Introduction to discrete 650 V TRENCHSTOP™ IGBT6 and 600 V reverse conducting IGBT RC-D2 families

About this document

Scope and purpose

The next generations of discrete IGBTs targeting the consumer drives market was released as a combination of two technology families that supersede Infineon's existing products, such as the short-circuit rated RC-D, RC-DF IGBT and the IR Gen6 IGBT.

The consumer drive market can be a challenging market. Even if it is a price-driven market accepting price effective products, it needs to comply with governmental regulations to reduce energy consumption and electromagnetic noise. For this reason, Infineon has released two families to help customers to address these topics.

The 600 V RC-D2 with the monolithically integrated diode offers improvements in performance, controllability and reliability compared to the 600V RC-DF.

The 650 V TRENCHSTOP™ IGBT6 has superior performance compared to RC-D2, RC-D and RC-DF technology. It is co-packed with the full-rated Rapid 1 diode, and highly controllable in case electromagnetic noise must be drastically reduced. IGBT6 can also be tuned to switch very fast if needed.

Intended audience

This application note is intended for people who would like an introduction to the discrete 600 V RC-D2 and 650V TRENCHSTOP™ IGBT6 family.

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1 Introduction

1.1 Instructions

The following information is provided as a reference for the implementation of the device and is not to be regarded as a description or warranty of certain functionality, condition or quality of the device. This application note is intended to explain the general improvements and benefits of the 600 RC-D2 and 650 V TRENCHSTOP™ IGBT6 discrete IGBT family. It provides background information for designers of power electronic systems as well as details concerning the benefits of designing discrete devices in consumer applications.

1.2 Discrete 600 V RC-D2 overview

600 V RC-D2 is the successor of the RC-DF IGBT. The diode is monolithically integrated, which makes this technology suited for price-driven applications such as consumer drives. The current rating of the diode was fine-tuned to make this product even more competitive in terms of price and performance.

RC-D2 is also the first IGBT family to introduce the SOT-223 package, which further improves the price as smaller packaging is required. The package is pin-to-pin compatible, and replaceable with the DPAK package, fitting on the same footprint.

The newest version of the RC-D2 technology has several improvements compared to the RC-DF IGBT:

- Adequate performance for the lowest price
- Better di/dt controllability to reduce electromagnetic noise
- Improved humidity robustness (HV-H3TRB test passed)
- Wide portfolio with current classes ranging from 3 A to 15 A in DPAK and SOT-223

1.3 Discrete 650 V TRENCHSTOP™ IGBT6 overview

TRENCHSTOP™ 650 V IGBT6 technology has superior performance compared to RC-D2 and RC-DF technology. It is co-packed with the full-rated Rapid 1 diode, and highly controllable in case electromagnetic noise must be drastically reduced. IGBT6 can be also tuned to switch very fast in case needed.

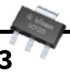
The IGBT features include:

- Lowest power losses compared to RC-D2 and RC-DF
- Great trade-off between controllability and switching losses
- 50 V higher breakdown voltage than RC-D2 and RC-DF
- Portfolio co-packed IGBT with antiparallel diode in DPAK (6A, 8A) and TO-220FP (8 A, 10 A, 15 A) and single IGTB die in DPAK (6 A, 10 A and 15 A)

1.4 RC-D2 vs. TRENCHSTOP™ IGBT6 technology

Both the IGBT6 and its co-packed Rapid 1 diode are optimized for the best performance. The RC-D2 diode is monolithically integrated, which enables the best cost situation. One drawback, however, is that it is very hard to optimize the performance of the monolithically integrated diode without influencing the performance of the IGBT. Therefore as a compromise, the diode has been designed to achieve the best possible trade-off with the IGBT for the target consumer drives market. In order to additionally improve the performance of both technologies, the short-circuit robustness is adjusted to 3 µs, which is sufficient to protect the circuitry against short-circuit events, as already proven by existing consumer-drive commercial systems.

1.5 Infineon consumer drives portfolio




Ic 100°C	SOT-223	DPAK		
	RC-D2	RC-D/DF	RC-D2	TRENCHSTOP™ IGBT 6
IGBT + diode				
3A	IKN03N60RC2	IKD03N60RF		
4A	IKN04N60RC2	IKD04N60R/RF	IKD04N60RC2	
6A	IKN06N60RC2	IKD06N60R/RF	IKD06N60RC2	IKD06N65ET6
8A				IKD08N65ET6
10A		IKD10N60R/RF	IKD10N60RC2	
15A		IKD15N60R/RF	IKD15N60RC2	
IGBT only				
6A				IGD06N65T6
10 A				IGD10N65T6
15A				IGD15N65T6

Figure 1 Overview of Infineon 600 V / 650 V IGBT technologies for consumer drives

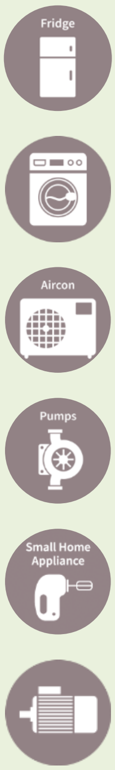
RC-D2 was introduced as an improvement to the RC-D and RC-DF DPAK portfolio, and as a cost reduction with regard to the SOT-223 compared to solutions offered in DPAK.

