AN1944
APPLICATION NOTE

TD350 advanced IGBT driver
Principle of operation and applications

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1 INTRODUCTION

The TD350 is an advanced IGBT driver with integrated control and protection functions. The TD350 is especially adapted to drive 1200V IGBT with current ratings from 15 to 75A in Econopak-like modules (see *Figure 2*).

Main features are:

- 1.2A sink / 0.75A source peak output current minimum over full temperature range (-20°C to 125°C).
- Desaturation protection with adjustable blanking time and fault status signal.
- Active Miller clamp function to reduce the risk of induced turn-on in high dV/dt conditions, without the need of negative gate drive in most cases.
- Optional 2-step turn-off sequence to reduce over voltage in case of over current or short-circuit event, to protect IGBT and avoid RBSOA problems.
- Input stage compatible with both optocoupler and pulse transformer.

Applications include three-phase full-bridge inverter like motor speed control and UPS systems (see *Figure 1*).

Figure 1: TD350 in 1200V 3-phase inverter application

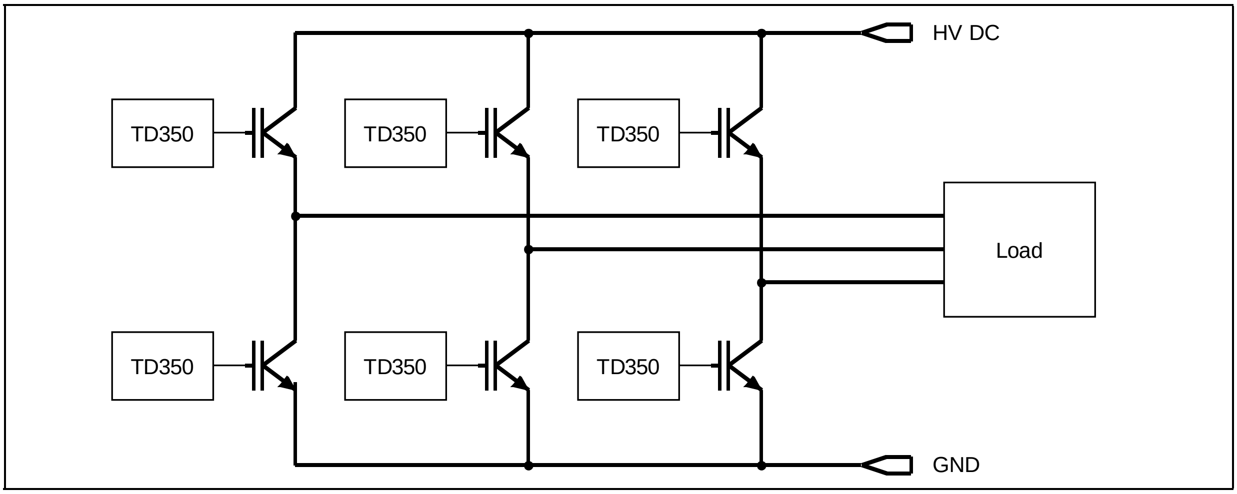
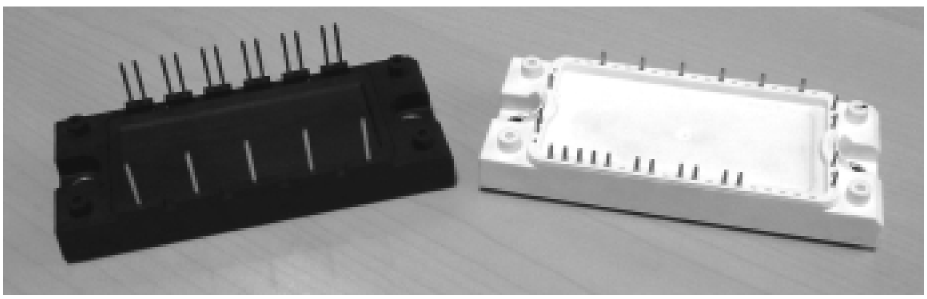


Figure 2: IGBT modules

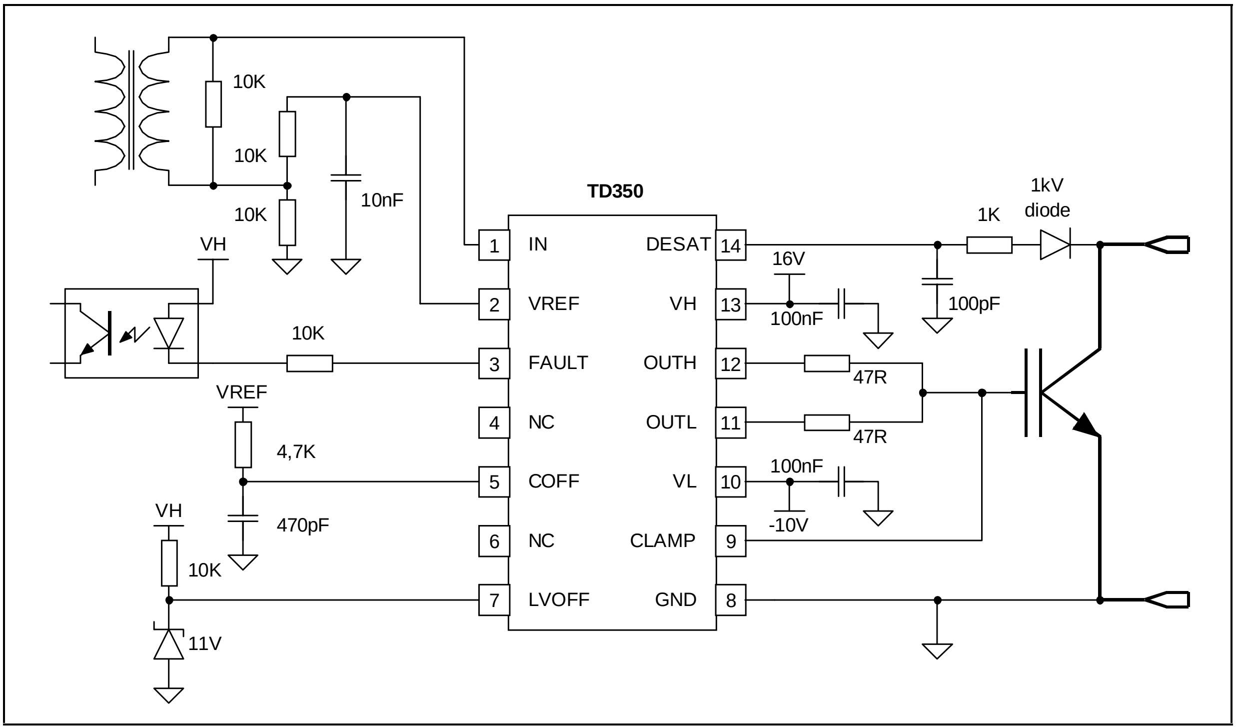


2 TD350 APPLICATION EXAMPLE

A TD350 application example is shown in *Figure 3*. In this example, the device is supplied by a +16V/-10V isolated voltage source, but a single voltage source can also be used. A pulse transformer is used for input signal galvanic isolation. Gate resistors at OUTH and OUTL pins (here 47 Ohms) are to be chosen depending on the IGBT specifications and the manufacturer recommendations. Sink and source resistor values can be independently tuned to optimize the turn-on and turn-off behaviors and can help to solve EMI issues.

