AN1944
Application note

Developing IGBT applications using an TD350 advanced IGBT driver

Introduction

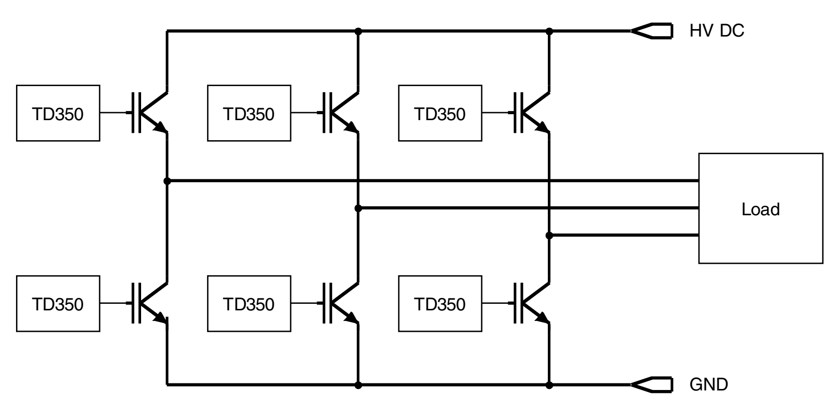
The TD350 is an advanced Insulated Gate Bipolar Transistor (IGBT) driver with integrated control and protection functions. The TD350 is especially adapted for driving 1200V IGBTs with current ratings from 15 to 75A in Ecopak-like modules.

Main features are:

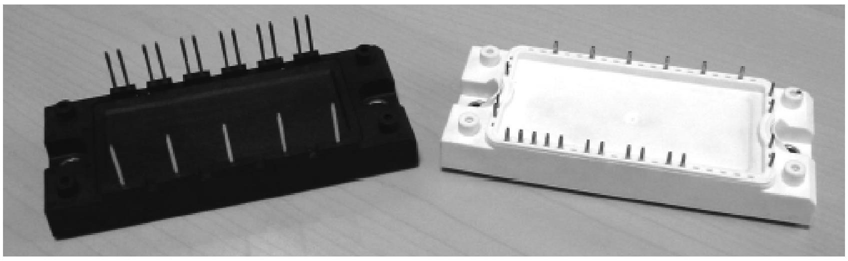
- Minimum1.2A sink / 0.75A source peak output current over full temperature range (-20°C to 125°C)
- Desaturation protection with adjustable blanking time and fault status signal
- Active Miller clamp function to reduce the risk of induced turn-on in high dV/dt conditions without the need of negative 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 optocouplers and pulse transformers

Applications include a three-phase full-bridge inverter used for motor speed control and UPS systems.

TD350 in 1200V 3-phase inverter application



IGBT modules



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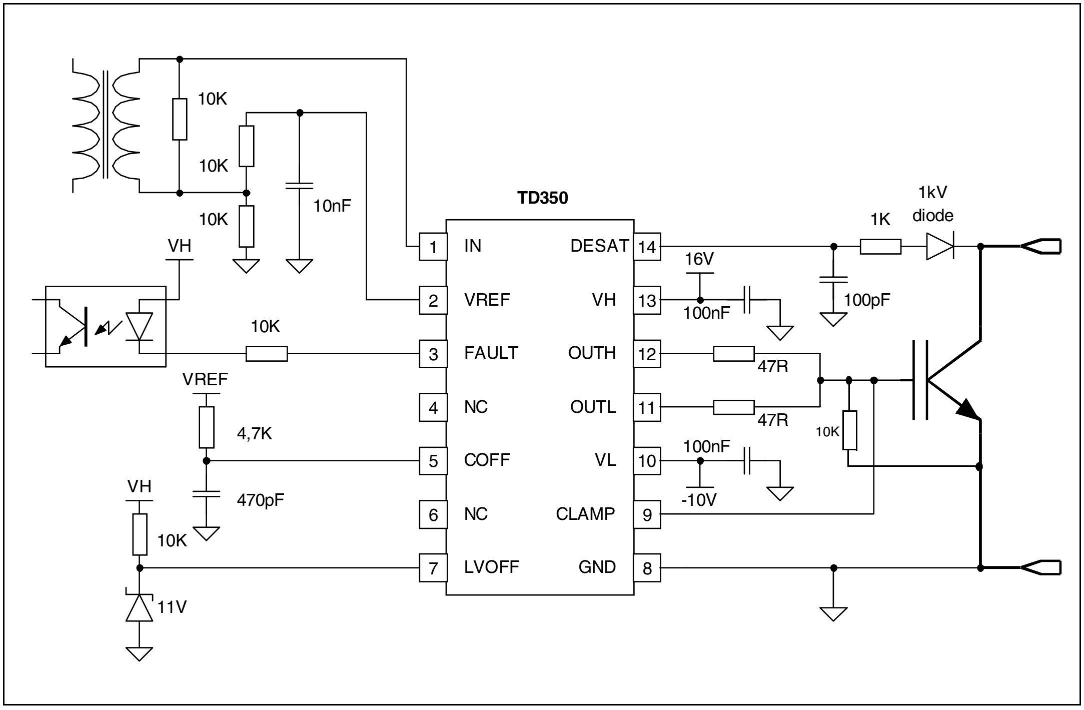
1 TD350 application example

Figure 1 shows an example of a TD350 application where 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.

The pull-down resistor (10kOhms in this example) connected between gate and emitter of the external IGBT ensures that the external IGBT remains OFF during the TD350 power-up sequence.

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 1. TD350 application example showing all the features



2 Input stage

The TD350 is compatible with both pulse transformers or optocouplers. The schematic diagram shown in *Figure 2* can be considered as example of use with both solutions.

