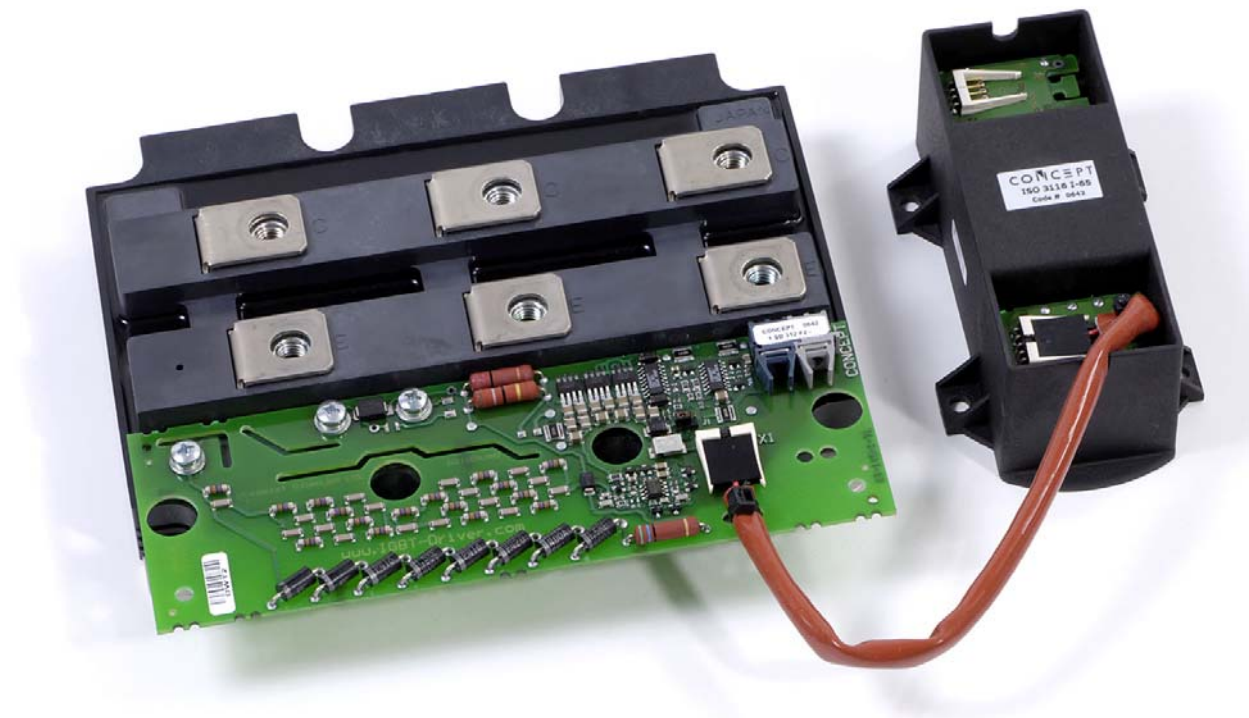


Fig. 4 Complete modular driver system with DC/DC converter, IGBT module and driver

Note that the DC/DC converter needs a stabilized +15V supply voltage.

An automatic-reset thermal fuse protects the power supply, wiring and driver PCB in case of incorrect polarity or IGBT and driver defects.

Separate data sheets [2] are available on the corresponding DC/DC converters.

Undervoltage protection

The driver circuitry includes an under-voltage protection unit which inhibits the turn-on of an IGBT in the event that the power supply voltage is too low.

Even in such a case, the driver provides a low impedance path between the IGBT gate and emitter.

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Within a half-bridge, it is strongly recommended not to operate the IGBTs in the event of a low supply voltage to any IGBT driver. Otherwise, a high rate of increase of V_{ce} might cause a partial turn-on of these IGBTs.

V_{ce} monitoring / short-circuit protection

The SCALE plug-and-play driver performs short-circuit protection based on V_{ce} monitoring, i.e. the collector-emitter voltage is monitored at turn-on and in the on-state.

