

# SCALE™-2 1SC0450E

## Preliminary Description & Application Manual

Single-Channel Cost-Effective Driver Core for IGBTs up to 4500V and 6500V

### Abstract

The 1SC0450E single-channel SCALE™-2 driver core combines unrivalled compactness with broad applicability and cost-effectiveness. It is designed for industrial and traction applications requiring high reliability. The 1SC0450E drives all usual high-voltage IGBT modules up to 4500V and 6500V. Up to four parallel-connected IGBT modules can be driven to cover higher power ratings. Multi-level topologies involving 3300V or 4500V IGBTs with higher isolation requirements can also be easily supported by the 1SC0450E.

The 1SC0450E supports maximal design flexibility as no fiber-optic links are assembled on the driver board. Gate drive input and output signals are provided over dedicated electrical interface connectors.

The 1SC0450E is the most compact driver core in its voltage and power range, featuring a footprint of only 60mm x 90mm and a maximum insertion height of 27.5mm. It allows even the most restricted insertion spaces to be efficiently used.

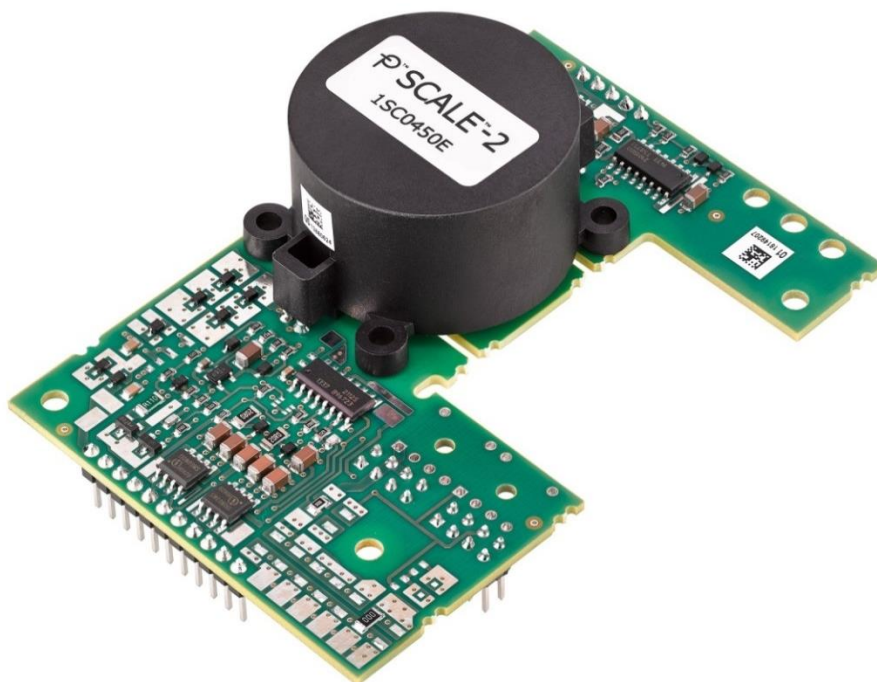


Fig. 1 1SC0450E driver core

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**Driver Overview**

The 1SC0450E is a driver core equipped with the latest SCALE-2 chipset from Power Integrations /1/. The SCALE-2 chipset comprises a set of application-specific integrated circuits (ASICs) that cover the main functions needed to design intelligent gate drivers. The SCALE-2 driver chipset is a further development of the proven SCALE™-1 technology /2/.

The 1SC0450E targets medium- and high-power IGBT applications up to 6500V. The driver supports switching frequencies up to 10kHz with best-in-class efficiency. The 1SC0450E comprises a complete single-channel IGBT driver core, fully equipped with an isolated DC/DC converter, electrical interface for the external use of fiber-optic transceivers, short-circuit protection, Advanced Active Clamping and supply-voltage monitoring. Additional features such as gate boosting or power supply short-circuit protection – which protects the driver in case of VISO to COM or gate-emitter short circuits – are also implemented and provide further driving benefits.

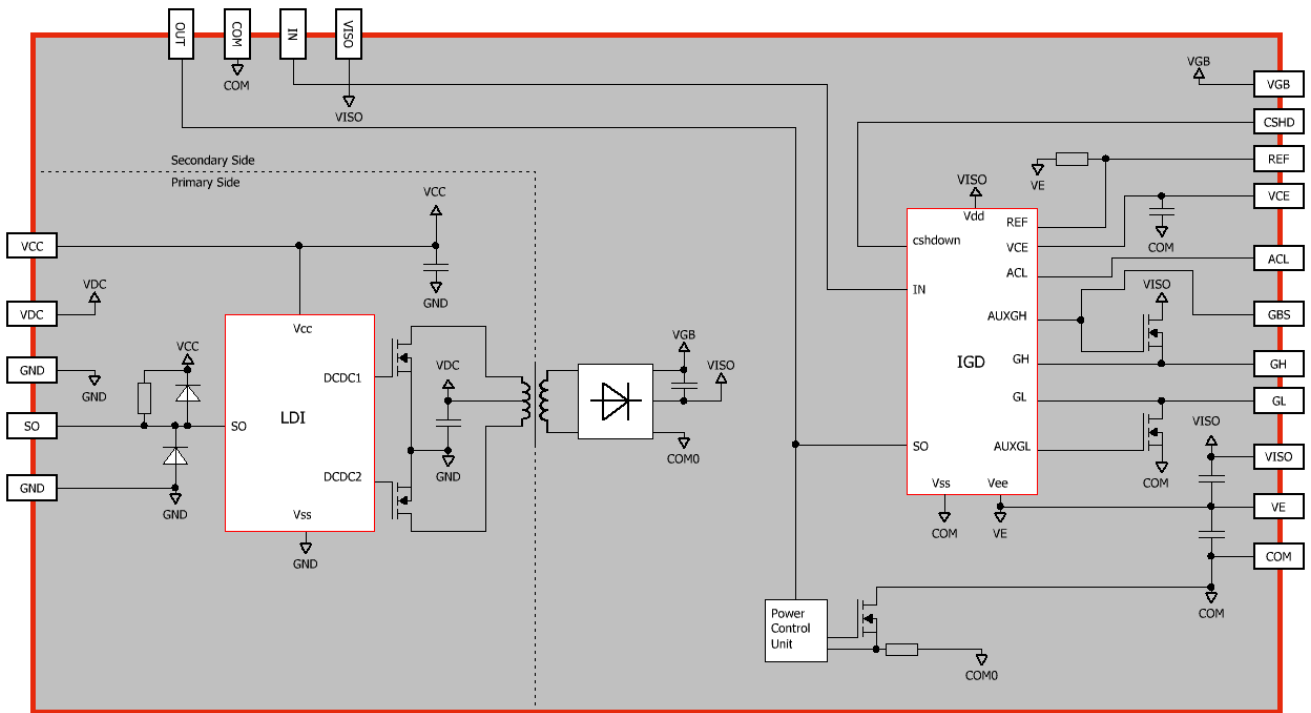
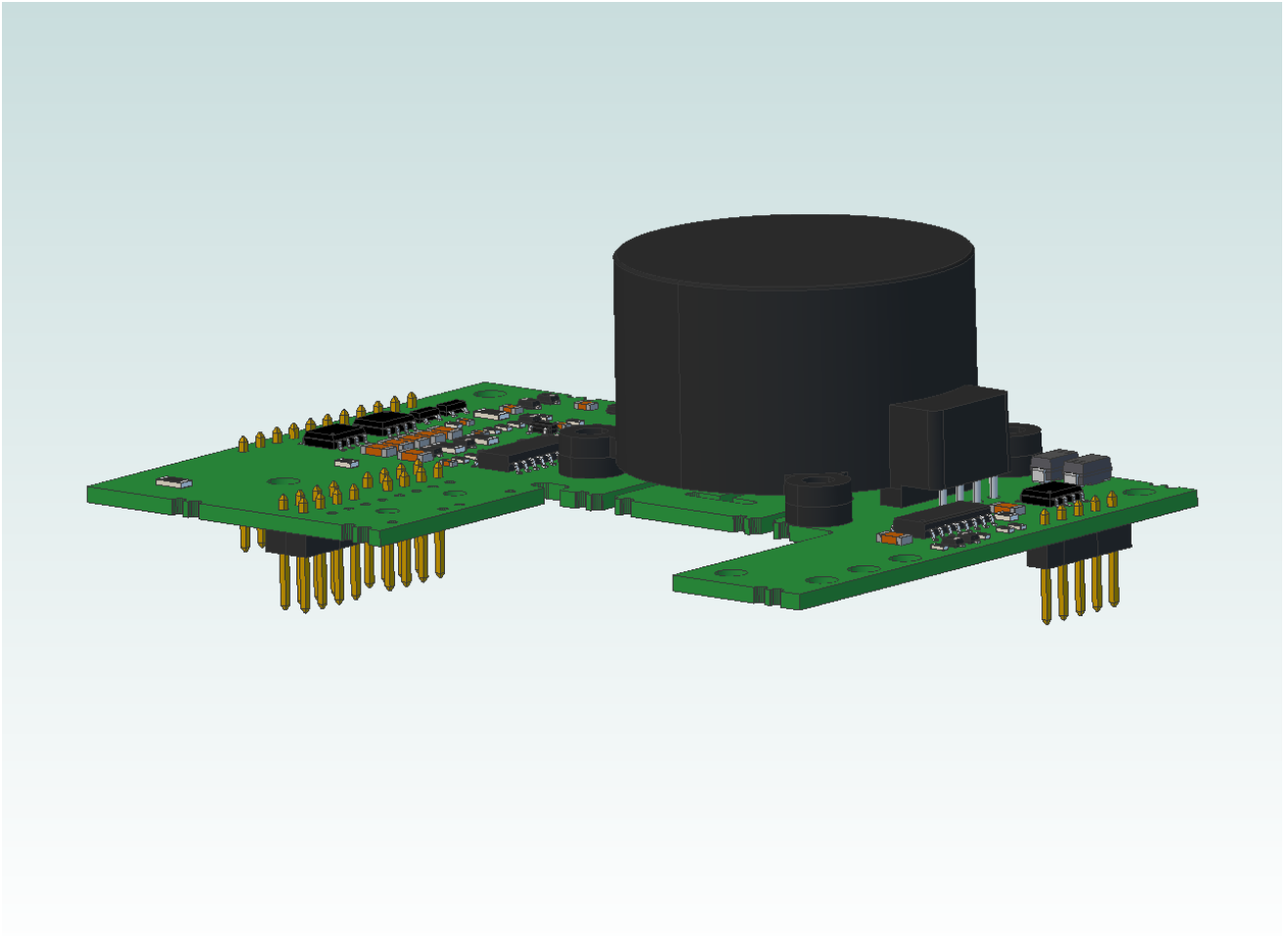