1.6 Applications description

The consumer drives market currently addresses 4 A and 6 A devices mostly sold in refrigerators. The power rating for refrigerators can be up to 300 W. Compared to other consumer drives, the refrigerator load profile is different in that it has two distinct load conditions used to define the proper power switch:

- **Pull-down or high-load condition**
  This condition occurs when the refrigerator is plugged in to the electric grid for the first time. The interior temperature of the refrigerator needs to be pulled-down from the ambient to the desired value in the predefined time, which is usually no longer than 6 hours. The refrigerator compressor inverter, and consequently the selection of the IGBTs, are defined specifically to keep the temperature of the board and the components below a certain level, usually limited by the PCB material, to approximately 120°C.
- **Nominal or low-load condition**
  During 90% of its lifetime, the refrigerator operates in nominal conditions in the range of approximately 40 W. This is why the efficiency of this appliance is defined at this condition.

Refrigerators are a special case in terms of load profile, which is not valid for other consumers' drive applications. In this case, the device is defined to withstand high load conditions. Figure 2 provides a rough estimate of the maximum power that could be expected for a certain appliance and the recommended current class in case an IGBT is used in the motor inverter.



Applications			Power rRating	IGBT recommended current class
Refrigerator	Fan		up to 100 W	3 A
	Compressor	Linear Rotary	up to 300 W	3 A to 6 A
Washing Machine	Drum drive		up to 600 W	6 A to 15 A
	Drain pump		up to 30 W	3 A
Air Conditioner	Indoor unit fan		up to 100 W	3 A
	Outdoor unit fan		up to 150 W	3 A to 4 A
Dish Washer	Circulation pump		up to 70 W	3 A
	Drain pump		up to 30 W	3 A
Air Purifier	Fan		up to 100 W	3 A
Heating Circulation Pump	Pump		up to 60 W	3 A
Ceiling & Upright Fans	Fan		up to 80 W	3 A
Kitchen/Range Hood Fan	Fan		up to 150 W	3 A-4 A
Hair Dryer	Fan		up to 60 W	3 A
Commercial Refrigeration Condenser Fan	Fan		up to 80 W	3 A
Blender	Main drive		up to 600 W	6 A to 15 A

Figure 2 Application cluster for consumer drives

The portfolio also includes single IGBTs to serve special topologies driving switched reluctance motors (SRM) that can be used for blenders, vacuum cleaners and other appliances.

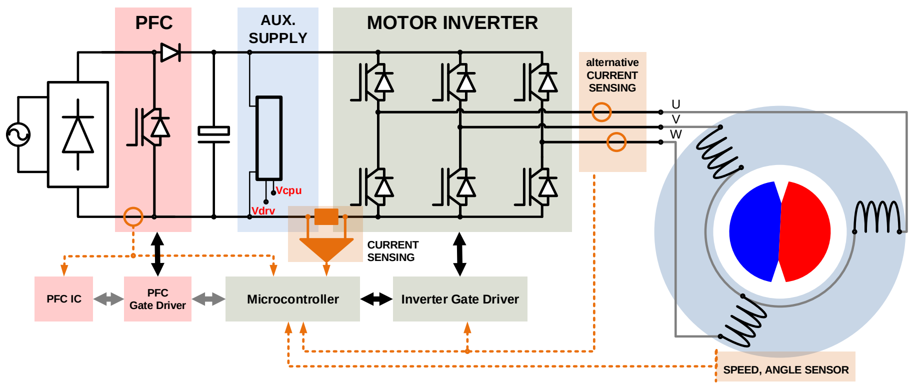


Figure 3 Low-power consumer drive system with three-phase, two-level (B6) inverter

Introduction

The consumer drive market is in most cases regulated by governmental policies with the goal to increase energy efficiency (EU energy labeling) and reduce the stress caused by current and voltage harmonics on low-voltage, alternating-current public mains networks (EMC standards EN 61000-3-2).

Energy efficiency can be significantly improved by moving from single-speed to variable-speed drives (VSD) where a six-bridge inverter (B6) is usually needed. This trend is called “inverterization.” Inverter losses are also influenced by the performance of the power switch. Figure 4 shows the ratio of the inverter losses compared to the inverter input energy consumed during the refrigerator lifetime. The results are obtained using a 200 W refrigerator load profile and by simulating the motor drive inverter losses. The difference in performance of the power devices does not have significant influence over total losses. This is also one reason why the cost optimization of the power switches with respect to performance optimization is preferred in the consumer drive market. Only for the high-end market segment, additional performance optimization may be more valuable.

Product name	$E_{INVERTER}$ [J] / E_{IN} [J]
IKD04N60RC2	3.3%
IKD04N60RF	3.7%
IKD06N65ET6	3.1%
IPS60R1K0PFD7S	2.7%
IPS60R1K5PFD7S	3.2%

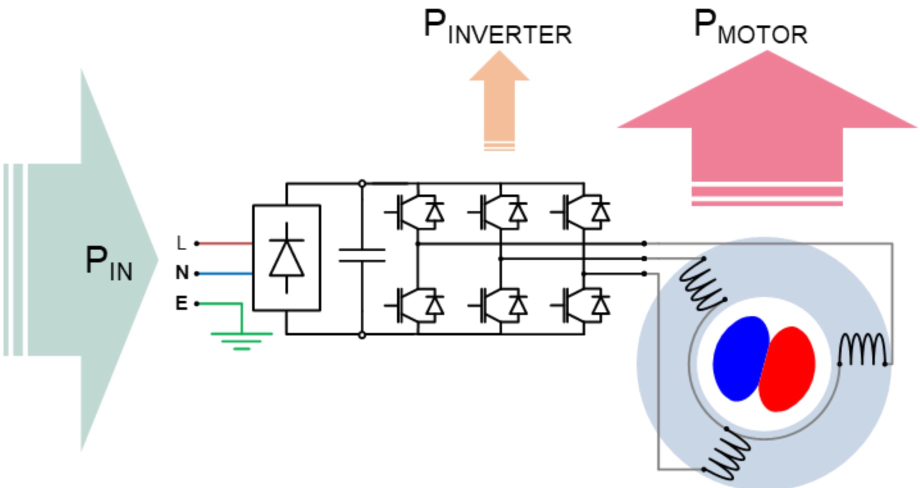


Figure 4 Refrigerator inverter loss comparison based on refrigerator load profile

