“RC-D Fast”: RC-Drives IGBT optimized for high switching frequency

Application Note

Application Engineering IGBT

July 2012, Mitja Rebec

Power Management Discretes

Published by
Infineon Technologies AG
81726 Munich, Germany

Legal Disclaimer

The information given in this document shall in no event be regarded as a guarantee of conditions or characteristics. With respect to any examples or hints given herein, any typical values stated herein and/or any information regarding the application of the device, Infineon Technologies hereby disclaims any and all warranties and liabilities of any kind, including without limitation, warranties of non-infringement of intellectual property rights of any third party.

Information

For further information on technology, delivery terms and conditions and prices, please contact the nearest Infineon Technologies Office (www.infineon.com).

Warnings

Due to technical requirements, components may contain dangerous substances. For information on the types in question, please contact the nearest Infineon Technologies Office.
Infineon Technologies components may be used in life-support devices or systems only with the express written approval of Infineon Technologies, if a failure of such components can reasonably be expected to cause the failure of that life-support device or system or to affect the safety or effectiveness of that device or system. Life support devices or systems are intended to be implanted in the human body or to support and/or maintain and sustain and/or protect human life. If they fail, it is reasonable to assume that the health of the user or other persons may be endangered.

Table of Contents

1 Introduction and Short Description of the Product Family

The RC-Drives IGBT technology was released by Infineon at the end of 2009 as a cost-optimized solution to address the price-sensitive Consumer drives market. This basic technology provides outstanding performance in BLDC motor drives adopting block commutation–type of modulations, were one or both IGBT in the half-bridge are left conducting for 120° of the motor electrical angle (Dae-Woong Chung et al., IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 46, No. 3, June 1999). Thanks to the low conduction losses of both IGBT and integrated diode the overall losses are drastically reduced. This type of control is commonly found in Fridge compressors: by limiting the hard switching events the dV/dt and dI/dt commutation slopes are avoided, therefore the harmonic content injected into the motor windings (hence the EMI) is reduced. Below a typical example of this type of commutation found on a 100W commercial fridge compressor:

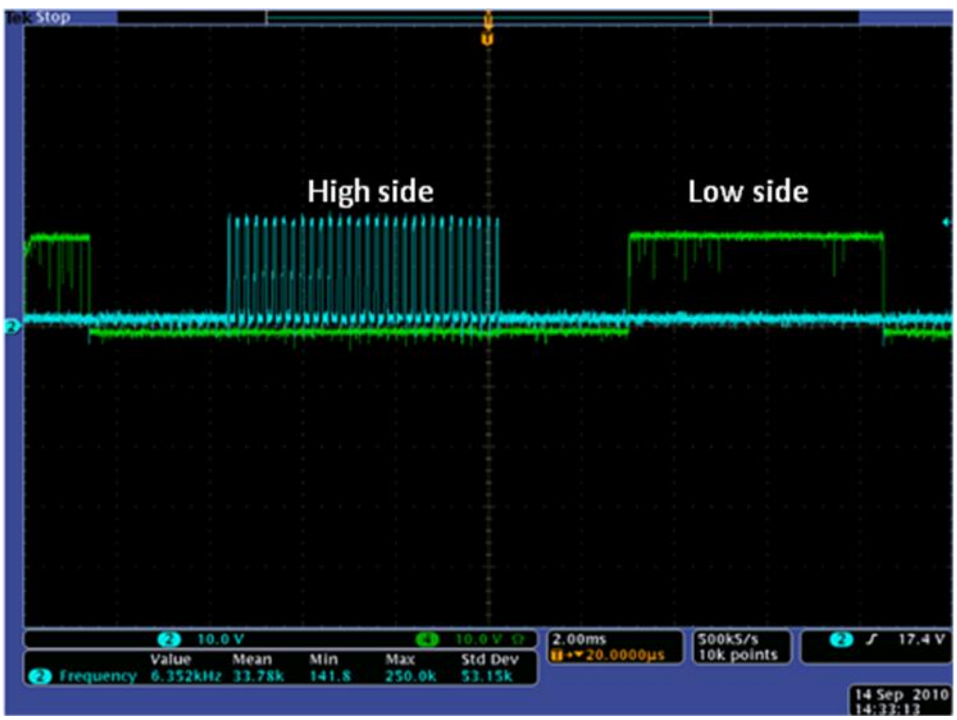


Figure 1: High side and low side gate signals for 120° PWM commutation switching

Another application that benefits from the low on-state losses or the RC-Drives is found in Domestic Aircon systems: the ~1.5 kW BLDC compressor is driven by IGBTs switched by full sinusoidal PWM hard switching at moderate switching frequencies of 5 to 8 kHz. Again in this case a device optimized for low conduction losses provides an overall loss reduction.

