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

About this document

Scope and purpose

The next generation 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 drives market can be a challenging market. Even though it is a price-driven market accepting price effective products, it needs to comply with government regulations in terms of energy consumption and electromagnetic noise. To help customers address these issues, Infineon has released two product families:

- The 600 V RC-D2 with a monolithically integrated diode offers improvements in performance, controllability, and reliability compared to the 600 V RC-DF.
- The 650 V TRENCHSTOP™ IGBT6 that has superior performance compared to RC-D2 and RC-DF technology. It is co-packed with the full-rated Rapid 1 diode and is highly controllable in case the electromagnetic noise has to be drastically reduced. IGBT6 can also be tuned to switch very fast when needed.

This application note explains the benefits and general improvements in the 600 V RC-D2 and the 650 V TRENCHSTOP™ IGBT6 discrete IGBT families. It provides background information for designers of power electronic systems and details about the benefits of designing discrete devices in consumer applications.

The information in this application note is provided as a reference for the implementation of the device and should not be regarded as a description or warranty of any functionality, condition, or quality of the device.

Intended audience

The intended audience for this document are design engineers, technicians, and developers of electronic systems.

Table of contents

1 Introduction

1.1 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 has been 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 that further improves its pricing as it requires a smaller packaging. 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

1.2 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 is highly controllable in case the electromagnetic noise has to be drastically reduced. IGBT6 can also be tuned to switch very fast when needed.

Features of the IGBT include:

- Lowest power losses compared to the 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 IGBT die in DPAK (6 A, 10 A and 15 A)

1.3 RC-D2 versus the 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 and provides the best cost option. 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. To further improve the performance of both technologies, the short-circuit robustness is adjusted to 3 µs that is sufficient to protect the circuitry against short-circuit events—this has already been proven in existing consumer drive commercial systems.

1.4 Infineon consumer drives portfolio

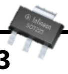
Ic 100°C	SOT-223 	DPAK 		
	RC-D2	RC-D/DF	RC-D2	TRENCHSTOP™ IGBT 6
IGBT + diode				
3A	IKN03N60RC2	IKD03N60RF		
4A	IKN04N60RC2	IKD04N60R/RF	IKD04N60RC2	
6A	IKN06N60RC2	IKD06N60R/RF	IKD06N60RC2	IKD06N65ET6
8A				IKD08N65ET6
10A		IKD10N60R/RF	IKD10N60RC2	
15A		IKD15N60R/RF	IKD15N60RC2	
IGBT only				
6A				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 low-cost option with the SOT-223 as compared to the solutions offered in DPAK.

1.5 Applications description

The consumer drives market currently addresses the 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 that are used for defining 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 a predefined time, which is usually no longer than six hours. The refrigerator's compressor inverter, and consequently the selection of the IGBTs, is defined specifically to keep the temperature of the board and the components below a certain level, usually limited by the printed circuit board (PCB) material, to approximately 120°C.
- **Nominal or low load condition**
  During 90% of its lifetime, a refrigerator operates in nominal conditions in the range of approximately 40 W. This is why the efficiency of a refrigerator is defined at this condition.

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

Applications			Power rating	IGBT recommended current class
Refrigerator	Fan		up to 100 W	3 A
	Compressor	Linear	up to 300 W	3 A to 6 A
		Rotary		
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
Dishwasher	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 and upright fan	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

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

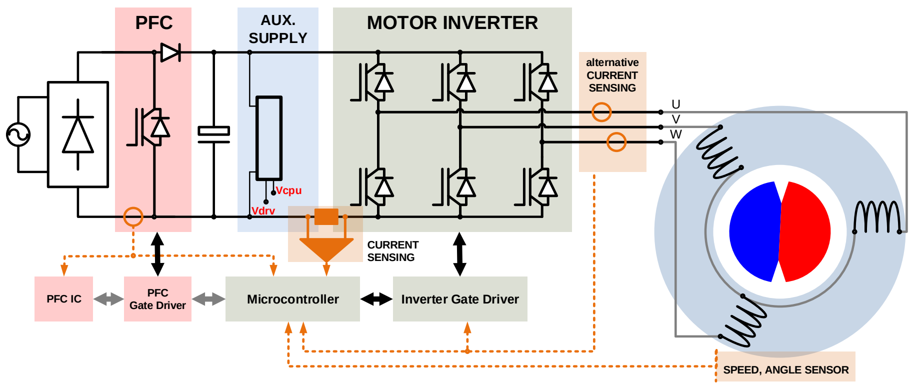


Figure 3 A low power consumer drives system with a 3-phase, 2-level (B6) inverter

The consumer drives market is in most cases regulated by government 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 a refrigerator's lifetime. The results were obtained using a 200 W refrigerator load profile and by simulating motor drive inverter losses. The difference in performance of the power devices does not have a significant influence over the total losses. This is also a reason why cost optimization of power switches instead of performance optimization is preferred in the consumer drives market. Only for the high-end market segment, additional performance optimization may be preferred.

