# IGBT Discrete

TRENCHSTOP™ 5

# TRENCHSTOP™ 5 IGBT in a Kelvin Emitter Configuration

Performance Comparison and Design Guidelines

Application Note

## About this document

**Scope and purpose**

Introduction of new package TO-247 4pin with Kelvin Emitter connection, including performance comparison and design-in guidelines.

**Intended audience**

Development Engineers in the field of UPS, photovoltaic inverters and welding machines.

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# 1 Introduction

Recent improvements in the IGBT technologies have reduced the switching losses of the devices considerably. Such benefit has been achieved through changes in the structure of the IGBT chip. Figure 1 presents a comparison of switching energies of discrete 50A IGBTs from different technologies. The IGBT and the co-packed diode technologies are indicated at the bottom of Figure 1, as well as the year they have been brought to the market. The energy has been measured in a switching cell, using as counterpart a device from the same family and of identical current rating.

A deeper look inside Figure 1 reveals how impressively the turn-off energy of the IGBTs has decreased in the recent families. This has been achieved by decreasing the fall time of the current during turn-off, thus removing the tail current almost completely.

On the other hand, turn-on energy has practically not changed. One of the main reasons is that the turn-on behavior of the IGBT is strongly depending on the counterpart diode and its amount of reverse recovery charge. Actually, the amount of recovery charge tends to increase when the diode is combined together with a faster IGBT, thus increasing the switch's turn-on losses.

In order to achieve a considerable reduction of turn-on losses, the TO-247 4pin package is now being introduced for devices of the TRENCHSTOP™ 5 family. This package contains an extra emitter pin to be connected exclusively to the control loop, and has been already used successfully in combination with super junction MOSFETs from CoolMOS™ C7 technology [1].

With the Kelvin emitter configuration, the switching speed is increased further. Consequently, the switching losses are reduced in both flanks, even if the same counterpart diode remains in use. Among the advantages, the adoption of the TO-247 4pin increases the overall system efficiency and allows the IGBT device to operate at lower temperature.

