Application Note

New Gen 3 650V IGBT

A Soft And Efficient Switch For Industrial Applications

Recent development of trench stop IGBTs has led to very performant devices. They present lower static and dynamic losses, thus increasing the efficiency of the systems they are applied, even at switching frequencies above 20 kHz. However, high performance comes together with some challenges. Some of them are related to the intrinsic behavior of the device. For instance, small and non-linear parasitic capacitances result in non-controllable switching speed. In addition, parasitic inductances of the IGBT package, combined with those from the printed circuit board (PCB), can generate persistent oscillations in both collector-to-emitter and gate-to-emitter voltage. Such application issues make modern IGBTs difficult to be handled, and limit their use.

The new family of trench stop IGBTs from ROHM Semiconductor, named Gen 3, is intended to offer an optimal compromise between performance and ease of use. Due to its fast but smooth switching behavior, Gen 3 IGBTs are easy to operate even with small values of external gate resistor. Consequently, it is possible to obtain high system efficiency with minimum effort in the PCB design and electromagnetic interference (EMI) filtering.

This application note introduces the technical features of Gen 3 IGBTs, as well as their benefits in industrial applications. As examples, a portable welding machine and a DC/AC inverter are used to compare the performance of Gen 3 with other IGBT devices available on the market.

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1 – IGBT Gen 3

ROHM Semiconductor started to manufacture IGBT devices in 2009. In its second generation, the light punch through (LPT) structure has been introduced, as shown in Figure 1. LPT structures bring several benefits to IGBTs, like lower saturation voltage $V_{CE(sat)}$ and faster switching. This is obtained since the carrier concentration gradient in the drift layer is smaller than in conventional punch through type, where epitaxial layer is used. This way, the electron current density – majority carriers - is in increased, whilst hole density – minority carriers - is decreased.
In the Gen 3 IGBTs, in addition to LPT structure, significant shrink of the cell structure has been obtained. This reduces the parasitic capacitances of the device, optimizing the dynamic behavior and reducing the driver efforts. Finally, a wafer thinning of 15 % with respect to former generation was achieved. This not only reduces the device losses in conduction state, but also the dynamic losses, as less carriers have to be extracted during the turn-off process.

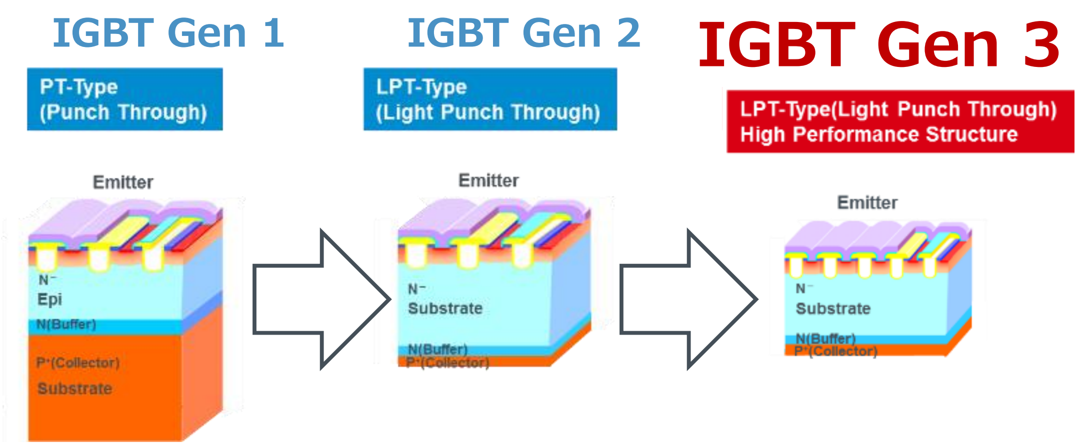


Figure 1 – Technology improvement of punch though IGBTs in ROHM Semiconductor.

2- Product portfolio

The complete portfolio of Gen 3 is presented in Table 1. Device names follow the code depicted in Figure 2. As an important difference from other IGBT vendors, the current portion of the device name contains **twice the rated current** at T_C=100°C. For each current class, there are two available devices: a single IGBT, or co-packed with fast recovery diode (FRD). In RGTV series, the co-packed FRD has the same rated current as the IGBT. In RGW series, the FRD is rated to a lower current than the IGBT. The rated current of FRDs is informed in brackets in Table 1.
In addition, Gen 3 portfolio is divided in two different series, namely:

- **RGTV** , for fast switching and with shot circuit withstand time (SCWT) of 2 µs;
- **RGW**, for even faster switching, in applications where SCWT is not required.

These series contain devices with different rated currents, from 30 A to 80 A at case temperature T_C=100°C. They are packaged in both TO-247N (non-isolated) and TO-3PFM (isolated).

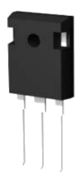
Table 1 – Product portfolio of Gen 3 IGBTs.

RGTV Series

	TO-247N		TO-3PFM	
	Single IGBT	Co-packed w/ FRD (diode rated current)	Single IGBT	Co-packed w/ FRD (diode rated current)
30A	RGTV60TS65	RGTV60TS65D (30A)	RGTV60TK65	RGTV60TK65D (30A)
50A	RGTV00TS65	RGTV00TS65D (50A)	RGTV00TK65	RGTV00TK65D (50A)
80A	RGTVX6TS65	RGTVX6TS65D (80A)	-	-

RGW Series

	TO-247N		TO-3PFM	
	Single IGBT	Co-packed w/ FRD (diode rated current)	Single IGBT	Co-packed w/ FRD (diode rated current)
30A	RGW60TS65	RGW60TS65D (20A)	RGW60TK65	RGW60TK65D (20A)
40A	RGW80TS65	RGW80TS65D (20A)	RGW80TK65	RGW80TK65D (20A)
50A	RGW00TS65	RGW00TS65D (30A)	RGW00TK65	RGW00TK65D (30A)