As the driver may be used in a very noisy environment, care should be taken to decouple the supplies. The use of 100nF ceramic capacitors connected from VH to GND (and from VL to GND if applicable) is recommended. The capacitors should be located as close as possible to the TD350 and the ground loops should be reduced as much as possible.

Figure 3: TD350 application example showing all the features



3 INPUT STAGE

The TD350 is compatible with both pulse transformer or optocoupler. The schematics shown in *Figure 4* can be considered as example of use with both solutions.

When using an optocoupler, the IN input must be limited to about 5V. The pull up resistor to VH is to be chosen between 5kOhms to 20kOhms depending on optocoupler characteristic. An optional filtering capacitor can be added in the event of a highly noisy environment, although the TD350 already includes a filtering on input signals and rejects signals smaller than 100ns (t_{onmin} specification).

When using a pulse transformer, a 2.5V reference point can be built from the 5V VREF pin with a resistor bridge. The capacitor between the VREF pin and the bridge middle-point provides decoupling of the 2.5V reference, and also insures a high level on the IN input pin at power-up to start the TD350 in OFF state. The waveform from the pulse transformer must comply with the t_{onmin} and V_{ton}/V_{toff} specifications. To turn the TD350 outputs on, the input signal must be lower than 0.8V for 220ns minimum. Conversely, input signal must be higher that 4.2V for 200ns minimum to turn off TD350 outputs. A pulse width of about 500ns at these threshold levels is recommended. In all cases, input signal at the IN pin must be between 0 and 5V.

Figure 4: Application schematic (pulse transformer: left / optocoupler: right)

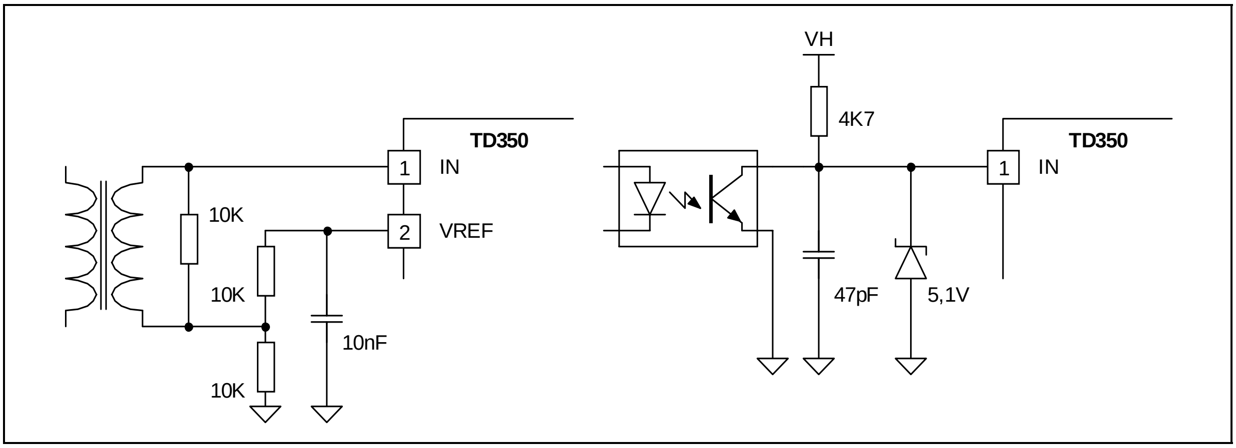
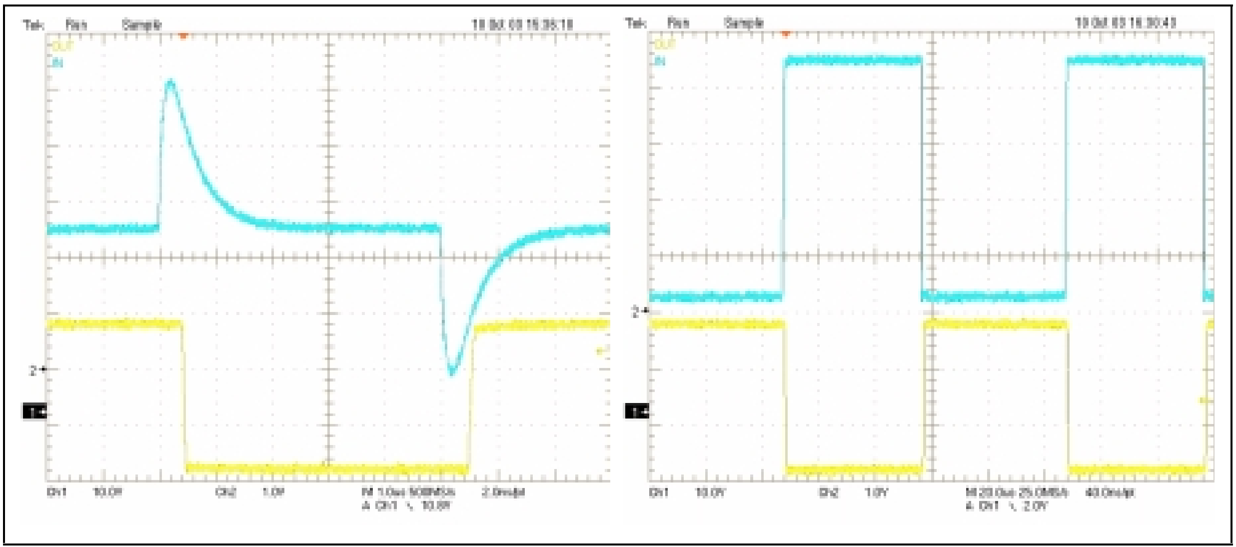


Figure 5: Typical input signal waveforms with pulse transformer (left) or optocoupler (right)



4 OUTPUT STAGE

The output stage is able to sink/source about 2A/1.5A typical at 25°C with a voltage drop VOL/VOH of 5V (see *Figure 6*). The minimum sink/source currents over the full temperature range (-20°C/+125°C) are 1.2A sink and 0.75A source. VOL and VOH voltage drops at 0.5A are guaranteed to 3V and 4V maximum respectively, over the temperature range (see *Figure 7*). This current capability sets the limit of IGBT driving, and the IGBT gate resistor should not be lower than about 15Ω.

The TD350 uses separate sink and source outputs (OUTL/OUTH) for easy gate driving. Output current capability can be increased by using an external buffer with two low-cost bipolar transistors.