Fig. 2 Block diagram of the 1SC0450E driver core

**Mechanical Dimensions**



*Fig. 3 Interactive 3D drawing of the 1SC0450E*

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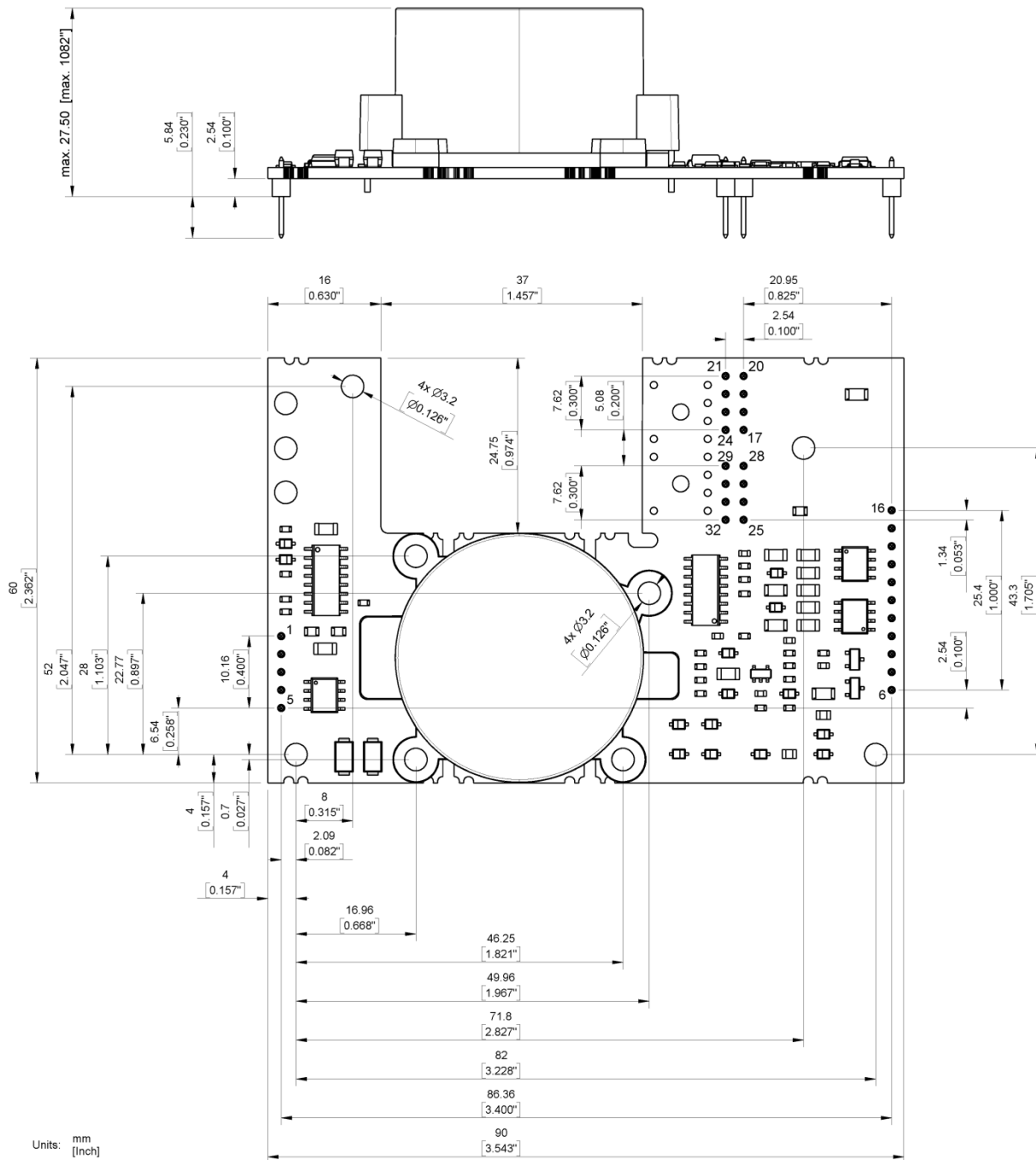


Fig. 4 Mechanical drawing of the 1SC0450E

The primary-side and secondary-side pin grid is 2.54mm (100mil) with a pin cross-section of 0.64mm x 0.64mm. Total outline dimensions of the board are 60mm x 90mm. The total height of the driver is maximum 27.5mm measured from the bottom of the pin bodies to the top of the populated PCB.

Note that the mechanical fixing points are placed in the clearance and creepage paths. Insulated fixation material (screws, distance bolts) must therefore be used in order not to reduce these. The fixing points support M3 screw size.

Recommended diameter of solder pads: Ø 2mm (79mil)

Recommended diameter of drill holes: Ø 1mm (39mil)

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### Pin Designation

Pin No. and Name	Function
<b>Primary Side</b>	
1 SO	Status output primary side; normally pulled up to VCC over a 10kΩ resistor, pulled down to low in case of a fault
2 GND	Ground
3 VCC	Supply voltage; 15V supply for primary side
4 VDC	DC/DC converter supply
5 GND	Ground
<b>Secondary Side</b>	
6 VGB	Gate-boosting power supply
7 VISO	DC/DC output
8 COM	Secondary-side ground
9 CSHD	Set turn-off delay after fault detection; capacitor to COM
10 GH	Gate high; pulls gate high through turn-on resistor
11 GBS	Gate-boosting signal
12 VE	IGBT emitter
13 GL	Gate low; pulls gate low through turn-off resistor
14 ACL	Active clamping feedback; leave open if not used
15 REF	Set $V_{CE}$ detection threshold through resistor to VE
16 VCE	$V_{CE}$ sense; connect to IGBT collector through impedance network
17 COM	Secondary-side ground
18 VISO	DC/DC output
19 COM	Secondary-side ground
20 COM	Secondary-side ground
21 COM	Secondary-side ground
22 IN	Gate driving input; Inverted non-isolated signal input
23 COM	Secondary-side ground
24 COM	Secondary-side ground
25 COM	Secondary-side ground
26 OUT	Status output and external fault input
27 COM	Secondary-side ground
28 COM	Secondary-side ground
29 COM	Secondary-side ground
30 OUT	Status output and external fault input
31 OUT	Status output and external fault input
32 COM	Secondary-side ground

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**Recommended Interface Circuitry for the Primary-Side Connector**