TO-247N

TO-3PFM

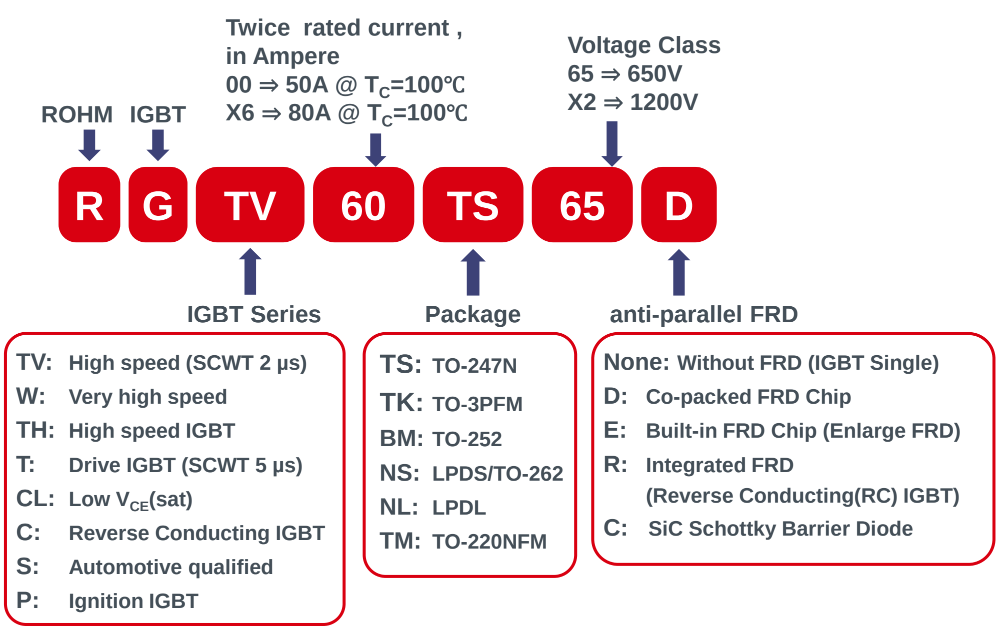


Figure 2 – Naming code for ROHM IGBTs.

3- Gen 3 Devices

ROHM Semiconductor offers several IGBT series, each of them focused on certain applications and markets. Parameters like short-circuit withstand time SCWT, saturation voltage $V_{CE(sat)}$ and dynamic losses are tailored to fit specific application requirements. Figure 3 plots the different IGBT series from ROHM, according to the rated SCWT (x-axis), and operation switching frequency (y-axis).

The Gen 1 of IGBTs was targeted to automotive ignition systems, which require blocking voltages from 360 V to 560 V. The Gen 2 was divided in RGCL series, focused on low $V_{CE(sat)}$, with consequent higher switching losses and lower frequency operation. The RGTH series, with lower switching losses, addresses in industrial applications like switched mode power supplies (SMPS) and battery chargers. These applications do not require short-circuit capability from the IGBTs. For industrial drive applications, instead, the RGT series is recommended, offering 5 µs SCWT. Finally, RGS series is Automotive qualified, and are used inside cars in systems like high voltage e-compressors.

As shown in Figure 3, the newest Gen 3 is targeting high efficiency industrial applications. They are for instance single-phase power supplies, photovoltaic inverters, uninterruptable power supplies (UPS), battery chargers and welding machines. In these applications, very short or no short circuit withstand time is required. Instead, maximum IGBT performance is requested. This is what devices from Gen 3 are able to offer, with low static and dynamical losses, as it is going to be presented in the next section.