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

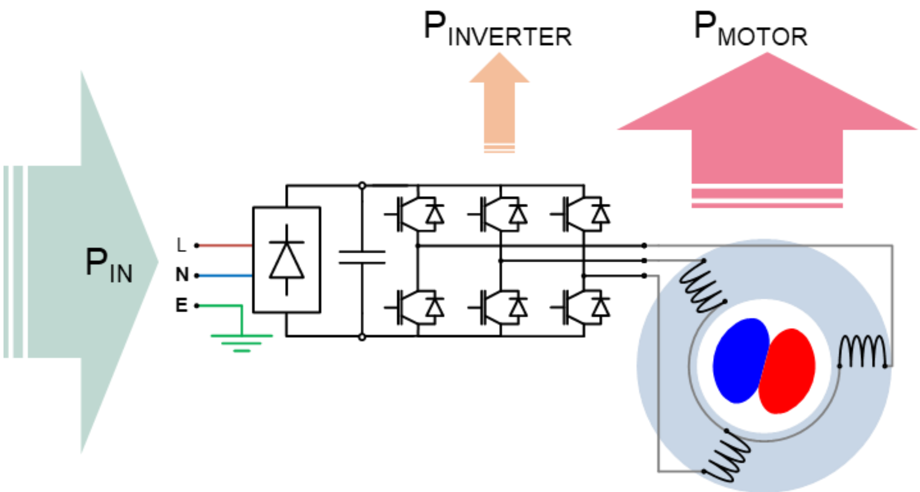


Figure 4 Refrigerator inverter loss comparison based on the refrigerator load profile

An additional aspect that is important when selecting a power device is its impact on the total electromagnetic emissions of the system. Electromagnetic compatibility (EMC) includes a list of norms that set the limits of electromagnetic field emissions and susceptibility for a system operating in a specific environment (e.g. in a household environment). EMC standards are classified into electromagnetic interference (EMI) and electromagnetic susceptibility (EMS) 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 galvanic contact to the power grid, and the other is radiated emissions that are radiated as electromagnetic waves. One of the most common sources of EMI is the power-semiconductor switching between the "on" and "off" states due to its steep voltage and current waveform slopes with high harmonic content, as shown in Figure 5. In consumer drives 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 rate of change, 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 can more or less be tuned by changing the gate resistance. This feature is called "device controllability." A device with higher controllability allows a wider range of regulation of commutation speeds, and can offer more flexibility to improve the EMI behavior of the system.