However the trend observed in low power drives for outdoor and indoor fan of domestic Aircon systems as well as industrial funs and pumps up to ~200W is to increase the PWM switching frequency. The reason is twofold: on one side the size of the output filter can be reduced by keeping the same current ripple. On the other side in small motor drives adopting sensor-less FOC (Field Oriented Control), were a high dynamic control (torque and speed) of the PMSM motor is required, the higher switching frequency allows to increase the sampling rate of current and hence the accuracy of reconstructed rotor position.

In order to meet the rising demands of the IGBTs for the low power motor drive consumer market, a new version of the RC-Drives IGBT is developed: the IGBT and diode losses are optimized to reduce the inverter losses at switching frequencies of 4~30kHz. The new family is called RC-DF, and released in the current classes from 2.5A to 15A in D-PAK packages.

Part number	Package Type	Power [W]	Switching frequency	VCE [V]	IC [A]		VCEsat [V]		Ets [mJ]		tSC [s]	VF [V]		Qrr [µC]	
					25°	100°C	25°C	175°C	25°C	175°C		25°C	175°C	25°C	175°C
IKD03N60RF	D-PAK	40..80	4..30 kHz	600	5	2.5	2.2	2.3	0.09	0.14	5	2.1	2.0	0.06	0.19
IKD04N60RF	D-PAK	80..150	4..30 kHz	600	8	4	2.2	2.3	0.11	0.19	5	2.1	2.0	0.09	0.26
IKD06N60RF	D-PAK	150..250	4..30 kHz	600	12	6	2.2	2.3	0.18	0.28	5	2.1	2.0	0.16	0.34
IKD10N60RF	D-PAK	250-600	4..30 kHz	600	20	10	2.2	2.3	0.35	0.52	5	2.1	2.0	0.27	0.62
IKD15N60RF	D-PAK	600..1000	4..30 kHz	600	30	15	2.2.	2.3	0.52	0.78	5	2.1	2.0	0.42	1.00
IKU04N60R	I-PAK	80..150	DC..5 kHz	600	8	4	1.65	1.85	0.24	0.4	5	1.7	1.7	0.22	0.52
IKD04N60R	D-PAK														
IKU06N60R	I-PAK	150-250	DC..5 kHz	600	12	6	1.65	1.85	0.33	0.56	5	1.7	1.7	0.37	0.80
IKD06N60R	D-PAK														
IKU10N60R	I-PAK	250-600	DC..8kHz	600	20	10	1.65	1.85	0.59	0.93	5	1.7	1.7	0.56	1.22
IKD10N60R	D-PAK														
IKU15N60R	I-PAK	600-1000	DC..8kHz	600	30	15	1.65	1.85	0.9	1.25	5	1.7	1.7	0.76	1.7
IKD15N60R	D-PAK														

Table 1: Product specification for RC-Drives and RC-Drives Fast

2 Static and Dynamic behavior

2.1 Static Behavior

Due to the optimization for fast switching, the V_{CEsat} of the RC-DF is increased compared to the RC-D. However for the target inverter applications in the range of ~100W the RMS currents are usually limited below 1A and here the V_{CEsat} increase is limited to ~ 200mV both at 25 °C and 175°C. A negative temperature coefficient of V_{CEsat} is observed in this current range, contributing to a reduction of conduction losses in normal operating conditions, with junction temperature Tj typically ranging from 60 to 100°C.