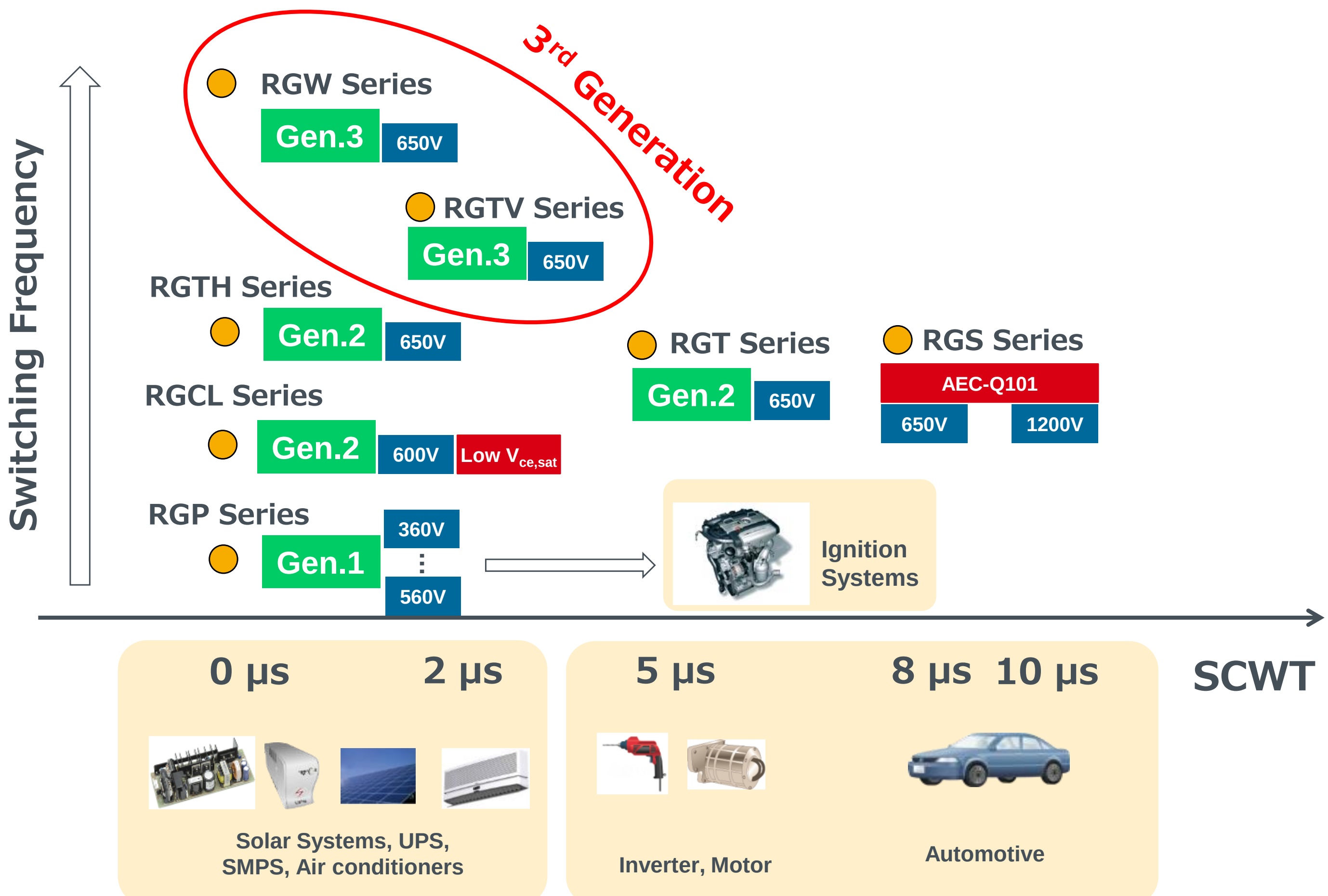


Figure 3 – Applications spectrum, and available IGBT series from ROHM Semiconductor.

4- IGBT performance

As discussed in Section 2, the structure of Gen 3 IGBT has features that enable a better trade-off between $V_{CE(sat)}$ and turn-off losses. It is possible to optimize these parameters and to obtain thus devices with both lower static and lower dynamic losses.

Figure 4 contains the comparison between same current rated devices from RGTH series – Gen 2 – and from RGTV series – Gen 3. On the left side graph, the $V_{CE(sat)}$ of both devices is plotted as function of collector current, for room temperature as well as for maximum junction temperature. The $V_{CE(sat)}$ of the new device is 0.1 V (6%) lower at T_j=25°C, and 0.25 V (12%) at T_j=175°C.

In the same way, right graph of Figure 4 shows the waveforms of both devices during turn-off, at same environmental conditions. It is possible to observe the effects of the optimized structure of Gen 3. In the **RGTV60TS65D**, the collector current rapidly goes to zero, with minimum tail current. As a result, 10% less turn-off losses E_{off} are achieved.

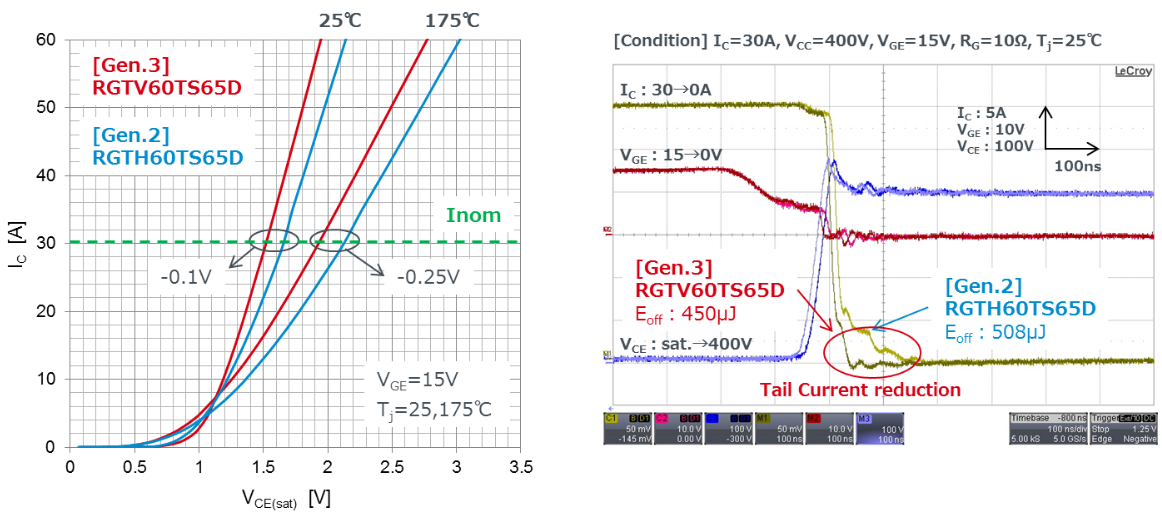


Figure 4 – Static and dynamic comparison between IGBT devices from Gen 2 and Gen 3 from ROHM.

As mentioned in the former section, the devices from RGW series are very fast IGBTs. This is proved by the waveforms from Figure 5, which compares the turn-off of a 50A rated IGBT from RGW series, compared to an equivalent device from RGTV series. Under same conditions, **RGW00TS65D** has an additional 25% reduction in the E_{off}.