When using an optocoupler, the IN input must be limited to approximately 5V. The pull-up resistor to VH must be between 5kOhms and 20kOhms, depending on optocoupler characteristics. 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 divider. The capacitor between the VREF pin and the resistor divider middle-point provides decoupling of the 2.5V reference, and also ensures 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 ON the TD350 outputs, the input signal must be lower than 0.8V for at least 220ns. Conversely, the input signal must be higher than 4.2V for at least 200ns to turn OFF TD350 outputs. A pulse width of about 500ns at these threshold levels is recommended. In all cases, the input signal at the IN pin must be between 0 and 5V.

Figure 2. Application schematic (pulse transformer: left / optocoupler: right)

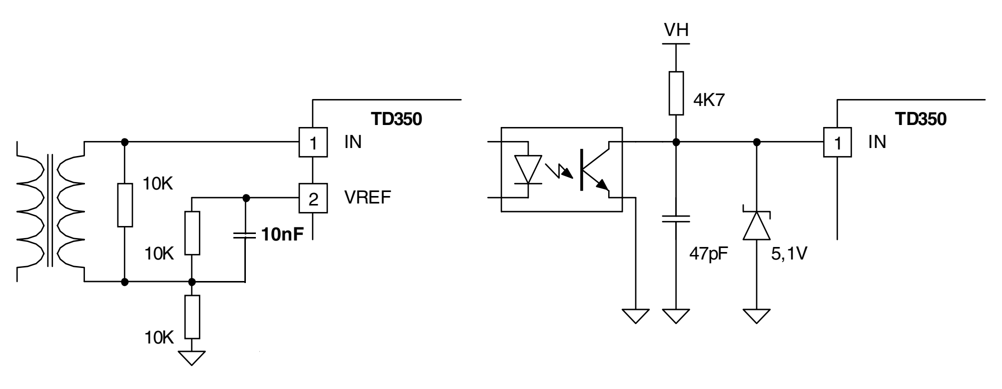
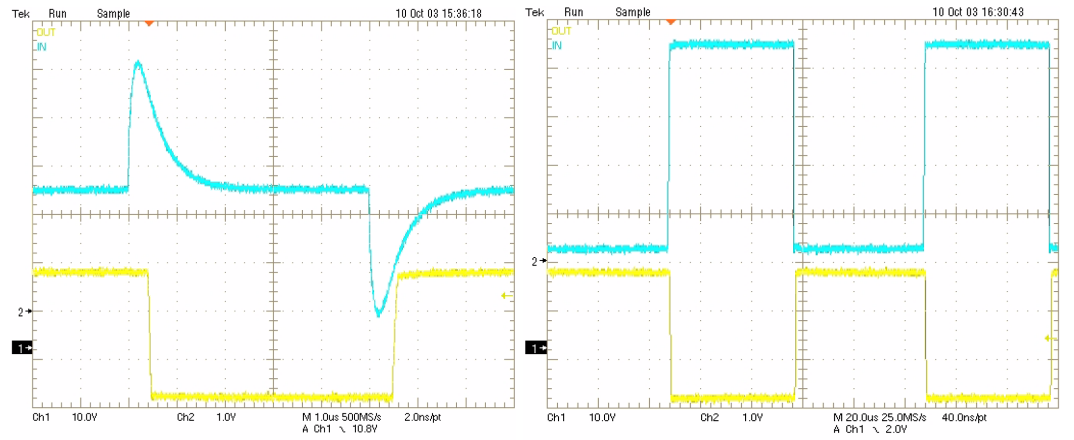


Figure 3. Typical input signal waveforms with pulse transformer (left) or optocoupler (right)



3 Output stage

The output stage is able to sink/source about 2A/1.5A typical at 25°C with a voltage drop V_{OL}/V_{OH} of 5V (*Figure 4*). The minimum sink/source currents over the full temperature range (-20°C/+125°C) are 1.2A sink and 0.75A source. V_{OL} and V_{OH} voltage drops at 0.5A are guaranteed to 3V and 4V maximum respectively, over the temperature range (*Figure 5*). This current capability sets the limit of IGBT driving, and the IGBT gate resistor should not be lower than approximately 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 4. Typical output stage current capability at 25°C (VH = 16V, VL = -10V)