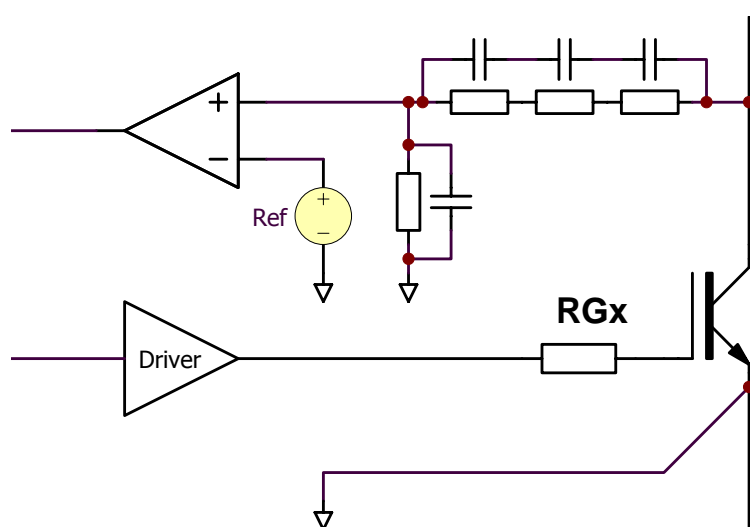


Fig. 5 V_{ce} desaturation monitoring

Figure 5 shows the basic circuit for V_{ce} monitoring implemented in 1SD312F2 drivers. The collector-emitter voltage is scaled down by a high-impedance voltage divider. To detect a short circuit, V_{ce} is checked a few microseconds after the turn-on command (response time). If this voltage exceeds 680 V, the driver detects a short circuit at the IGBT. The IGBT is then (depending on the operating mode, see page 13) either turned off immediately, or else a failure status is transferred to the host controller which then initiates turn-off of the IGBTs. The failure state is locked for a period of 1 second and then fed back to the optical link (the light is off for 1 second). The V_{ce} monitoring threshold cannot be changed according to the application.

This relatively high threshold voltage is required because high-voltage IGBTs, particularly in the event of higher load currents, do not approach the specified saturation voltage within a period of 10 μ s which defines the maximum short-circuit time. This must not be exceeded in order to avoid thermal breakdown of the IGBT.

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Note: This particular function is for short-circuit detection only and cannot provide overcurrent protection. However, overcurrent detection has a lower time priority and can be easily ensured by the application.

Note: In contrast to some other approaches, the V_{ce} -monitoring mode implemented here does not charge the DC-link capacitors during the IGBT's off-state.

Turning the IGBT on / commutation of diode current

When light enters the fiber-optic receiver, the gate driver instructs the IGBT to turn on. The driver already includes the gate resistors which are matched to the particular IGBT module.

The driver is optimized to minimize switching losses in the case of relatively low inductances within the power stack. It is recommended that the commutation behavior within the final system assembly be verified against the data provided by the IGBT module manufacturer.

Turning the IGBT off

The IGBT is turned off when no light enters the fiber-optic receiver. The gate resistors are determined by CONCEPT and should not be altered.

Fast turn-off of the IGBT may cause an overvoltage which increases with a rising DC-link voltage or load current. The turn-off overvoltage can be approximated by:

$$V_{tr} = -L_s * di/dt$$

where V_{tr} is the turn-off overvoltage and L_s the stray inductance.

See Fig. 6 for the test circuit and switching behavior.

Most drivers cannot limit the overvoltage in the event of overload and short circuit. However, this capability is essential for high-power IGBTs. To solve this problem, SCALE plug-and-play drivers provide the active clamping function described below.

Active clamping

Active clamping is a technique designed to turn the IGBT on partially whenever the collector-emitter voltage exceeds a predefined threshold. The IGBT is then kept in linear operation. The basic circuitry is shown in Fig. 7. For further details, refer to /4/.