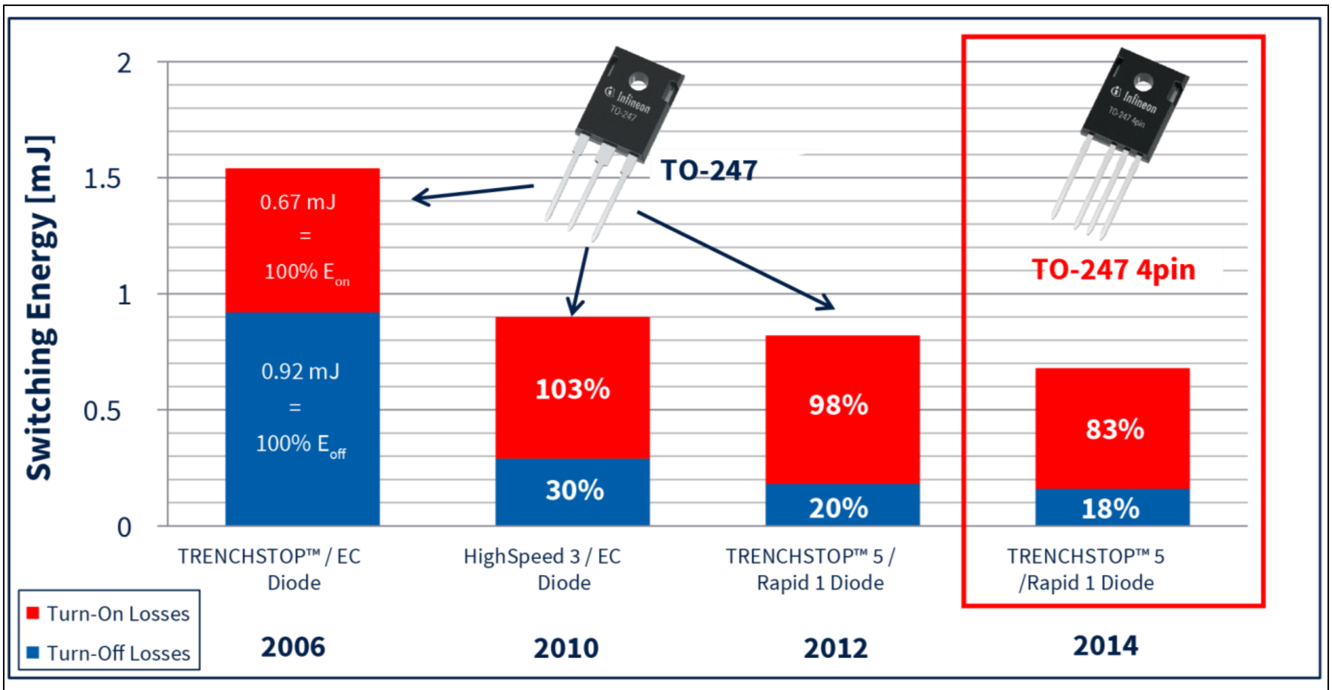


**Figure 1 Switching losses of 50A rated IGBT devices. Switching conditions $I_C$=50A, $T_j$=25°C**

# 2 The Kelvin Emitter Configuration

In standard through-hole packages, as for instance TO-220 or TO-247, each lead pad resembles a parasitic inductance. The inductance from the emitter pad in particular is a part of both, power and control loops.

As indicated in Figure 2, the power loop also includes the parasitic inductances coming from the collector lead and from the PCB tracks which connect the switching devices to the DC-link capacitor. The gate loop contains the inductances coming from the gate lead and from the PCB tracks which connect the gate and emitter pads to the gate resistor and the gate driver.

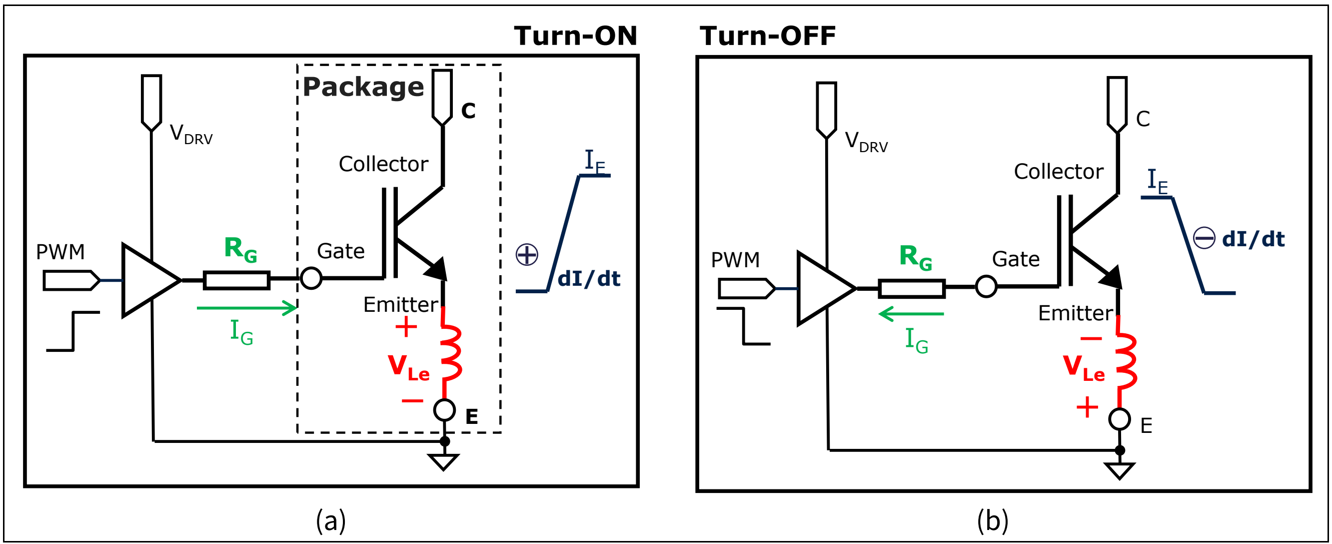


**Figure 2 Emitter current variation and induced voltage over the emitter stray inductance during (a) turn-on and (b) turn-off of the IGBT**

The impact of the emitter lead inductance Le to the effective gate to emitter voltage during both, turn-on and turn-off can be quantified respectively as:

$$V_{GE.Eff(Turn-on)} = V_{DRV.ON} - R_G \cdot I_G - \underbrace{L_e \cdot dI_C/dt}_{V_{Le}} \tag{1}$$

$$V_{GE.Eff(Turn-off)} = V_{DRV.OFF} - R_G \cdot I_G + \underbrace{L_e \cdot dI_C/dt}_{V_{Le}} \tag{2}$$

As it can be deduced by equations (1) and (2), the effective gate to emitter voltage is attenuated during transient conditions in both, turn-on and turn-off. Due to this attenuating, the commutation time is extended, leading to higher switching losses.