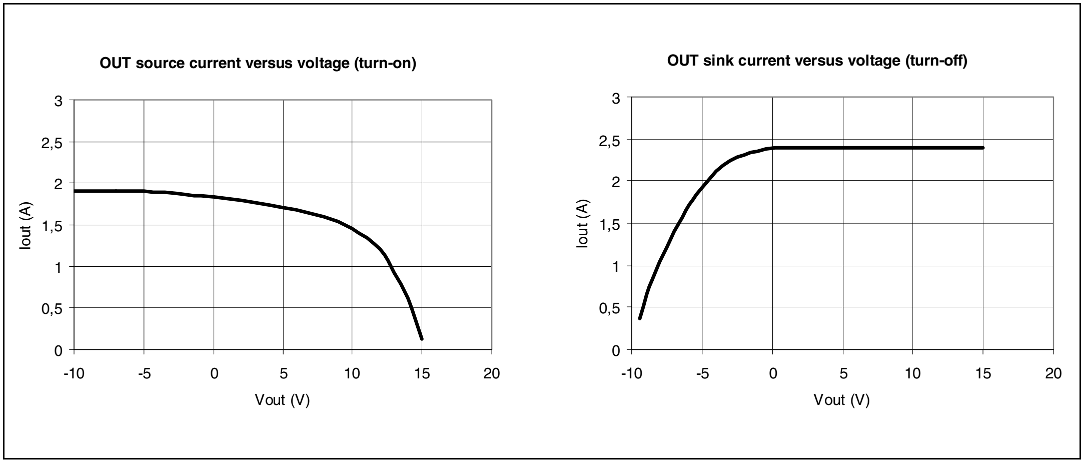
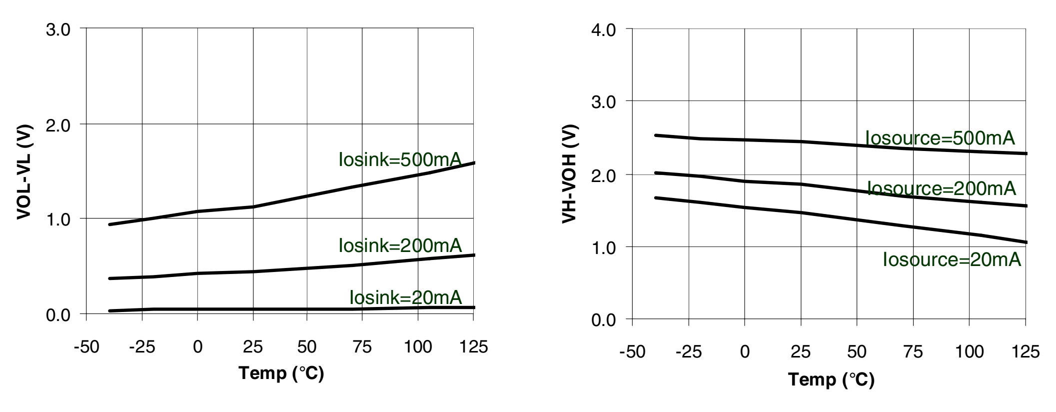


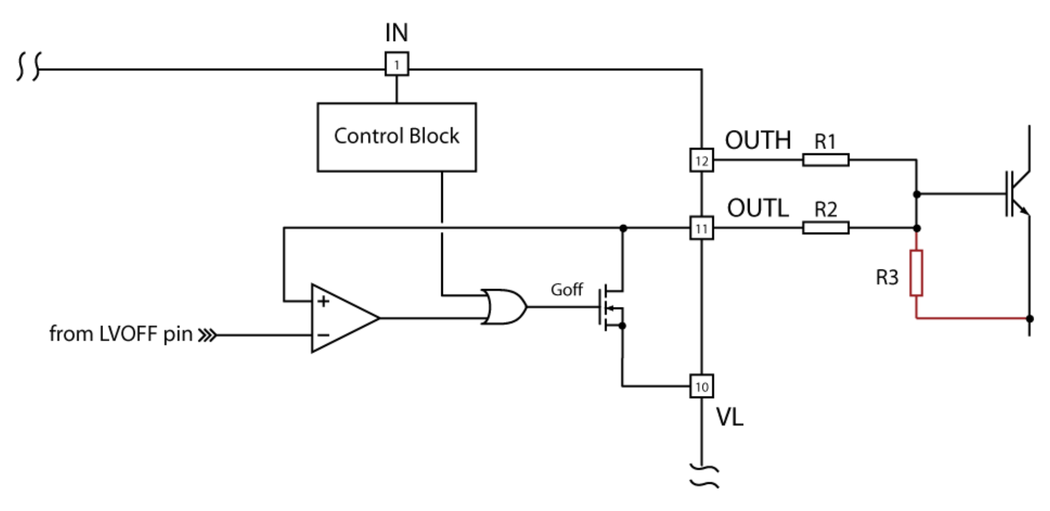
Figure 5. Typical VOL and VOH voltage variation with temperature



During the power-on sequence, it is not guaranteed that the Goff signal, which controls the OUTL-MOS (see TD350 output stage schematic diagram in *Figure 6*), stays HIGH. In this case when TD350 goes out from UVLO condition, the OUTL-MOS is turned off and OUTL is in High-Impedance state until the first IN transition occurs. In these conditions some leakage effects might slowly charge the external IGBT gate-emitter capacitance.

Thus, it is recommended the use of a pull-down resistor of 10 kOhm or less (R3 in *Figure 6*) connected between the gate and emitter of the external IGBT.

Figure 6. TD350 output stage schematic



4 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 7*). 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 8* proves how using the Active Miller clamp provides a consistent reduction of the voltage spike on IGBT gate.