Figure 6: Typical Output stage current capability at 25°C (VH=16V, VL=-10V)

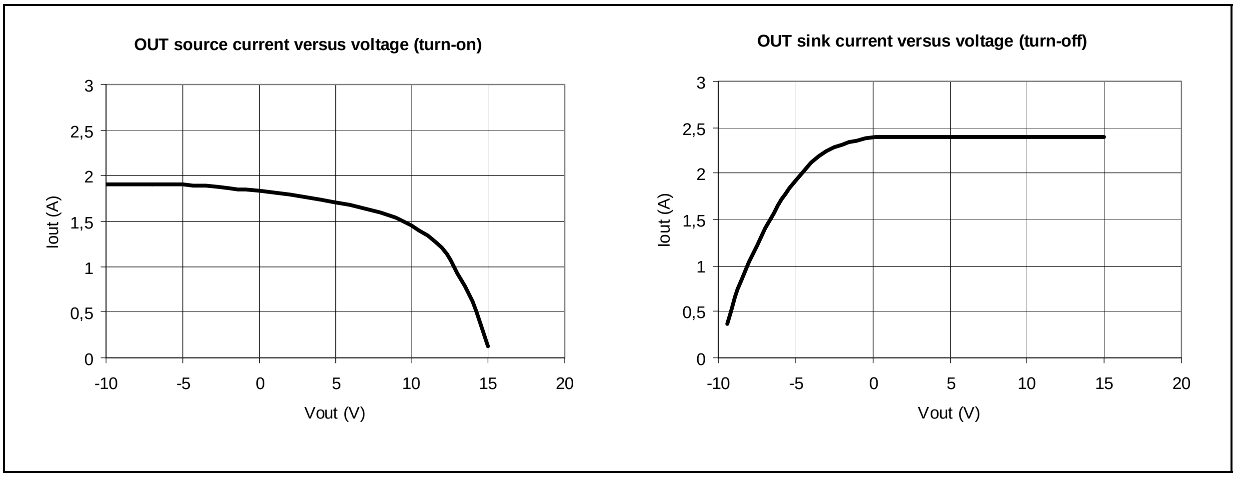
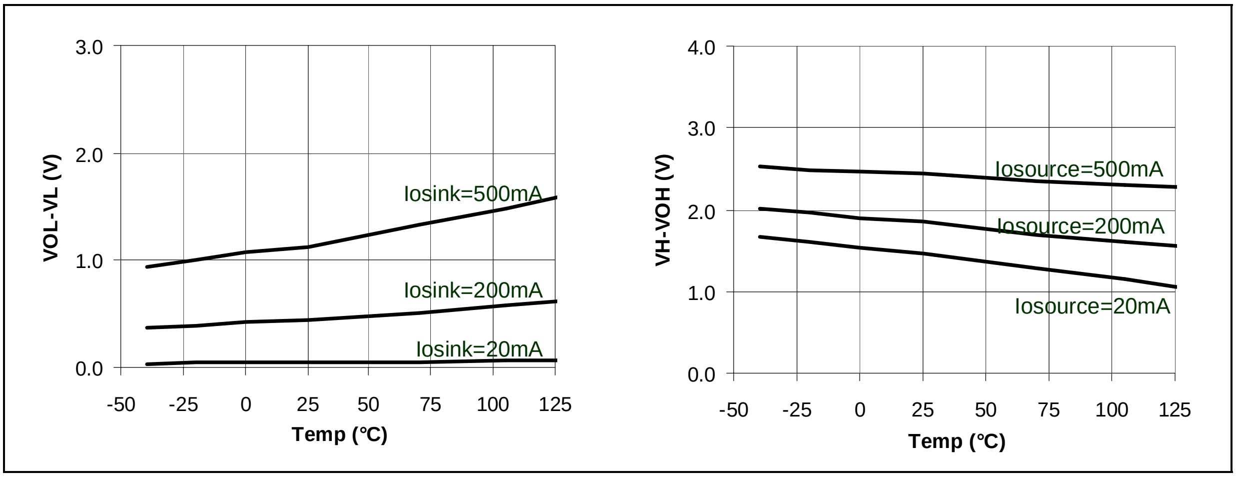


Figure 7: Typical VOL and VOH voltage variation with temperature



5 ACTIVE MILLER CLAMP

The TD350 offers an alternative solution to the problem of the Miller current in IGBT switching applications. Instead of driving the IGBT gate to a negative voltage to increase the safety margin, the TD350 uses a dedicated CLAMP pin to control the Miller current. When the IGBT is off, a low impedance path is established between IGBT gate and emitter to carry the Miller current, and the voltage spike on the IGBT gate is greatly reduced (see *Figure 8*). The CLAMP switch is opened when the input is activated and is closed when the actual gate voltage goes close to the ground level. In this way, the CLAMP function doesn't affect the turn-off characteristic, but only keeps the gate to the low level throughout the off time. The main benefit is that negative voltage can be avoided in many cases, allowing a bootstrap technique for the high side driver supply.
The waveform shown in *Figure 9* proves how the Active Miller Clamp can allow a consistent reduction of the voltage spike on IGBT gate.

Figure 8: Active Miller Clamp: principle of operation

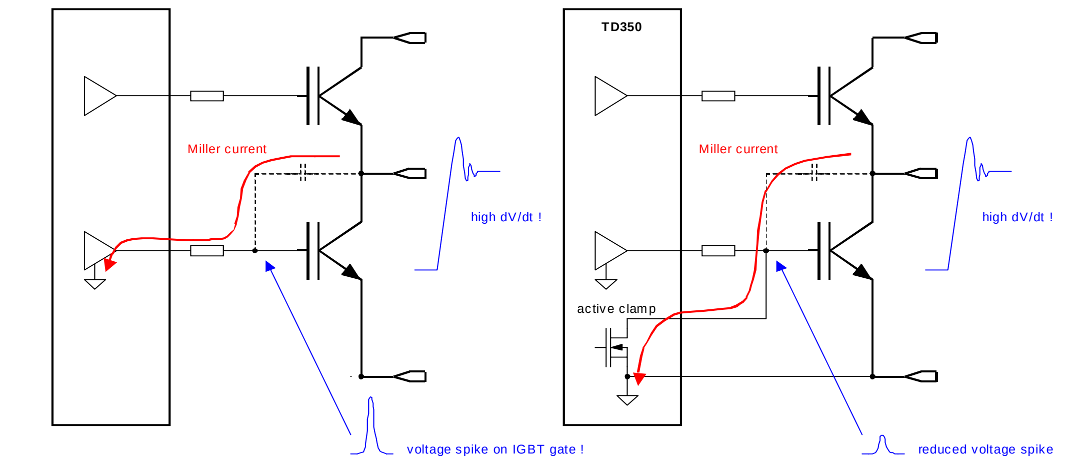
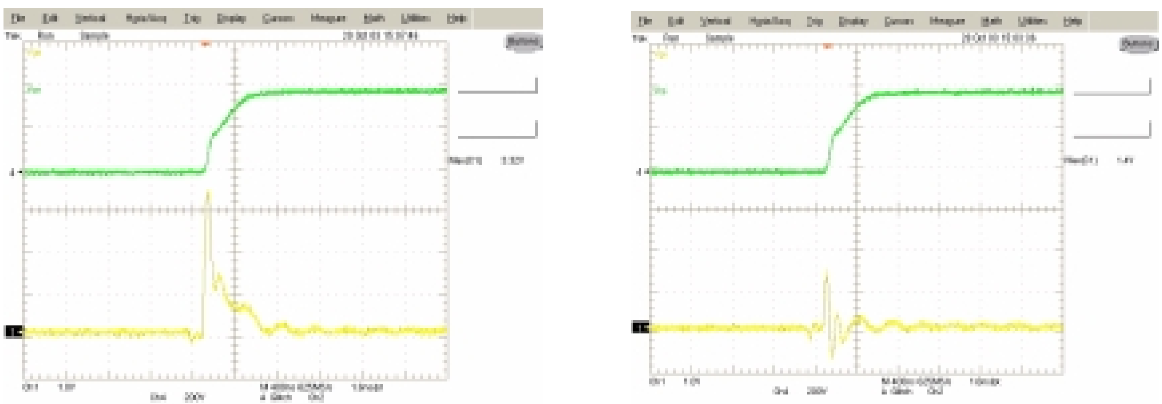