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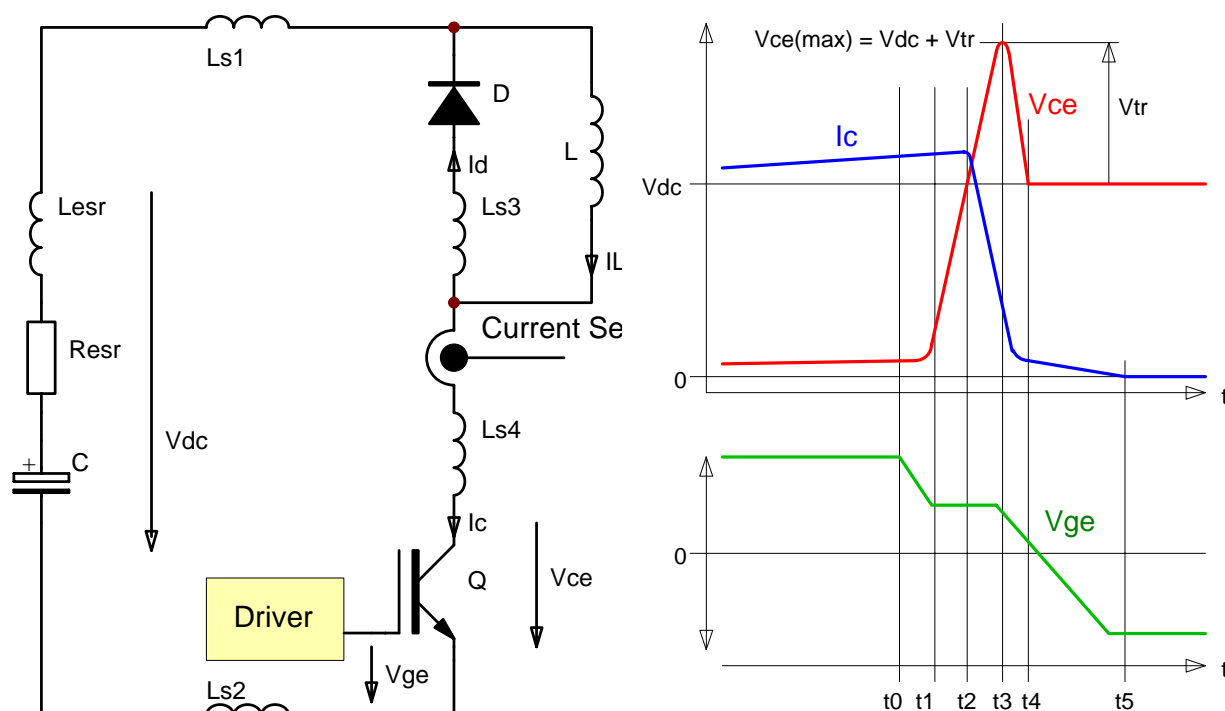


Fig. 6 Test circuit (left) and typical switching behavior (right) at turn-off

Legend to Fig. 6

- t0 = Initiation of the turn-off process
- t1 = Start of turn-off time
- t2 = Start of collector-current fall time
- t3 = Maximum collector voltage
- t4 = IGBT is blocking, start of tail current
- t5 = End of tail current

In comparison with other driving methods, active clamping allows enhanced utilization of the IGBT modules during normal operation by increasing the switching speed and thus reducing switching losses. Even so, the overvoltage at fault-current turn-off is managed by active clamping. For the maximum permitted DC-link voltage, refer to the gate driver data sheets /1/.

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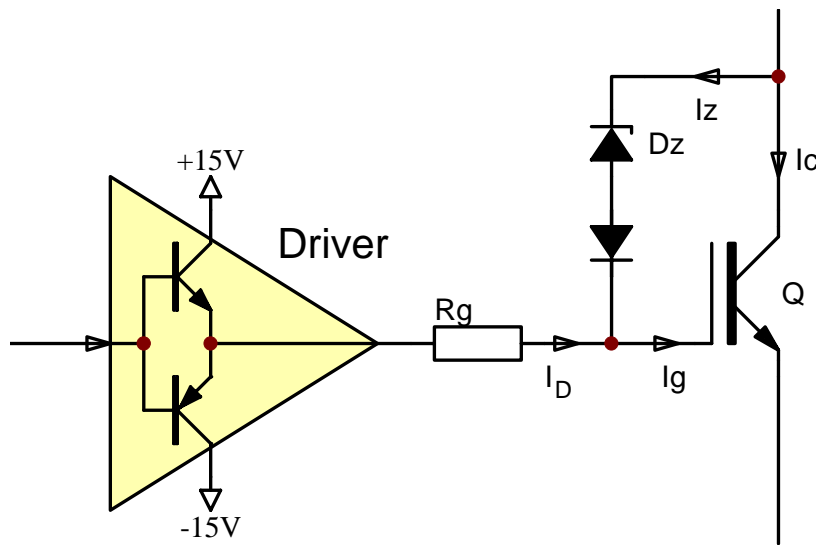


Fig. 7 Principle of the active clamping circuitry

Low-inductance layout

The active clamping function should not lead the user to forget about the inductances of the power stack. For several reasons, it is still recommended to reduce the stray inductance to about 50 to 200 nH. It is not usually advantageous to reduce this inductance further. Nevertheless, the driver can manage the overvoltages in such cases.