Figure 7. Active Miller clamp: principle of operation

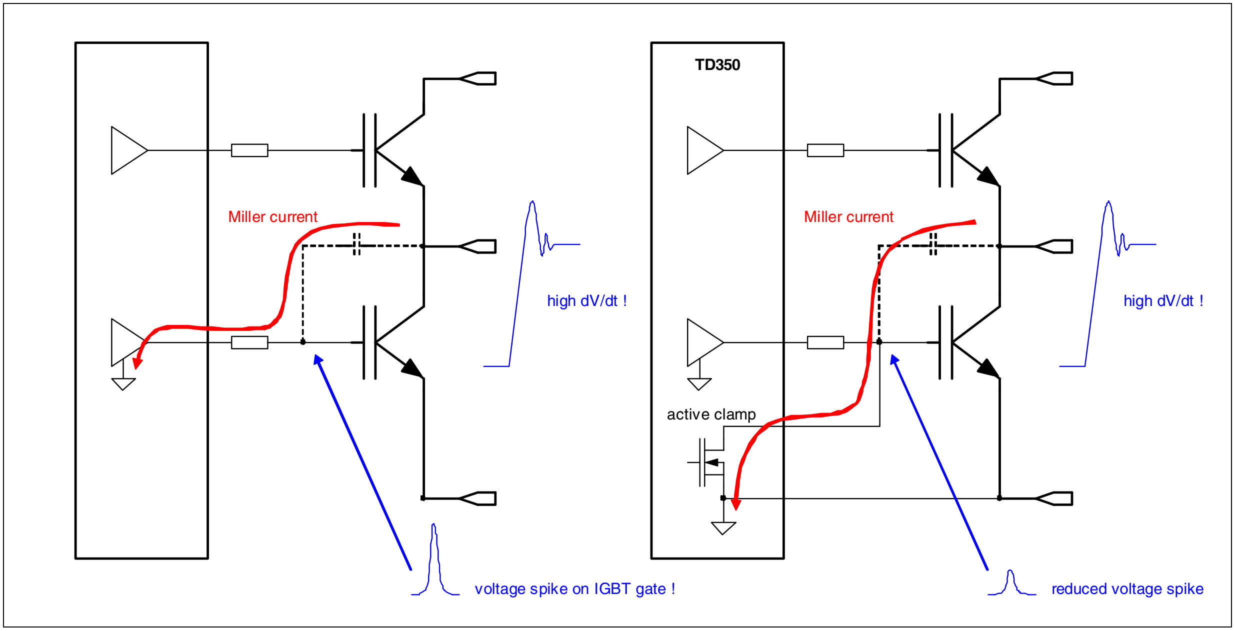
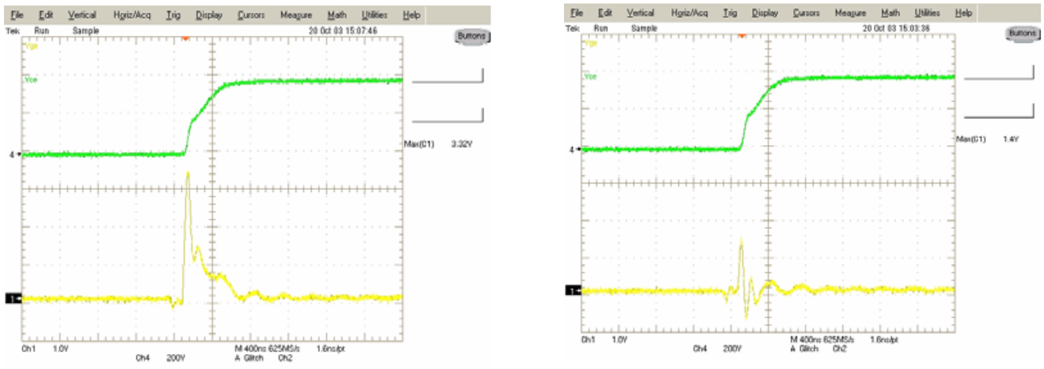


Figure 8. Reduction of gate voltage spike by active Miller clamp

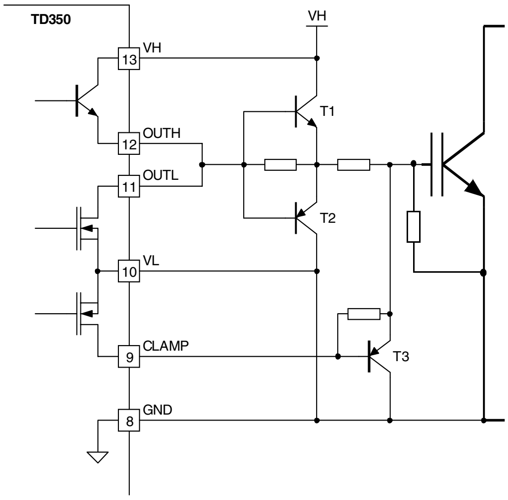


without Miller clamp
Vgs spike higher than 3V!

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 9* shows a schematic principle with external buffers for both the driver output and the CLAMP function.

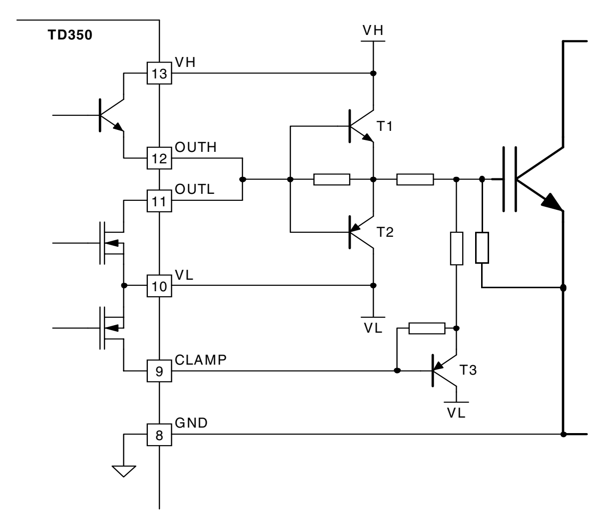
Figure 9. Using external buffer to increase the current capability of the driver and CLAMP outputs



For very high-power applications, the Active Clamp function cannot replace the negative gate drive, due to the effect of the parasitic inductance of the Active Clamp path. In these cases, the application can benefit from the CLAMP output as an secondary gate discharge path (see *Figure 10*).

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 10. CLAMP used as secondary gate discharge path in large power applications



Caution: What to do with the CLAMP pin when not used?

Connect the CLAMP pin to VL.