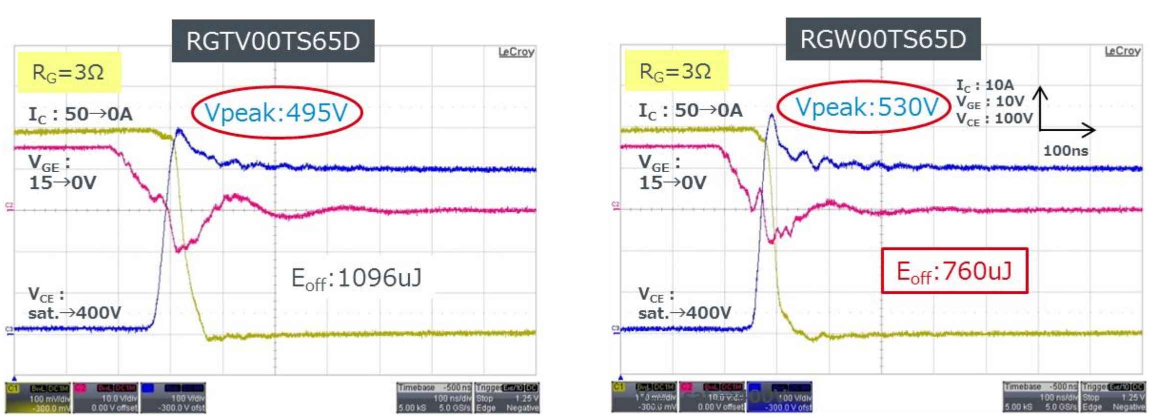


Figure 5 – Comparison between 50A rated IGBTs from RGTV and RGW series.

In the same way as the IGBT, the fast recovery diode (FRD) technology that is co-packed with Gen 3 has also been improved. The new Gen 6 FRD technology presents thinner wafer and field stop structure. This results in both lower forward voltage V_F and lower reverse recovery charge Q_{RR}. These are important parameters in inverter applications, in order to reduce losses not only in the diode itself but also in the counterpart IGBT. At the same time, Gen 6 FRD has a very smooth response during its turn-off. This guarantees a fast but soft commutation, avoiding oscillations in the FRD as well as in the IGBT. This is presented in the waveforms of Figure 6, where the turn-off of the former ROHM Gen 3 FRD, the new Gen 6 and a competitor part are compared. Gen 6 presents almost no oscillations in the current and voltage. In addition, it is also the tested device whose Q_{RR} increases the least with temperature.

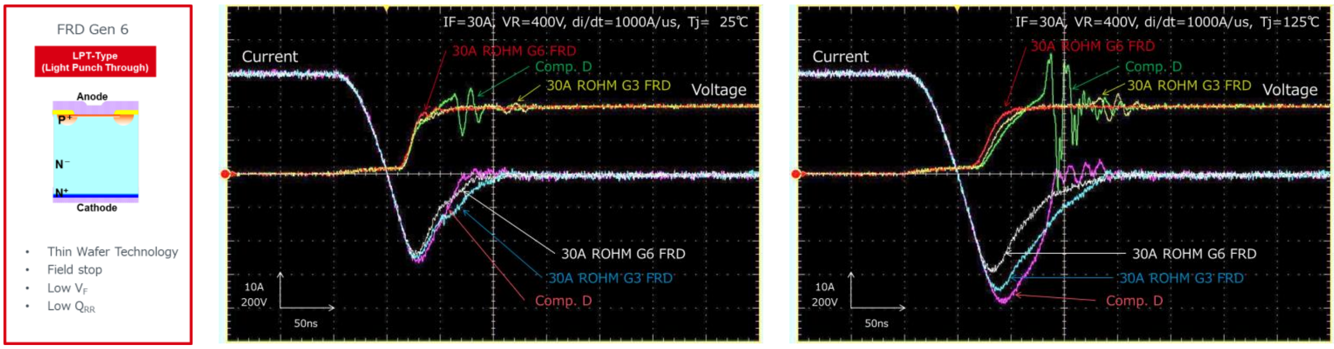


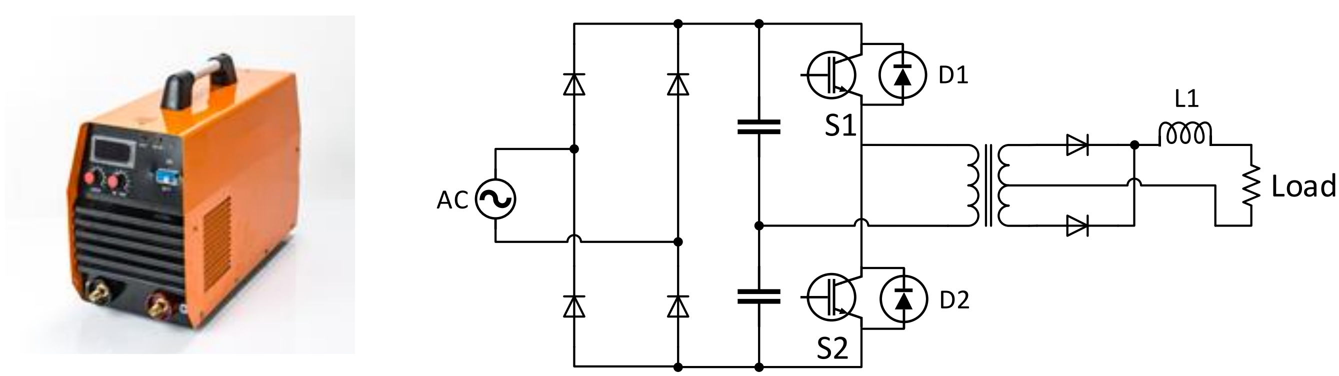
Figure 6 – Simplified Gen 6 FRD technology (left), and turn-off of 30A rated FRDs at T_j=25°C and T_j=125°C.

The improvement in the IGBT $V_{CE(sat)}$ and E_{off}, in combination to lower Q_{RR} of the anti-parallel diode lower the overall device losses. This results in higher system efficiency, and relieves the requirements for the cooling system. This allows smaller heat-sinks and fewer fans to be used. The benefits of Gen 3 devices are presented in the next section in two different applications, namely portable welding machines and DC-AC inverters.

5- Benefits in Portable Welding Machine

5.1 – Operation principle

Portable welding machines are isolated AC-DC converters. Depending on their welding characteristics, they can be from tungsten inert gas (TIG) or manual metal arc (MMA). Figure 7 presents a typical portable welding machine and its main circuit, based on the half-bridge topology. As their input power is limited to 5 kW, they are typically single-phase machines, and switches **S1** and **S2** are implemented with discrete devices, like IGBTs or MOSFETs. In the same way, discrete diodes are used in the secondary side.