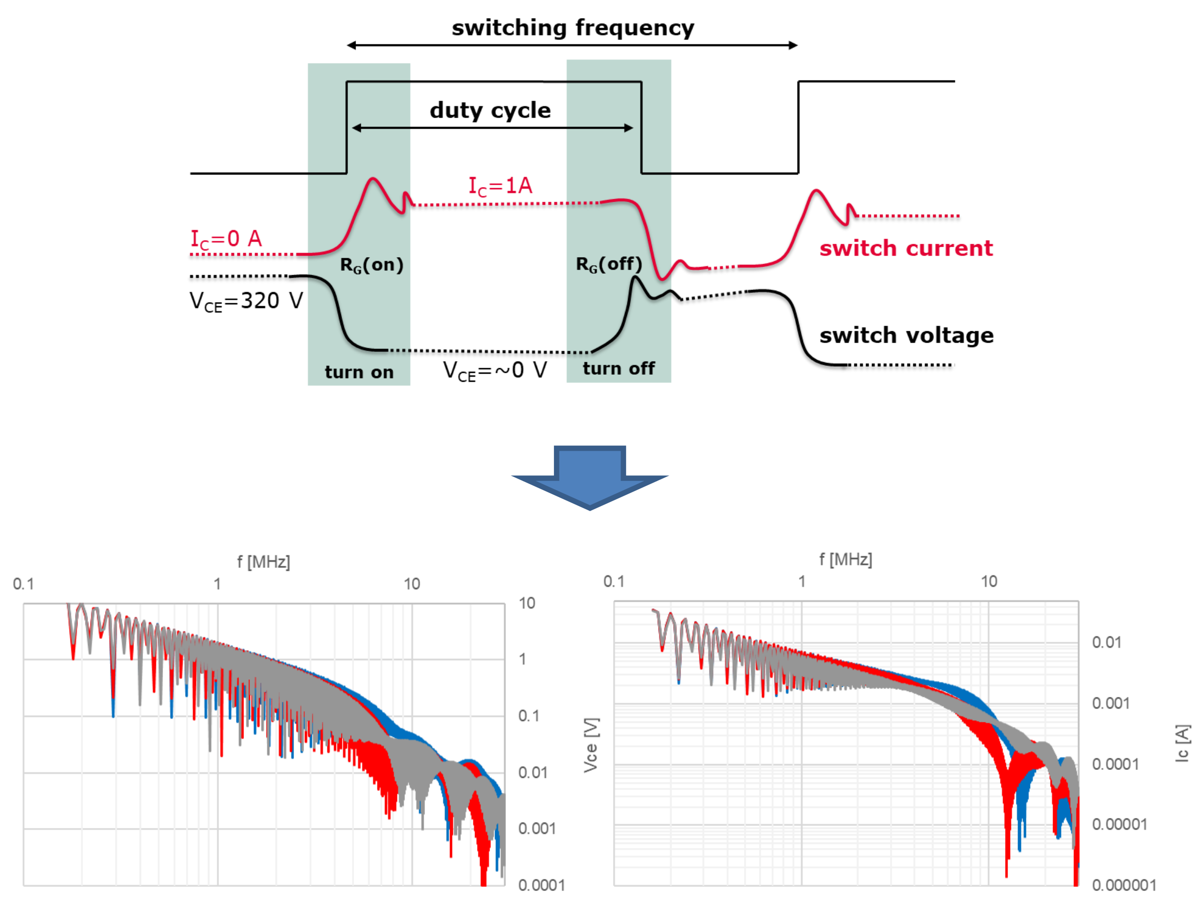


Figure 5 EMI displayed in a time and frequency domain

Power devices are, however, not the only source of emission in a system. EMI can also be strongly influenced by the PCB layout and choice and positioning of passive components (e.g. bypass capacitors). The EMI filter must also be designed to conform to the EMI regulations. Therefore, to properly address the EMI topic, special attention must be given to the PCB design and passive component choice.

2 Product benefits

2.1 Improved performance

To serve the consumer drives market, the performance of RC-D2 and IGBT6 has been improved by optimizing the conduction and switching losses.

RC-D2 technology is an improved version of RC-DF technology. RC-D stands for reverse-conducting for drives. IGBT6 is an 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 the RC-D2.

The performance comparison shown in Figure 6 is for the refrigerator application in pull down (high load) condition. Depending on the inverter layout and the thermal management, customers can choose between 3 A and 6 A. Gate resistance is selected keeping in mind the EMI tests required by government policies. Comparison of conduction versus switching losses was done by simulating the motor drive application based on dynamic and static measurements. Based on customer experience, gate resistances were selected to switch the device with dv/dt = 2 V/ns and switching frequency of 7.5 kHz.

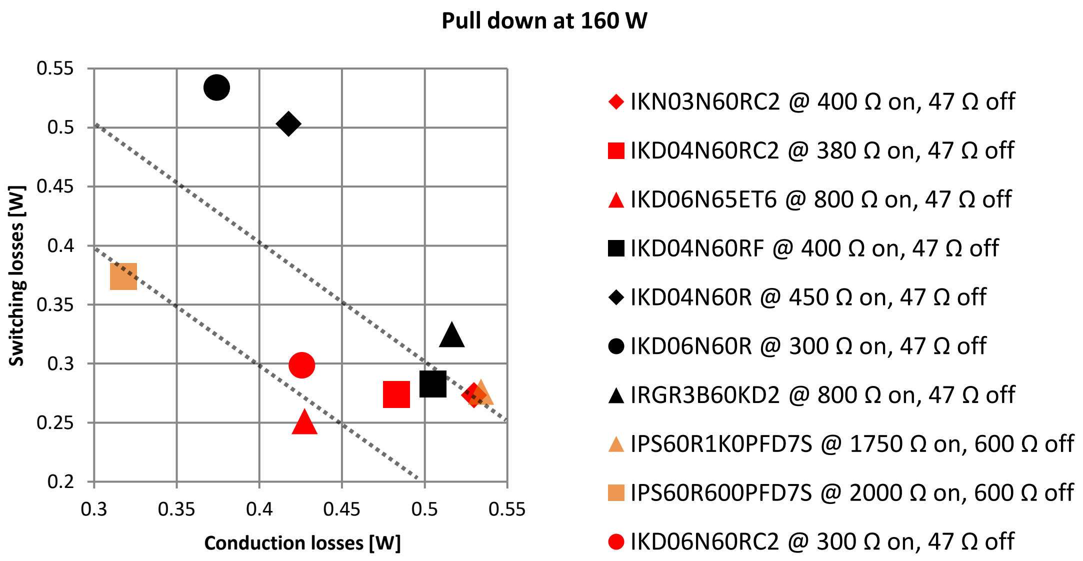


Figure 6 Power loss split for a refrigerator's pull down motor condition at 160 W