## 2.1 TO-247 4pin Package

The newly introduced TO-247 4pin package has an extra connection to the IGBT's emitter, labeled $E_2$ in Figure 3. This point shall be connected to the gate driver as shown in Fig. 3. Also known as Kelvin emitter terminal, this pin is not subject to the attenuation coming from the power loop. The current coming from the IGBT's collector is solely conducted by the power emitter lead $E_1$.

Another difference from the TO-247 4pin package is the pin-out, which is different from the standard TO-247-3, as it can be seen in Figure 3. This is done to keep the creepage distance between the high voltage pins. In addition, the pins which are connected to the power loop, C and $E_1$, are put side by side, so are those for the control loop $E_2$ and G.

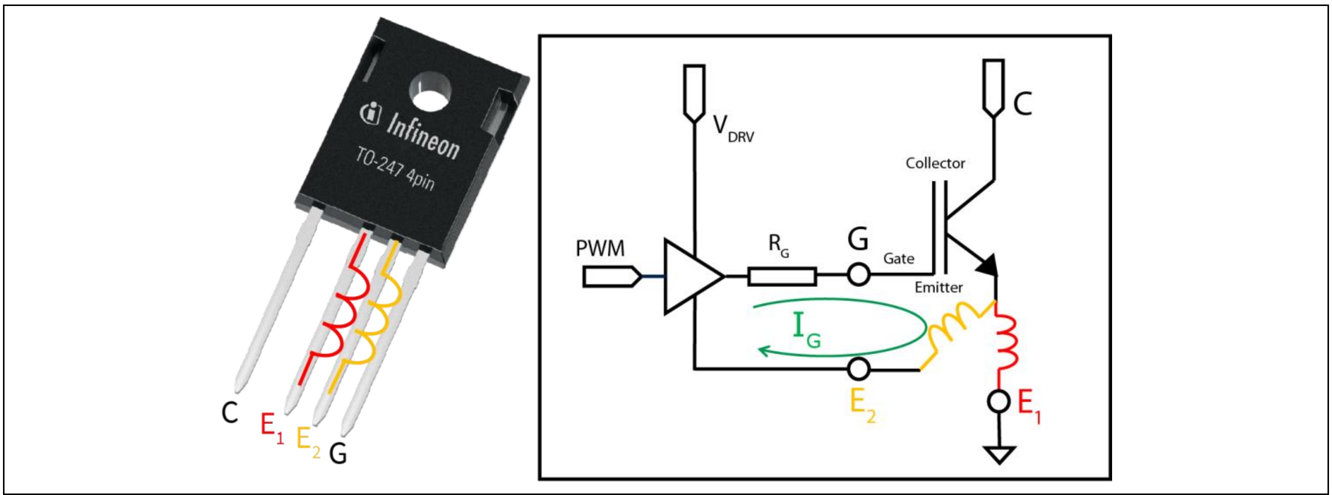


**Figure 3 IGBT connection in Kelvin emitter configuration**

This package will be identified in the Infineon's IGBT nomenclature with the Letter "Z" at the third position. This is indicated by the nomenclature scheme in Figure 4.