(a) **(b)**

Figure 7 – (a) Example of portable welding machine and (b) simplified schematic based on half-bridge topology.

The main waveforms of such a welding machine are depicted in Figure 8. The waveforms are referred to the low side switch **S2** in Figure 7. At t_1 the switch **S2** turns on. Between t_1 and t_2, **S2** is conducting. At t_2, **S2** turns off and the anti-parallel diode **D1** – whose waveforms are not shown in the Figure 8 – assumes the winding current. At t_3 the current through **D1** is zeroed, and the collector-to-emitter voltage of **S2** starts to resonate around half of DC voltage. At t_4 the high-side IGBT **S1** turns on, and **S2** assumes the entire voltage. At t_5, S1 turns off. At this point, the anti-parallel diode D2 starts to conduct. At t_6 the current of **D2** is zeroed and again the V_{CE} of **S2** starts to resonate. In t_7 the switch S2 turns on, and the cycle starts again.

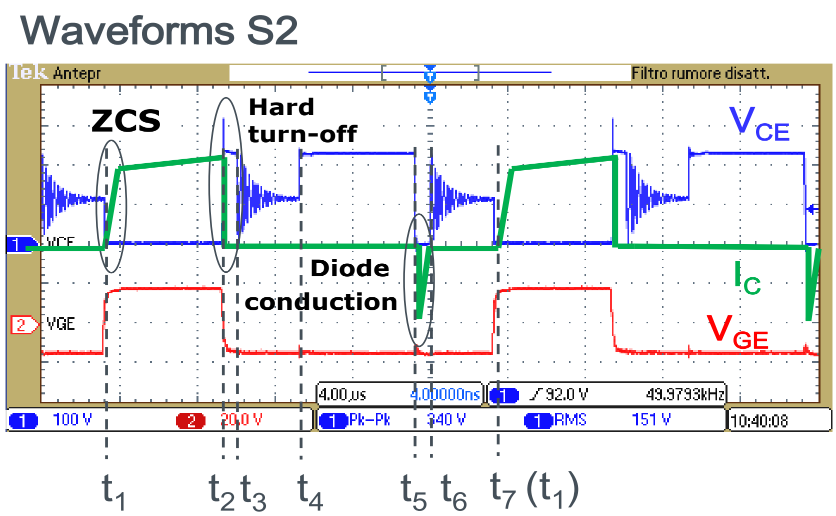


Figure 8 – Simplified schematic of a portable welding machine based on half-bridge topology.

5.2 – IGBT losses and parameter comparison

Based on the waveforms from Figure 8, it is also possible to identify the losses mechanisms coming from the semiconductors in the primary side. When **S2** turns on (t_1 and t_7), there is no current flowing through the primary winding. Therefore, this switching is said to occur in zero current, and the amount of losses involved in this process is negligible. On the other hand, during the turn-off of **S2** (t_2), the current of the primary winding is turned to zero, while the IGBT voltage goes from almost zero to the full DC voltage. This is of course a dissipative process, and energy involved will be function of IGBT technology and circuit parameters, like: gate switched voltage and current, external gate resistor, parasitic loop inductance, among others. In addition to these dynamic losses, there are also static losses coming from the IGBT between t_1 and t_2, and from the diode between t_5 and t_6. As the diode conduction period is much shorter than that of the IGBT, it has a much lower influence on the total system losses.

According to the losses mechanisms described above, the following IGBT parameters are relevant for its performance in portable welding machines:

- $V_{CE(sat)}$, to minimize static losses;
- E_{off}, to minimize dynamic losses.

In addition, the $R_{th;JC}$ can also play an important role to maintain lower chip temperatures, especially if there is no isolation foil between the IGBT device and its heat-sink.

Table 2 contains the relevant parameters from several 40A rated IGBTs. The values have been extracted from datasheets available in internet. By comparing **RGTH80TS65D** and **RGW80TS65D** it is possible to identify the improvement brought by Gen 3. **Comp. A** has similar values of $V_{ce(sat)}$ and E_{off} than Gen 2 device from ROHM, whilst **Comp. B** has the lowest value of E_{off} than the **RGW80TS65D**.

Table 2 –Comparison between 650V IGBTs, 40 A rated.

Device	$V_{ce(sat)}$ @ 40A (25°C/175°C, typ)*	E_{off} @ 40A, 400V & 175°C (E_{off}, $R_{g,off}$)*	$R_{th,JC}$ (max)*
RGW80TS65D (Gen 3)	1.5V / 1.85V	910 µJ, 10 Ω	0.70 K/W
RGTH80TS65D (Gen 2)	1.6 V / 2.1 V	1200 µJ, 10 Ω	0.64 K/W
Comp. A	1.6 V / 2.1 V	1200 µJ, 22 Ω	0.53 K/W
Comp. B	1.65 V / 1.95 V	625 µJ, 15 Ω	0.65 K/W

* Based on devices' datasheets available in internet.

5.3 – Practical tests in a portable welding machine

The E_{off} values presented in Table 2 have been obtained for different values of gate resistor $R_{g,off}$. The values have been selected according to the voltage overshoot that each IGBT presented inside a real portable welding machine. As this system has typically a high loop inductance above 100 nH, IGBTs with high current fall rate dI_C/dt may present high voltage spikes during turn-off. In order to reserve a minimum of 20% margin from the breakdown voltage, the spikes shall not reach more than 520 V. And by considering a rectified voltage of 360 V, the overshoot shall not be higher than 160 V. Figure 9 presents the overshoot values obtained with the devices compared in Table 2, for different values of gate resistor. For $R_{g,off}$ = 10 Ω, only **RGTH80TS65D** and **RGW80TS65D** present overshoot below the allowed value. For both **Comp. A** and **Comp. B**, $R_{g,off}$ has to be increased to 22 Ω.