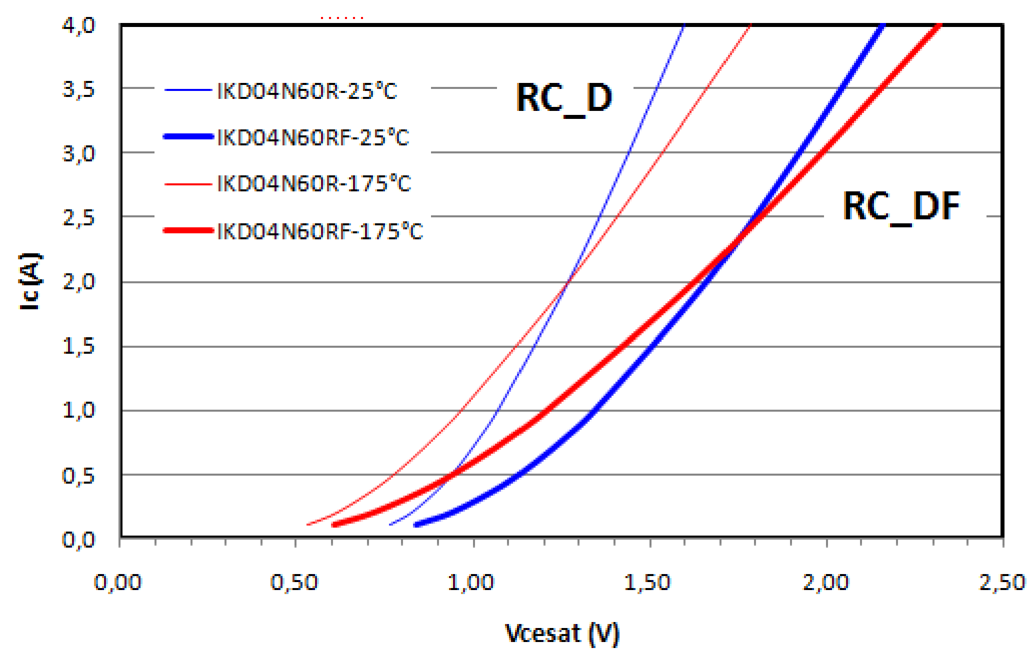


Figure 2: V_{CEsat} comparison of the RC-DF vs. the RC-D technology

2.2 Dynamic Behavior

The RC-DF maintains the smooth switching behavior and Rg controllability of the basic RC-D technology, by providing drastically reduced turn-off losses of the IGBT. The internal diode is also optimized to reduce