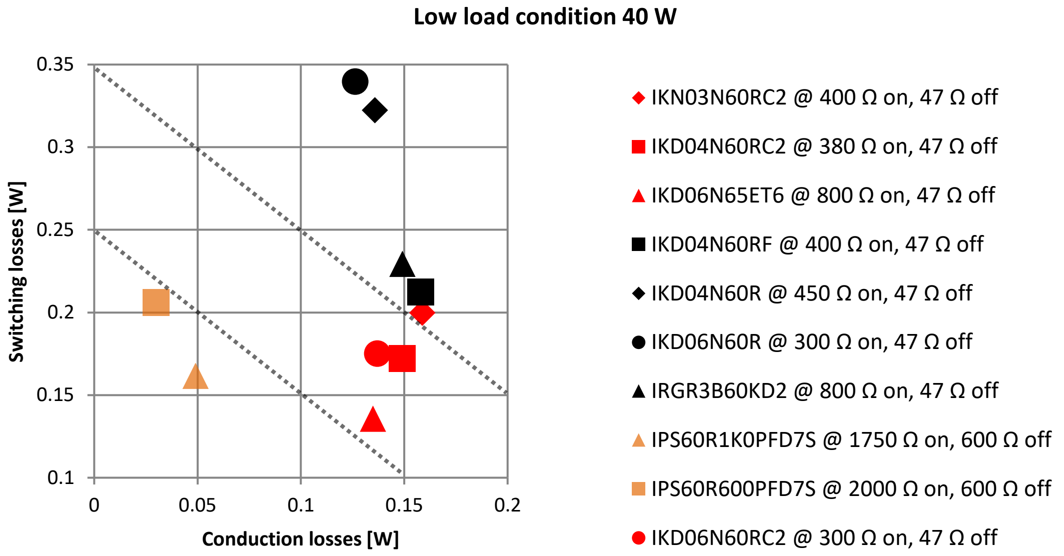


Figure 7 Power loss split for a refrigerator's nominal motor condition at 40 W

Figure 7 shows that IGBT6 is the most performant device followed by the RC-D2. The comparison was also done for the CoolMOS™ PFD devices with two R_{DSon}—600 mΩ and 1 Ω.

CoolMOS™ PFD devices are used for high-end appliances to additionally reduce the inverter losses at nominal condition (typically 40 W). However, compared to the IGBTs, they are less controllable and less performant in high load conditions (above 100 W).

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 in reducing the emissions by adjusting the gate resistance. The controllability of the device can be shown by the dv/dt versus R_g and di/dt versus R_g dependency. Another way of quantifying the EMI and checking which frequencies are the most critical is by looking 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 were 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 was selected to match the application conditions. The resolution of the sampled waveforms was 5 ns. The turn-on and turn-off waveforms were connected together to recreate the pulse width modulation (PWM) signal with a switching frequency of 10 kHz and a duty cycle of 80%. This signal was then analyzed using fast Fourier transform (FFT) methods, and charted separately for currents and voltages ranging from 1 MHz to 300 MHz to partially cover the frequency ranges of conducted EMI (150 kHz - 30 MHz) and radiated EMI (30 MHz - 1 GHz). In the figure, the dotted black line separates the conducted from the radiated EMI region.