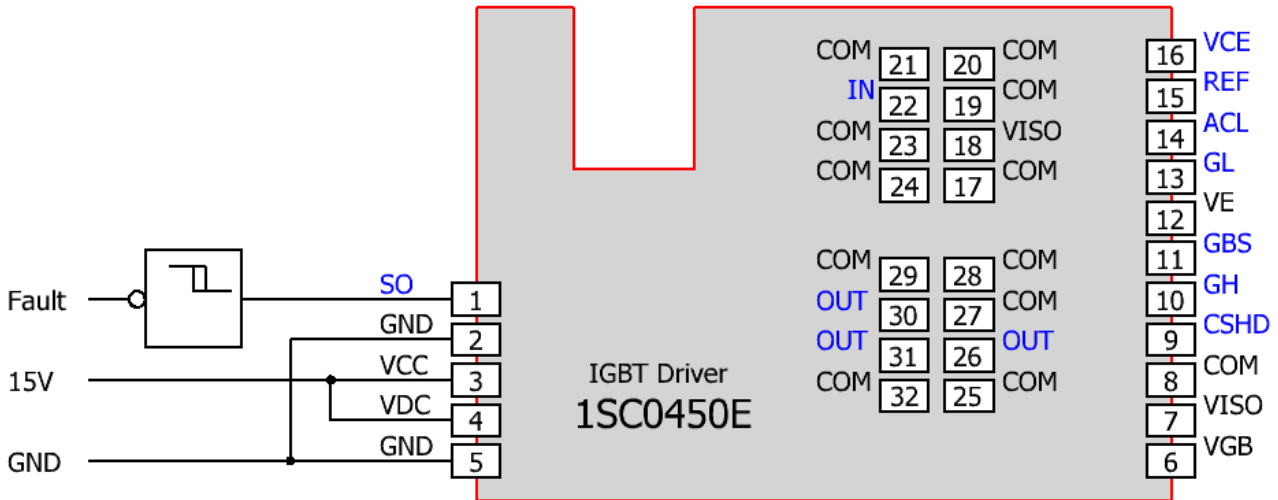


Fig. 5 Recommended user interface of the 1SC0450E (primary side)

**Description of Primary-Side Interface**

**General**

The primary-side interface of the 1SC0450E driver is very simple and easy to use.

The driver primary side is equipped with a 5-pin interface connector with the following terminals:

- 2x power-supply terminals VCC and VDC
- 2x ground terminals GND
- 1x status output SO (indicating a fault during primary-side under-voltage)

All inputs and outputs are ESD-protected.

**VCC terminal**

The driver has one VCC terminal on the interface connector to supply the primary-side electronics with 15V.

**VDC terminal**

The driver has one VDC terminal on the interface connector to supply the DC/DC converter for the secondary side.

VDC should be supplied with 15V. It is recommended to connect the VCC and VDC terminals to a common 15V power supply. In that case, the driver limits the inrush current at startup and no external current limitation of the voltage source for VDC is needed.



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**GND**

Both ground pins must be connected together with low parasitic inductance. A common ground plane is strongly recommended. Furthermore it is recommended to shield all primary-side circuitry with the ground plane. The connecting distance between the ground pins must be kept to a minimum.

**SO (status output)**

When no primary-side under-voltage condition is detected, an internal pull-up resistor of 10kΩ keeps the output level at the voltage level of VCC. When a primary-side supply under-voltage is detected, the status output SO goes to low (connected to GND). The SO output is automatically reset (returning to the voltage level of VCC) when the under-voltage on the primary side disappears.

The maximum SO current in a fault condition must not exceed the value specified in the driver data sheet /3/.

**Recommended Interface Circuitry for the Secondary Side Connectors**

**Pins 6 to 16**

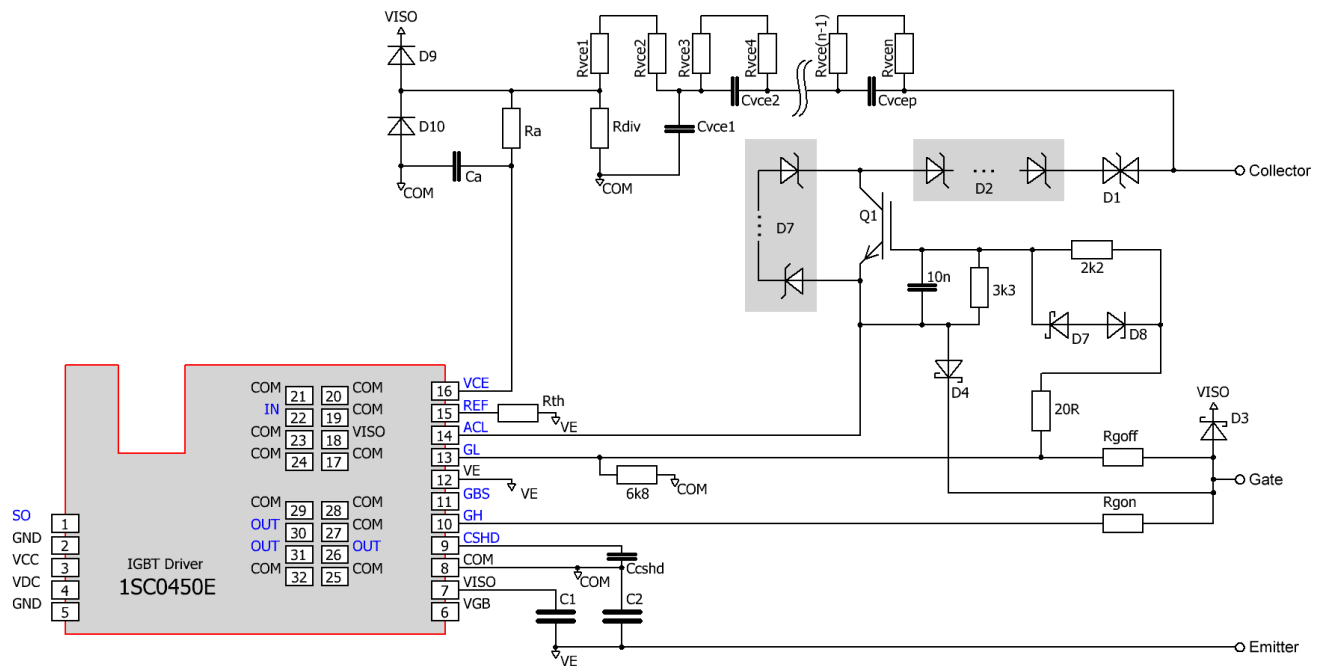


Fig. 6 Recommended user interface of the 1SC0450E (secondary-side pins 6 to 16) without gate boosting (refer to chapter "Gate Boosting" and Fig. 11 for gate-boosting circuitry)

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### Pins 17 to 32

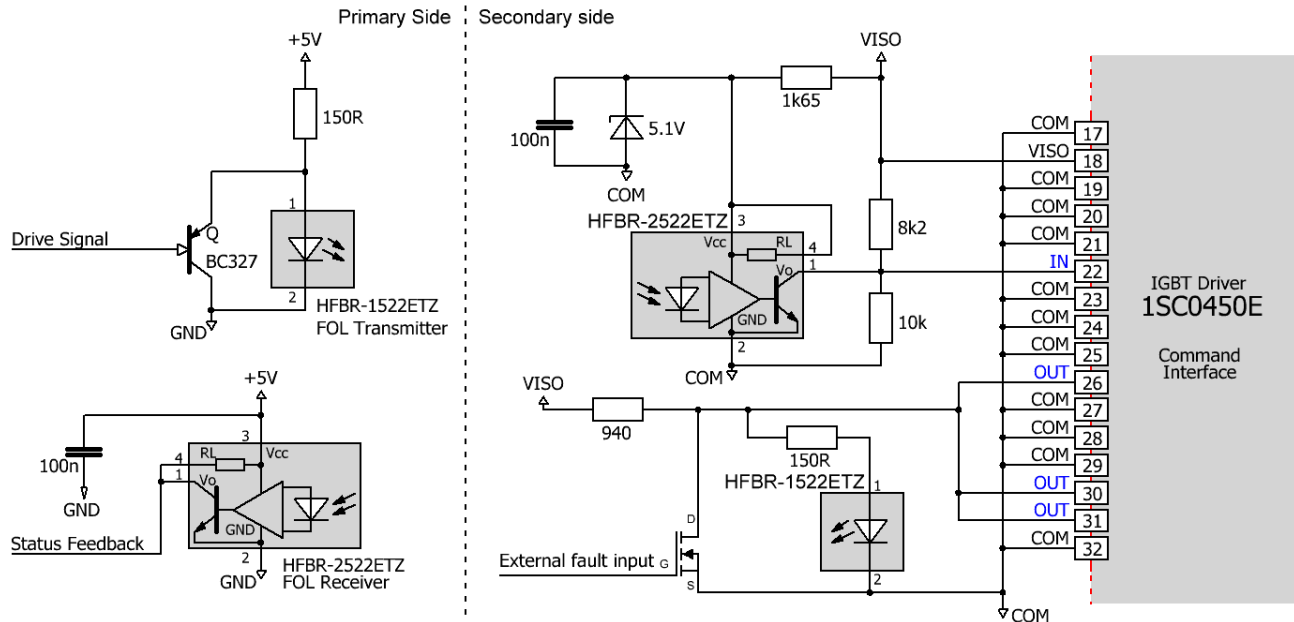


Fig. 7 Recommended command interface circuitry with Avago fiber-optic links HFBR-x522ETZ

## Description of Secondary-Side Interfaces

### General

The driver's secondary side is equipped with an 11-pin and two 8-pin interface connectors.