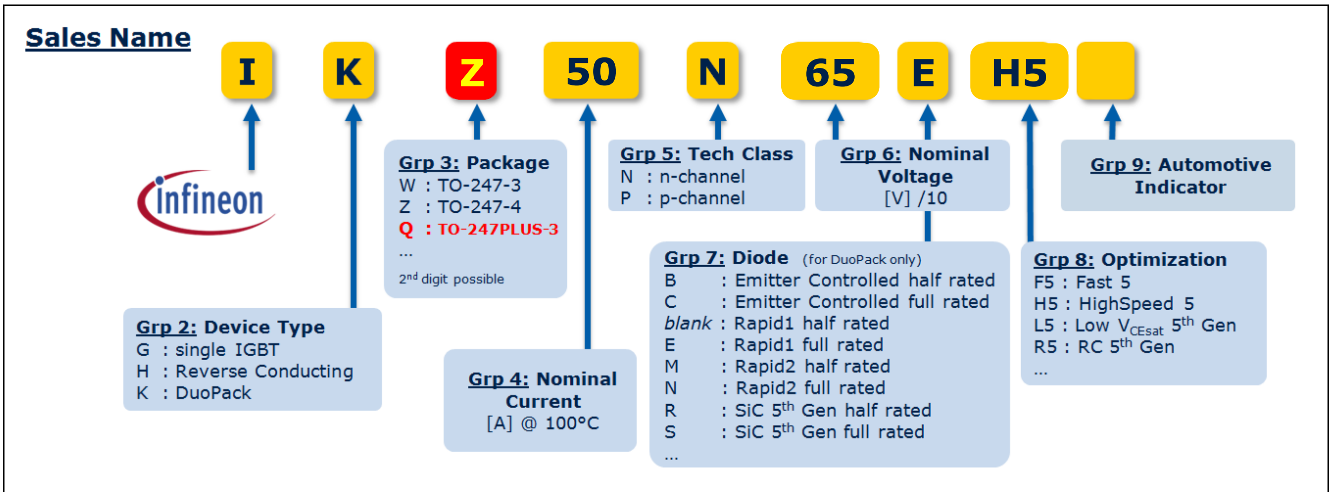


**Figure 4 Example of the nomenclature of an IKZ50N65EH5. The letter "Z" at the third digit identifies the TO-247 4pin package**

# 3 Electrical Switching Performance

Without the attenuation of the gate voltage coming from the power emitter, the switching of the IGBT becomes faster than in the standard TO-247 package. The impact on the switching energy is quantified in the next sections, firstly during turn-on and later for turn-off.

## 3.1 Behavior during Turn-on

To quantify the benefit of the Kelvin emitter configuration during turn-on, the IGBT IKZ50N65EH5 has been used as the device under test (DUT). It is a 50A rated IGBT from the TRENCHSTOP™ 5 family in TO-247 4pin package.

In the first set of tests, the emitter pin $E_2$ has not been connected. The output of the gate driver has been connected to pins G and $E_1$. This emulates the standard TO-247 package and is referred to as 3-pin configuration in Figure 5. In the second set, pins $E_1$ and $E_2$ have been connected as in Figure 3. This configuration is referred to as 4pin in Figure 5.

The comparison of the turn-on losses between both configurations is shown in Figure 5. A part available on the market with the same rated current in standard TO-247 has been included as reference. By switching at the nominal current, 50A, the benefit of the Kelvin emitter configuration reaches 23% lower turn-on losses. The IKZ50N65EH5 reveals 14% less turn-on losses than the part compared to.

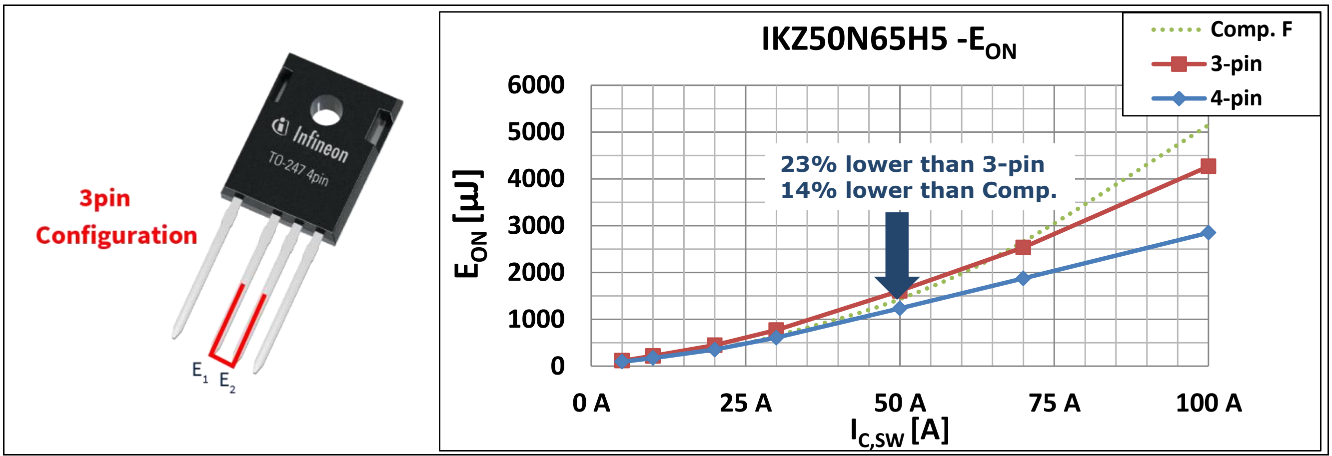


**Figure 5** **Turn-off losses of an IKZ50N65EH5 in both 3pin and 4pin configurations. The losses from a state-of-the-art part of the same current rating are also shown as reference**

## 3.2 Behavior during Turn-off

As for the turn-on, the IGBT's turn-off becomes faster inside the TO-247 4pin as well. Consequently, the current change rate $dI_C/dt$ is increased. In case the loop inductance is not improved, this will lead to a higher overvoltage peak. Due to its very short rise time and low output capacity, the TRENCHSTOP™ 5 IGBTs are likely to present overvoltage peaks during turn-off [2]. This effect increases with the loop inductance $L_{loop}$ according to:

$$\Delta V_{CE} = L_{loop} \cdot {dI_C}/_{dt} \quad (3)$$

This effect shall be considered in depth, since some applications like SMPS and UPS reserve a safety margin of 20% to the nominal breakdown voltage.