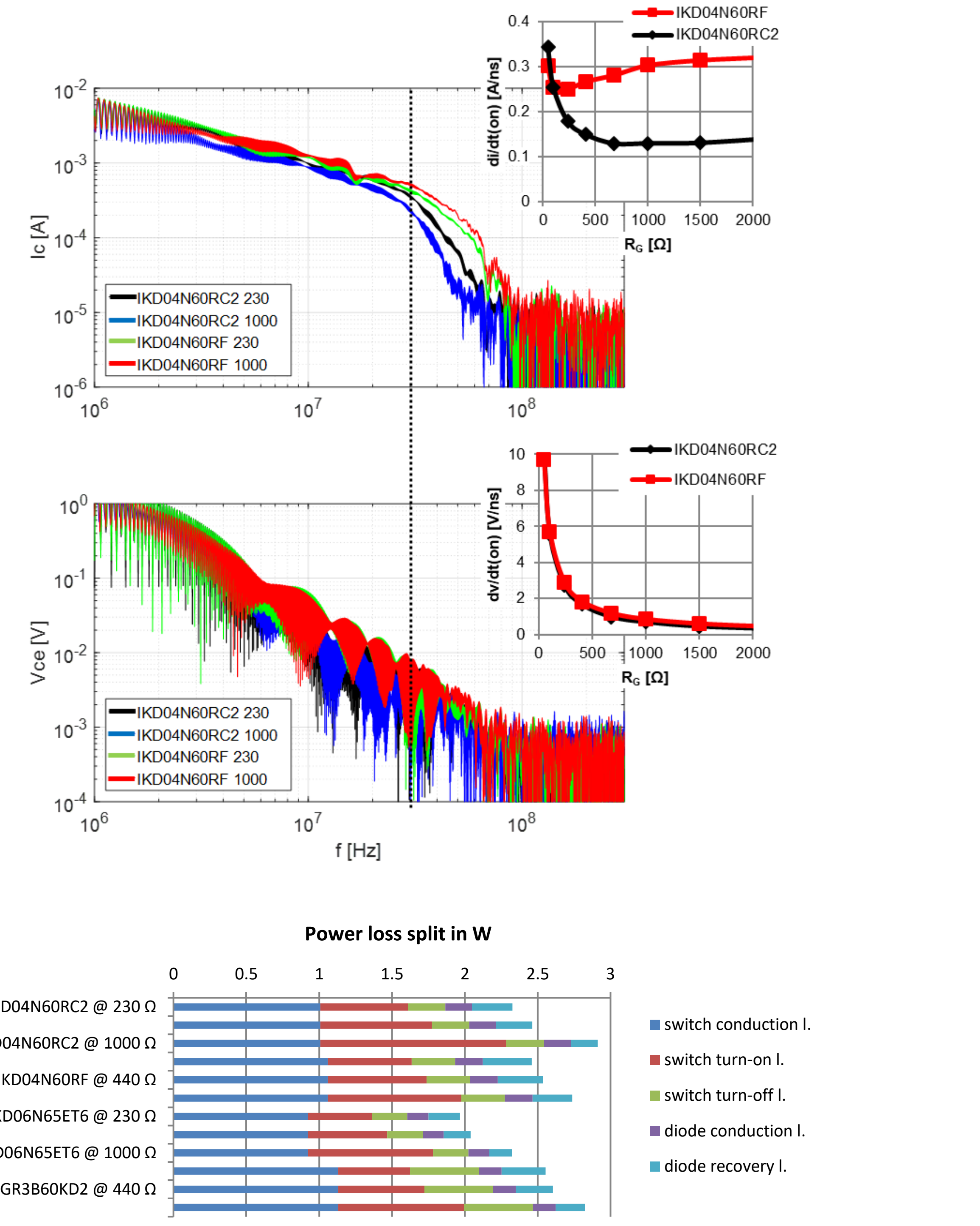


Figure 8 RC-DF versus RC-D2: Controllability, harmonic analysis comparison, and split of losses

The RC-DF technology does not feature good current controllability as di/dt increases even at higher gate resistance values. This is also visible in the harmonic analysis where the IKD04N60RF when driven with R_G(on) of 1000 Ω has higher current harmonics than when driven with R_G(on) of 230 Ω.

Compared to the RC-DF, RC-D2 offers significant improvements in terms of current controllability that begins to saturate after ~700 Ω. It is not recommended to drive the RC-D2 with a R_G(on) higher than 1 kΩ, as the switching losses will increase without any significant EMI noise reduction. Both technologies are comparable in terms of dv/dt.