Introduction

An additional aspect that is important when selecting a power device is its impact on the total electromagnetic emissions of the system. EMC (electromagnetic compatibility) includes a list of norms that set the limits of electromagnetic-field emissivity and susceptibility for a system operating in a specific environment (e.g. in a household environment). EMC standard are classified into EMI (electromagnetic interference) and EMS (electromagnetic susceptibility) norms. EMI norms consider the adverse effects of electronic devices on peripheral equipment. There are two kinds of EMIs: one is conducted emissions that are conducted by means of galvanic contact to the power grid, and the other is radiated emissions, which are radiated as electromagnetic waves. One of the most common sources of EMI is the power-semiconductor switching between on and off states, due to its steep voltage and current waveform slopes with high harmonic content, as shown in Figure 5. In consumer drive systems, the contributors to EMI can come from the PFC stage, the auxiliary power supply and the motor inverter. By increasing the gate resistance value, voltage and current slopes dv/dt and di/dt of the power switches can be reduced, and thus, the EMI. Depending on the device technology, dv/dt and di/dt are more or less tunable by changing the gate resistance. This feature is called “device controllability.” A device with higher controllability allows a wider range of regulation of commutations speed, and can offer more flexibility to improve the EMI behavior of the system.

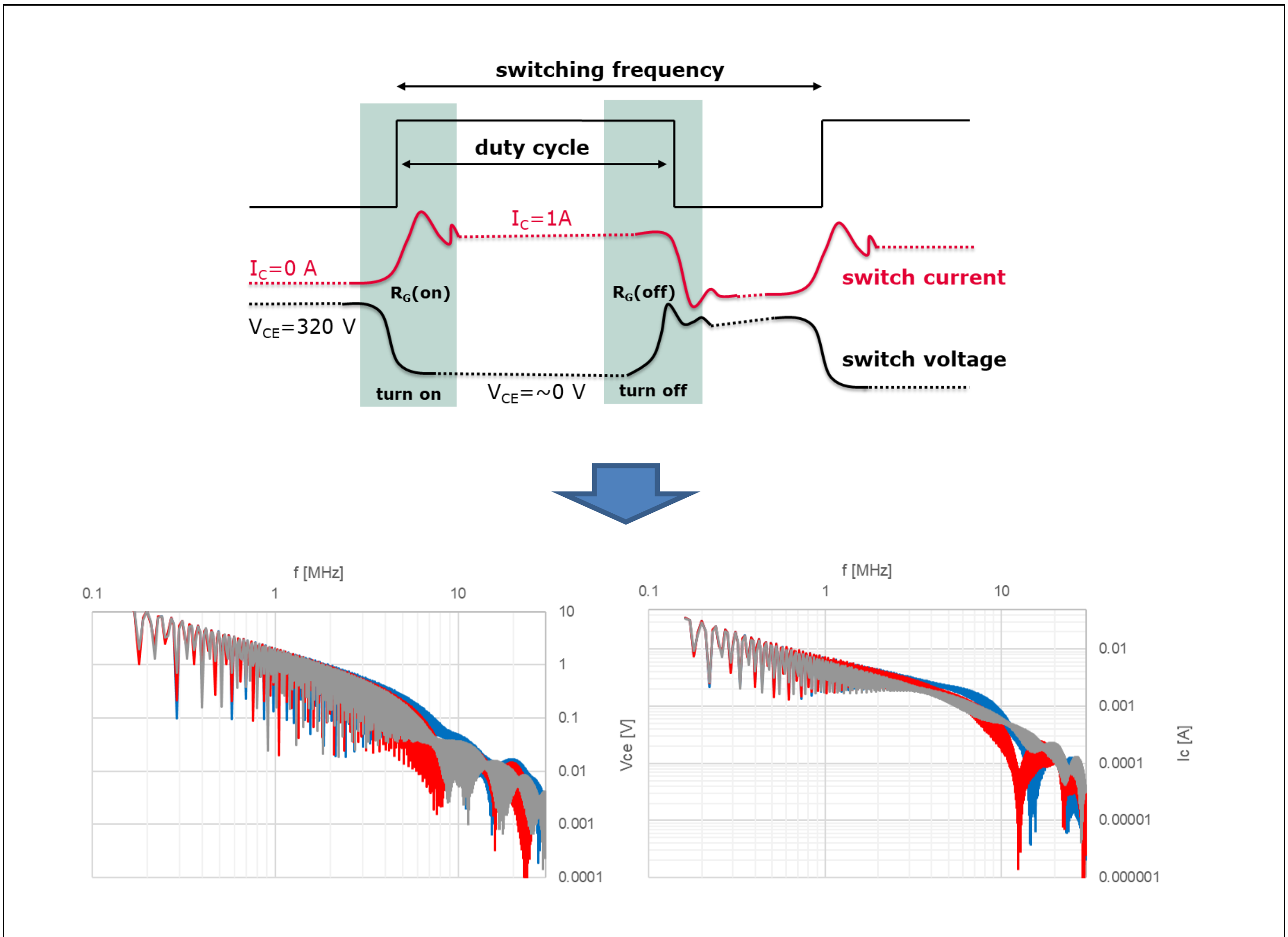


Figure 5 EMI displayed in time and frequency domain

Nevertheless, power devices are not the only source of emission in the system. EMI can be also strongly influenced by the PCB layout, choice and positioning of passive components (e.g. bypass capacitors). In addition, a proper design of the EMI filter is always needed to conform with EMI regulations. That is why special care is needed in the PCB design and passive component choice to address the EMI topic properly.