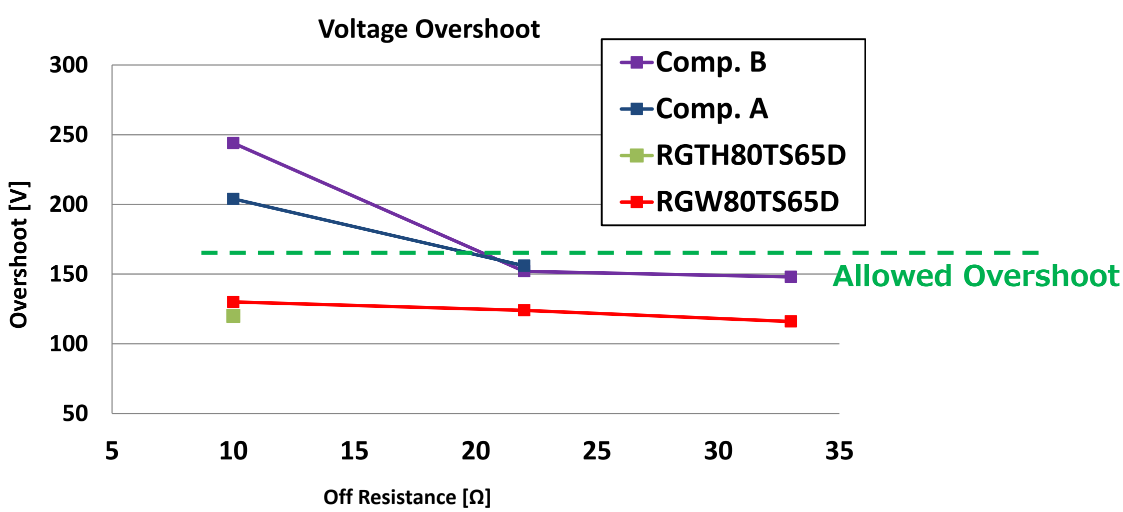


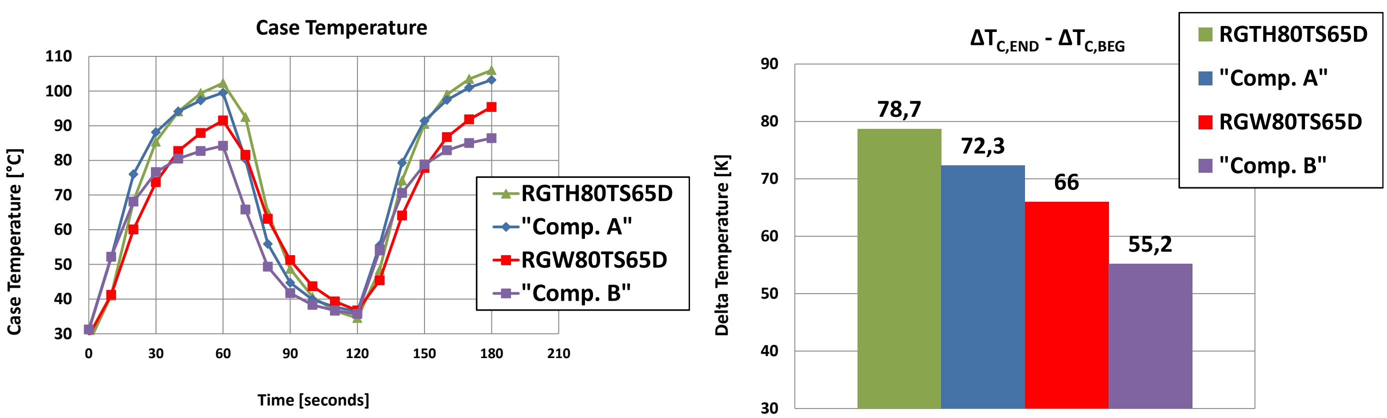
Figure 9 – Voltage overshoot during turn-off for different IGBTs, as function of the used external gate resistor.

The performance of the different IGBT devices has been evaluated inside a welding machine, whose main characteristics are shown in Table 3. In addition, forced cooling is used, and the IGBTs are assembled without thermal foil. Therefore, the $R_{th,JC}$ from the IGBTs is important to define the junction temperature of the IGBT.

Table 3 – Electrical characteristics of the welding machine used for IGBT performance comparison.

Parameter	Value
Topology	Half Bridge
Output current:	175A
Switching frequency	50 kHz
Nominal output power	2.5 kW
Duty cycle	~ 40%
S1/S2 average current	~ 16A @ nominal power
S1/S2 switching current	~ 40A @ nominal power
Gate voltage ON/OFF	15 V / 0 V

A 3-minute test is applied to the welding machine. In the first minute, the welding machine is activated to its nominal power. In the second minute it is deactivated, and in the third test minute the machine is again operated at its nominal power. The top side (mold) temperature of the tested IGBT is monitored. The left side of Figure 10 depicts the plot of the case temperature during the 3-minute test. The values of $R_{g,off}$ used are those extracted in Figure 8. In the right side of Figure 10, final and initial temperature values have been subtracted, allowing an easier comparison between the tested IGBTs.



(a) (b)

Figure 10 – (a) Case (top side) temperature during 3 minute test of the welding machine, assembled with different IGBTs, and (b) difference between final and initial case temperature, obtained in the same test.

As expected, **RGW80TS65D** (Gen 3) had a much lower temperature increase than **RGTH80TS65D** (Gen 2). The temperature variation in **Comp. A** was lower than Gen 2 but higher than G3 device. **Comp. B** presented the lowest temperature increase among the tested IGBTs.

Besides performance, an important characteristic of the IGBT is its behavior during turn-off. This characteristic is related to the oscillations which can be generated in both collector-to-emitter and gate-to-emitter voltages. Figure 11 shows main waveforms of **RGW80TS65D** (left side) and from **Comp. B** (right side) IGBTs, obtained during the tests in the welding machine.