the turn-on losses. The devices are characterized in a classical half-bridge test circuit with inductive load: the LS IGBT (DUT) is commutated over the HS diode. Therefore the Diode switching improvement is visible in the IGBT turn-on behavior (see below).

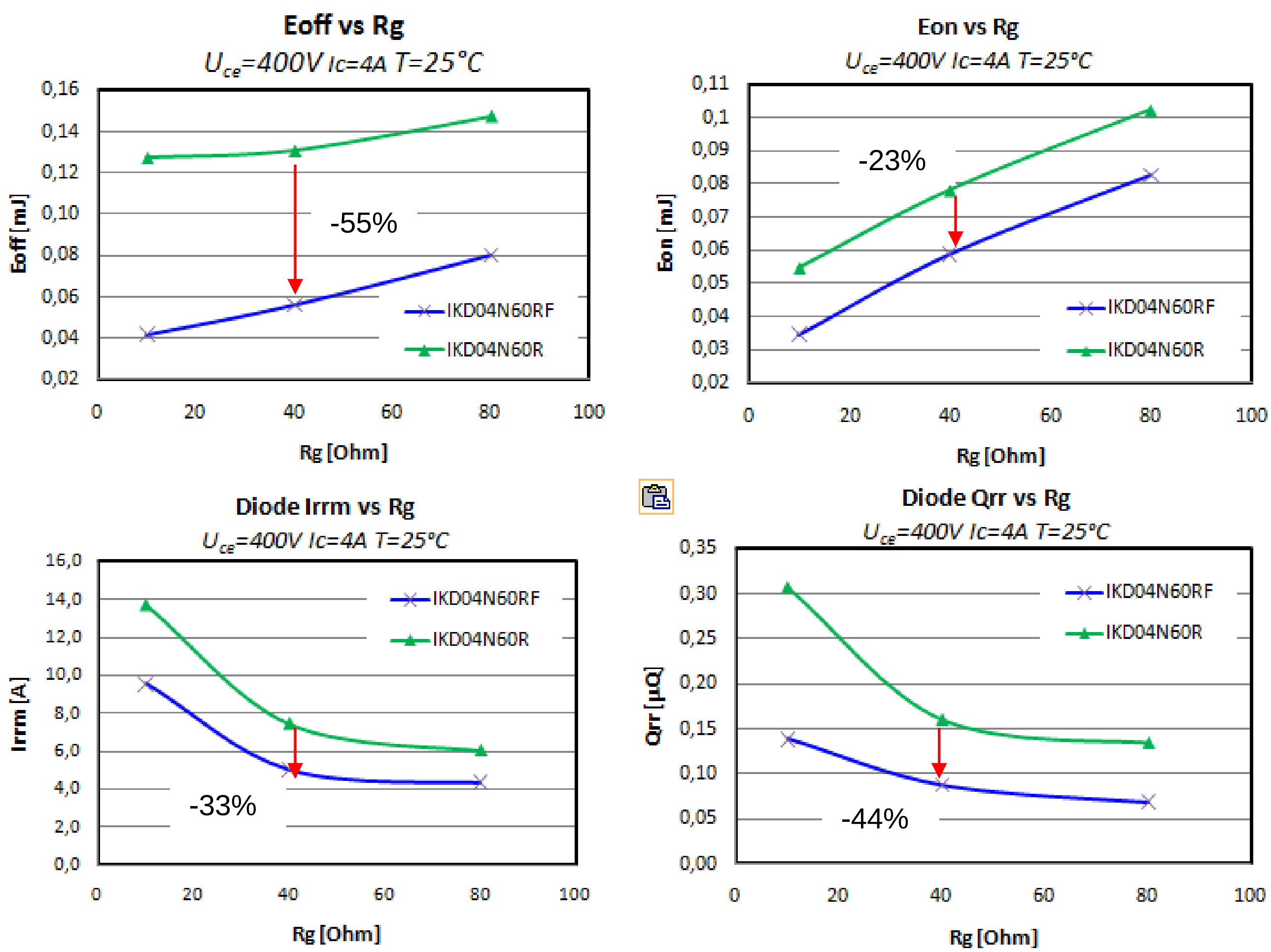
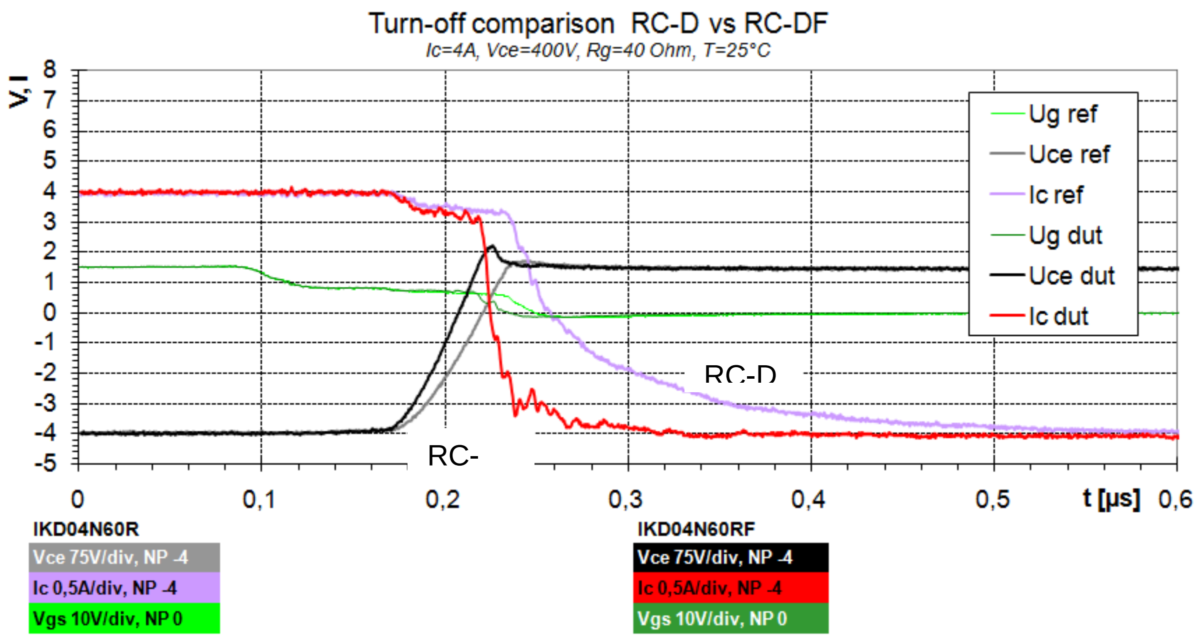