2 Product benefits

2.1 Improved performance

RC-D2 and IGBT6 have been improved in terms of performance by optimizing the conduction and switching losses in order to serve the consumer drives' market.

RC-D2 technology has been developed as an improved version of RC-DF technology. RC-D stands for reverse-conducting for drives. The IGBT6 is the improved version of the former Gen5 IR IGBT technology, and is co-packed with a diode-based on the Rapid 1 technology. IGBT6 has lower losses and better controllability compared to RC-D2.

The performance comparison visualized in Figure 6 is done using the refrigerator application for the pull-down (high-load) condition. Depending on the inverter layout and thermal management, customer choice can be between 3 A and 6 A . The gate resistance selection is done in order to pass the EMI tests required by the governmental policies. Comparison of conduction vs. switching losses was done simulating the motor drive application based on dynamic and static measurements. Based on customer experience, gate resistances were selected in order to switch the device with dv/dt of 2 V/ns and switching frequency of 7.5 kHz.

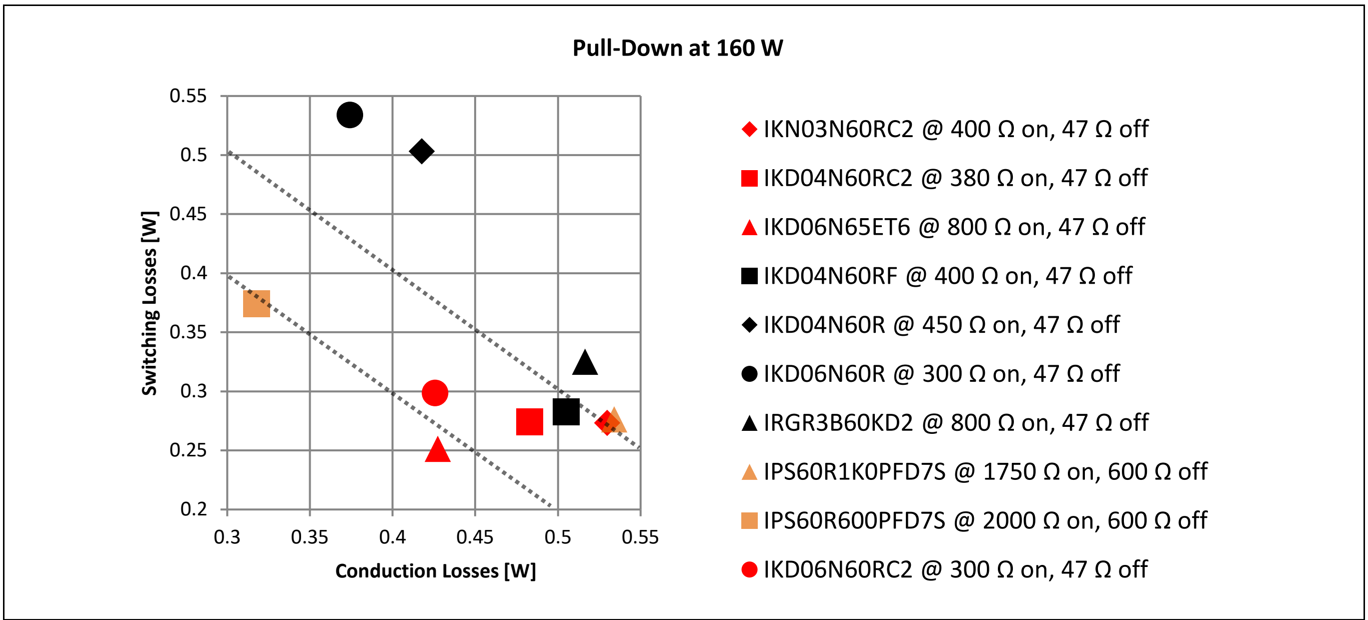


Figure 6 Power loss split for the refrigerator pull-down motor condition at 160 W