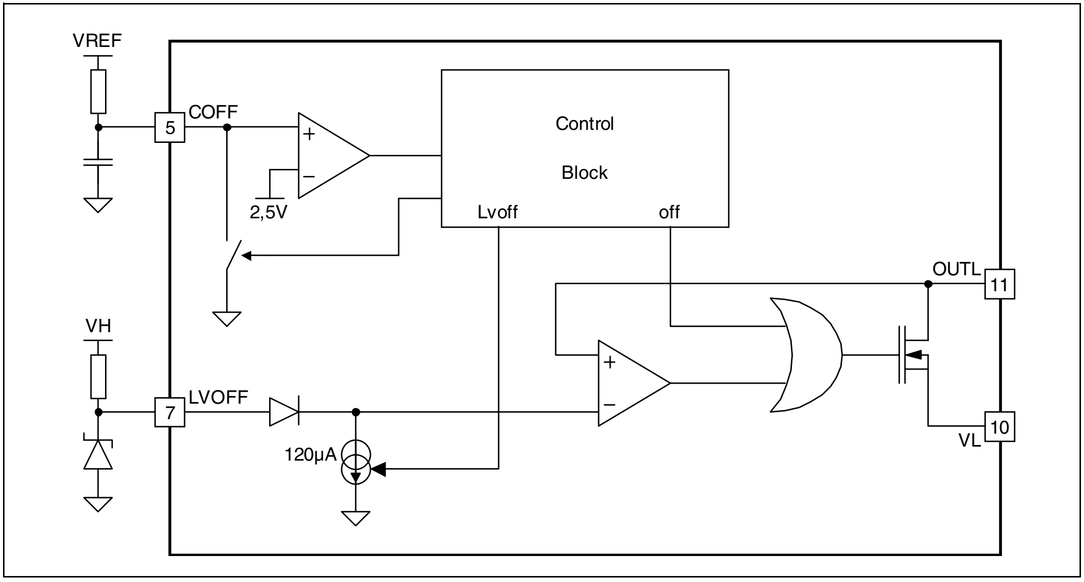
5 2-Level turn-off

In the event of a short-circuit or over-current 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 a 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 selected depending on the IGBT characteristics. This 2-level turn-off sequence takes place at each cycle; it has no effect if the current does not exceed the normal maximum-rated value, but protects the IGBT in case of over-current (with a slight increase of conduction losses).

This principle is shown on *Figure 11*. 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 as the 2-level turn-off delay (*Figure 12*).

Figure 11. Principle schematic for 2-level turn-off feature



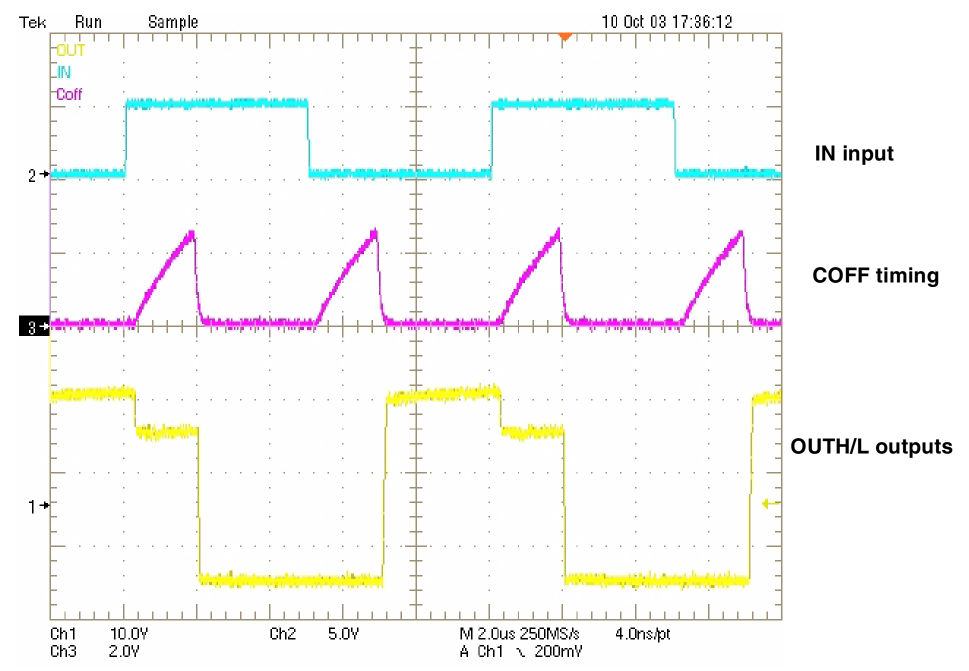
The duration of the 2-level turn-off is set by the external RC components, and is given by the formula:

Equation 1

$$t_A[\mu s] = 0.7 \bullet R_{off}[K\Omega] \bullet C_{off}[nF]$$

For example: With R_{off}=10kΩ and C_{off}=220pF, t_A delay is approximately 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 approximately 0.7 to 4.6 microseconds.

Figure 12. Waveforms of the 2-level turn-off function (COFF timing exaggerated for illustration)

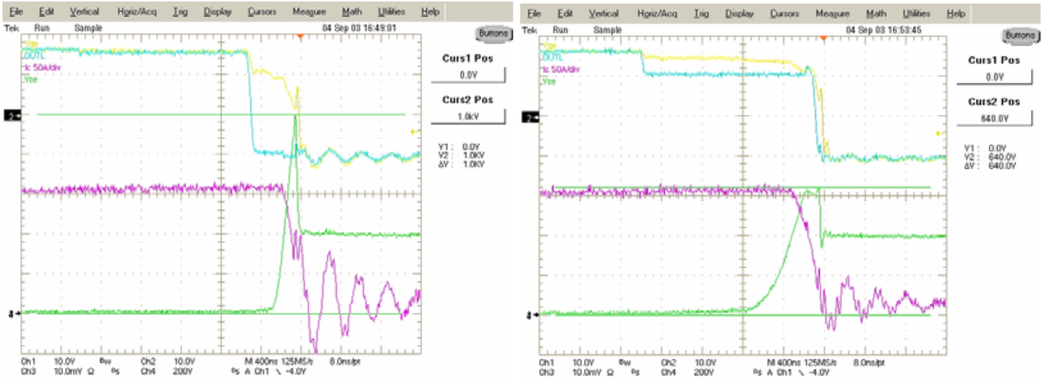


Tests with an IGBT module of 1200V and 25A (Eupec FP25R12KE) are shown in *Figure 13* for a 150A over-current event.