Figure 6 presents the impact of the package on the turn-off of the IKZ50N65H5, where the commutation voltage and current are 400V and 100A respectively. The junction temperature was $T_j$=25 °C. On the left side of Figure 6, the IGBT device is switched in the 3pin configuration. The maximum change rate of the collector current is 1.5A/ns, leading to an overvoltage peak of 530V.

On the right side of Figure 6, the same device is now switched in the 4pin configuration. The commutation speed is increased up to 2A/ns, leading to lower losses. However, the overvoltage peak reaches 570V, a value which is well above the margin of 20% to the breakdown voltage of the IGBT.

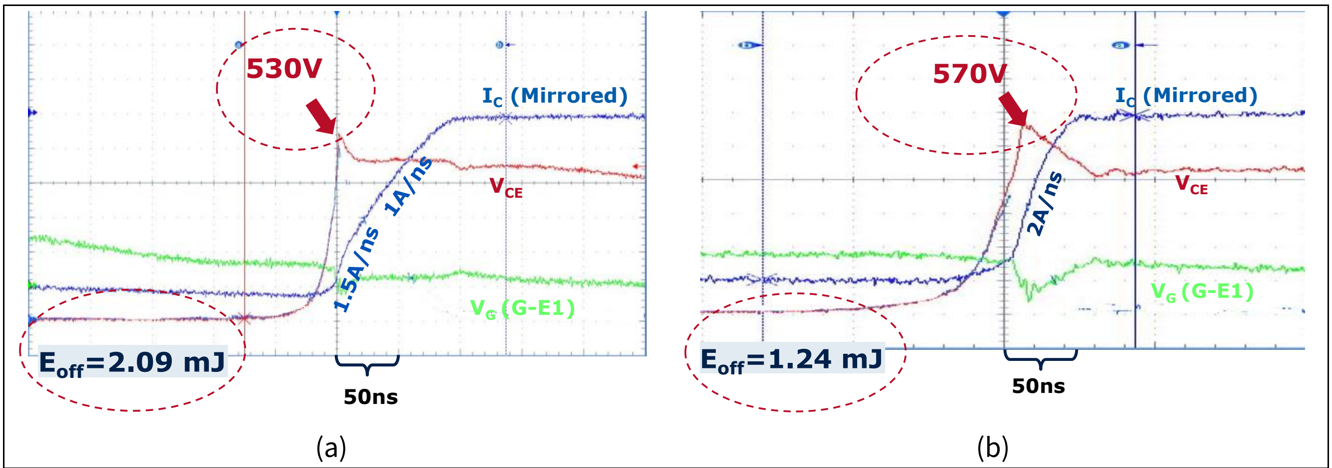


**Figure 6 Waveforms during the turn-off of an IKZ50N65EH5 in both (a) 3pin and (b) 4pin configurations**

To avoid such a high overvoltage, the loop inductance has to be reduced. This is done by optimizing the PCB tracks and the placement of the components [2]. Alternatively, the gate resistor $R_{G.OFF}$ can be increased, leading to a slower commutation and lower $dI_C/dt$. Figure 7 presents the overshoot voltage during turn-off of an IKZ50N65EH5 for different gate resistors and collector currents.