The 11-pin interface connector features the following terminals:

- 1x DC/DC output terminal VISO
- 1x emitter terminal VE
- 1x secondary-side ground COM
- 1x collector sense terminal VCE
- 1x reference terminal REF for short-circuit protection
- 1x input terminal CSHD to set the turn-off delay after fault
- 1x active clamping terminal ACL
- 1x turn-on gate terminal GH
- 1x turn-off gate terminal GL
- 1x gate-boosting power supply VGB
- 1x gate-boosting signal GBS

The two 8-pin interface connectors combine the command interface and feature the following terminals:

- 1x DC/DC output terminal VISO
- 11x secondary-side ground COM
- 1x PWM input (inverted)
- 3x status feedback input/output (inverted)

All inputs and outputs are ESD-protected.

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### DC/DC output (VISO), emitter (VE) and COM terminals

The driver is equipped with blocking capacitors on the secondary side of the DC/DC converter (for values refer to the data sheet /3/). IGBTs with a gate charge of up to 4.7μC can be driven without additional external capacitors ( $C_1$  and  $C_2$  in Fig. 6 are not assembled). Eq. 1 and Eq. 2 give the recommended capacitance value of  $C_1$  and  $C_2$  for gate charges above this value:

$$C_1[\mu\text{F}] \geq (Q_G[\mu\text{C}] - 4.7) \cdot 4 \quad \begin{array}{l} C_1 \text{ in Fig. 6; } 4\mu\text{F blocking capacitance} \\ \text{per } 1\mu\text{C gate charge between VISO} \\ \text{and VE} \end{array} \quad \text{Eq. 1}$$

$$C_2 = \frac{C_1}{2} \quad \begin{array}{l} C_2 \text{ in in Fig. 6; blocking capacitance} \\ \text{between VE and COM, half of the } C_1 \\ \text{value} \end{array} \quad \text{Eq. 2}$$

**Example:** IGBT modules with a gate charge of up to 42μC can be driven with external capacitances of 149.2μF between the VISO and VE terminals and 74.6μF between the VE and COM terminals ( $C_1$  and  $C_2$  of Fig. 6).

If the capacitance  $C_1$  (or  $C_2$ ) exceeds 200μF (or 100μF), please contact the Power Integrations support service.

The blocking capacitors must be connected as close as possible to the driver's terminal pins with minimum inductance. Ceramic capacitors with a dielectric strength  $\geq 25\text{V}$  are recommended.

No static load must be applied between VISO and VE, or between VE and COM. A static load can be applied between VISO and COM if necessary.

### Reference terminal (REF)

The reference terminal REF allows the threshold to be set for short-circuit protection with a resistor placed between REF and VE ( $R_{th}$  of Fig. 6). An internal resistor of 68kΩ sets the default threshold value to 10.2V. It can be reduced with the use of an external resistor  $R_{th}$  according to the following Eq. 3:

$$R_{th}[\text{k}\Omega] = \frac{68 \cdot V_{th}[\text{V}]}{10.2 - V_{th}[\text{V}]} \quad \text{with } V_{th} < 10.2\text{V} \quad \text{Eq. 3}$$

It is recommended to keep the reference voltage at its maximum default value of 10.2V (without using an external resistor  $R_{th}$ ).

### Collector sense (VCE)

The collector sense must be connected to the IGBT collector with the circuit shown in Fig. 6 in order to detect a short circuit condition.

General information and recommendations:

- The overall value  $R_{tot}$  of the resistors  $R_{Vcei}$  is calculated with equation Eq. 4:

$$R_{tot} = \sum_{i=1}^n R_{Vcei} = R_{Vce1} + \dots + R_{Vcen} \quad \text{Eq. 4}$$

- It is recommended to dimension the overall value  $R_{tot}$  of the resistors in order for a current  $I_{Vce}$  of about 0.6...0.8mA to flow through them at the maximum DC-link voltage (Eq. 5). This current must not exceed 0.8mA. It is recommended to use series-connected resistors; the minimum creepage and clearance distances required for the application must be considered and the maximum voltage,

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power and temperature rating of the resistors used must not be exceeded. Dimensioning recommendations are given below.

$$I_{V_{ce}} \cong \frac{V_{DC-link(max)}}{R_{tot}} = 0.6...0.8mA \quad \text{Eq. 5}$$

- All resistors  $R_{V_{cei}}$  ( $i \geq 1$ ) must have the same value.
- $R_{div}$  allows the static threshold detection level  $V_{CEth}$  to be increased if required (resistive voltage divider with  $R_{tot}$ ).  $R_{div}$  can be calculated with Eq. 6 in order to determine the static detection level  $V_{CEth}$ .

$$R_{div}[k\Omega] = R_{tot}[k\Omega] \cdot \frac{V_{th}[V] + |V_{GL}[V]|}{V_{CEth}[V] - V_{th}[V]} \quad (V_{CEth} > V_{th}) \quad \text{Eq. 6}$$

$|V_{GL}|$  is the absolute value of the gate-emitter turn-off voltage at the driver output. It depends on the driver load and can be found in the driver data sheet /3/.  $V_{th}$  is the reference value set at the reference terminal REF as described in the "Reference terminal (REF)" section.

- The recommended range for the overall capacitance value  $C_{tot}$  is given in Eq. 7:

$$C_{tot} = \frac{1}{\sum_{k=1}^p \frac{1}{C_{V_{cek}}}} = 1...4pF \quad \text{Eq. 7}$$

- All capacitances  $C_{V_{cek}}$  with  $k \geq 2$  must have the same value.
- The capacitance  $C_{V_{ce1}}$  must be chosen such that the Eq. 8 is satisfied:

$$\frac{C_{V_{ce1}}}{C_{tot}} = (0.7...0.9) \cdot \frac{R_{tot}}{R_{V_{ce1}} + R_{V_{ce2}}} \quad \text{Eq. 8}$$

- The maximum voltage rating of the resistors and capacitors used must not be exceeded. Peak values and average values must be considered. Dimensioning recommendations are given below.
- The diodes  $D_9$  and  $D_{10}$  must have a very low leakage current and a blocking voltage of  $>40V$  (e.g. BAS416). Schottky diodes must be explicitly avoided.
- $R_a$  and  $C_a$  are used to set the response time.

### **Recommended values for 6500V IGBTs with DC-link voltages up to 4500V**

- $R_{V_{ce1}} = R_{V_{ce2}} = \dots = R_{V_{ce30}} = 200k\Omega$  (500mW, 400V<sub>peak</sub>, 1%)
- $R_{div} = 620k\Omega$  (0603, 1%)
- $C_{V_{ce1}} = 15pF$  (C0G, 1000V, 5%)
- $C_{V_{ce2}} = C_{V_{ce3}} = \dots = C_{V_{ce15}} = 22pF$  (C0G, 630V, 5%)
- $C_a = 22pF$  (C0G, 50V, 5%)
- $R_{th} = \text{not assembled}$
- $R_a = \text{refer to Table 1 below}$  (0603, 1%)

This setup uses 30 resistors  $R_{V_{cei}}$  and 15 capacitors  $C_{V_{cek}}$  and leads to a static desaturation detection threshold of about 201V.

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$V_{DC-Link}$	$R_a=68k\Omega$	$R_a=91k\Omega$	$R_a=120k\Omega$
4500V	5.3 $\mu$ s	6.9 $\mu$ s	9.0 $\mu$ s
3000V	5.3 $\mu$ s	7.0 $\mu$ s	9.1 $\mu$ s
2250V	5.5 $\mu$ s	7.0 $\mu$ s	9.1 $\mu$ s
1500V	7.2 $\mu$ s	8.0 $\mu$ s	9.4 $\mu$ s
1125V	9.9 $\mu$ s	10.3 $\mu$ s	11.1 $\mu$ s
900V	14.1 $\mu$ s	14.1 $\mu$ s	14.2 $\mu$ s

Table 1 Typical response time as a function of the resistance  $R_a$  and the DC-link voltage  $V_{DC-Link}$

Table 1 gives indicative values only. The response time depends on the specific layout and the IGBT module used. It is therefore recommended to measure the short-circuit duration in the final design.