Figure 9: Reduction of gate voltage spike by Active Miller Clamp

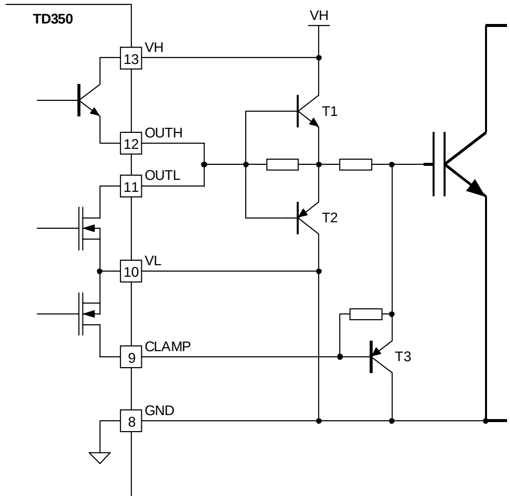


without Miller clamp
Vgs spike higher than 3V!

Miller clamp implemented
in the same conditions,
the Vgs spike is reduced to less than 1V

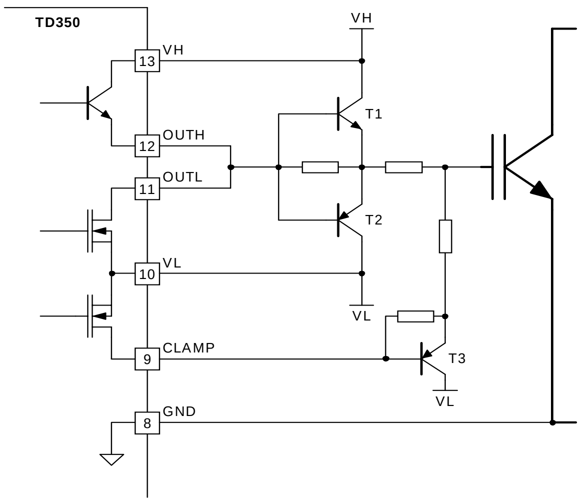
For high power applications, a buffer can be used at the CLAMP pin, in the same way as at the driver output. *Figure 10* shows a schematic principle with external buffers for both the driver output and the Clamp function.

Figure 10: Using external buffer to increase the current capability of the driver and Clamp outputs



For very high-power applications, the Active Clamp function can not replace the negative gate drive, due to the effect of the parasitic inductance of the Active Clamp path. In these cases, the application can take benefit from the CLAMP output as an secondary gate discharge path (see *Figure 11*). When the gate voltage goes below 2V (i.e. the IGBT is already driven off), the CLAMP pin is activated and the gate is rapidly driven to the negative voltage. Again, the benefit is to improve the time to drive IGBT with large gate capacitance to the low level without affecting the IGBT turn-off characteristics.

Figure 11: CLAMP used as secondary gate discharge path in large power application



Tip: ***What to do with the CLAMP pin when not used?***
Connect CLAMP to VL.

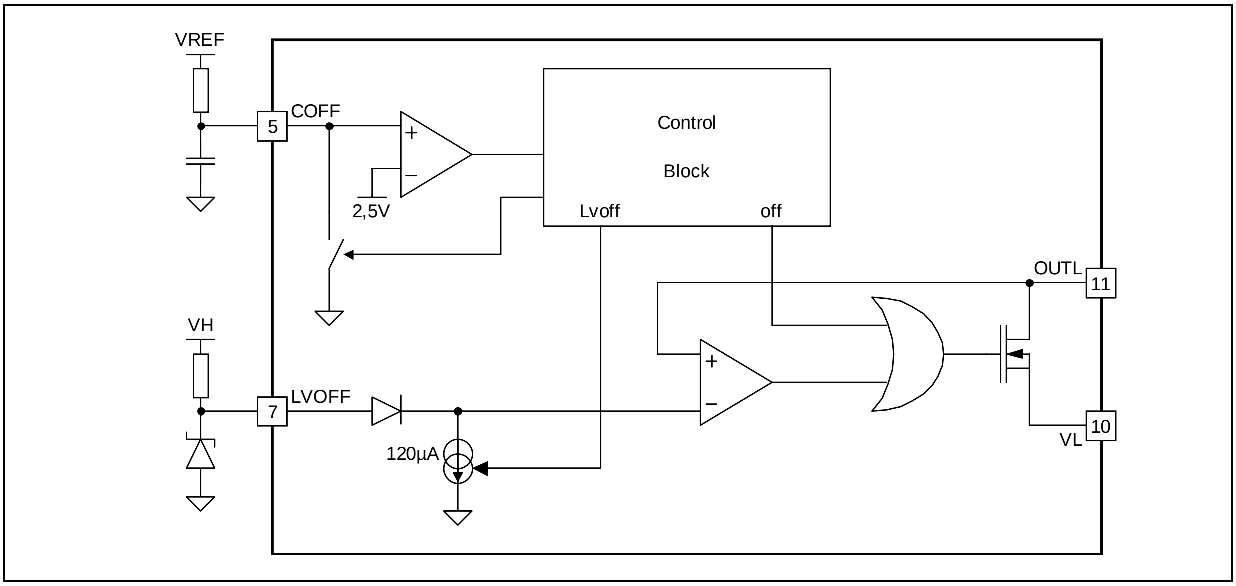
6 2-LEVEL TURN-OFF

In the event of a short-circuit or overcurrent in the load, a large voltage overshoot can occur across the IGBT at turn-off and can exceed the IGBT breakdown voltage. By reducing the gate voltage before turn-off, the IGBT current is limited and the potential over voltage is reduced. This technique is called 2-level turn-off. Both the level and duration of the intermediate off level are adjustable. Duration is set by an external resistor/capacitor in conjunction with the integrated voltage reference for accurate timing. The level can be easily set by an external Zener diode, and its value is chosen depending upon the IGBT characteristics. This 2-level turn-off sequence takes place at each cycle; it has no effect if the current doesn't exceed the normal maximum-rated value, but protects the IGBT in case of overcurrent (with a slight increase of conduction losses).