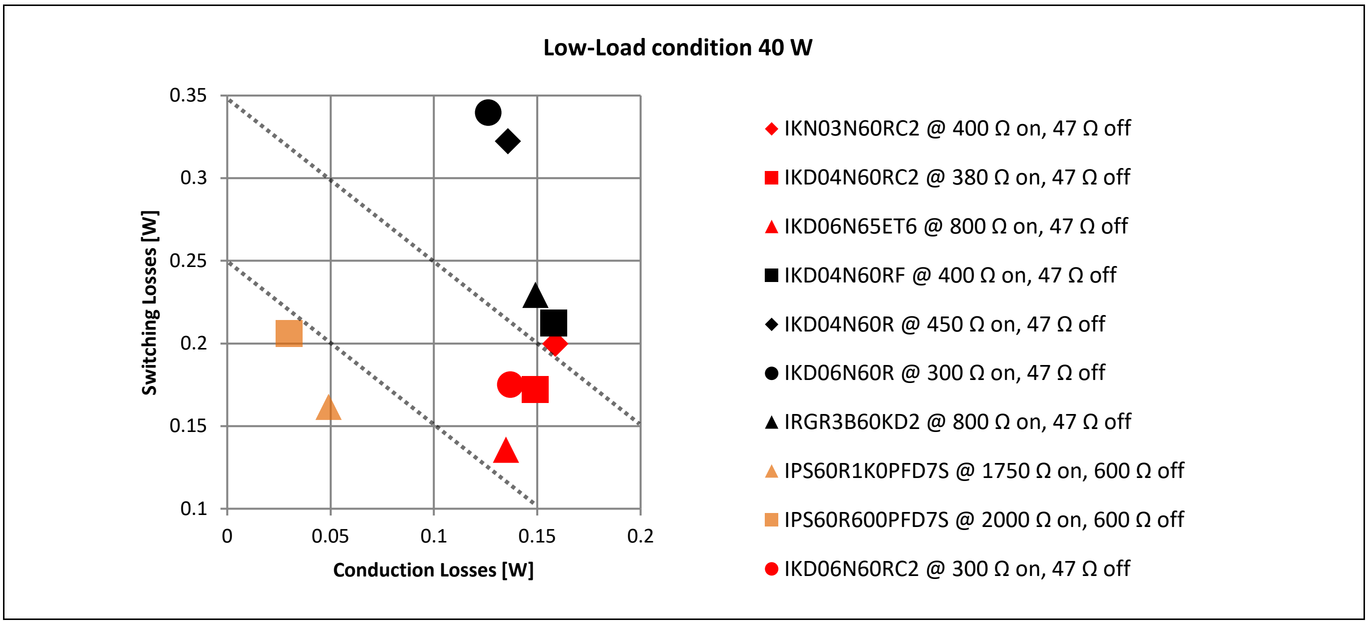


Figure 7 Power loss split for the refrigerator nominal motor condition at 40 W

Figure 7 shows that IGBT6 is the most performant device followed by the RC-D2. The comparison is also done for the CoolMOS™ PFD devices with two R_{DSon} of 600 mΩ and 1 Ω. CoolMOS™ PFD devices are used for high-end appliances to additionally reduce the inverter losses at nominal condition of typically 40 W. However, they are less controllable and less performant in the high load conditions (above 100 W) compared to IGBTs.

2.2 Device controllability for reducing EMI

In consumer drives, the EMI needs to be limited. Using a controllable power switch in the motor inverter helps to reduce the emissions by adjusting the gate resistance. The controllability of the device can be shown by dv/dt vs. $R_{g,}$ and di/dt vs. R_g dependency. Another way to quantify the EMI and check which frequencies are the most critical is to look at the current and voltage turn-on and turn-off waveforms, connecting them to form a periodical signal with the target-switching frequency, and then performing a Fourier analysis to get the signal harmonic content.

The harmonic analysis shown in Figure 8 is based on double-pulse measured waveforms. The waveforms have been measured at I_C=1 A, DC link voltage V_{DC}=400 V and junction temperature T_J=100°C. A 47 Ω turn-off resistance has been selected to be similar to application conditions. The resolution of the sampled waveforms is 5 ns. The turn-on and turn-off waveforms have been connected together to re-create the PWM signal with switching frequency of 10 kHz and duty cycle of 80%. This signal is then analyzed using FFT methods, and charted separately for the currents and voltages from 1 MHz to 300 MHz to partly cover conducted EMI (150 kHz - 30 MHz) and radiated EMI (30 MHz - 1 GHz) frequency range. The dotted black line separates the conducted from the radiated EMI region.