Note that slow IGBT modules may report a wrong  $V_{CE}$  desaturation fault at turn-on. It is therefore recommended to test the setup under worst case conditions (maximum DC-link voltage, maximum collector current and highest IGBT junction temperature). Please also refer to AN-1101 /4/ for more information.

### **Recommended values for 4500V IGBTs with DC-link voltages up to 3200V**

- $R_{vce1}=R_{vce2}=\dots=R_{vce20}=220k\Omega$  (500mW, 400V<sub>peak</sub>, 1%)
- $R_{div}=620k\Omega$  (0603, 1%)
- $C_{vce1}=15pF$  (C0G, 1000V, 5%)
- $C_{vce2}=C_{vce3}=\dots=C_{vce10}=22pF$  (C0G, 630V, 5%)
- $C_a=22pF$  (C0G, 50V, 5%)
- $R_{th}$ =not assembled
- $R_a$ =refer to Table 2 below (0603, 1%)

This setup uses 20 resistors  $R_{vcei}$  and 10 capacitors  $C_{vcek}$  and leads to a static desaturation detection threshold of about 150V.

$V_{DC-Link}$	$R_a=68k\Omega$	$R_a=91k\Omega$	$R_a=120k\Omega$
3200V	5.1 $\mu$ s	6.8 $\mu$ s	8.8 $\mu$ s
2000V	5.2 $\mu$ s	6.8 $\mu$ s	8.9 $\mu$ s
1500V	6.1 $\mu$ s	7.0 $\mu$ s	8.9 $\mu$ s
1000V	8.8 $\mu$ s	9.3 $\mu$ s	10.3 $\mu$ s
800V	12.7 $\mu$ s	13.1 $\mu$ s	12.9 $\mu$ s

Table 2 Typical response time as a function of the resistance  $R_a$  and the DC-link voltage  $V_{DC-Link}$

Table 2 gives indicative values only. The response time depends on the specific layout and the IGBT module used. It is therefore recommended to measure the short-circuit duration in the final design.

Note that slow IGBT modules may report a wrong  $V_{CE}$  desaturation fault at turn-on. It is therefore recommended to test the setup under worst case conditions (maximum DC-link voltage, maximum collector current and highest IGBT junction temperature). Please also refer to AN-1101 /4/ for more information.

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### **Recommended values for 3300V IGBTs with DC-link voltages up to 2200V**

- $R_{vce1}=R_{vce2}=\dots=R_{vce14}=220k\Omega$  (500mW, 400V<sub>peak</sub>, 1%)
- $R_{div}=1.5M\Omega$  (0603, 1%)
- $C_{vce1}=15pF$  (C0G, 1000V, 5%)
- $C_{vce2}=C_{vce3}=\dots=C_{vce7}=22pF$  (C0G, 630V, 5%)
- $C_a=22pF$  (C0G, 50V, 5%)
- $R_{th}$ =not assembled
- $R_a$ =refer to Table 3 below (0603, 1%)

This setup uses 14 resistors  $R_{vcei}$  and 7 capacitors  $C_{vcek}$  per channel and leads to a static desaturation detection threshold of about 50V.

$V_{DC-Link}$	$R_a=68k\Omega$	$R_a=91k\Omega$	$R_a=120k\Omega$
2200V	5.3 $\mu$ s	7.0 $\mu$ s	9.0 $\mu$ s
1500V	5.3 $\mu$ s	7.0 $\mu$ s	9.0 $\mu$ s
1100V	5.4 $\mu$ s	7.0 $\mu$ s	9.1 $\mu$ s
700V	7.6 $\mu$ s	8.1 $\mu$ s	9.3 $\mu$ s
600V	17.0 $\mu$ s	14.4 $\mu$ s	13.7 $\mu$ s

Table 3 Typical response time as a function of the resistance  $R_a$  and the DC-link voltage  $V_{DC-Link}$

Table 3 gives indicative values only. The response time depends on the specific layout and the IGBT module used. It is therefore recommended to measure the short-circuit duration in the final design.

Note that slow IGBT modules may report a wrong  $V_{CE}$  desaturation fault at turn-on. It is therefore recommended to test the setup under worst case conditions (maximum DC-link voltage, maximum collector current and highest IGBT junction temperature). Please also refer to AN-1101 /4/ for more information.

### **Input for adjusting the turn-off delay in fault condition (CSHD)**

The terminal CSHD allows the delay in turning off the IGBT after a fault detection on the driver's secondary side (short-circuit, undervoltage, power supply short-circuit/overload, external fault input) to be determined with a capacitor  $C_{cshd}$  (C0G/50V) connected to COM. Table 4 shows the resulting delay as a function of the circuit used at pin CSHD.

Circuit at pin CSHD	Typical turn-off delay $T_{cshd}$	
Left open:	$T_{cshd}=0.2\mu s$	Eq. 9
Capacitor between CSHD and COM:	$T_{cshd}[\mu s]=\frac{C_{cshd}[pF]}{50}$	Eq. 10
CSHD connected to COM (short circuit):	$T_{cshd}=\infty$ (The driver does not turn off automatically.)	Eq. 11

Table 4 Turn-off delay as a function of CSHD wiring

As soon as the fault turn-off delay time  $T_{cshd}$  has elapsed, the driver's channel is automatically turned off.

The driver's channel can also be turned off from the driver's input IN within the turn-off delay time  $T_{cshd}$  determined by the CSHD pin after a secondary-side fault detection.

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Note that it will not be possible to turn the IGBT on during about 100ns per 100pF capacitance applied to CSHD after a fault condition, starting from the turn-off event of the IGBT (minimum off-time required).

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### Active Clamping (ACL)

Active clamping is a technique designed to partially turn on the power semiconductor as soon as the collector-emitter voltage exceeds a predefined threshold. The power semiconductor is then kept in linear operation.

Basic active clamping topologies implement a single feedback path from the IGBT's collector through transient voltage suppressor devices (TVS) to the IGBT gate. The 1SC0450E supports Advanced Active Clamping from Power Integrations, where the feedback is also provided to the driver's secondary side at pin ACL (Fig. 6): as soon as the voltage at pin ACL exceeds about 1.3V, the turn-off MOSFET is progressively switched off in order to improve the effectiveness of the active clamping and to reduce the losses in the TVS. The turn-off MOSFET is turned completely off when the voltage at pin ACL approaches 20V (measured to COM).

It is recommended to use the circuit shown in Fig. 6. The following parameters must be adapted to the application:

- For TVS D<sub>1</sub>, D<sub>2</sub> it is recommended to use:
  - 3300V IGBTs with DC-link voltages up to 2200V: Seven unidirectional 300V TVS and one bidirectional 350V TVS. Good clamping results can be obtained with seven unidirectional TVS P6SMB300A and one bidirectional TVS P6SMB350CA from Diotec.
  - 4500V IGBTs with DC-link voltages up to 3200V: Eight unidirectional 400V TVS and one bidirectional 350V TVS. Good clamping results can be obtained with eight unidirectional TVS P6SMB400A and one bidirectional TVS P6SMB350CA from Diotec.
  - 6500V IGBTs with DC-link voltages up to 4350V: Ten unidirectional 440V TVS and one bidirectional 440V TVS. Good clamping results can be obtained with ten unidirectional TVS P6SMB440A and one bidirectional TVS P6SMB440CA from Diotec.

At least one bidirectional TVS (D<sub>1</sub>) ( $\geq 300V$  for 3300V IGBTs,  $\geq 350V$  for 4500V IGBTs,  $\geq 440V$  for 6500V IGBTs) must be used in order to avoid negative current flowing through the TVS chain during turn-on of the anti-parallel diode of the IGBT module due to its forward recovery behavior. Such a current could, depending on the application, lead to under-voltage of the driver secondary-side voltage VISO to VE (15V).

Note that it is possible to modify the number of TVS in a chain. The active clamping efficiency can be improved by increasing the number of TVS used in a chain if the total breakdown voltage remains at the same value. Note also that the active clamping efficiency is highly dependent on the type of TVS used (e.g. manufacturer).

- D<sub>3</sub> and D<sub>4</sub>: It is recommended to use Schottky diodes with blocking voltages  $> 35V$  ( $> 1A$  depending on the application).

Please note that the diodes D<sub>3</sub> and D<sub>4</sub> must not be omitted if Advanced Active Clamping is used.

If active clamping is not used, the diode D<sub>4</sub> can be omitted. The pin ACLx must then be left open.