This principle is shown on *Figure 12*. During the 2-level turn-off time, the OUTL output is controlled by a comparator between the actual OUTL pin and an external reference voltage. When the voltage on OUTL goes down as a result of the turn-off and reach the reference threshold, then the OUTL output is disabled and the IGBT gate is not discharged further. After the 2-level turn-off delay, the OUTL output is enabled again to end the turn-off sequence.

To keep the output signal width unchanged relative to the input signal, the turn-on is delayed by the same value than the 2-level turn-off delay (see *Figure 13*).

Figure 12: Principle schematic for 2-level turn-off feature

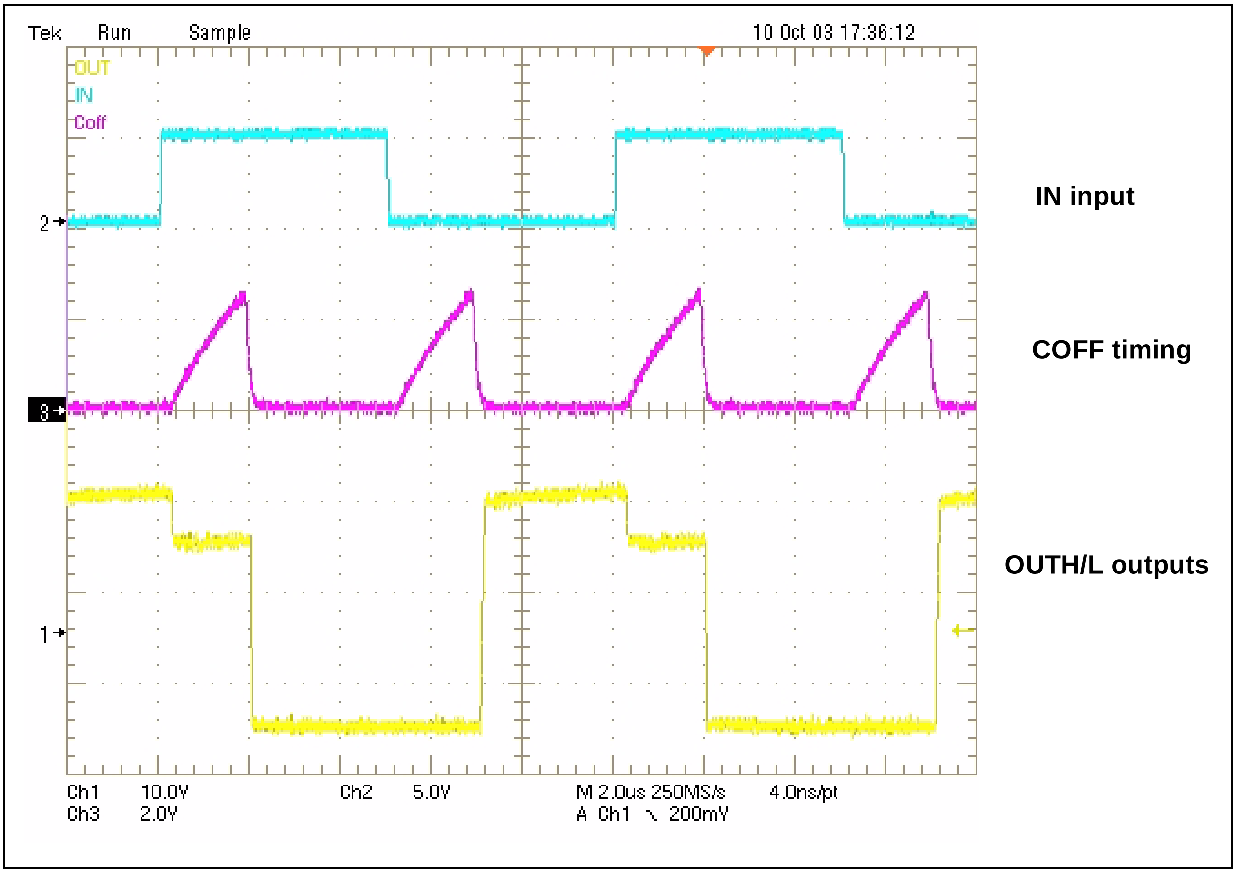


The duration of the 2-level turn-off is set by the external R-C components, and is given by the formula:

T_a (in µs) = *0.7* * R_{off} (in kΩ) * C_{off} (in nF)

For example: With R_{off}=10kΩ and C_{off}=220pF, T_a delay is about 1.5 microseconds. Recommended values are R_{off} from 10kΩ to 20kΩ, and C_{off} from 100pF to 330pF, providing a range of delay from about 0.7 to 4.6 microseconds.

Figure 13: Waveforms of the 2-level turn-off function (COFF timing exaggerated for illustration)

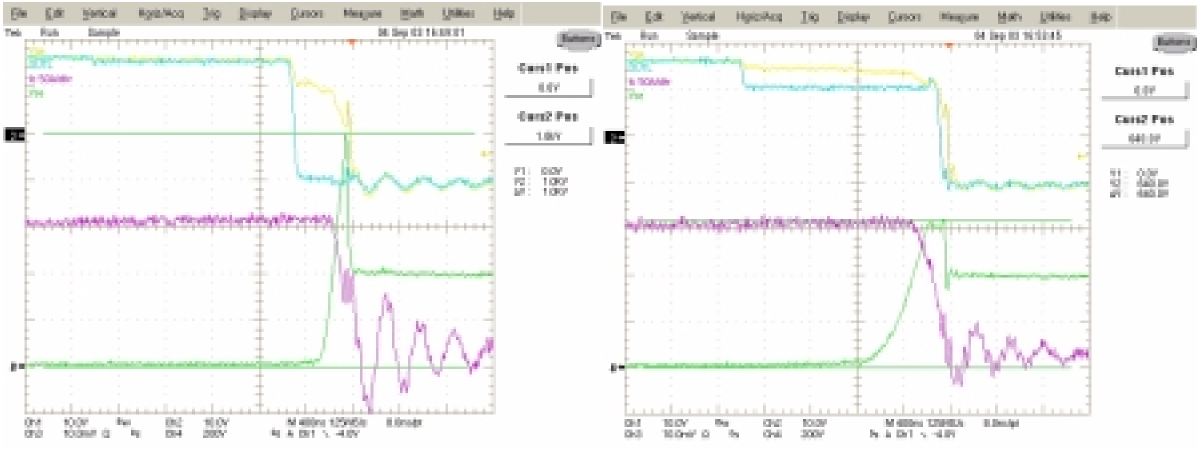


Tests with an IGBT module of 1200V and 25A (Eupec FP25R12KE) are shown in *Figure 14* for a 150A overcurrent event.