Figure 3: Dynamic switching behavior as a function of external Rg.

The turn-on and turn-off waveforms are clearly showing significantly faster switching: both the tail current of the IGBT, the Qrr, Irrm and trr of the integrated diode are drastically reduced.



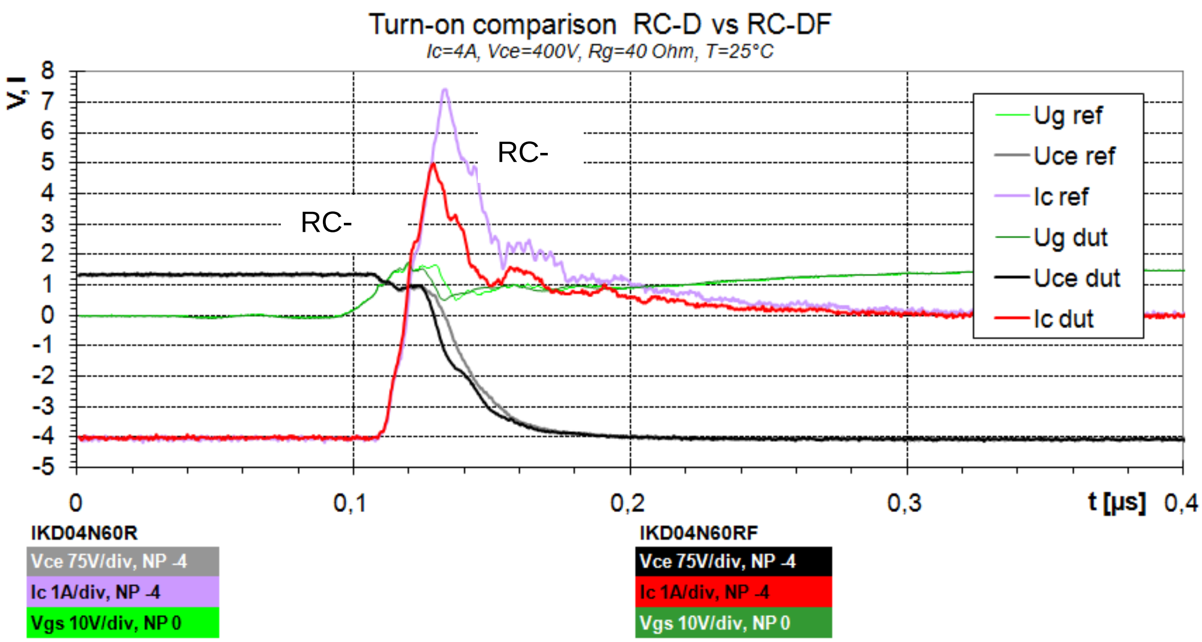


Figure 4: dynamic switching waveforms: turn-off (top) and turn-on (bottom). Note that the current scales are different.

3 In-circuit Application Test on 200W Motor Drive board

3.1 Efficiency

In order to verify the improvement of the RC-DF in a real application conditions, the new devices were tested on a demo board developed by Infineon and used as test bench to simulate a real Air-conditioning outdoor fan. The board is designed for a 200W output and consists of an input rectifier stage, inverter stage and output filter. The IGBTs are driven by a 600V 3-phase driver IC from Infineon (6ED003L06-F), and the modulation pattern is provided by an 8 Bit Infineon Microcontroller (XC-878) mounted on an external card. No heat-sink is required, just thermal Vias through the PCB. The control method is sensor-less FOC using a single shunt-based feedback loop. The board is driving a 200W induction motor coupled to an adjustable DC brake, which allows controlling the output power from the inverter. The efficiency is monitored by a Siemens Power meter and case temperature is monitored by an IR camera.