- 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 over-current (150A) conditions. There is no noticeable difference at nominal current, and the over-voltage is greatly reduced in case of over-current event.

Figure 13. Reduction of IGBT over-voltage 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

Turn-off mode	400V/40A		400V/150A	
	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

Caution: 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.

6 Desaturation protection feature

The desaturation function provides a protection against over-current 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 (a standard 1kV or more diode is usable); the 1kΩ (approx.) resistor filters parasitic spikes and also protects the DESAT input (see *Figure 14*).

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 (t_B).

Equation 2

$$t_B = 7.2[V] \bullet \frac{Cdesat}{250[\mu A]}$$

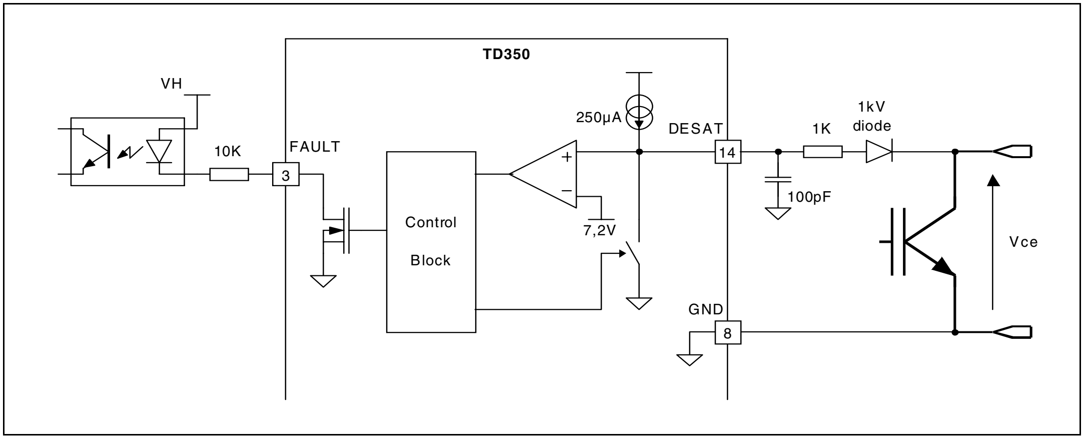
Equation 3

$$t_B[\mu s] = 0.03 \bullet Cdesat[pF]$$

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).

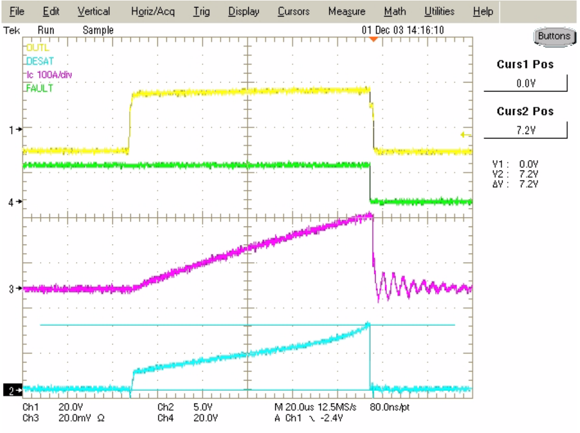
Figure 15 shows a desaturation fault at 150A on a typical 25A module.

Figure 14. Application schematic for DESAT feature



Note that during half-bridge commutation, the DESAT pin can experience a voltage peak. It can depend proportionally to the parasitic capacitante (Cj) of the desaturation diode, to the voltage value of the DC bus and in inverse proportion to the value of the capacitance placed on the DESAT pin and to the value of the resistor in series with the desaturation diode. The voltage peak on the DESAT pin must not exceed the absolute maximum rating indicated in the TD350 datasheet.

Figure 15. The collector current ramp-up to 150A triggers the DESAT feature (test on 25A module)



Caution: What should one do with the DESAT pin when it is not used?