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### Gate turn-on (GH) and turn-off (GL) terminals

These terminals allow the turn-on (GH) and turn-off (GL) gate resistors to be connected to the gate of the power semiconductor. The GH and GL pins are available as separated terminals in order to set the turn-on and turn-off resistors independently without the use of an additional diode. Please refer to the driver data sheet /3/ for the limit values of the gate resistors used.

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A resistor between GL and COM of 6.8kΩ (other values are also possible) may be used in order to provide a low-impedance path from the IGBT gate to the emitter even if the driver is not supplied with power. No static load (e.g. resistors) must be placed between GL and the emitter terminal VE.

Note, however, that it is not advisable to operate the power semiconductors within a half-bridge with a driver in the event of a low supply voltage. Otherwise, a steep increase of  $V_{CE}$  may cause partial turn-on of these IGBTs.

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### Gate Boosting Power Supply (VGB)

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The driver supports an increased IGBT turn-on voltage source VGB to perform gate boosting. The voltage is generated by internal circuitry. No static load must be applied to VGB. Refer to the driver data sheet /3/ for more information.

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### Gate Boosting Signal (GBS)

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The gate-boosting signal GBS is an auxiliary signal that has the same time waveform – but different voltage values – as the GH signal. Please refer to the driver data sheet for the exact voltage values /3/ and to the “Gate Boosting” section for more information.

Note that no static load must be applied to GBS. Refer to the driver data sheet /3/ for more information.

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### Gate Drive Input (IN)

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The gate drive input signal IN is inverted to the gate output. A transition to a low-level state at IN generates a driver turn-on command while a transition to a high-level state generates a driver turn-off command. Also refer to Table 5 and Fig. 8.

It is recommended to use the input circuitry of Fig. 7. The drive signal is then not inverted to the gate output according to Table 5.

If other drive circuits are used, the following information must be considered:

- The absolute maximum ratings of the driver data sheet /3/ must be respected.
- The logic level thresholds of the input IN are given in the driver data sheet /3/.
- The input IN features an internal pull-up current source of about 500μA which sets its potential to a high-level state and assures an IGBT off-state condition if the pin is floating. Refer to the driver data sheet /3/ for values.
- Pin IN belongs to the secondary-side electrical circuit and follows the emitter potential of the driven IGBT. It must be isolated against primary-side circuits, e. g. with fiber-optic links.

Drive Signal	T/R <sup>(1)</sup> Light	Input IN	Gate Output
Low	Off	High	Off-state
High	On	Low	On-state

Table 5 Signal input truth table correlated with the schematics of Fig. 7

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<sup>(1)</sup> T/R: Transmitter and receiver pair of a fiber-optic link



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**Status Feedback / Fault input (OUT)**

The OUT terminal is mainly used as a status feedback output. However, it also works as an input. When OUT is externally shorted to COM for a minimum period of time (timing and threshold values according to the driver data sheet /3/), the driver detects an external fault. The IGBT is then turned off after a delay  $T_{CSHD}$  (refer to the chapter "Input for adjusting the turn-off delay in fault condition (CSHD)"). Note that failure to respect the minimum hold time may lead to incorrect driver behavior.

The recommended circuitry for using the OUT terminal as an external fault input is shown in Fig. 7 (transistor connected to "External fault input"). The external effective capacitance (components and board parasitic capacitances referred to VISO, VE and COM) must not exceed the value given in the driver data sheet /3/ to avoid unexpected driver fault triggering in normal operation.

In normal operation, each edge of the control signal IN is acknowledged by the driver with a short pulse (OUT is switched to low for a short period of time; refer to driver data sheet /3/ for details). As this can be observed by the host controller, this method allows simple and continuous monitoring of all drivers and fiber-optic links of the system (Fig. 8).

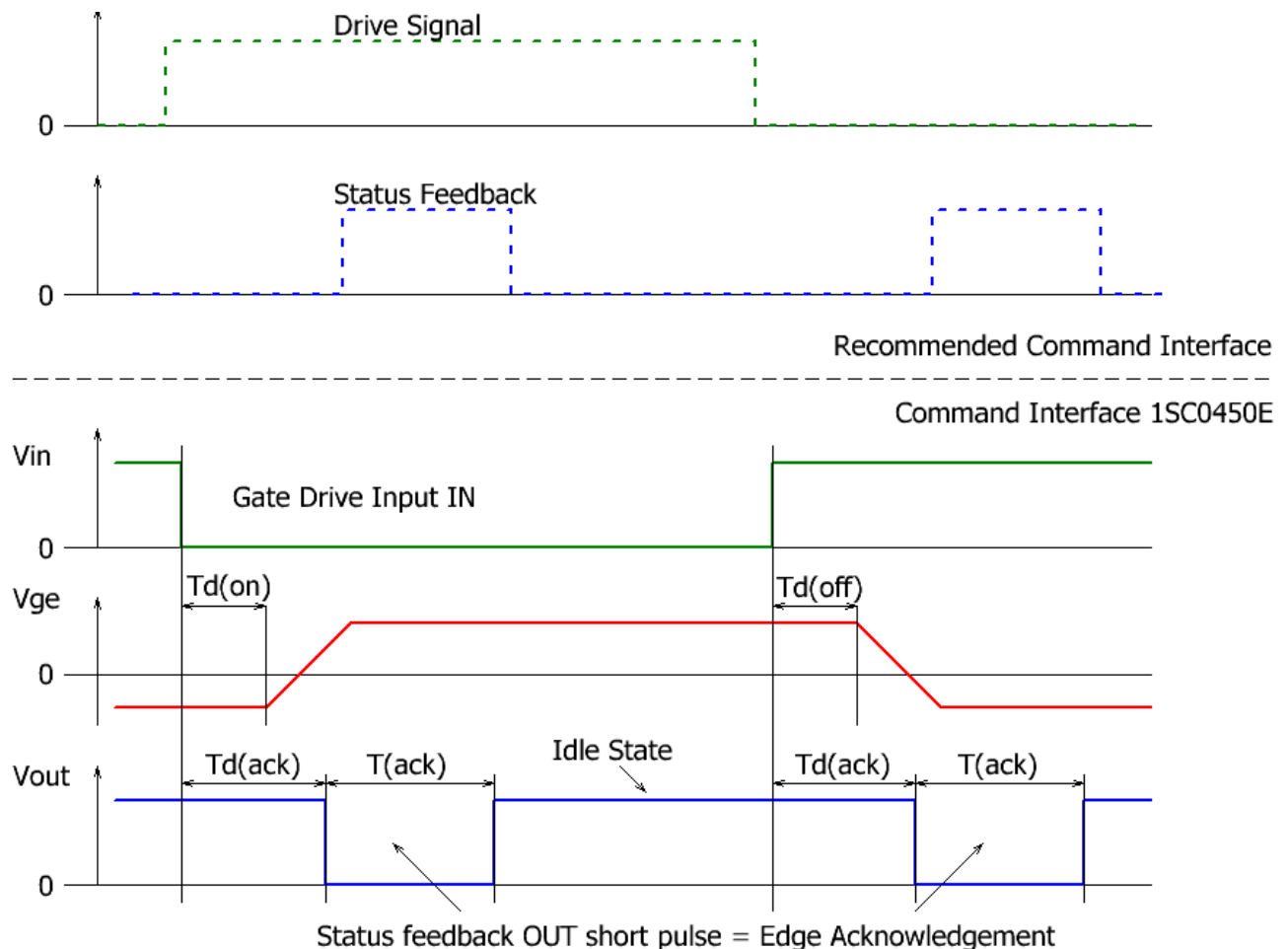


Fig. 8 Driver behavior and status feedback in normal operation (Refer to Fig. 7 for the recommended command interface)

The driver can detect four different secondary-side faults:

- $V_{CE}$ -desaturation detection in case of a short-circuit; refer to chapter "Collector sense (VCE)"
- Secondary-side supply under-voltage; refer to chapter "Power-supply monitoring"

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- Output short-circuit/heavy overload protection; refer to chapter “Power-supply monitoring”
- External fault (as described above)

The signal truth table of Table 6 shows the behavior of the OUT signal in normal operation as well as in a fault condition. Only the pulse length of OUT differs between normal operation (acknowledge) and the different fault conditions.

Status	OUT	T/R <sup>(2)</sup> Light	Status Feedback
Idle	High	On	Low
Acknowledge or fault pulse	Low	Off	High

Table 6 Signal truth table correlated with the schematics of Fig. 7

Fig. 9 shows the response of the driver in the event of an IGBT short-circuit condition. The fault status is transferred to the status feedback terminal after the response time. The light is then driven “off” during the delay to clear the fault state ( $8\mu\text{s} + T_{\text{cshd}}$ ). The driver turns the IGBT off after the response time + delay time  $T_{\text{cshd}}$ . The IGBT can be turned on again by applying a negative edge to the input IN after the fault status has disappeared.