Operating mode

The correct response of a gate driver to a short-circuit event may depend on the particular topology of the power converter.

2-level mode

For a conventional 2-level topology, the necessary turn-off of the IGBT can be managed autonomously by the gate driver, i.e. turn-off is controlled locally, ignoring the actual operation of other IGBTs within the system. To select this kind of operation, set jumper J1 to "2-level mode".

3-level and multi-level mode

The right way of turning the IGBT off under fault conditions in 3-level or multi-level topologies is to apply a hierarchical control, i.e. the turn-off is instructed by the host control in response to a locally detected fault. The short-circuit event is consequently transferred to the host controller via the status feedback signal while the IGBT is

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temporarily kept in an on-state according to the command signal. So the correct switching sequence of series-connected IGBTs must be determined by the host controller. To select this kind of operation, set jumper J1 to "3-level mode".

Jumper J1

J1 → 1-2 = 2-level mode

J1 → 2-3 = 3-level and multi-level mode

The jumper mentioned above is shown in Fig. 8. Position 1 is marked at the top of the printed circuit board. Underneath, position 1 corresponds to the square pad of the jumper terminals.

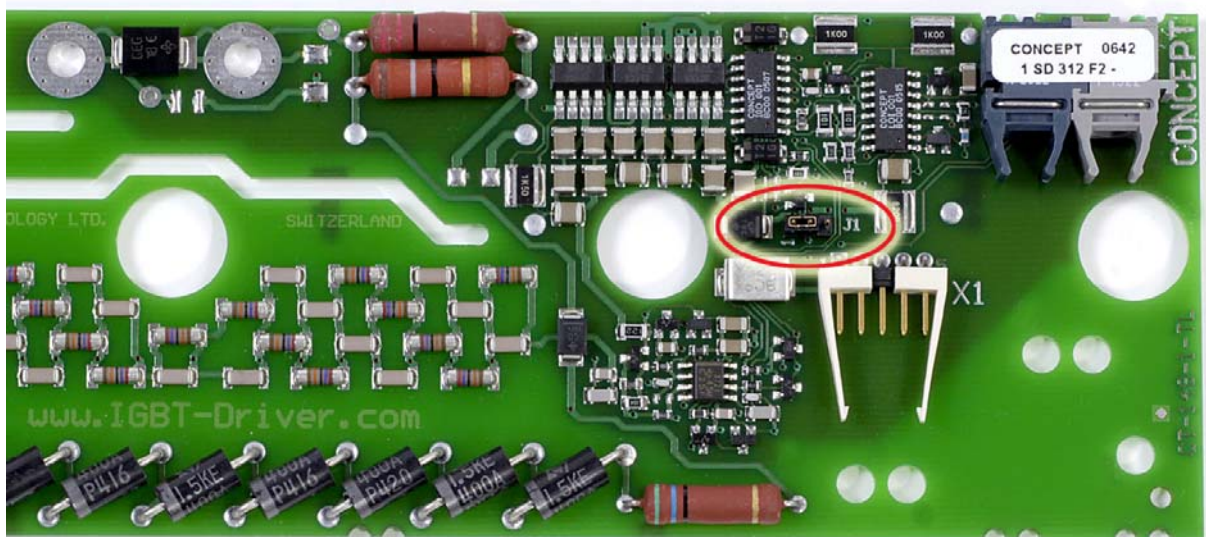


Fig. 8 Jumper J1 used to set the operating mode

Interfaces

Fiber-optic links are used for the electrical insulation of the command and status-feedback signals.

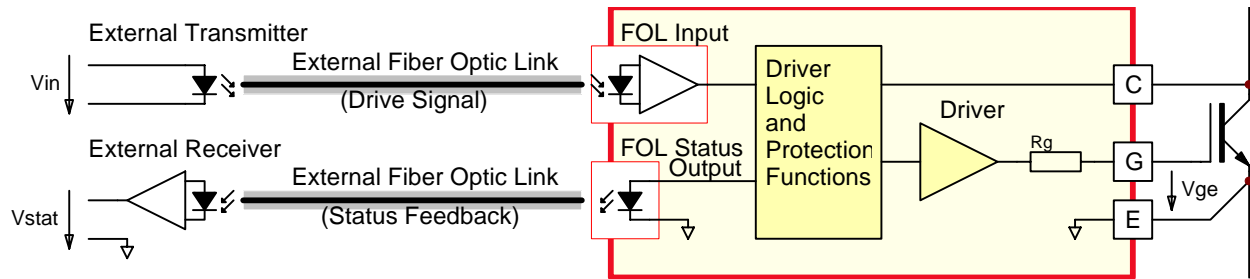


Fig. 9 Test circuit for signal slopes and delay time

The signal delay of a driver, including the external fiber-optic links, complies with the test environment of Fig. 9. For the relevant data, see Figs 10, 11 and 12.