Product benefits

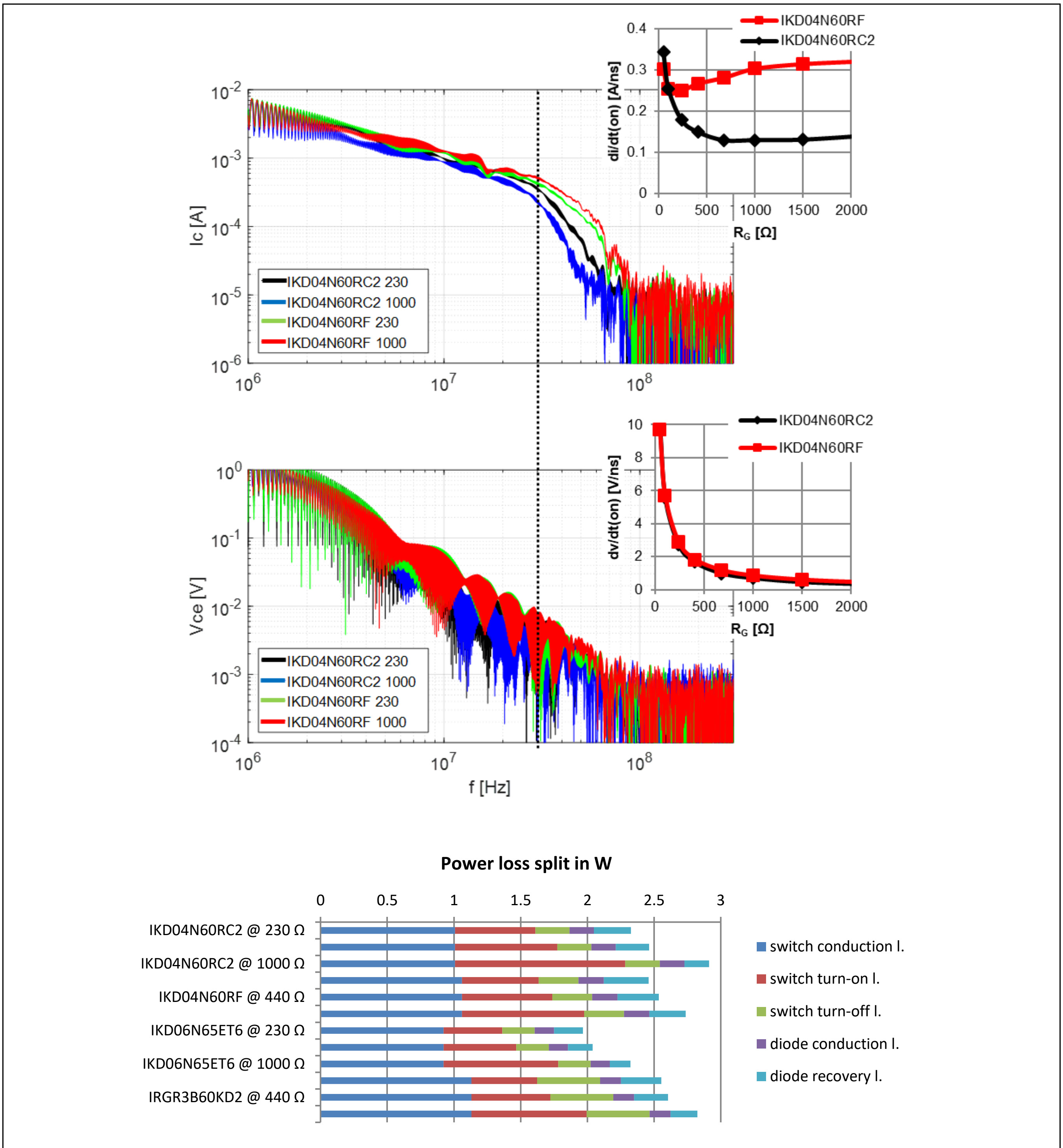


Figure 8 RC-DF vs. RC-D2 controllability, harmonic analysis comparison and split of losses

RC-DF technology does not feature good current controllability, as di/dt even increases at higher gate resistance values. This is also visible in the harmonic analysis where the IKD04N60RF driven with R_G(on) of 1000 Ω has higher current harmonics than when driven with R_G(on) of 230 Ω. Compared to RC-DF, RC-D2 offers significant improvements in terms of current controllability, which begin to saturate after ~700 Ω. Therefore, it is not recommended to drive RC-D2 with R_G(on) higher than 1 kΩ, as the switching losses will increase without having any significant EMI noise reduction. Both technologies are comparable in terms of dv/dt.

Product benefits

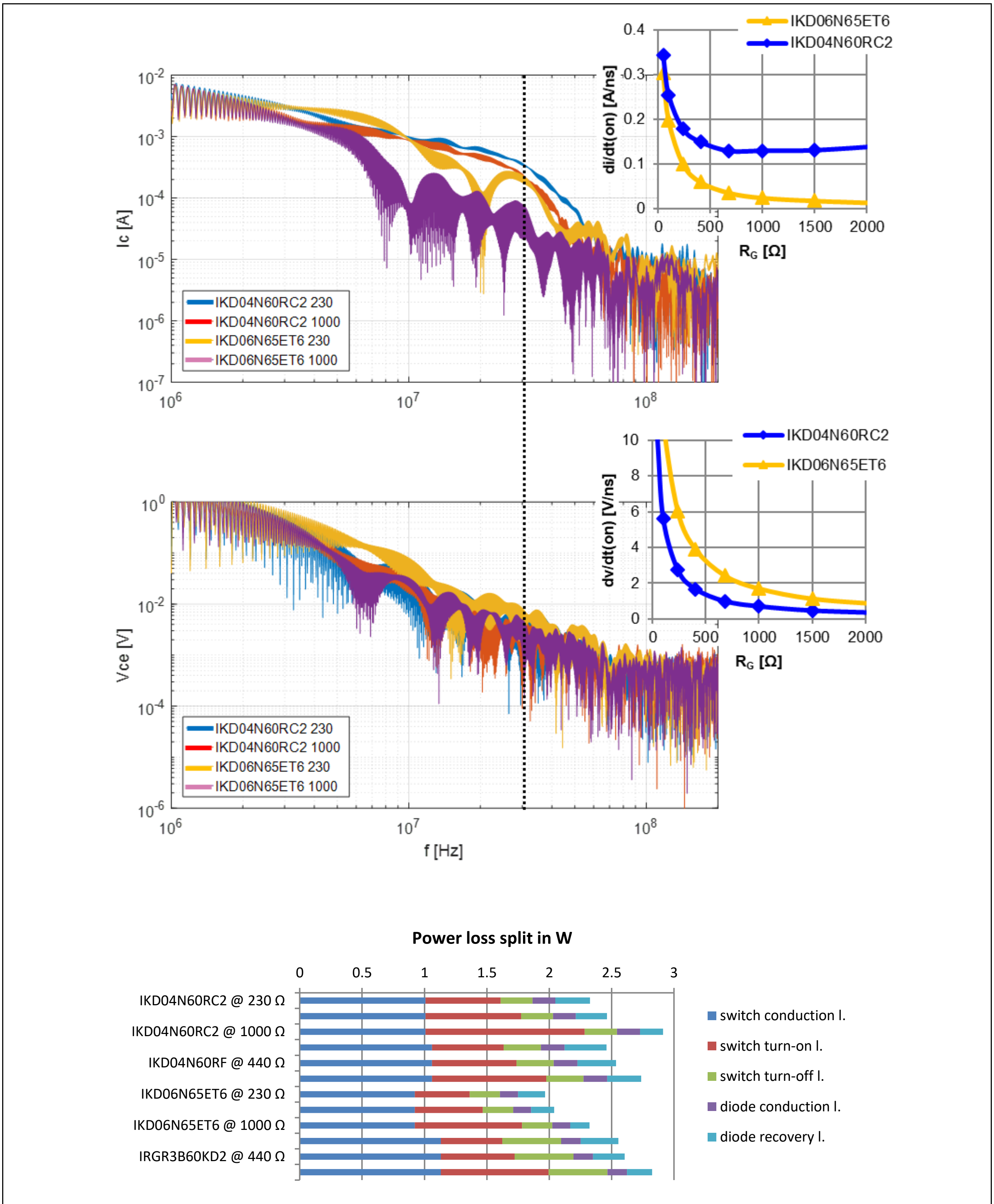


Figure 9 RC-D2 vs. IGBT6 controllability, harmonic analysis comparison and split of losses