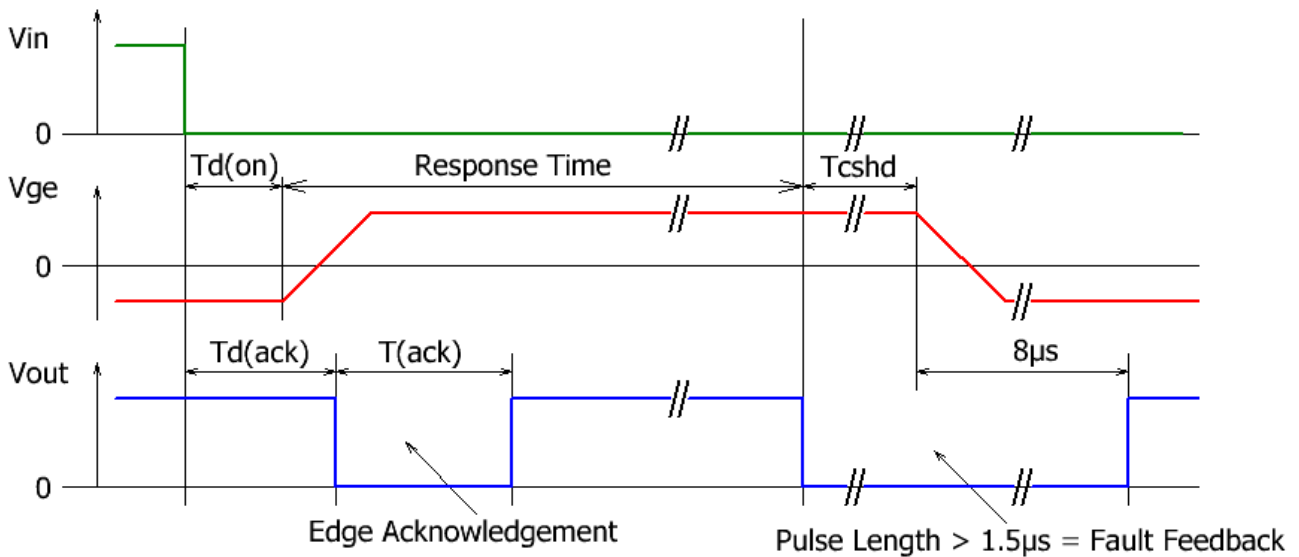


Fig. 9 Driver behavior and status feedback in the IGBT short-circuit condition

In case of a secondary-side supply under-voltage fault, the fault status remains active as long as this under-voltage remains. The driver response in the event of a supply under-voltage on VISO-VE is shown in Fig. 10.

<sup>(2)</sup> T/R: Transmitter and receiver pair of a fiber-optic link

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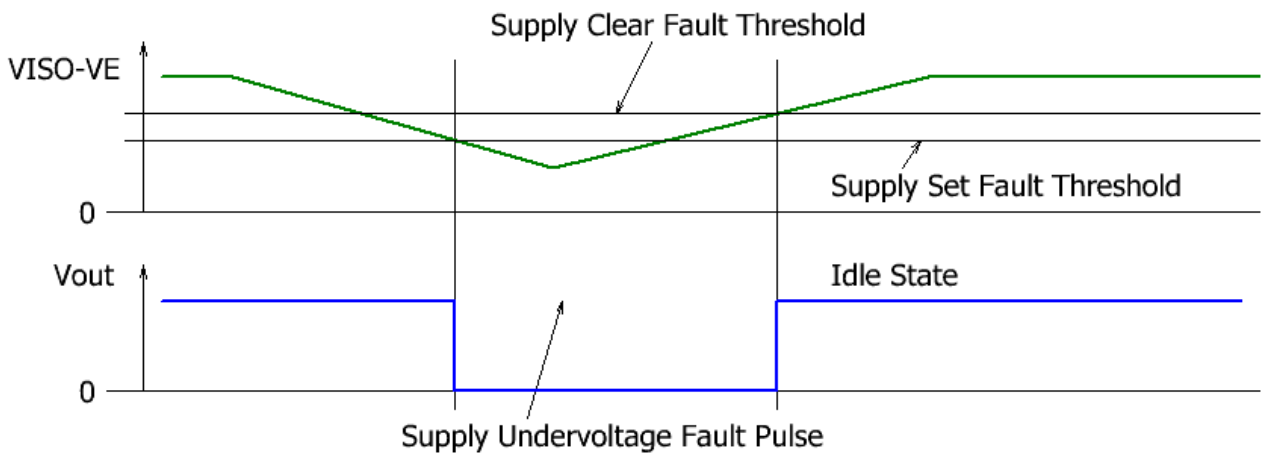


Fig. 10 Status feedback in the event of a secondary-side supply under-voltage

In case of power supply short-circuit/overload, the fault status is repetitively activated for about 1ms.

During power-up, the status feedback will also show a fault condition until the supply under-voltage/power supply overload protection disappears.

If the OUT terminal is not used, it is recommended to connect the OUT pin to VISO via a pull-up resistor in the range of 1.5k $\Omega$  to 10k $\Omega$ .

### How Do 1SC0450E SCALE-2 Drivers Work in Detail?

#### Power supply and electrical isolation

The driver is equipped with a DC/DC converter to provide an electrically insulated power supply to the gate driver circuitry. The transformer features basic insulation according to IEC 61800-5-1 as well as IEC 60664-1 between the primary and secondary sides.

Note that the driver requires a stabilized supply voltage.

#### Power-supply monitoring

The driver's primary and secondary sides are equipped with a local under-voltage monitoring circuit.

In the event of a primary-side supply under-voltage, the under-voltage is signaled by the electrical status output SO. A primary-side under-voltage will not automatically cause a gate turn-off command. This condition has to be detected by the control logic which has to switch off and block the gate drive signal.

In case of a secondary-side supply under-voltage, the corresponding power semiconductor is driven with a negative gate voltage after the delay in IGBT turn-off (refer to "Input for adjusting the turn-off delay in fault condition (CSHD)") to keep it in the off-state (the channel is blocked) and a fault condition is monitored on the status output OUT until the supply voltage exceeds the reference level for enabling.

The driver 1SC0450E is further equipped with an output short-circuit/heavy overload protection. The driver detects any short-circuit/overload current higher than the detection threshold (refer to the data sheet /3/ for more information) between gate and emitter as well as between VISO and COM. There is no protection against light overload of the power supply.

Note that a short circuit between gate and emitter might not be detected in the IGBT off-state (GL is connected to COM). The short circuit would then be detected when the driver turns on (GH is switched to VISO). A short-circuit/overload between VISO and COM is detected immediately.

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In the event of a driver's power supply short-circuit/overload, the fault is immediately reported by the optical status feedback output. The fault signal applies – depending on the short circuit/overload condition – permanently or repeatedly for about 1ms. The primary-side supply VDC has to be switched off within the time frame given in the driver data sheet /3/ to prevent driver damage.

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### Parallel connection of IGBT modules

It is recommended to drive parallel-connected IGBT modules using a single 1SC0450E driver core. Appropriate gate circuitry has to be used. Please contact the Power Integrations support service for more information.

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### 3-level or multilevel topologies

In applications with multi-level topologies, the turn-off sequence of the individual power semiconductors usually needs to be controlled by the host controller in case of a detected fault condition (e.g. short circuit, over-current), especially if no Advanced Active Clamping or Dynamic Advanced Active Clamping is implemented.

In that case, the turn-off delay in the fault condition of the different drivers can be adjusted to match the corresponding timing specifications. It is in particular possible to determine a specific turn-off delay for the inner IGBTs of a 3-level NPC topology as described in the section: "Input for adjusting the turn-off delay in fault condition (CSHD)". The driver's response time can also be adapted accordingly if required.

Note however that Advanced Active Clamping offers simple and safe protection that allows excessive collector-emitter overvoltages to be avoided in case of wrong commutation sequences in the short-circuit condition of 3-level converter topologies (refer to /6/ and /7/ for more information).

---

### Gate Boosting

The 1SC0450E driver supports gate boosting. This feature allows the commutation speed of the collector-emitter voltage to be accelerated at turn-on after the critical phase of the diode reverse recovery behavior to reduce the IGBT turn-on losses.

A dedicated external circuit as shown in Fig. 11 is required. Detailed gate-boosting recommendations are not currently available.