In the right upper corner of Figure 11, **Comp. B** was tested with $R_{g,off}$ =10 Ω. Compared with the waveforms from **RGW80TS65D** (left), one can see that not only the overshoot of V_{CE} of **Comp. B** is twice as high – 244 V against 120 V, - but also that a series of further oscillations occur after the first peak. In the **RGW80TS65D**, there is a single overshoot, after which the V_{CE} is reaching the DC link voltage smoothly. It is expected that **Comp. B** generates thus a higher level of

electromagnetic interference (EMI) than **RGW80TS65D**. Additionally, the oscillations in V_{CE} make V_{GE} also swing. This generates positive peaks much higher than the threshold voltage of the IGBT. This leads to the risk of parasitic turn-on and leg shoot through, with consequent destruction of the entire machine.
In order to reduce the oscillations in the IGBT, the off gate resistor can be increased. This is proved by the waveforms in the lower right corner of Figure 11, for $R_{g,off}$ =33 Ω. However, even if the peaks are now reduced, the oscillation in V_{CE} in **Comp. B** will occur during a much longer time than in **RGW80TS65D** with $R_{g,off}$ =10 Ω. In addition, the peak in V_{GE} is still higher than the IGBT threshold voltage.

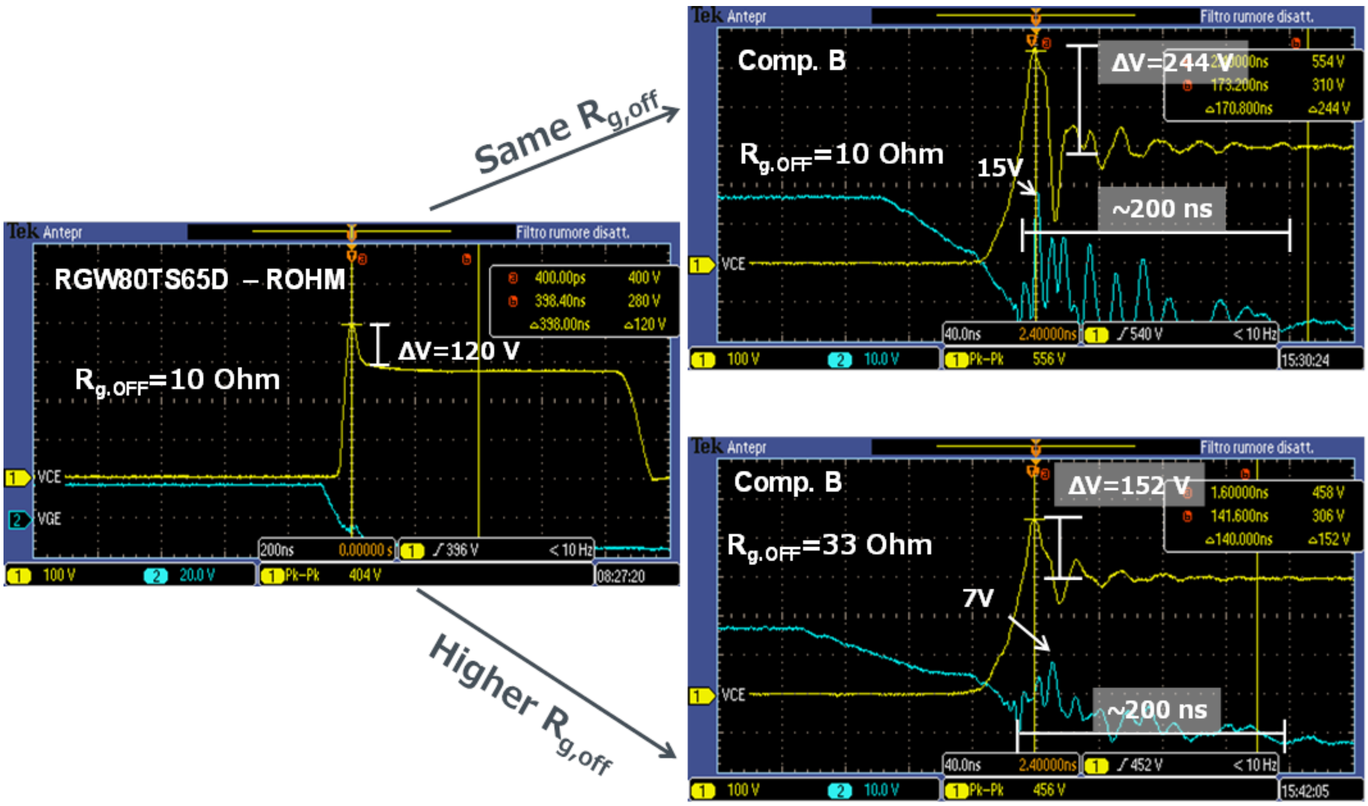
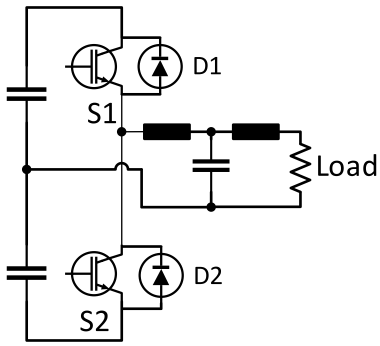


Figure 11– IGBT waveforms of V_{CE} (yellow) and V_{GE} (light blue) during turn-off in tested welding machines.