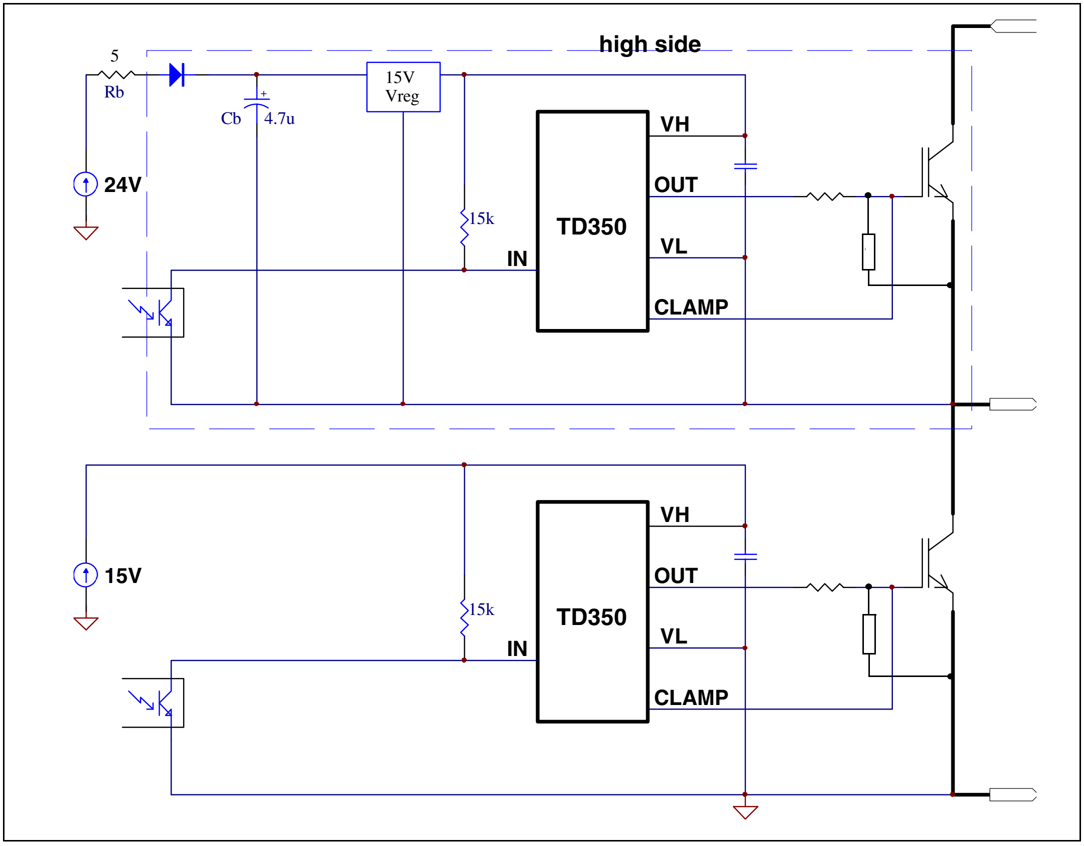
Connect the DESAT pin to GND.

7 Application schematics

The TD350 application designs presented below 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 15*). This concept is applicable to low and medium power systems, up to approximately 10kW. The main benefit of this is to reduce the global application cost by making the supply system simpler. *Figure 16* 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 does not require any special action from the system controller.

Figure 16. 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

Application power	1.5	2	3	4	3	7	11	15	[kW]
Eupec: FP*xx*R12KE3		**15**	**25**		**40**	**50**	75		[A]
Rgate		75	36		27	18	5		[Ohm]
Ipeak		0.2	0.4		0.55	0.8	3		[A]
Fuji: 6MBI*xx*S-120	**10**	**15**	**25**	**35**		**50**	**75**	100	[A]
Rgate	120	82	51	33		24	16	12	[Ohm]
Ipeak	0.12	0.2	0.3	0.45		0.6	0.9	1.3	[A]

IGBT modules suitable for the 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 does not affect the application performance.

An external buffer will be required for higher power applications.

Reference schematics are shown in *Figure 17* and *Figure 18*. 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 bulk capacitor (C_B) 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 17* uses desaturation detection for protection in case of over-current. Fault feedback is not used.

The application in *Figure 18* 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 diagram.