IGBT6 technology is more flexible in controlling di/dt and dv/dt compared to RC-D2 IGBT technology. Even if IGBT6 needs higher R_G(on) to match the RC-D2 (as shown in Figure 9), the turn-on switching losses are still lower, making IGBT6 the best-in-class technology in terms of controllability and performance. IGBT6

Product benefits

technology behaves as a fast-switching device compared to other IGBTs designed for consumer drive applications. Therefore it is recommended to use a two times or even higher $R_{G(on)}$ compared to the conventional IGBTs if EMI needs to be addressed. For example the same voltage harmonics of the RC-D2 driven with $R_{G(on)}$=230 Ω are matched using IGBT6 driven with $R_{G(on)}$=1 kΩ still having lower total losses compared to RC-D2.

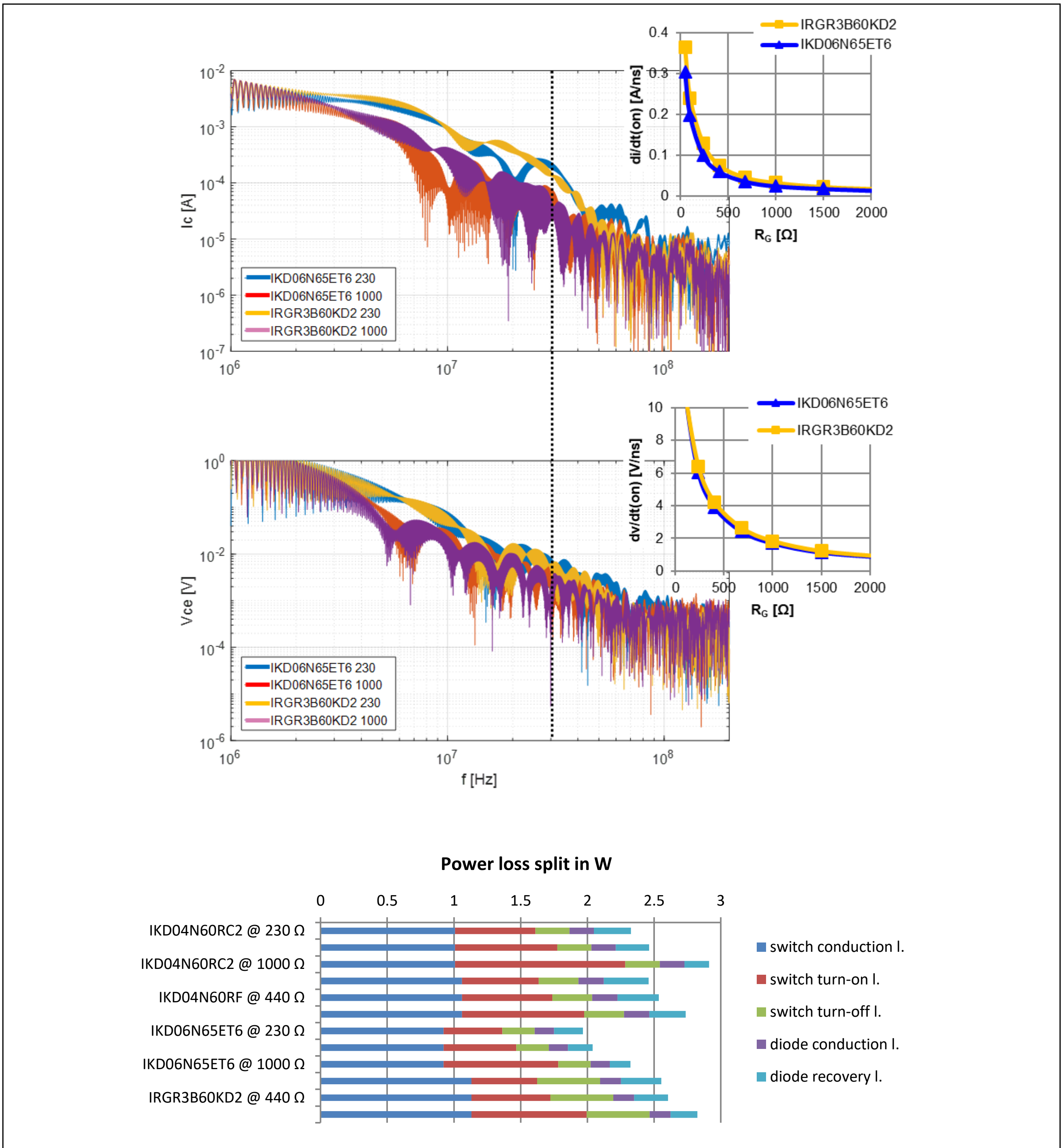


Figure 10 RC-D2 vs. IGBT6 controllability, harmonic analysis comparison and split of losses

Product benefits

A former IR device has been discontinued, but is still present in some designs. In case a replacement is needed, the closest device in terms of controllability is the IGBT6. The performance if the IRGR3B60KD2 device is worse than both IGBT6 and RC-D2, as shown in the power loss split in Figure 10.