Status feedback & edge acknowledge

During normal operation (i.e. the driver is supplied with power at nominal voltage and there is no fault anywhere), the status feedback is "light on" at the optical link. A malfunction is signaled by "light off".

Each edge of the control signal is acknowledged by the driver via a short pulse (the light remains off for about 900 ns). Because this can be detected by the host controller, all the drivers and fiber-optic links of the system can be simply and continuously monitored. Figure 10 shows the control and response signals of a gate driver in normal operation.

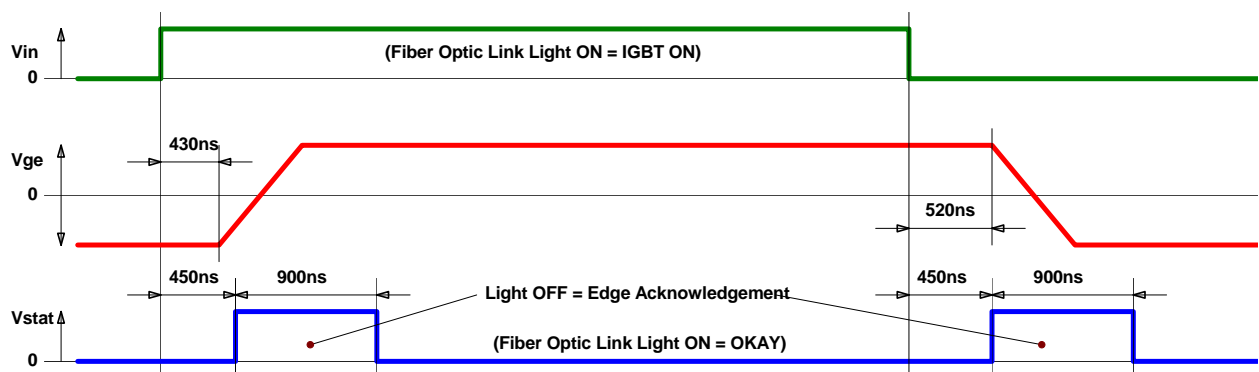


Fig. 10 Status feedback; signals for normal operation

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It is strongly recommended to check this status signal via the host controller. Note that this signal also identifies a malfunction of the fiber-optic links, which may otherwise cause a defect of the gate drivers or IGBTs, or even a malfunction of the entire system.

The control signal interface via a fiber-optic link is compatible with other SCALE plug-and-play drivers such as the 1SD418F2 or 1SD536F2, so that all existing control and protection circuitry may be used directly.

Figure 11 shows the response of the driver in the case of a short circuit in 2-level mode. The driver shuts the IGBT off within 10 μ s (response time). The failure status is transferred to the status feedback terminal, which is driven to "light off" for approx. 1 second.