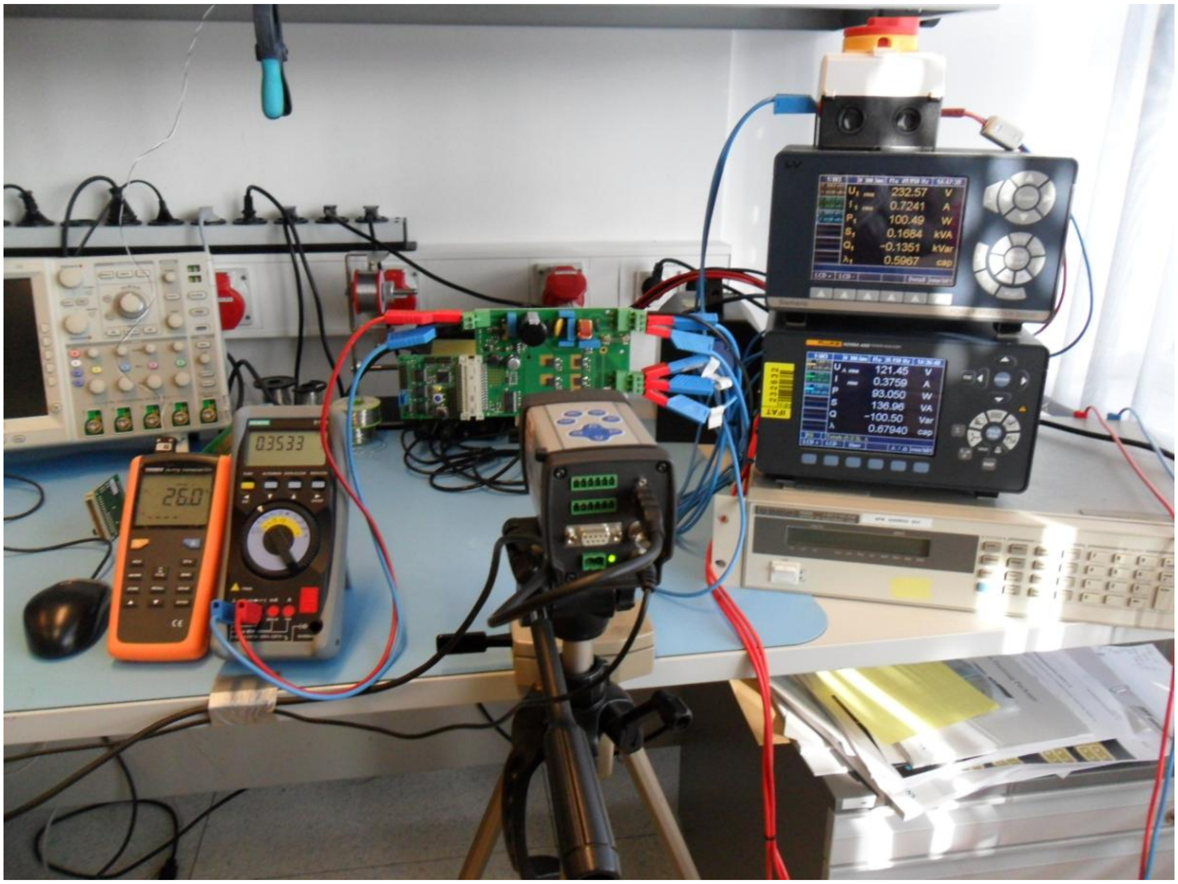


Figure 5: Test set-up for the application measurements

Already at switching frequency of 10 kHz a clear efficiency improvement is observed. At the target f_sw of 18 kHz the RC-DF provides 2.8% improvement at 50W input power and 1.6% at 100W:

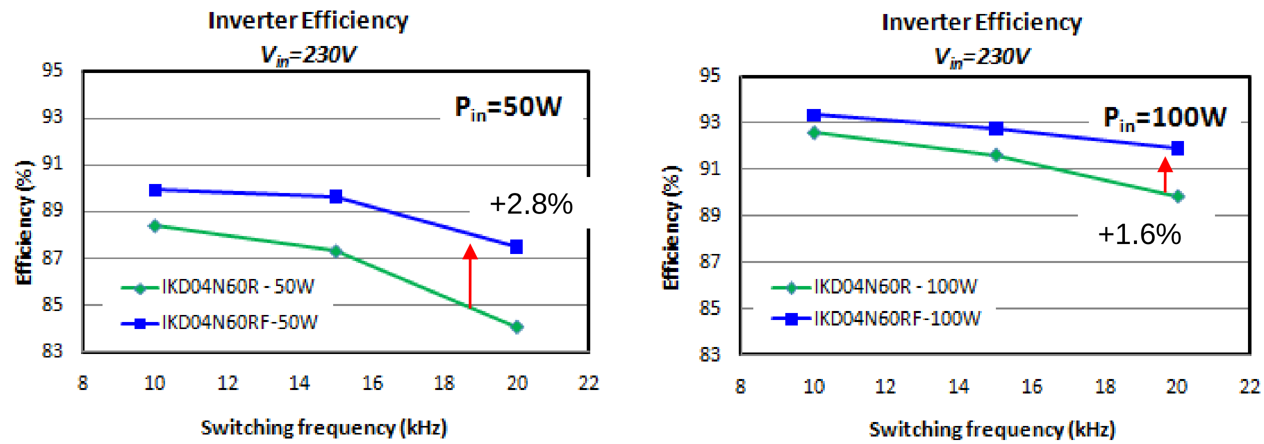


Figure 6: Inverter efficiency as a function of input power and switching frequency

3.2 Thermal behavior

The increased efficiency for the RC-DF translates in lower case temperature, as verified by thermal images with Infrared camera:

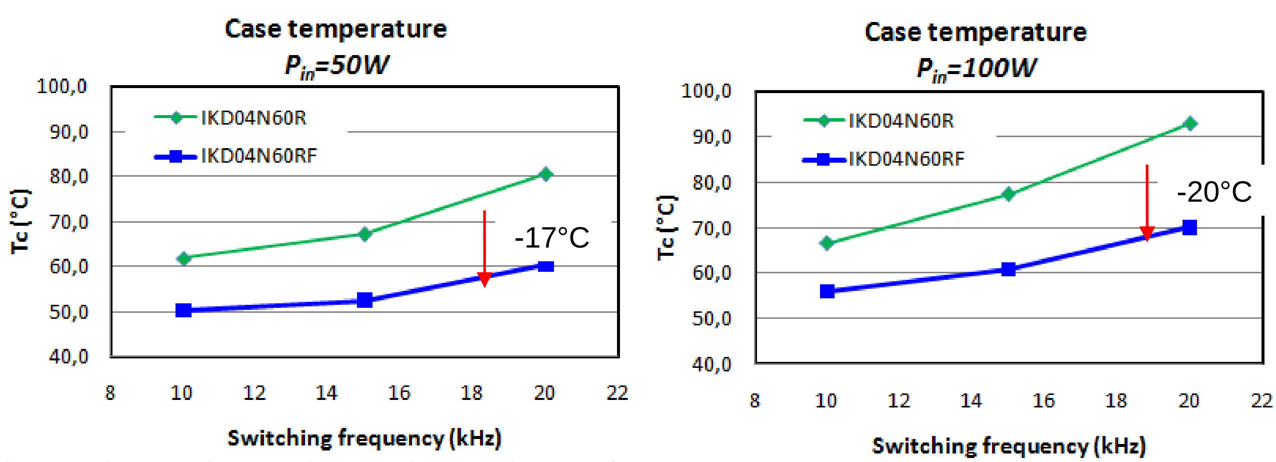


Figure 7: Case temperature as a function of input power and switching frequency

The RC-DF shows outstanding thermal performance providing lower case temperature over the entire frequency range: at the target switching frequency of 18 kHz, the case temperature is lowered by 20°C.