6 – Benefits in DC-AC Inverters

Systems like photovoltaic (PV) inverters and uninterruptable power supplies (UPS) contain at least one inverter stage, which converts DC into AC voltage. The resulting sinusoidal energy will be injected into the grid in the case of PV inverters, or feed an AC load in case of the UPS. Typically used topologies are half-bridge (HB) and full-bridge (FB) in case of single-phase systems, and 3-level, neutral point clamped (NPC) topologies in case of 3-phase systems. IGBT discretes and modules are widely used in all these topologies. In contrast to the welding machine in these applications the IGBTs commutate in hard-switching both for turn-on and turn-off. Therefore, the performance of the co-packed anti-parallel diode plays an important role. As mentioned in Section 4, the co-packed Gen 6 FRDs have low forward voltage and reduced reverse recovery charge.
In order to evaluate the performance of Gen 3 IGBTs in hard switched operation, a single-phase FB inverter has been used. Figure 12 presents on its left side its simplified schematic, while the right side contains a table with main electrical

parameters.



Parameter	Value
Input Voltage	400 V_{DC}
Output Voltage	130 V_{AC}
Nominal Power	2 kW
Frequency	24 kHz
Gate Voltage On/Off	15V / -3V

Figure 12– Simplified schematic of the inverter used for tests (left) and its main electrical parameters (right).

For comparison in the inverter circuit the same Gen 2 (**RGTH80TS65D**) and Gen 3 (**RGW80TS65D**) devices that were previously used in the welding machine have been used. Additionally, the soft variation of device **Comp. B** has also been tested. This device is labeled **Comp C** here. Similarly as for the previous tests, before operating the IGBT devices in the inverter prototype, the correct $R_{g,off}$ has been selected. The inverter loop inductance is much lower, around 50 nH, thus smaller gate resistors can be used. For both **RGTH80TS65D** and **RGW80TS65D**, an $R_{g,off}$ = 5 Ω resulted in a maximum voltage spike during turn-off of 520 V, i.e. 20% below breakdown voltage. For **Comp. C**, $R_{g,off}$ was increased to 10 Ω in order to reach 20% margin. The on gate resistor was equal $R_{g,on}$= 5 Ω for all three devices.
With the above defined gate resistors, the efficiency of the inverter has been measured, from 10% to 100% nominal load. The obtained values are plotted in Figure 13. They include the losses in the IGBTs, as well as in the output filters, cables and connectors. The only difference between the curves is the type of IGBT device used for **S1** and **S2**.
It is possible to observe in Figure 13 the improvement of Gen 3 with respect to Gen 2. For low power conditions, up to 1.4% efficiency improvement, and 0.4% improvement for middle and high power conditions. The difference between **Comp. C** and **RGW80TS65D** (Gen 3) is inside the accuracy of the measurements, and can be therefore neglected.

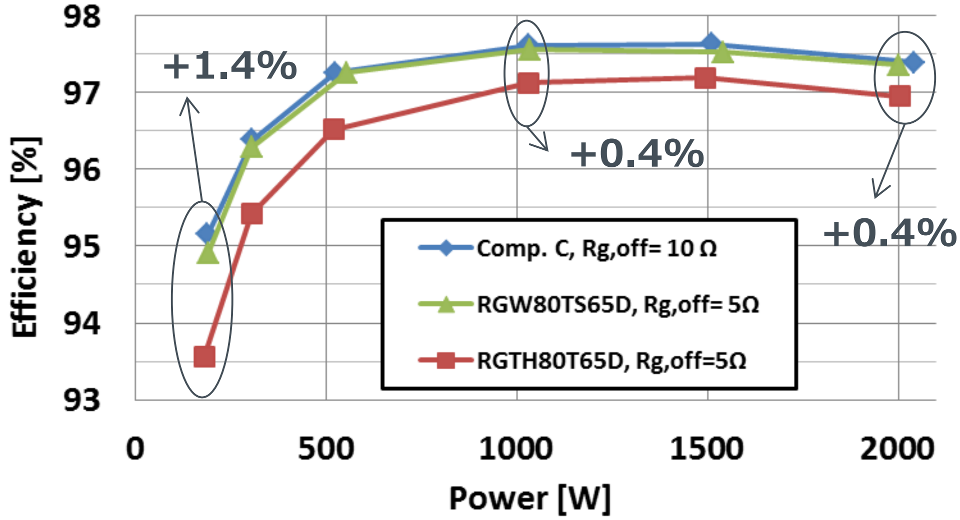


Figure 13– Efficiency comparison between 40A rated IGBTs from Gen 2, Gen 3 and Comp. C.

7 – Summary

Gen 3 IGBT from ROHM Semiconductor represents a remarkable technology improvement. Both versions RGTV and RGW offer IGBT devices rated up to 50A (RGW) and 80A (RGTV) at T_C=100°C, in standard TO-247N package.
The performance of Gen 3 matches the needs of many industrial applications, as: single phase power supply, welding machines, photovoltaic inverters, UPSs and battery chargers.
Experimental tests of Gen 3 IGBTs in a portable welding machine and in DC/AC inverter showed a minimal performance difference when compared to the market benchmark. Differently to other high speed IGBTs in the market, though, Gen 3 has a soft and oscillation free turn-off. This guarantees safe operation even if small values of external gate resistance are used. In combination with the new Gen 6 co-packed fast recovery diode technology, Gen 3 IGBTs offer an optimal compromise between performance, design simplicity and filtering effort.

Notes

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2) Before you use our Products, please contact our sales representative and verify the latest specifications :

3) Although ROHM is continuously working to improve product reliability and quality, semiconductors can break down and malfunction due to various factors.
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4) Examples of application circuits, circuit constants and any other information contained herein are provided only to illustrate the standard usage and operations of the Products. The peripheral conditions must be taken into account when designing circuits for mass production.

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7) For use of our Products in applications requiring a high degree of reliability (as exemplified below), please contact and consult with a ROHM representative : transportation equipment (i.e. cars, ships, trains), primary communication equipment, traffic lights, fire/crime prevention, safety equipment, medical systems, servers, solar cells, and power transmission systems.

8) Do not use our Products in applications requiring extremely high reliability, such as aerospace equipment, nuclear power control systems, and submarine repeaters.

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