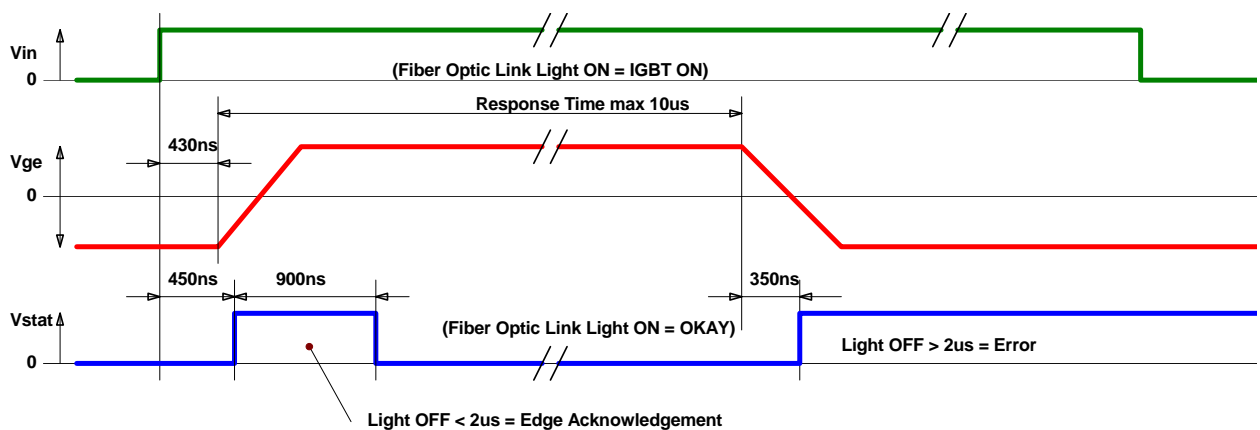


Fig. 11 Failure status feedback; signals under short-circuit conditions in 2-level mode

Figure 12 shows the response when operating in 3-level mode. As in 2-level mode, the driver reports an error to the host controller. But the IGBT is kept in the on-state until the host controller instructs the IGBT to be turned off.

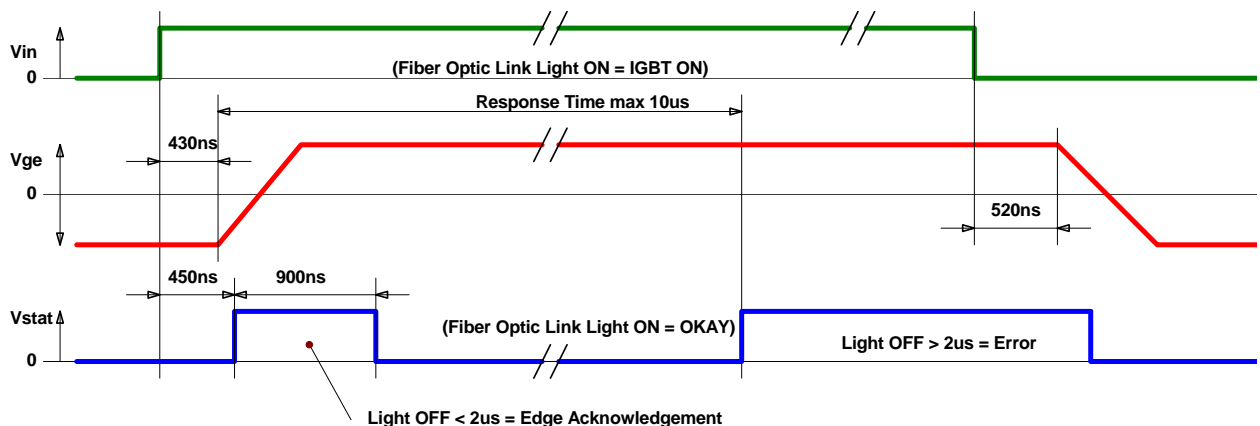


Fig. 12 Failure status feedback; signals under short-circuit conditions in 3-level mode

Suggested interface circuitry for fiber-optic links

The recommended interface circuitry for the fiber-optic links on the control electronics side is given in Fig. 13.