Figure 17. TD350 application schematic diagram with desaturation protection

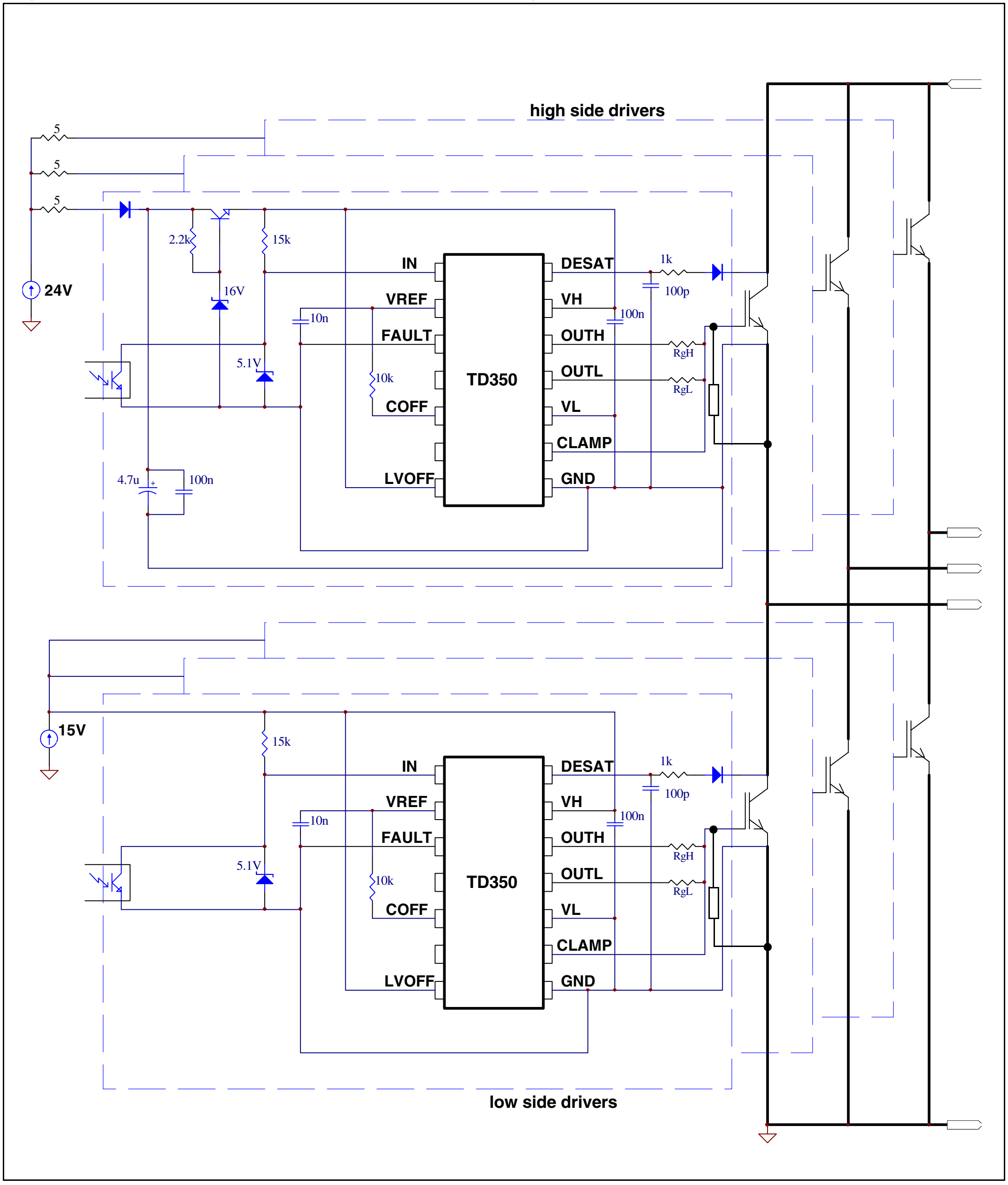
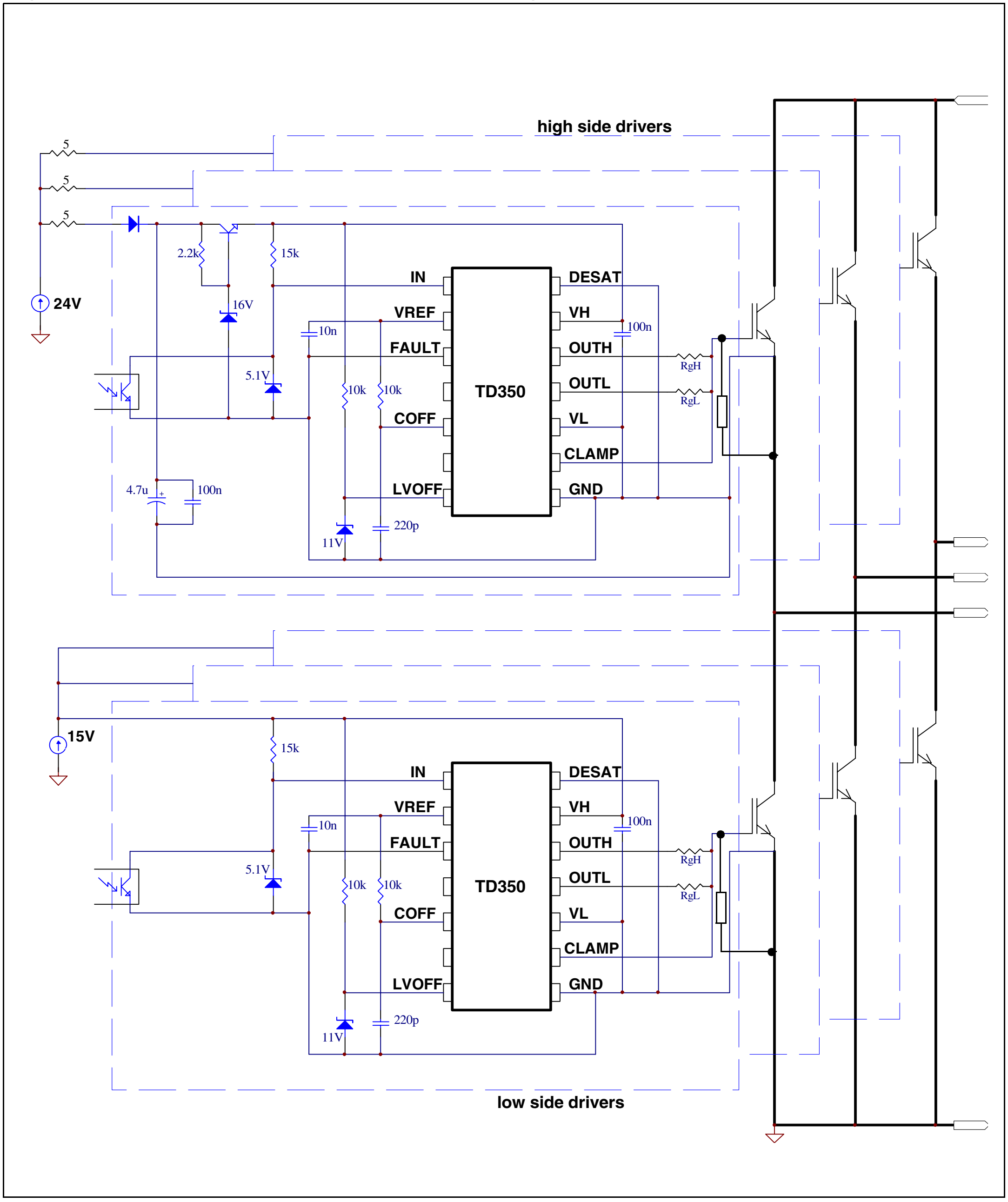


Figure 18. TD350 application schematic diagram with 2-level turn-off



8 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.

9 Revision history

Table 3. Revision history

Date	Revision	Changes
09-Sep-2004	1	Initial release
03-May-2006	2	- Quality of drawings improved according to A. Boimond remark. - AN reviewed according to CCD comments
26-Sept-2006	3	- New template - Minor editing changes
09-Oct-2006	4	-*Figure 2.* modified

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