Classical turn-off: OUT voltage is turned-off from VH=16V to VL=-10V
2-level turn-off: OUT voltage is turned-off from VH=16V to LVOFF=11V during 1.5µs and ultimately OUT is pulled to VL=-10V

The maximum voltage reached on the IGBT collector and commutation losses are shown in *Table 1* for both nominal rated current at 25°C (40A) and overcurrent (150A) conditions. There is no noticeable difference at nominal current, and the overvoltage is greatly reduced in case of overcurrent event.

Figure 14: Reduction of IGBT overvoltage stress using 2-level turn-off feature



Without 2-level turn-off
Vce max reaches 1000V!

2-level turn-off implemented
Vce max is reduced to 640V

Table 1: Comparison between classical turn-off and 2-level turn-off

	400V/40A		400V/150A	
Turn-off mode	**Eoff (mJ)**	**Vce max (V)**	**Eoff (mJ)**	**Vce max (V)**
classical turn-off	2.5	620	15	**1000**
2-level turn-off with LVoff=11V	2.5	620	23	**640**

Tip: ***How does one disable the 2-level turn-off feature?***
Connect LVOFF to VH, remove C_{off} capacitor and keep COFF pin connected to Vref by a 4.7kΩ to 10kΩ resistor.

7 DESATURATION PROTECTION FEATURE

The desaturation function provides a protection against overcurrent events. Voltage across the IGBT is monitored, and the IGBT is turned off if the voltage threshold is reached. A blanking time is made of an internal 250µA current source and an external capacitor. The high voltage diode blocks the high voltage during IGBT off state. This diode doesn't need to be fast, a standard 1kV (or more) diode is usable. The 1kΩ (or so) resistor filters parasitic spikes and also protects the DESAT input (see *Figure 15*).

During operation, the DESAT capacitor is discharged when TD350 output is low (IGBT off). When the IGBT is turned on, the DESAT capacitor starts charging and desaturation protection is effective after the blanking time tb = 7.2V * Cdesat / 250µA

*tb (in µs) = 0.03 * Cdesat (in pF)*

When a desaturation event occurs, the fault output is pulled down and TD350 outputs are low (IGBT off) until the IN input signal is released (high level), then activated again (low level).

Figure 16 shows a desaturation fault at 150A on a typical 25A module.

Figure 15: Application schematic for DESAT feature

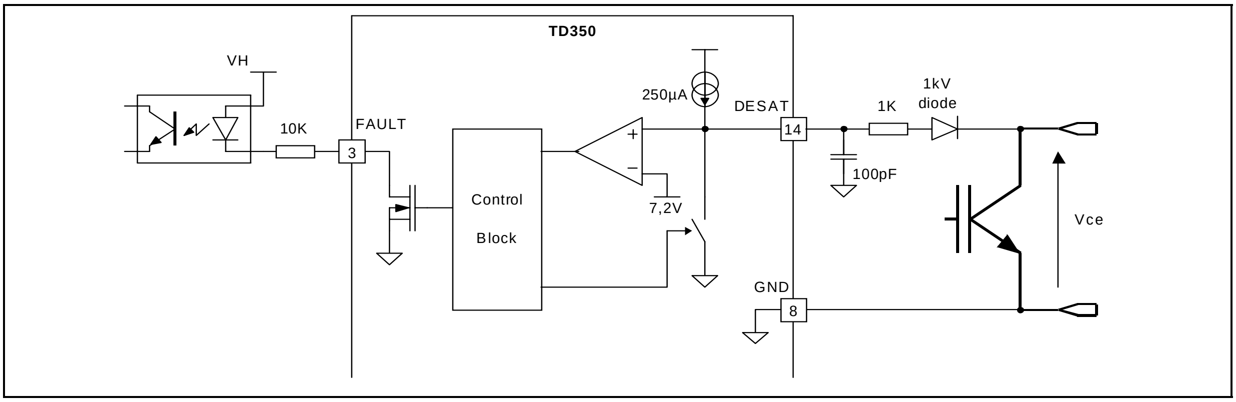
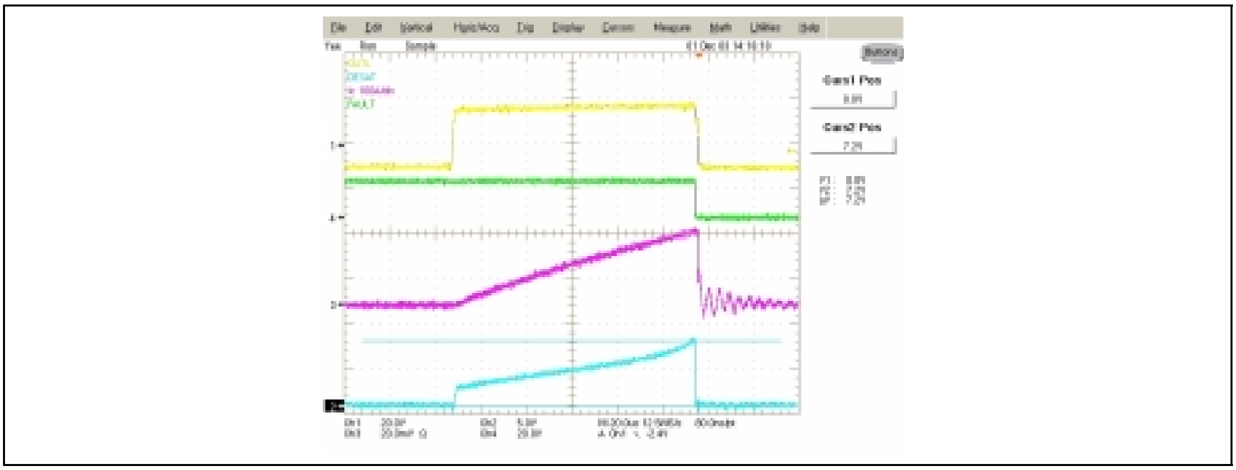


Figure 16: The collector current ramp-up to 150A triggers the DESAT feature (test on 25A module)