The temperature distribution is quite uniform, as demonstrated by detailed analysis of the thermal images:

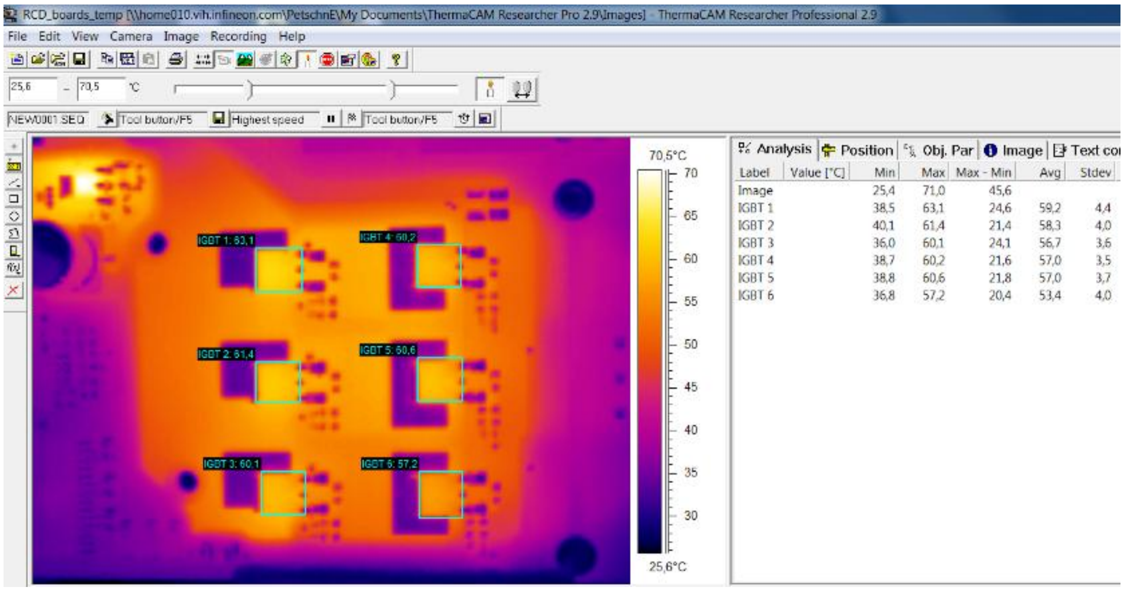


Figure 8: thermal images at Pin=50W, f_sw=20 kHz

This translates in increased reliability and longer life expectancy for the device, especially in the harsh thermal environments to be encountered in a real application. In the case of outdoor fan for domestic split Aircon systems, for example, the board is mounted directly on the back of the motor in a close environment without airflow. In this case high ambient temperature up to ~60°C can be expected:

Figure 9: Commercial Air-conditioning split system, showing the motor drive card housed on the back of the BLDC fan motor

3.3 Cooling considerations

When the power range of the inverter exceeds ~200W, along with careful PCB design (avoid placing devices too close to each other or to the edge of the PCB), some type of cooling is required for the SMD devices. In case of DPAK packages, top side cooling is not effective due to the relatively high thickness of the mold compound on top of the chip and the poor heat exchange. Infineon recommends cooling from the bottom of the chip by thermal vias through the PCB. Several methods for Vias formation are adopted in the Industry:

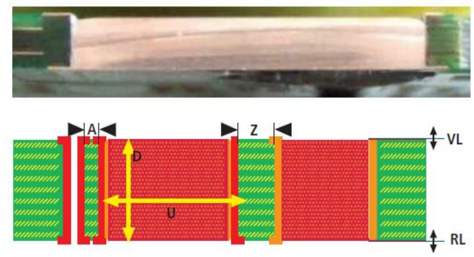
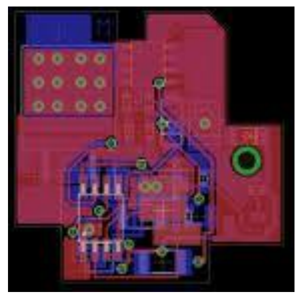
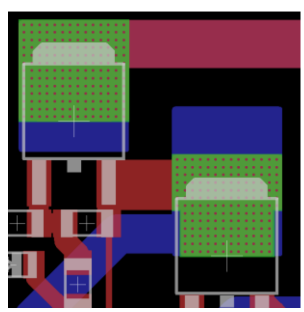
Copper inlays	Production limited and quite expensive concept. Adopted in high efficiency converter for SMPS applications	 Copper Inlays (Ruwel GmbH)
Thermal vias	Placed around the leadframe or partially under the drain contact. Typical Vias diameter is 400um. Filled with synthetic resin to avoid solder voids at RC-Drives leadframe due to a solder reflow through the Vias. Most common solution in consumer drives.	 Classical Thermal Vias with resin
Small drill holes	Holes diameter below 0.2 mm for the thermal vias are filled during Cu galvanic deposition to avoid solder reflow. They can be placed under the drain for the most effective heat exchange.	 Thin-Via-Concept (Small drill holes)