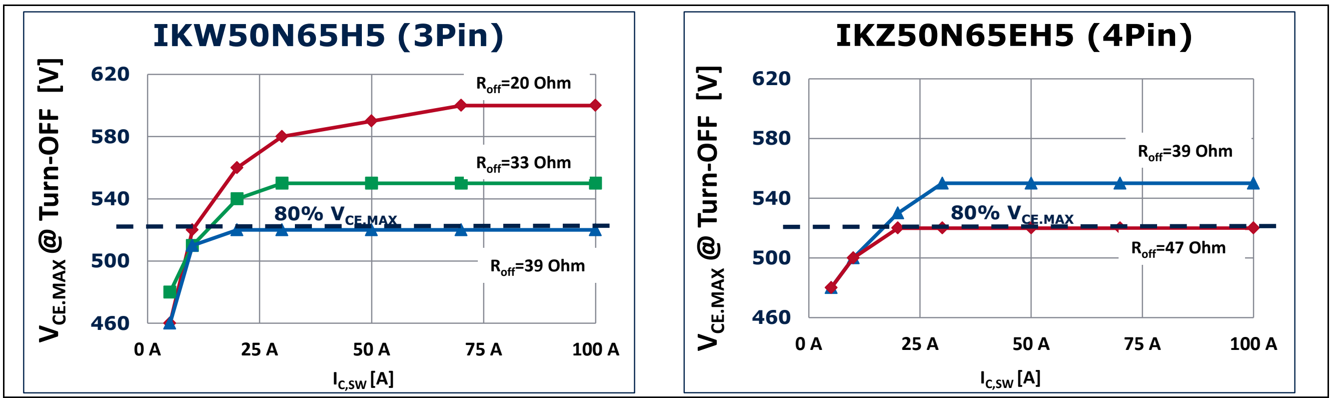


**Figure 7 Voltage overshoot at turn-off for the 50A TRENCHSTOP™ 5 H5 IGBT as a function of the collector current and gate resistor**

As a consequence of increasing $R_{G.OFF}$, the turn-off losses will increase and the benefit given by the TO-247 4pin will be partially cancelled at turn-off as depicted in the graph of Figure 8. By comparing the

turn-off losses of the 50A TRENCHSTOP™ 5 H5 IGBT, it is possible that a considerable benefit of the Kelvin emitter configuration is reached only for values exceeding the IGBT's nominal current.

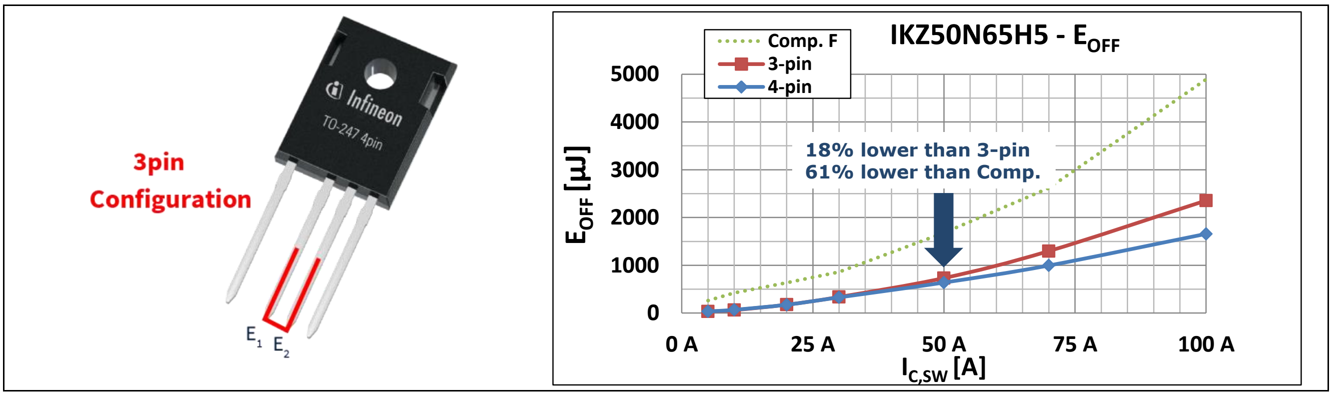


**Figure 8 Turn-off losses of an IKZ50N65EH5 in both 3pin and 4pin configurations. The losses from a comparable part of the same current rating are also shown as a reference**

## 3.3 Total switching losses

The sum of switching losses of the three devices tested is presented in Figure 9 (a). The advantage of the Kelvin emitter configuration is bigger for the highest currents. These are the conditions where highest current change rates are expected. Therefore, the lead inductance will attenuate the gate voltage the most in the 3-pin configuration.