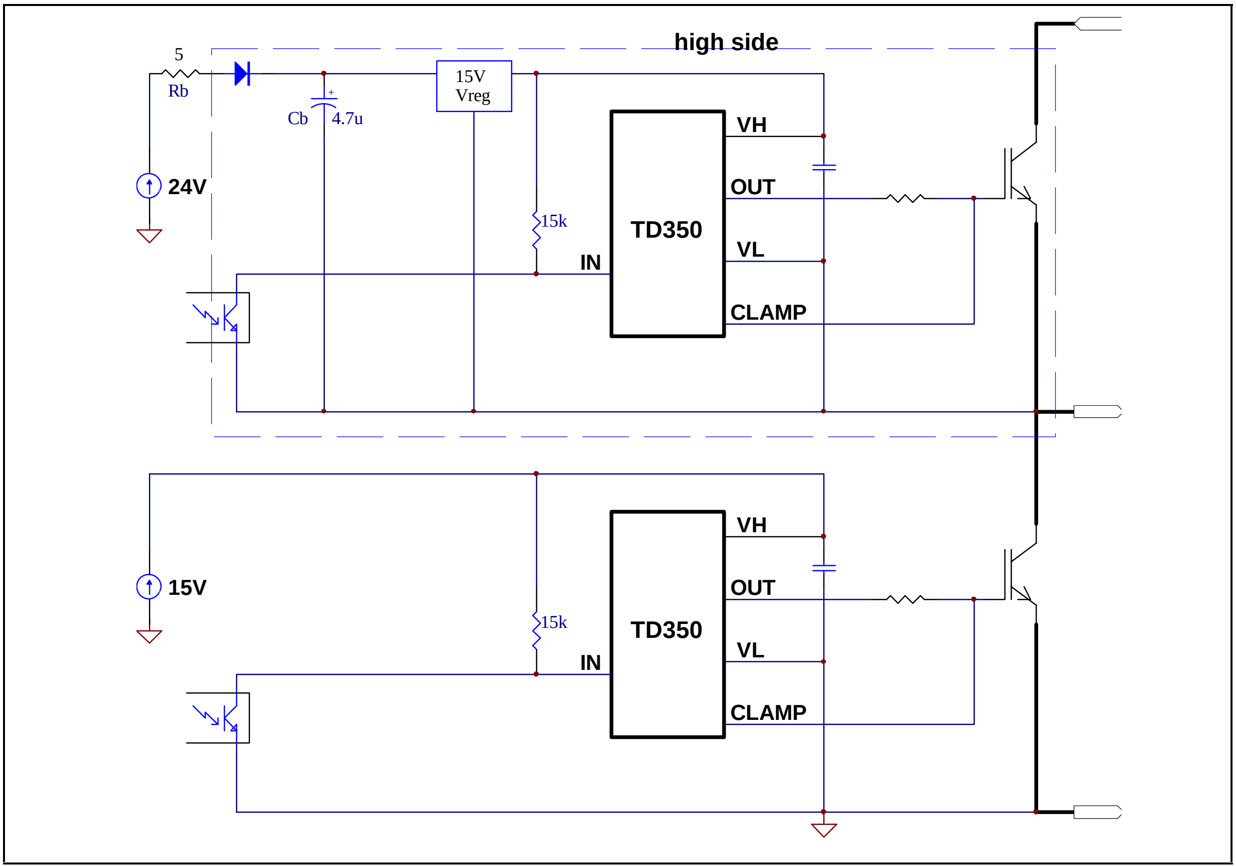
Tip: ***What should one do with the DESAT pin when it's not used?***
Connect DESAT to GND.

8 APPLICATION SCHEMATICS

The TD350 application designs presented hereafter are based on the Active Miller Clamp concept. With this function, the high side driver can be supplied with a bootstrap system instead of using a floating positive/negative supply (see *Figure 16*). This concept is applicable to low and medium power systems, up to about 10kW. The main benefit of this is to reduce the global application cost by making the supply system simpler. *Figure 17* shows the half bridge design concept using the TD350.

It should be highlighted that the Active Miller Clamp is fully managed by the TD350 and doesn't require any special action from the system controller.

Figure 17: TD350 Application Concept



The TD350 is able to drive 1200V IGBT modules up to 50A or 75A (depending on IGBT technology and manufacturer). Key parameters to consider are the TD350 peak output current (0.75A source / 1.2A sink) and the IGBT gate resistor.

The values of gate resistors should be chosen starting with the recommended values from the IGBT manufacturer. The TD350 allows different values for source and sink. Thanks to the Active Miller Clamp function, the gate resistors can be tuned independently from the Miller effect that normally put some constraints on the gate resistor. The benefit of this is the optimization of turn-on and turn-off behavior, especially regarding switching loses and EMI issues.

Table 2 shows the recommended gate resistors values from two major IGBT module manufacturers, and the peak gate current (with a 15V supply) required for 10A to 100A IGBT modules. Approximate application power is indicated.

Table 2: Recommended Gate Resistors

Eupec: FPxxR12KE3		**15**	**25**		**40**	**50**	75		A
Rgate		**75**	**36**		**27**	**18**	5		ohms
Ipeak		**0.2**	**0.4**		**0.55**	**0.8**	3		A
Fuji: 6MBIxxS-120	**10**	**15**	**25**	**35**		**50**	**75**	100	A
Rgate	**120**	**82**	**51**	**33**		**24**	**16**	12	ohms
Ipeak	**0.12**	**0.2**	**0.3**	**0.45**		**0.6**	**0.9**	1.3	A
App. Power	**1.5**	**2**	**3**	**4**	**5**	**7**	**11**	15	kW

IGBT modules suitable for TD350 are indicated in bold. For the FP50R12KE3 and 6MBI75S-120 modules, the source (charging) peak current will be limited to 0.75A in worst-case conditions instead of the theoretical 0.8A or 0.9A peak values, this usually doesn't affect the application performance.
An external buffer will be required for higher power applications.

Reference schematics are shown in *Figure 18* and *Figure 19*. Both use the bootstrap principle for the high side driver supply. A very simple voltage regulator is used in front of the TD350 high side driver. In this way, the bootstrap supply voltage can be made significantly higher than the target driver supply, and the voltage across the Cb bulk capacitor can exhibit large voltage variations during each cycle with no impact on the driver operation.
Gate resistors RgL and RgH depend on the IGBT. It should be noted that the applications only use two supplies referenced to the ground level.

The application in *Figure 18* uses desaturation detection for protection in case of overcurrent. Fault feedback is not used.

Application on *Figure 19* uses the two-level turn-off function (level=11V, duration=1.5µs) instead of desaturation detection, with the benefit of saving a high voltage diode and avoiding a connection to the IGBT collector.

It may be useful to use both methods together. In this case, just add the components for desaturation detection together with the 2-level turn-off schematic.