#### Gate-boosting circuit principle

The "Gate Boosting Logic" according to Fig. 11 has to trigger the boosting function at the appropriate time during the IGBT turn on transition as illustrated in Fig. 12:

- The delay time between GBS and the required boosting time needs to be determined by the "Gate Boosting Logic" circuit.
- The pulse length of the boosting pulse also needs to be determined by the "Gate Boosting Logic" circuit. It must be limited to a few microseconds.

A turn-on pulse of the gate-boosting power switch  $Q_1$  will be generated. This will lead to an increased turn-on gate current that will be injected into the IGBT gate over  $R_{gb}$ .

The boosting charge capability can be increased by adding an external capacitor  $C_{gb}$ . The minimum value  $C_{gb}$  of the external capacitor can be calculated according to Eq. 12.

$$C_{gb}[\text{nF}] = \frac{Q_{gb}[\text{nC}]}{V_{GH}[\text{V}] + |V_{GL}[\text{V}]|} - 22 \quad C_{gb} \geq 0 \quad \text{Eq. 12}$$

where  $Q_{gb}$  stands for the required boosting gate charge and has to be determined according to the IGBT module gate charge requirements.  $V_{GH}$  and  $V_{GL}$  are the absolute values of the turn-on and turn-off voltage at

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the driver output respectively. Their value can be found in the driver data sheet /3/. Note that Eq. 12 assumes a full discharge of  $C_{gb}$  during a gate-boasting event (worst case).

The gate-boasting capability is further limited by the minimum time span between two consecutive gate turn-on commands as well as by the gate-boasting power. The minimum required time  $T_{min}$  between two consecutive gate turn-on commands is given by Eq. 13. The gate-boasting efficiency is reduced if Eq. 13 is not respected.

$$T_{min}[\mu s] = 11 \cdot \left( 1 + \frac{22 + C_{gb}[\text{nF}]}{22} \right) + T_{gb}[\mu s] \tag{Eq. 13}$$

$T_{gb}$  stands for the gate-boasting pulse length (Fig. 12). It is recommended to limit it to 1...5 $\mu s$ .

The maximum gate-boasting power must be within the absolute maximum ratings of the driver data sheet /3/. Eq. 14 gives a worst case approximation of the real gate-boasting power  $P_{gb}$ . It is sufficient to design the gate boosting such that  $P_{gb}$  is lower than the corresponding absolute maximum rating of the driver data sheet /3/.

$$P_{gb}[\text{W}] = 10^{-6} \cdot (C_{gb}[\text{nF}] + 22 + 6.5 \cdot T_{gb}[\mu s]) \cdot (V_{GH}[\text{V}] + |V_{GL}[\text{V}]|)^2 \cdot f[\text{kHz}] \tag{Eq. 14}$$

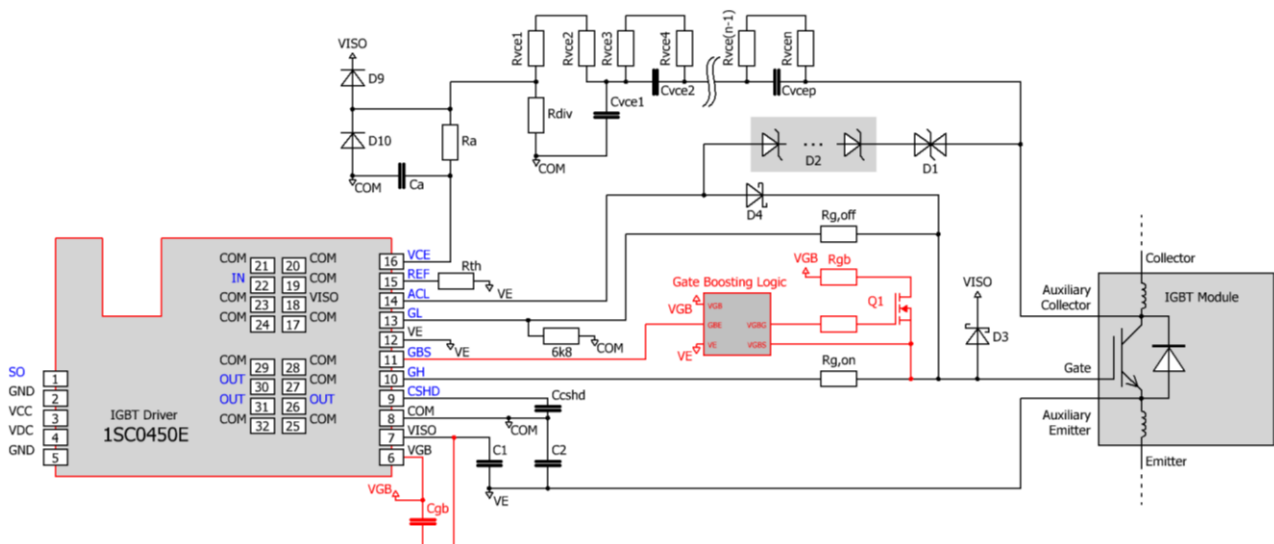


Fig. 11 Gate-boasting circuit principle – highlighted in red color

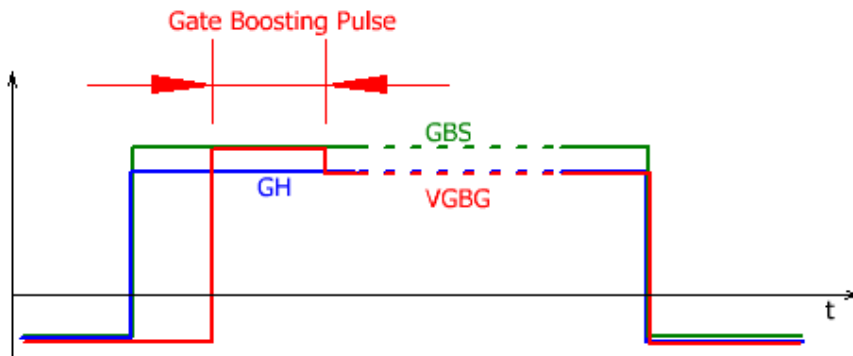


Fig. 12 Gate-boasting signals

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### **How to disable gate boosting?**

Pins VGB and GBS must be left open. Note that the voltage values of the pins VGB and GBS are 50V and 35V respectively referred to COM (creepage and clearance distances).

### **Bibliography**

- /1/ Paper: Smart Power Chip Tuning, Bodo's Power Systems, May 2007
- /2/ "Description and Application Manual for SCALE™ Drivers", Power Integrations
- /3/ Data sheet SCALE™-2 driver core 1SC0450E, Power Integrations
- /4/ Application note AN-1101: Application with SCALE™-2 and SCALE™-2+ Gate Driver Cores, Power Integrations
- /5/ Application note AN-0904: Direct Paralleling of SCALE™-2 Gate Driver Cores, Power Integrations
- /6/ Application note AN-0901: Methodology for Controlling Multi-Level Converter Topologies with SCALE™-2 IGBT Drivers, Power Integrations
- /7/ Paper: Safe Driving of Multi-Level Converters Using Sophisticated Gate Driver Technology, PCIM Asia, June 2013

**Note:** The Application Notes are available on the Internet at [www.power.com/igbt-driver/go/app-note](http://www.power.com/igbt-driver/go/app-note) and the papers at [www.power.com/igbt-driver/go/papers](http://www.power.com/igbt-driver/go/papers).

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### **The Information Source: SCALE-2 Driver Data Sheets**

Power Integrations offers the widest selection of gate drivers for power MOSFETs and IGBTs for almost any application requirements. The largest website on gate-drive circuitry anywhere contains all data sheets, application notes and manuals, technical information and support sections: [www.power.com](http://www.power.com).

### **Quite Special: Customized SCALE-2 Drivers**

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

Power Integrations has more than 25 years of experience in the development and manufacturing of intelligent gate drivers for power MOSFETs and IGBTs and has already implemented a huge number of customized solutions.

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### Ordering Information

The general terms and conditions of delivery of Power Integrations Switzerland GmbH apply.

Type Designation	Description
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1SC0450E2A0-45	Single-channel SCALE-2 driver core for 4500V IGBTs
1SC0450E2A0-65	Single-channel SCALE-2 driver core for 6500V IGBTs

Product home page: [www.power.com/igbt-driver/go/1SC0450](http://www.power.com/igbt-driver/go/1SC0450)

Refer to [www.power.com/igbt-driver/go/nomenclature](http://www.power.com/igbt-driver/go/nomenclature) for information on driver nomenclature.

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Direct link: [www.power.com/igbt-driver/go/cores](http://www.power.com/igbt-driver/go/cores)

#### For other drivers, product documentation and application support:

Please click: [www.power.com](http://www.power.com)

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