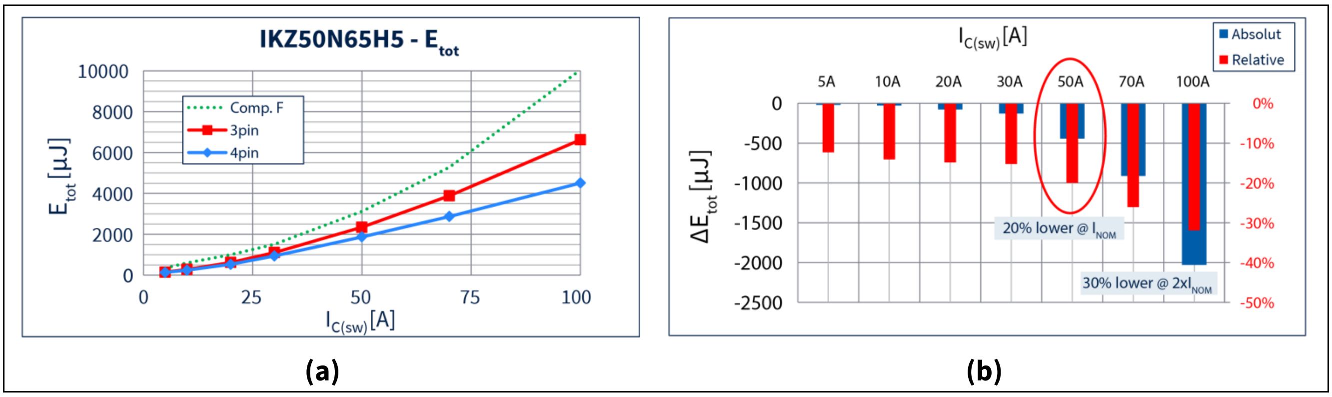


**Figure 9 (a) Total switching energy of an IKZ50N65EH5, in both 3pin and 4pin configurations**
**(b) Switching energy reduction from 4pin configuration in both absolute and relative values**

As a consequence, in applications where the current is higher than the rated current of the IGBT, the switching loss reduction can be higher than 20%. This often is the case in Uninterruptable Power Supplies. For applications where the current is typically around half the IGBT's current rating, like for example photovoltaic inverters or switch mode power supplies (SMPS), the benefit is slightly lower but is still there, in the form of up to 15% lower switching losses.

# 4 Design guidelines

To achieve a correct design-in of the new package, some points shall be considered. They are especially valid when a migration from traditional TO-247 is taking place. Those points will be discussed in the following sections.

## 4.1 Package Compatibility

TRENCHSTOP™ 5 is so far the only IGBT generation in TO-247 4pin offered on the market. In case a second source is required, an arrangement on the part's socket would enable to use a part in standard TO-247. One possibility is presented in Figure 10.

For a correct thermal design, the difference in losses between the two packages shall be considered.

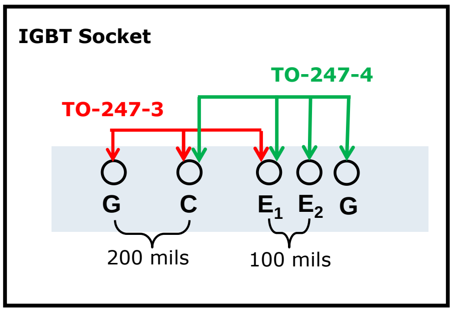


**Figure 10 Possible arrangement of the IGBT socket to accept both TO-247 and TO-247 4pin packages**

## 4.2 Recommended Gate Driver

Some recommendations with respect to the gate driver are:

- The driver's local ground, referenced to the auxiliary emitter, must be isolated from the power ground. This is mandatory to prevent shortening pins $E_1$ and $E_2$
- Separated $R_{G.ON}$ and $R_{G.OFF}$ are recommended since the optimized resistance for turn-on and turn-off can be very different from each other. This prevents an unnecessary increase in switching losses

Considering the above points, a good match for the driver IC is the EiceDRIVER™ Compact, recently launched [3]. Figure 11 depicts a typical connection between the driver and an IGBT in TO-247 4pin package.

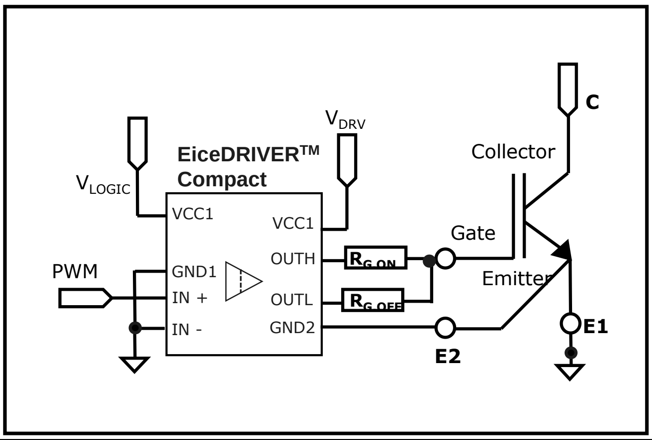


**Figure 11 Typical connection of EiceDRIVER™ Compact to an IGBT in TO-247 4pin package**

## 4.3 Paralleling devices

When devices in TO-247 4pin package are paralleled, a further path exists for the circulating current between the devices. This path is through the connected Kelvin emitter terminals of the devices, as it can be seen in Figure 12 (a) Due to the low impedance of the path, a minor difference in the induced emitter voltage $V_{Le}$ can generate an extremely high circulating current. This can happen for instance if the paralleled IGBTs have different switching times, therefore different $dI_C/dt$ ratios.