Figure 18: TD350 Application Schematic with Desaturation Protection

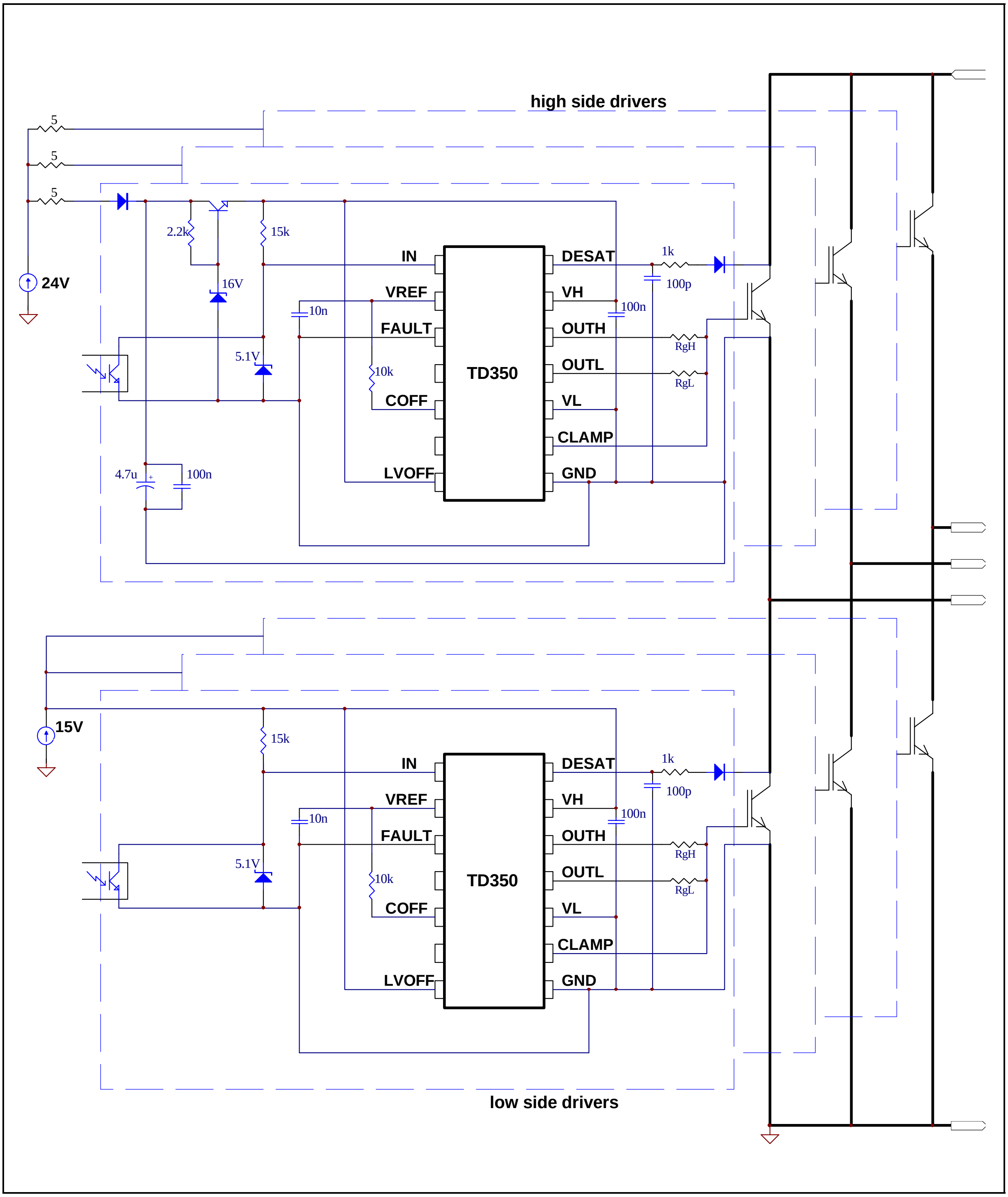
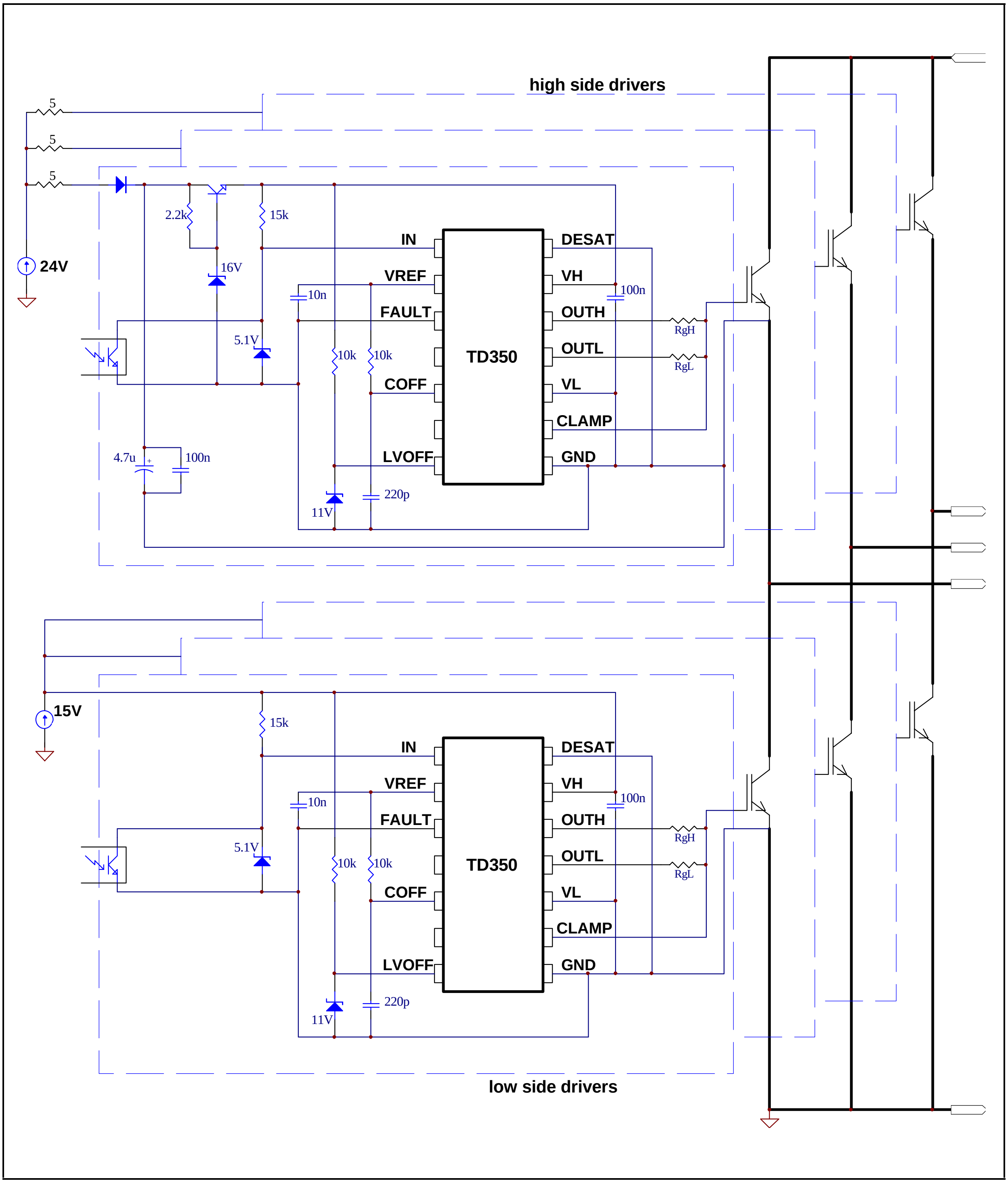


Figure 19: TD350 Application Schematic with 2-Level Turn-off



9 CONCLUSION

The TD350 is a versatile device designed for 1200V, 3-phase inverter applications, especially for motor control and UPS systems. It covers a large range of power applications, from 0.5kW to more than 100kW. Thanks to its Active Miller Clamp feature and low quiescent current, it can help avoid using negative gate driving for applications up to 10kW and simplifies the global power supply system for cost-sensitive applications.

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