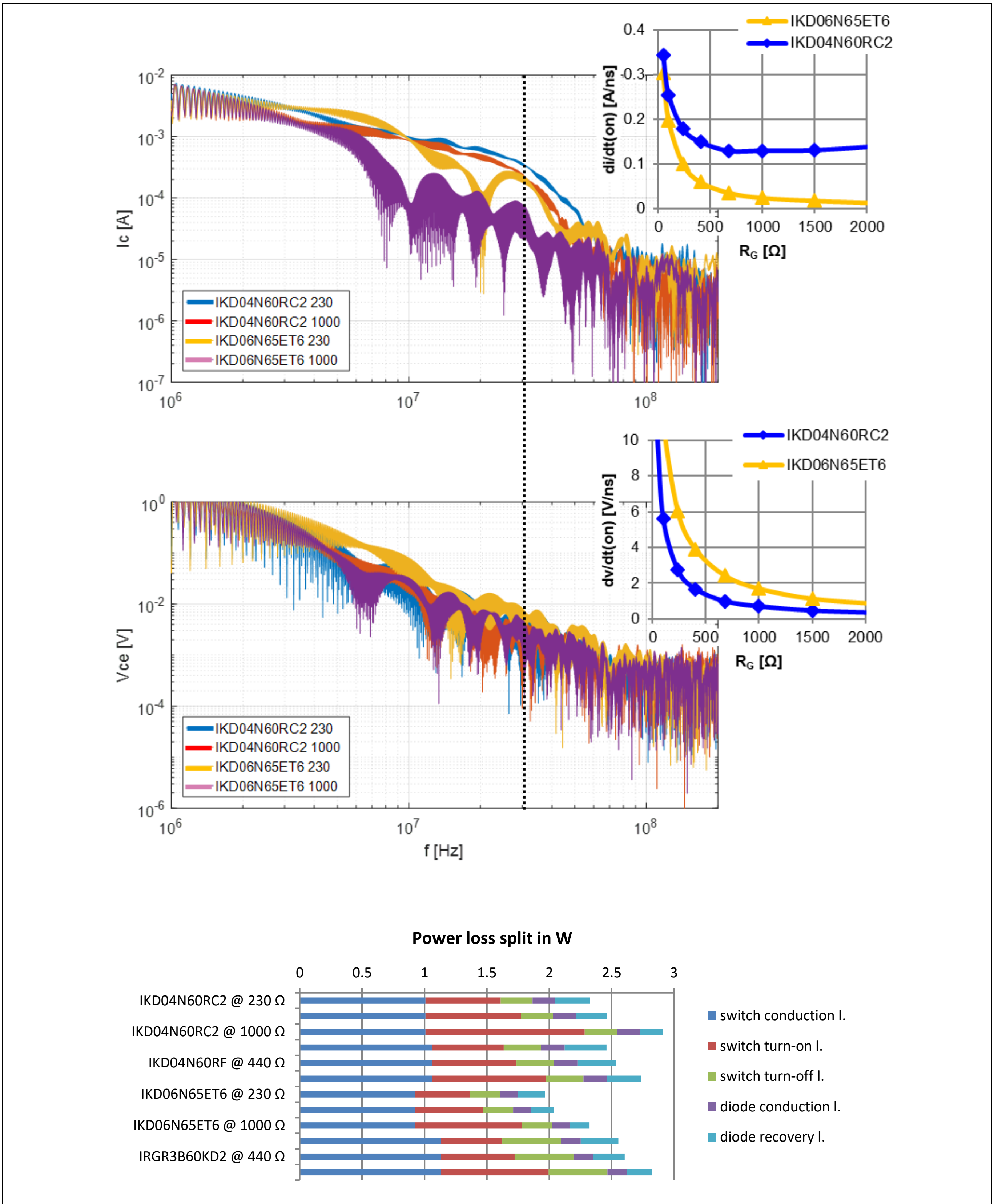


Figure 9 RC-D2 versus IGBT6: Controllability, harmonic analysis comparison, and split of losses

The IGBT6 technology is more flexible in controlling di/dt and dv/dt compared to the RC-D2 IGBT technology. Even if IGBT6 needs higher R_G(on) to match the RC-D2 (s 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. The IGBT6 technology behaves as a fast-switching device when compared to other IGBTs designed for consumer drives applications. Therefore, for IGBT6, it is recommended to use twice or even higher $R_{G(on)}$ compared to conventional IGBTs if EMI needs to be addressed. For example, the voltage harmonics of an RC-D2 driven with $R_{G(on)}$ = 230 Ω are matched by an IGBT6 driven with $R_{G(on)}$ = 1 kΩ and it still has lower total losses compared to the RC-D2.