3 Using DPAK vs. SOT-223 package

The need for improved power density and lower system cost pushes designers to find new and innovative package alternatives to traditional design choices. One area where cost and space reduction is possible is in the design and packaging selection of high-voltage power switches such as IGBTs. This is especially valid for low-power home appliances where a heat sink is not desirable. Infineon Technologies have released an IGBT with a monolithically integrated reverse-conducting diode in a small SOT-223 package to reduce the package cost and size compared to the conventional DPAK package. This cost-optimized product portfolio called RC-D2 will enable further system-level cost improvement.

One of the most noticeable differences between the DPAK and the SOT-223 packages is clearly visible when the devices are compared side-by-side as shown in Fig. 11. Besides the different sizes, the DPAK has an exposed lead frame, while the SOT-223 does not. The IGBT in SOT-223 can be used as a plug-and-play replacement for DPAK if higher operating and case temperatures is accepted, or if the application design operates with lower power. However, extensive testing has shown that an SOT-223 package can perform as well as a DPAK, albeit with a few limitations.

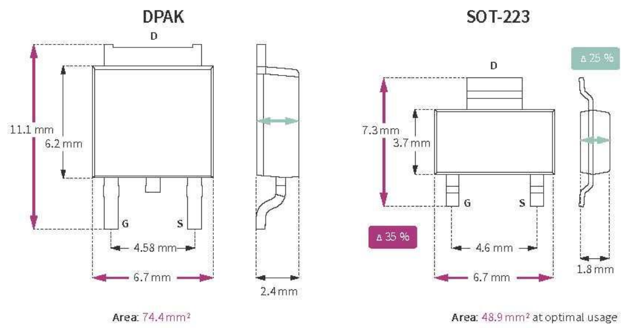


Figure 11 DPAK and SOT-223 dimensions and differences

The thermal measurements shown in Figure 12 are done on the small PCB adapter exposing the die and measuring the temperature on the collector lead with a thermocouple, and the junction temperature with a thermal camera. The power is applied to the diode and adjusted to match the junction temperature approximately 150°C. Ambient temperature is 25°C. From DPAK to SOT-223 package, the junction to lead thermal resistance R_{TH}(j-l) slightly increases. One of the effects that compensates thermally the reduction of the lead frame in the SOT-223 is the exposed copper on the PCB, which improves the heat radiation into the air.

package	die type	P [W]	T_J [°C]	R_{TH} (j-l) [K/W]	T_L [°C]	R_{TH}(j-a) [K/W]
DPAK	IGBT	2.00	150	20.6	109	63
	Diode	1.94	148	24.1	100	63
SOT-223	IGBT	1.81	149	22.1	109	69
	Diode	1.76	146	25.0	102	69

Figure 12 SOT-223 and DPAK thermal measurements on the same footprint

Using DPAK vs. SOT-223 package

Similar thermal tests have been performed in the application while driving the motor with an output power of 188 W and phase current of 0.86 A_{RMS}. The temperature is measured on the emitter lead using a thermocouple and with a thermal camera to identify the hottest spot on the package. Both measurements are taken from the hottest among the six devices of the inverter. Two tests have been done with six IKD04N60RC2 (DPAK) and six IKN04N60RC2 (SOT-223) with the same PCB footprint. The lead temperature measured on the SOT-223 package is 91°C and on the DPAK package 77°C. A temperature increase of 10°C should be expected using SOT-223 for the PCB design in Figure 13 below.

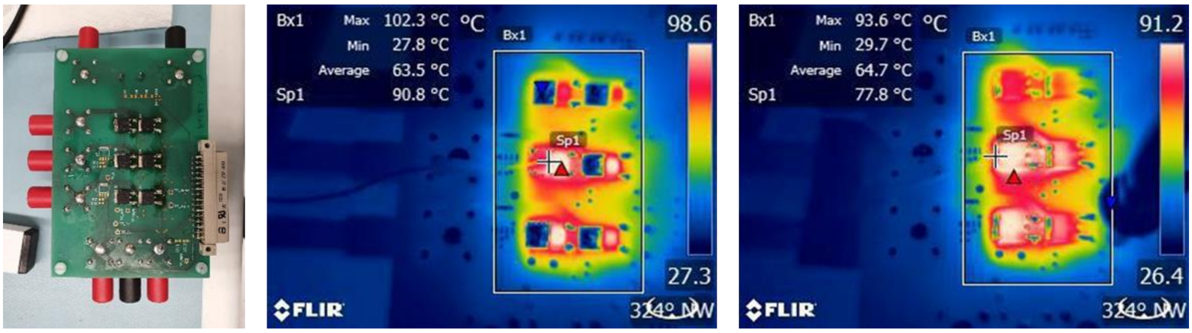


Figure 13 SOT-223 and DPAK thermal measurements on the same footprint

Simulation and experience show that additional reduction of the SOT-223 temperature can be done by:

- Increasing the conductivity of the PCB
- Increasing the footprint area
- Adding a copper plane on the other side of the PCB to act as an efficient heat spreader
- Top-side cooling with application of a thermal paste and metal plate on the top of the SOT-223, which some customers are already using with DPAK packages. This concept is even more effective with SOT-223 packages having less mold compound. Special care needs be applied to avoid electrical contact.

4 Conclusion

The new RC-D2 and TRENCHSTOP™ IGBT6 generation of Infineon represent a technological improvement over their predecessors to address consumer drives from lowest cost to highest performance. In case EMI is an issue, then the right technology can be selected to address this subject as well.

The SOT-223 can be used to reduce the size of the inverter by a factor of 3. The drawback is the reduction of the maximum output power by approximately 1/3 compared to the thermally optimized solution, targeting applications in the power range below 150 W depending on the PCB layout design.

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