To limit the circulating current, a possible reconfiguration of the parallel circuit is shown in Figure 12 (b). The gate resistors are now split between $R_G$ and $R_E$. This way, the extra path features a higher resistance, limiting the potentially dangerous current to non-critical values.

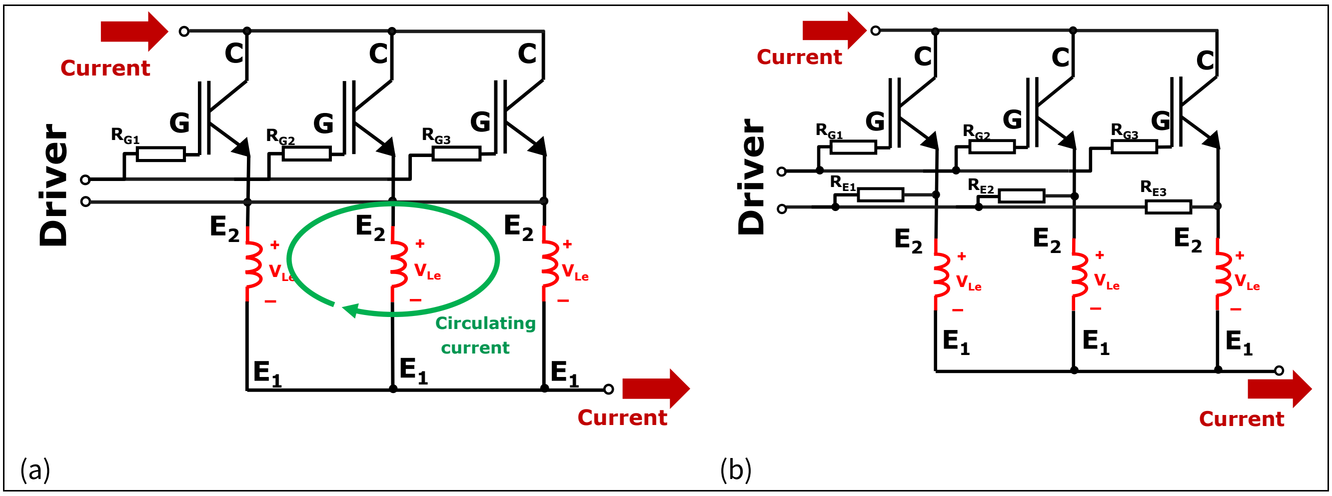


**Figure 12 (a) Parallel connection of three IGBTs and equalization current through the Kelvin emitter connections (b) reconfiguration of the circuit with the split of gate resistor**

As the total resistance seen by the driver will be the sum of $R_G$ and $R_E$, these must be chosen accordingly. As a rule of thumb, the ratio $R_E/R_G$ is between 1/5 and 1/10. In order to achieve proper limitations, $R_E$ shall not be chosen lower than 0.5Ω.

# 5 Summary

This application note has introduced the new TRENCHSTOP™ 5 IGBTs in a Kelvin emitter configuration using a TO-247 4pin package. The benefit in terms of switching energy reduction in comparison to the standard TO-247 package has been obtained from practical measurements. It has been quantified as up to 20% lower switching energy for the nominal current.

This achievement helps TRENCHSTOP™ 5 to even further increase its distance to comparable parts and to set itself as a benchmark in terms of switching losses.

The document also includes general hints on the driver IC to be used to drive the new IGBTs, so as how to implement a socket able to handle both, 3pin and 4pin packages.

Finally, the paralleling of two or more devices in TO-247 4pin has been discussed, including some hints to reduce the circulating current between devices.

# 6 References

[1] Infineon Technologies AG: AN 2013-05, “CoolMOS™ C7 650 V Switch in a Kelvin Source Configuration”

[2] Brucchi, F., “How to Deal with TRENCHSTOP™ 5 IGBT in Power Applications”, Bodo’s Power, October 2013

[3] http://www.infineon.com/cms/en/product/power/gate-driver/eicedrivershigh-voltage-gate-driver-ics-and-boards/gate-driver-ic-eicedriver-compact/channel.html?channel=ff80808112ab681d0112ab6a547004ac

Revision History

**Major changes since the last revision**

| Page or Reference | Description of change |
|---|---|
| -- | First Release |
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