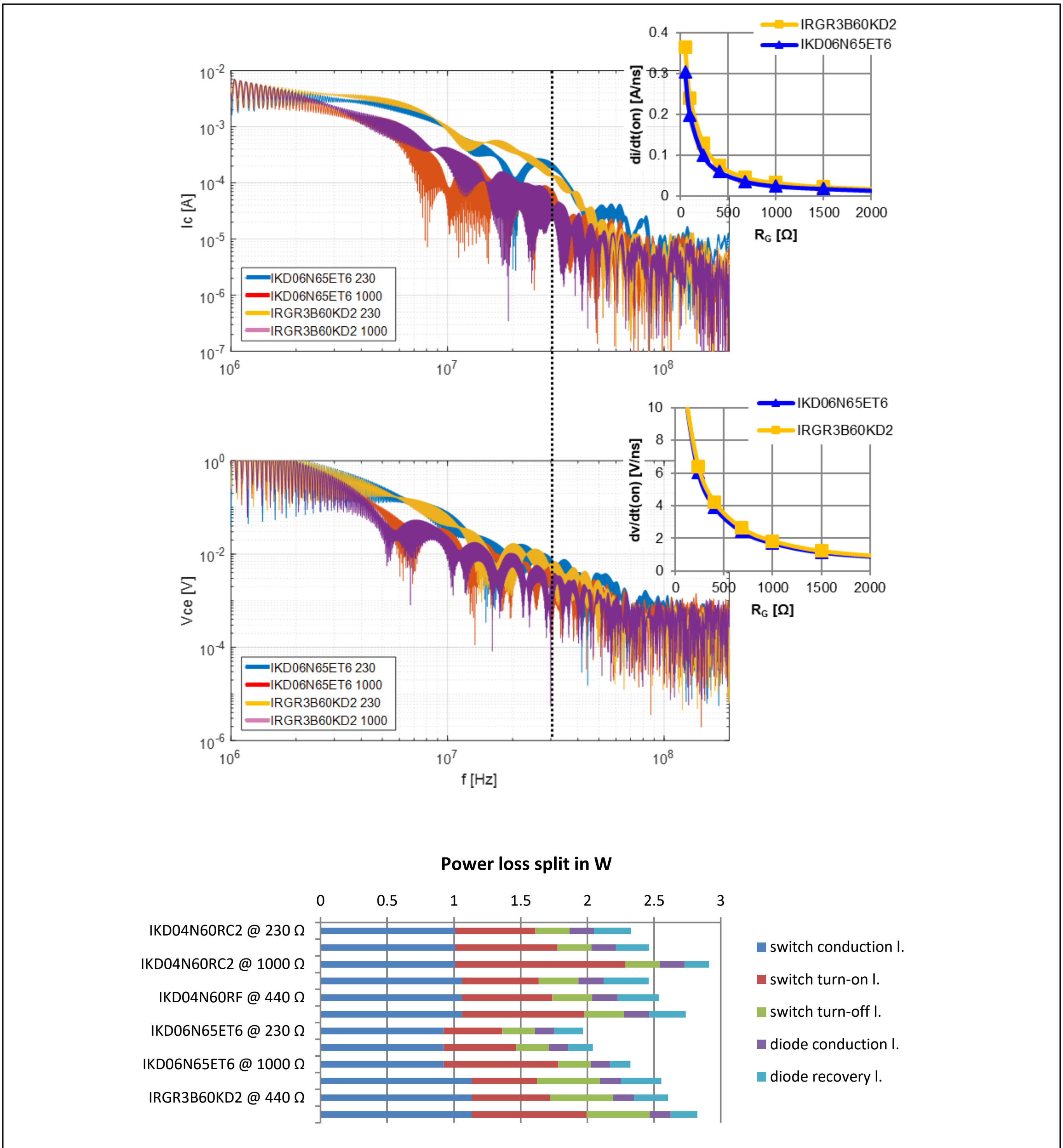


Figure 10 RC-D2 versus IGBT6: Controllability, harmonic analysis comparison, and split of losses

Former IR devices have been discontinued, but they are still present in some designs. If a replacement is needed, the closest device in terms of controllability is the IGBT6. As shown in the power loss split in Figure 10, the performance of the IRGR3B60KD2 device is worse than both IGBT6 and RC-D2.

3 Using DPAK versus the SOT-223 package

The need for improved power density and lower system costs pushes designers to find new and innovative package alternatives to traditional ones. One area where cost and space reduction is possible is in the design and packaging 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 has released an IGBT with a monolithically integrated reverse-conducting diode in a small SOT-223 package to reduce both package cost and size compared to a conventional DPAK package. This cost-optimized product portfolio called RC-D2 will boost system-level cost improvements.

The size difference between the DPAK and the SOT-223 packages is clearly visible when the devices are compared side-by-side as shown in Figure 11. Apart from a larger size, the DPAK has an exposed lead frame, while the SOT-223 does not. The IGBT in an SOT-223 can be used as a plug-and-play replacement for the DPAK if higher operating and case temperatures are accepted, or if the application design operates with lower power. Extensive testing has shown that an SOT-223 package can perform as well as a DPAK, albeit with a few limitations.