Figure 10: Commonly adopted Vias concepts

Infineon recommends, when allowed by the process capability of PCB supplier, the small drill holes concept for optimum power dissipation. The concept was tested successfully on several reference designs and allowed to reach up to 1.2kW Output power utilizing RC-D devices in DPAK package.

Below an example of small drill holes vias design and related heatsink mounting with isolation foil:

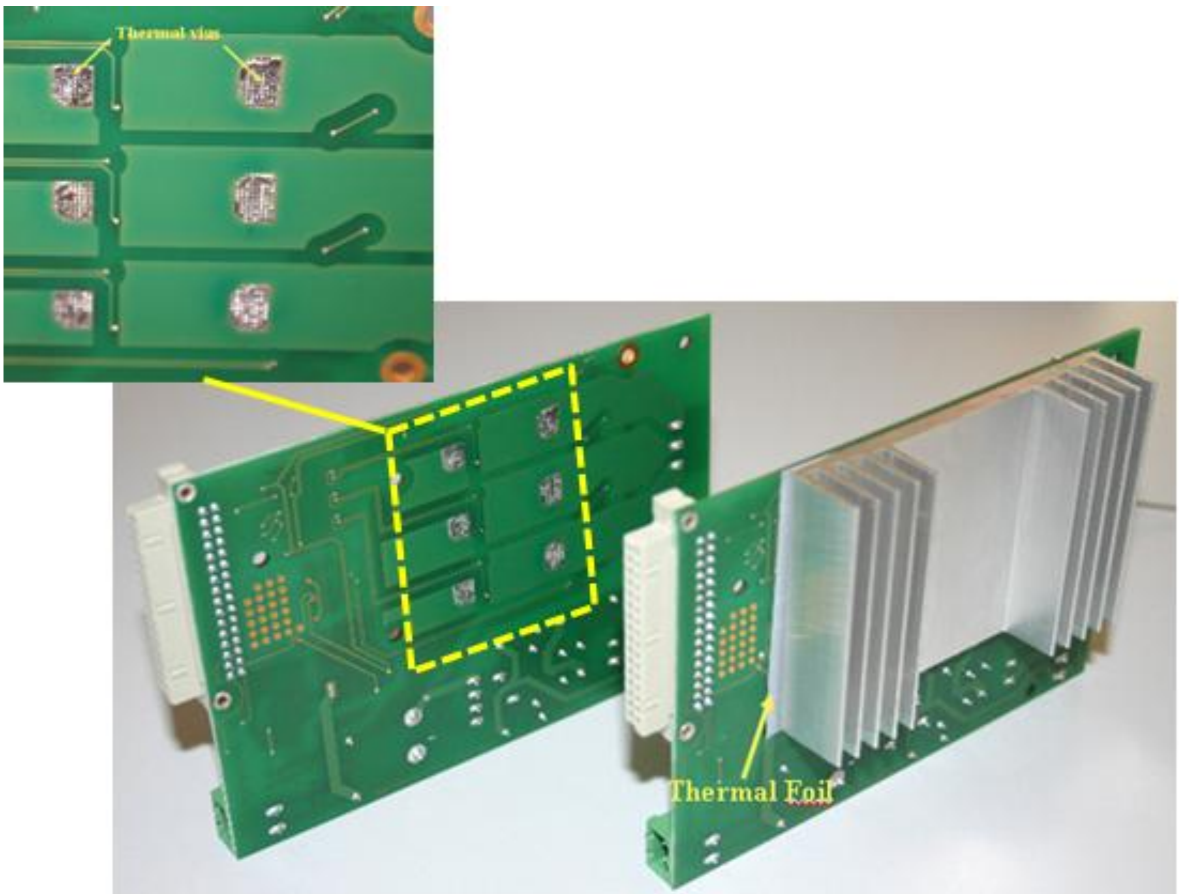


Fig 11: Example of thermal Vias and Heatsink mounting for RC-D and RC-DF test boards

w w w . i n f i n e o n . c o m / r c d f

Published by Infineon Technologies AG