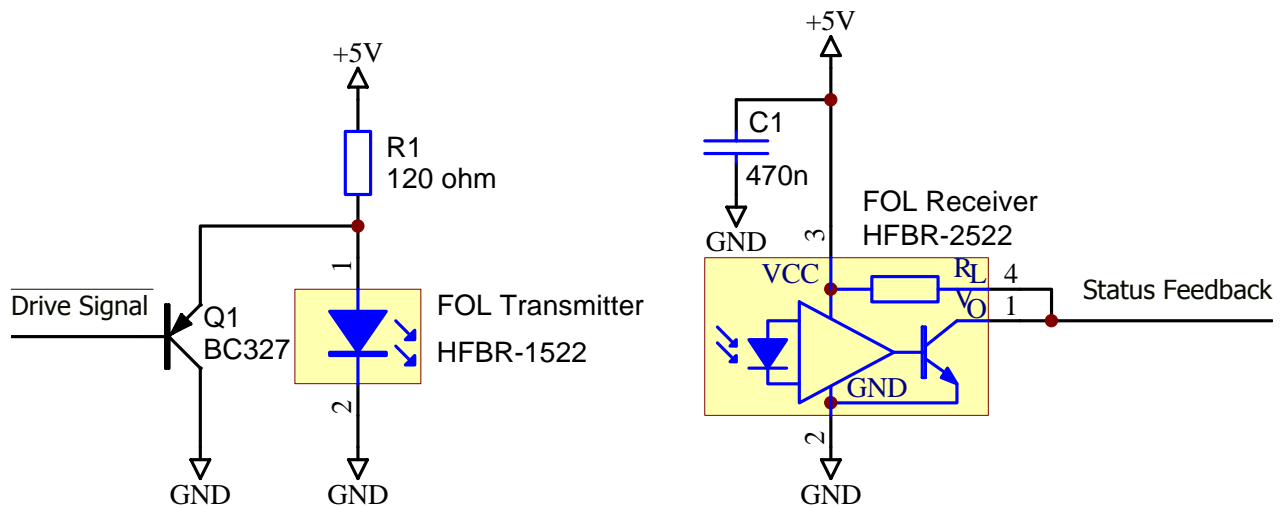


Fig. 13 Recommended circuitry for the fiber-optic links

Note for traction application or similar

The vibration withstand capability can be improved by fixing the gate driver at the holes provided. However, it should be noted that these connections must be electrically insulated to comply with the particular creepage distance requirements.

Basically, the power supply plug provides a mechanical interlock. If desired, the supply cables may also be fixed to the driver board. Moreover, an interlocking version of the fiber-optic links is also available (from Agilent, the manufacturer of the fiber-optic components).

Bibliography

- /1/ Data sheets: SCALE plug-and-play driver 1SD312F2-xxx, CONCEPT
- /2/ Data Sheets: DC/DC converter ISO 3116I-xx, CONCEPT
- /3/ Description and Application Manual for SCALE Drivers, CONCEPT
- /4/ Driver Solutions for High-Voltage IGBTs, PCIM Europe Magazine, April 2002

Note: The paper /4/ is available on the Internet at: www.IGBT-Driver.com/go/papers

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The Information Source: SCALE Driver Data Sheets

CONCEPT offers the widest selection of gate drivers for power MOSFETs and IGBTs for almost any application needs. The largest website on gate-drive circuitry anywhere contains all data sheets, application notes and manuals, technical information and support sections: www.IGBT-Driver.com

Quite Special: Customized SCALE Drivers

If you need an IGBT driver that is not included in the delivery range, please don't hesitate to contact CONCEPT or your CONCEPT sales partner.

CONCEPT engineers have more than 20 years experience in the development and manufacture of intelligent gate drivers for power MOSFETs and IGBTs and have already implemented a large number of customized solutions.

Evaluation Systems

We supply a half-bridge evaluation system with high voltage IGBTs designed particularly for development, verification, qualification and testing. It is fully equipped with high-voltage IGBTs, SCALE plug-and-play drivers, a current sensor, a safety case and, if requested, with IGBT heating for measurements at higher temperature; 100% tested.

For details see: www.IGBT-Driver.com/go/plug-and-play

Customer-Specific Systems

CONCEPT develops and produces complete power equipment and systems according to the customer's specifications.

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Consulting and Training

CONCEPT provides consulting and training services to customers on optimal procedures in power control, ideal circuit topologies as well as general do's and don'ts in the development of power electronics.

Technical Support

CONCEPT provides expert help with your questions and problems:

www.IGBT-Driver.com/go/support

Quality

The obligation to high quality is one of the central features laid down in the mission statement of CT-Concept Technology Ltd. The quality management system covers all stages of product development and production up to delivery. The drivers of the SCALE series are manufactured according to the ISO9001:2000 quality standard.

Disclaimer

This data sheet specifies devices but cannot promise to deliver any specific characteristics. No warranty or guarantee is given – either expressly or implicitly – regarding delivery, performance or suitability.

CT-Concept Technology AG reserves the right to make modifications to its technical data and product specifications at any time without prior notice. The general terms and conditions of delivery of CT-Concept Technology AG apply.

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Ordering Information

The general terms and conditions of delivery of CT-Concept Technologie AG apply.

Related IGBT

CONCEPT Driver Type

See current list on www.IGBT-Driver.com/go/1SD312F2

Suitable DC/DC Converters for 1SD210F2 Drivers

See current list on www.IGBT-Driver.com/go/ISO3116I

Information about Other Products

For drivers adapted to other high-voltage or high-power IGBT modules

Direct link: www.IGBT-Driver.com/go/plug-and-play

For other drivers and evaluation systems

Please click: www.IGBT-Driver.com

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