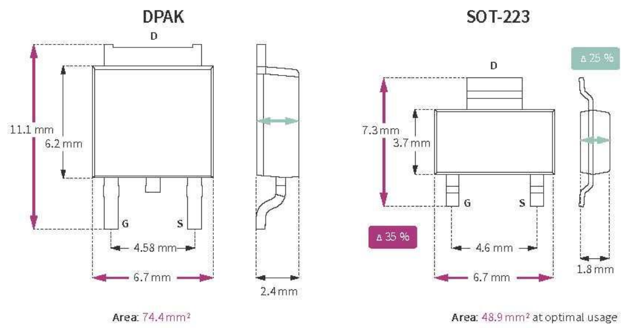


Figure 11 DPAK and SOT-223 dimensions and contrasts

The thermal measurements shown in Figure 12 were done on a small PCB adapter by exposing the die and measuring the temperature on the collector lead using a thermocouple, and the junction temperature using a thermal camera. Power was applied to the diode and adjusted to match the junction temperature (approximately 150°C). The ambient temperature was 25°C. From the DPAK to the SOT-223 package, the junction-to-lead thermal resistance R_{TH}(j-l) increases slightly. One of the factors that compensates thermally for the reduction of the junction-to-ambient thermal resistance of the SOT-223 is the exposed PCB copper that increases the heat radiated 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

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

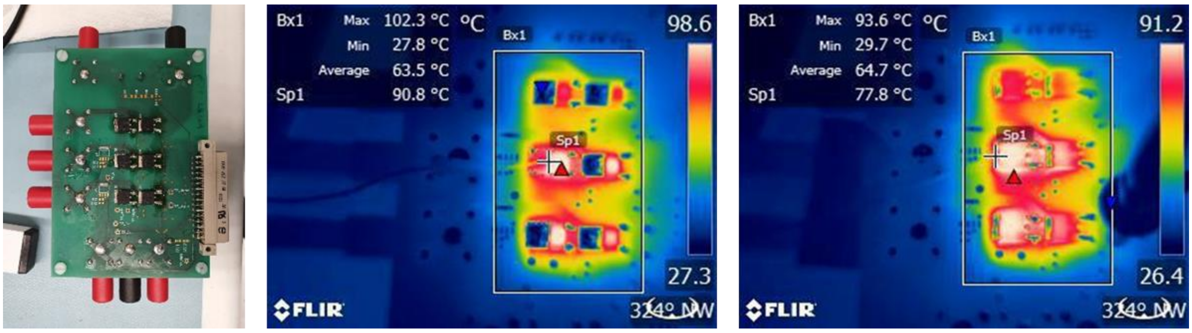


Figure 13 SOT-223 and DPAK thermal measurements on the same footprint

Simulation and experiments show that additional reduction in the SOT-223 temperature can be achieved 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
- Topside cooling by applying thermal paste and metal plate on the top of the SOT-223. Some customers are already using this with the DPAK packages. This concept is even more effective with SOT-223 packages having less mold compound. Special care must be taken to avoid electrical contact

4 Conclusion

Infineon's new RC-D2 and TRENCHSTOP™ IGBT6 represent a technological improvement over their predecessors to address consumer drives' requirements from lowest cost to highest performance. If EMI is an issue, the right technology can be selected to address that too.

The SOT-223 can reduce the size of the inverter by a factor of three. However, the drawback is the reduction of the maximum output power by approximately one third compared to thermally optimized solutions that target applications in the power range below 150 W.

5 References

[1] Infineon Technologies AG PCIM Asia 2019 paper “Using IGBT with antiparallel diode in SOT-223” https://ieeexplore.ieee.org/abstract/document/8836040

[2] Infineon Technologies AG “Revision 1.0, 2019-06-05 Evaluation Board - EVAL-M3-TS6-665PN” https://www.infineon.com/dgdl/Infineon-EVAL-M3-TS6-665PN-UserManual-v01_00-EN.pdf?fileId=5546d46269e1c019016ae5476e793bda

[3] Infineon Technologies AG “Revision 1.1, 2017-10-13 “High voltage CoolMOS™ P7 superjunction MOSFET in SOT-223 package applications” https://www.infineon.com/dgdl/Infineon-ApplicationNote_CoolMOS_P7_in_SOT-223_package-AN-v01_00-EN.pdf?fileId=5546d4625debb399015e08c6fa3d401f

Revision history

Document version	Date of release	Description of changes
1.0	2020-12-04	First release
1.01	2022-09-09	Content: Edited
		Text amendments

Trademarks
All referenced product or service names and trademarks are the property of their respective owners.

Edition 2022-09-09

Published by

Infineon Technologies AG

81726 Munich, Germany

Do you have a question about this document?

Email: erratum@infineon.com

Document reference
AN-2020-18